Report Submitted to

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RECOMMENDATIONS FOR IMPROVEMENT OF CLASSROOMS AT WPI

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ABSTRACT

This project identified inadequate classrooms at WPI. Students were surveyed on-line to evaluate the conditions of classrooms on campus. Flaws in the existing classroom designs were determined through student/faculty interviews and analysis of the premises. Physical measurements of the air quality, seating, lighting, acoustics, and disabled access were recorded to assess the current state of the classrooms. Substantial design flaws in AK116 and OH107 suggest the renovation of these classrooms would be beneficial to WPI.

EXECUTIVE SUMMARY

Classrooms on campus need to undergo renovations and upgrades routinely to keep up with the evolution of education. Our project goal was to find and redesign the worst classroom at Worcester Polytechnic Institute. To determine the classrooms in question, the following three criteria were developed.

The first criterion considers the opinion of the students. The student's benefit from well designed classrooms.

The second criterion reflects the concept that larger lecture halls at Worcester Polytechnic Institute are likely to impact more students then smaller classrooms. Redesigning the larger lecture halls will have a broader influence on the majority of the students.

Third, the classroom or classrooms that failed to provide for new teaching styles and techniques were considered.

The goals of the project were the following:

1. To find what classroom at WPI, students think is the "worst".
2. To interview the faculty members that taught in the classrooms on campus named the by the students.
3. To interview a portion of the students who thought the classroom that received the most votes was the worst classroom on campus.
4. To investigate design elements of the classroom named by the students as the worst on campus by reviewing the interviews results.
5. To determine faults in the current design and suggests alternatives.

The students of Worcester Polytechnic Institute were surveyed to find the worst classroom at WPI. The lighting and air quality in response to the interviews were tested in the troubled classrooms to determine if the classroom provides a healthy and comfortable environment to learn. Research in the fields of ergonomics, acoustics, and disabled access helped evaluate the design elements of the classroom under review.

The survey clearly indicated OH107 and AK116 as the classrooms the students would like to see renovated. Eleven students and three faculty members were interviewed. The first topic commented on was the lighting in both classrooms. The students and faculty indicated that the acoustics were a major problem in the classrooms. The temperature in both classrooms was indicated as uncomfortable for one reason or another.

The overall classroom lighting is clearly deficient for both AK 116 and OH 107. This is primarily due the following findings.

1. Not enough lights in the classroom.
2. The positioning of the lighting fixtures.
3. The misuse of the lighting fixtures.
4. Classroom architecture.
5. Poor central lighting controls.

The indoor air quality level of the rooms was objectively evaluated and compared to the standards for indoor air quality established by the EPA and the ASHRAE. The resulting data from these measurements indicated poor indoor air quality for both AK 116 and OH 107 as compared to the EPA standards.

It was determined that the carbon dioxide level in AK 116 had the potential to create uncomfortable conditions inhibiting learning. The high carbon dioxide levels in both classrooms indicate poor ventilation. The HVAC system did not alter the relative humidity in the classroom based upon the data.

In OH 107 the carbon dioxide level was determined to be well above the initial hazardous level. The students were uncomfortable due to the temperature in this room, which was above the comfort level set by the EPA. The relative humidity level measured inside the classroom showed the same levels as the outdoor readings taken. The HVAC system is clearly shown an inability to manage the ventilation, temperature, and relative humidity.

The two classrooms determined to be the least liked by students, AK116 and OH107, were both fingered for having poor acoustics. Subsequently, they were tested for excessive noise levels. SL115 having been recently renovated was measured for excessive noise to serve as a control.

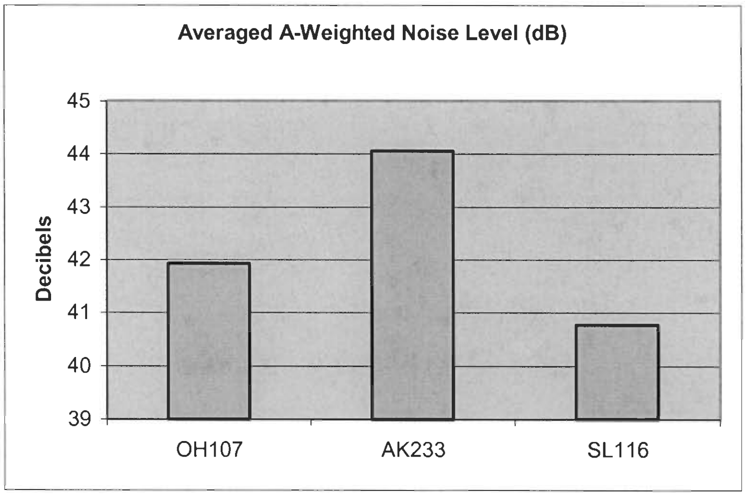

Figure 4.19: Average noise level per room

OH107 reveled to have background noise levels in accordance with EPA recommendations (see Figure 4.21). However, a qualitative assessment of the echo produced as compared to AK116 and SL115 indicated the room to be highly reverberant. The other two lecture halls did not appear to have a substantial echo. It is known that the capacity for human beings to differentiate between primary and echoed sound requires a delay of 70 milli-seconds. That is equivalent to a difference of 70 feet traveled by the primary sound and that of the reverberant sound [25].

This poorly damped reverberation is most likely due to the acoustical properties of the materials that constitute a substantial portion of the room's surface area. OH107 is different from the other two rooms in that there are no cushions on the seating and that the floor is not carpeted. The seating in OH107 is made of wood that is designed to reflect sound towards the front wall of the lecture hall. The surfaces of the lecture hall are mainly rigid and non-absorbent. Therefore it is no surprise that OH107 is highly reverberant. OH107 ($V=35{,}000\ ft^3$) is larger than SL115 ($V=28{,}000\ ft^3$) so it is expected to have a slightly longer reverberation time by volume alone, but AK116 is even larger ($V=39{,}000\ ft^3$) and didn't have a substantially long echo.

A committee has been formed to plan the renovation of Olin Hall. This project and its findings will be submitted to a member of the renovation committee at WPI to aid in the reconstruction of OH107.

AUTHORSHIP PAGE

Martin Graham, Thomas A Plunkett, and Mike Titus contributed equally in the composition of the project.

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CHAPTER 1 - INTRODUCTION

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CHAPTER 2 – BACKGROUND

The background investigates common classroom design problems and solutions to fix those problems. Question construction techniques and common types of survey error are identified to accurately portray the opinions of the population. Current lighting design was studied to correct insufficient lighting in the classrooms. Air quality was explored in the background to interpret our results from the data collection and suggest resolutions to problems. Ergonomics and design requirements were studied to evaluate the design of the classrooms on campus.

2.1 STUDENT SURVEY INTRODUCTION

The first phase of our project is to conduct a survey. The focus of this interactive qualifying project was to examine the classrooms at Worcester Polytechnic Institute. A student survey, if conducted properly, can provide useful data in evaluating all the classrooms at the Institute. Teaching styles and techniques that are insufficiently supported by the current classroom design may surface out of a student survey.

2.2 SURVEY PROTOCOL

The survey data can easily be rendered useless if it introduces unacceptable levels of error [1]. The four most important and common types of error are discussed below [1].

The first common type of error that surveys can encounter is called "coverage error". This type of error is introduced when most of the individuals in the sample group possess a certain characteristic that makes their participation in the survey inaccurately model the larger population [1,3].

a. Conducting a survey to find out how an average American brushes his or her teeth using a sample group consisting of mostly dentists is likely to present coverage error rendering the survey inaccurate. Surveying mostly dentists in this example creates a common characteristic inaccurately modeling the population of America.

The second type of survey error is referred to as "sampling error". Surveys cannot accurately model the population if an inadequate percentage of the population is surveyed. If a very low percentage of the population is asked about the issues involved, the conclusions drawn from the data are not scaleable to the entire population [1,2] With sixty surveys returned results can accurately model the population of 2500 to 3000 people with a 95% confidence level plus or minus 10% [1].

a. If we tried to model the general opinions of the entire student body by randomly selecting only two students, the survey error would render the study useless. Those two students selected may not accurately model the entire school's opinion. The other twenty-one hundred students at WPI could have a different perspective on the matter.

The third type of common survey error is "measurement error". This type of error exists when the person taking the survey misinterprets a question. The resulting data will inaccurately represent the opinion of the respondent. This type of error is difficult to identify. Special attention to question construction must be given to avoid measurement error at all costs [1,2].

a. An example of measurement error would be a survey that asks the respondent to reveal the amount of gasoline their families' cars consume in a year. This survey question fails because of the difficulty involved in calculating a whole years consumption of gasoline correctly.

b. A more effective approach could be to give quantifiers to the respondent to aid their answer. The question would be more successful if reworded to ask the respondent if they consumed:

i. An average amount of gasoline (Two cars, 20 to 40 MPG, Average yearly travel 40,000 miles each).

ii. Above average amount of gasoline (Two cars or one SUV, 15 - 20 MPG, Average yearly travel 40,000 miles).

iii. Below average consumption of gasoline (one car 20 to 40 MPG, Average yearly travel 40,000 miles).

The fourth common type of survey error is called "non-response error". This type of error occurs when there is a very low useable amount of respondents. Even if the amount of useable surveys is enough to model the population, the ratio of respondents to non-respondents may not be high enough for accurate results [1,2].

a. If we tried to receive 100 valid responses to our survey by emailing the survey to all 2,100 students, non-response error would render the survey useless. If a hundred responses were obtained the response rate would only be

4.5% of the population. This is not allowed because those who responded are prone to exhibit a like characteristic that would inaccurately model the whole population.

Completely eliminating all these types of error is impossible. A survey must make tradeoffs in minimizing the different types of error. Steps must be taken to minimize each type of error.

2.3 QUESTION CONSTRUCTION

Question construction is the most vital component to a survey's success. When composing the questions in a survey, constant attention must be paid to minimize the four most common types of surveying errors. Other basic principles and guidelines discussed above should be obeyed to receive an accurate model of the population. Many survey concepts focus on engineering the smooth execution of the survey process from start to finish [4].

Keeping the questions short and the decision choices to a minimum will increase the accuracy of the results [4]. The more in-depth the answers become, the more stress is put on the respondent. The questions of the survey must be tailored to the group of individuals that will be receiving it. Question difficulty should exist on the same level or lower then the respondent's ability [2]. Questions that are too difficult to answer will produce incomplete results because the participant will skip over those questions or abandon the survey altogether [1]. For best results, the questionnaire should be easy to fill out, and the survey process should be an interesting experience.

Asking questions about a person's own attitudes or beliefs, tends to yield inaccurate results [2,4]. When asked about their attitudes or beliefs, survey respondents usually do not wish to divulge their personal information. To counteract this, survey questions should ask about the attributes and behaviors of an individual [1]. Questions that are structured in this manner tend to produce more accurate results and will not aggravate people.

When constructing a survey, sufficient technologies should be used to accomplish the goals of the survey. If long lists are needed to answer questions, the survey must present the information in an organized manner.

The Internet today presents many unique opportunities and different survey approaches[3]. The Internet also minimizes transaction costs. Transaction costs are the costs associated with (1) finding the individuals in the sample group, (2) giving them the survey, and (3) recording the results. This way, administration of the survey takes place whenever the respondent wishes, and they can take as long as they want.

Computer programs and scripts record the answers to the survey exactly. Programs also assemble and classify the resulting information automatically with very little overall cost. The use of search engines can be incorporated into survey questions to help the user browse a very long list of choices. Internet based surveys can also take advantage of linking in alternative web sites, presenting the respondent with background information on a subject.

Internet accessibility issues however, make Internet based surveys prone to coverage error [3]. Only those persons surveyed with computers and Internet access can respond to the survey. In a high-tech college environment where all individuals have full web access, this consideration is minimized.

Surveys should present the question to the respondent in a manner that can produce a distinct type of result. There are three different types of questions that are used in surveys today. The types of questions are (1) open-ended questions, (2) closed-ended questions with ordered or unordered choices, and (3), a hybrid that is a combination of both the closed and open-ended question.

Open-ended questions do not provide any choices or answers to the respondent [1,3]. Open-ended questions generally provide space for the participant to write in their own answers. An example of an open-ended question is one that asks, "Please list the number of times you brush your teeth a day."

Open-ended questions carry many drawbacks that prevent their use in most surveys [1]. One drawback to open-ended questions is that it can take a long time to decipher the results. Misspellings, sloppy handwriting, and the use of slang are typical factors that can make interpreting open-ended questions very demanding. Surveys that try to statistically analyze a situation with an open-ended question fail because of the varying interpretations and measurements used.

Another drawback to open-ended questions is that the results do not compile efficiently. A simple open-ended question that is worded improperly could receive hundreds of different responses. Sorting through the different replies to surveys with many open-ended questions is likely to tax the resources of a project.

Open-ended questions rarely provide accurate measurements of the subject in question. When a survey is being used to explore unknown subject matter, open-ended questions could be the perfect tool [1]. Open-ended questions can provide an array of new information.

Open-ended questions are more effective when they follow closed-ended questions. A closed-ended question followed by the open-ended question provides background information and stimulates thought on the subject matter. This approach can lead to a more precise data collection [1]. When used in conjunction with a closed-ended question, an open-ended question can also determine the participants' previous knowledge on a subject.

Closed-ended questions with ordered and unordered choices yield a more consistent response then open-ended questions. The exploration into unknown subjects is inhibited with the closed-ended format [1].

The following is an example of a closed-ended question with ordered choices:

How many times a day do you brush your teeth?

1. I do not brush my teeth
2. Once a day
3. Twice a day
4. More than twice a day
5. Every other day
6. Once a week

The greatest advantage of using closed-ended questions is the easy way results are compiled. Closed-ended questions are easily documented and graphed so data trends become easy to recognize.

The following is an example of a closed-ended question with unordered choices. Please note the choices do not have a number in the front of them. The answer choices to a survey question should be labeled in an unordered manner to display choices to a survey question independently of each other.

How many times a day do you brush your teeth?

I do not brush my teeth	Twice a day	Every other day
Once a day	More than twice a day	Once a week

Hybrid mixes of open-ended questions and close-ended questions can be used to obtain results, which reap the benefits of both types of questions [1]. The hybrid question presents ordered or unordered answers to the question leaving the option for the correspondent to answer in their own words. This type of question can probe the respondent for new information on a subject while keeping the question easy to answer [2].

Poorly worded open-ended questions can stray the participants into misinterpreting the question. Without the direction of closed-ended answers choices, an open-ended question can render a vital survey question useless.

The following is an example of a hybrid question:

How many times a day do you brush your teeth?

I do not brush my teeth

Once a day

Twice a day

More than twice a day

Other ____

Ideally questions should be tailored to a specific demographic of people receiving the survey. When constructing the survey questions, the target group must be identified. Distinguishing the target and tailoring to a specific group produces a larger return and more accurate results. Presenting fourth graders with a survey formatted with complex language will fail miserably. Keeping the target in mind also gives insight into what incentives can be used to promote the survey [1].

Some words chosen are likely to stimulate an emotional response. Affectively worded questions can inhibit the respondent from answering honestly. Affectively worded questions associated with a negative undertone.

Double-barreled questions are one of the most common survey problems. Double-barreled questions try to get the respondent to answer a question asking two different things [2]. Double-barreled questions must be divided up into two separate questions. The analysis of double-barreled questions produces inaccurate results and must be avoided at all costs.

If questions are too complex the participants' attention can easily be lost [4]. It is imperative that questions be simple to understand and easy to answer. Answers should be concise and clear so that they can be compiled and analyzed with ease.

The order that the questions appear on the survey can affect the outcome. Questions should be presented so the complexity of the questions increases as the survey progresses [1]. "Throw-away" questions are designed to stimulate topic interest [5]. The most important question in the survey should be located towards the end in order to insure that the respondent finishes the survey. "Throw-away" questions are also used at the end of the survey to continue interest in the subject insuring the successful completion and return of the survey.

The interview process indicated problems with the lighting, air quality, and acoustics. These subjects are researched in the following background sections.

2.4 LIGHTING INTRODUCTION

The interview data indicated that the classrooms voted by the students as the worst had insufficient lighting.

2.5 COMPONENTS OF LIGHTING

The purpose of lighting research is to optimize adequate lighting for note taking, clear viewing of the presentation area, and proper illumination of the projection screen. A key aspect of lighting is the ability to control the direction of illumination and prevent the seepage of ambient light from washing out images on the projection screen [6].

Constructing lighting plans consists of choosing what type of lights, ballast, and zoning that is necessary. After the lighting zones are established, the next thing to consider is how to control these lighting zones for ease of use.

A typical classroom is composed of four lighting zones: (1) back row, (2) center seating area, (3) front presentation area, and (4) lectern/side board lights. In lecture halls the first and second sets of lighting banks are usually a combination of 240-volt tungsten filament down-lighting and fluorescent light fittings. These types of lighting are used for illumination in the student seating area. Recessed lamps in sharp cutoff luminaries should be used in the front of the classroom to provide for presentation space. Controlled lighting minimizes light spill on projection screens and avoids shining light directly in the audience's view [8].

Table 2.1: Suggests common light intensities [7]

Location	Foot Candles
desktop level	40-60
overhead projection	10
slide projection	5
video data projection	2

Use of incandescent lighting should be avoided due to its lack of energy efficiency and its high maintenance needs. All the lighting banks should be parallel to the front of the room to ensure better illumination on the student seating area.

When lighting zones are established the location of the control interface needs to be determined. There should be a control panel located on either side of the chalkboard, at the lecture podium, and the master lighting control located at the entrance to the room. Preset options on the control panel allow lighting to be geared toward a specific lighting presentation type. Each preset option will set the room lighting to its corresponding intensity [8]. Electronically dimmable ballasts must be purchased to interface with a programmable light control panel.

To maintain fluorescent lighting equipped with electronic dimmable ballasts the lights in the room must be replaced simultaneously. Dimming characteristics of the light from fluorescents decay as they age. Aged lights will give off a noticeably different amount of light [7].

2.6 INDOOR AIR QUALITY INTRODUCTION

Air conduits provide a source of fresh air for a classroom. Excessive levels of moisture, carbon dioxide, carbon monoxide, or excessive temperature adversely affect a student's performance and ability to learn.

2.7 AIR QUALITY

The indoor air quality (IAQ) of a classroom or a building should be measured periodically and maintained. The Environmental Protection Agency (EPA) in conjunction with the National Institute for Occupational Safety and Health (NIOSH) first performed studies of indoor air quality in the United States in 1971. Since then, they have jointly conducted over 600 indoor air quality profiles. Good air quality is important to the health and comfort of the occupants of the building [12].

Good air quality can be maintained by the introduction of adequate air ventilation, control of airborne contaminants, and maintaining comfortable room temperature and humidity levels. Poor indoor air quality can result in health problems including coughing, eye irritation, headache, allergic reactions, the reduction of productivity, and accelerated deterioration of equipment [12].

The EPA has made the following assumptions with this topic. Investigating in the prevention of indoor air quality problems is cheaper then updating an inadequate system. The resolution of IAQ problems is similar for buildings of various designs and functions. The building management and caretakers can resolve many IAQ problems without any outside assistance, though these problems in many cases can be prevented by educating the building staff and occupants. If the problem is too large or complicated for the management to repair, it would be best if they were educated enough to be informed consumers [12].

2.8 TERMINOLOGY

The main components that affect the indoor air quality are: (1) the source of ventilated air, (2) the heating, ventilation and cooling system, (3) the pathways bringing the air in. The source is the point of entry for a pollutant or contaminant entering the room. The route that the pollutant travels from the source to the room is the pathway. How the pollutant gets from the source into the room is called the driving force of that pollutant. In most cases the HVAC system is the driving force for the pollutant because it controls the air velocity [12].

2.9 SOURCES OF POLLUTION

The sources of indoor air contaminants come from various indoor and outdoor sources. Outdoor sources of air-pollution come from but are not limited to pollen, dust, fungal spores, emissions from nearby sources, i.e. industrial plants, road vehicles, and soil gas [12].

Pollutants could be emitted from sources close to the building such as exhaust from vehicles on surrounding roads, parking lots, or garages. These pollutants could also come from loading docks, dumpsters, or even re-entrained exhaust from the building or from neighboring buildings [12].

Pollutant sources can be found below the building in soil gas. Radon, underground fuel tanks, or contaminants from the previous use of the site can seep through cracks in the foundation [12].

Indoor sources of pollution are likely to come from housekeeping, furnishings, unsanitary conditions, and accidental events. Moisture and standing water promotes excessive microbial growth. Standing water can collect on rooftops after rainfall and it can leak into crawlspaces producing excessive microbial growth. This growth or fungus can be spread throughout the building by air currents created by the HVAC system[12].

The equipment used in the building such as the HVAC system can collect dust or dirt in the ductwork. Improper use of biocides, sealants, and other cleaning supplies can work their way to the occupants. Improper ventilation of the furnace or leaks in air condition systems are other sources of pollution spawned from the HVAC system.

Indoor sources of air pollution that come from non-HVAC equipment are: emissions from office equipment like ozone and volatile organic compounds, equipment supplies like solvent, toners, and ammonia for copy machines, and printers, emissions from maintenance shops and labs like saw, or metal dust and volatile chemical fumes. Elevator motors and other mechanical systems can aid in the circulation of dust and debris [12].

There are a plethora of contaminant sources, which are all brought to the occupants via the driving force. The buildings central heating, cooling and ventilation equipment bring pollutants into the classroom.

2.10 THE HVAC SYSTEM

It is recommended that to keep the occupants of a building comfortable, the temperature should be between 68-72 degrees Fahrenheit. The relative humidity is the amount of water vaporized in the air. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers provide standards for temperature and humidity ranges based on various ages, activity levels, and physiology (55-1981 ASHRAE). These standards were made under the assumption that the occupants are normally dressed. The relative humidity in the room is important because when the humidity is high, occupants feel hotter. A high relative humidity also promotes the growth of mold and mildew creating a nasty environment[12].

Table 2.2: Acceptable temperature and humidity ranges for summer and winter[12]

Relative Humidity %	Winter Temperature °F	Summer Temperature °F
30	68.5 - 76.0	74.0 - 80.0
40	68.5 - 75.5	73.5 - 79.5
50	68.5 - 74.5	73.0 - 79.0
60	68.0 - 74.0	72.5 - 78.0

The temperature must be uniform throughout the room. Without proper ventilation and circulation, temperature variations will result. A deadband is the temperature range where the thermostat is allowed to fluctuate without resulting in the heating or cooling of the room. The deadband can cause temperature fluctuations that make the room uncomfortable. Large window, even when closed often produce complaints of draftiness. This situation can be remedied by getting curtains for the windows[12].

There are three basic types of HVAC systems: one that uses 100% outdoor air for the ventilation, one that uses 100% re-circulated indoor air, and one that is a combination of the outdoor air and re-circulated indoor air. ASHRAE has set standards for the amount of outdoor air intake necessary for proper ventilation seen in table 2.3 [12].

Table 2.3: Selected ventilation recommendations[12]

Application	Occupancy people/1000 ft^2	Cfm/person
Classroom	50	15
Auditorium	150	15

Proper ventilation will help the control of odors and contaminants. Filters are used to remove pollen and dust from the air[12].

2.11 HEALTH PROBLEMS

The health problems or symptoms caused by poor indoor air quality can be a distraction to the students from the professor. Medication students take to reduce these symptoms may cause drowsiness or inhibit their perception. Building occupants with allergies, respiratory disease, and other immune deficiencies are more susceptible to poor air quality[12]. Headaches, fatigue, shortness of breath, sinus congestion and other flu-like symptoms are likely outcomes of poor air quality[12].

When people experience health effects from spending time confined in a building they are considered to have Sick Building Syndrome (SBS). SBS harms the well-being of the building's inhabitants but does so without the scientific proof [12].

A Building Related Illness (BRI) is an illness diagnosable and can be linked directly to exposure. Two examples of BRI are Legionnaire's disease and hypersensitivity pneumonitis[12]. Environmental stressors inhibit learning by subjecting the students and professors to an uncomfortable environment. Uncomfortable conditions in a classroom will not surmount to an identifiable health problem but will inhibit learning nonetheless.

2.12 IAQ PROFILE

To evaluate the indoor air quality of an existing building an IAQ profile should be developed. An IAQ profile is a description of the buildings function, structure, and occupancy that impacts the indoor air quality. To fully understand and analyze the IAQ the following measurements should be made: airflow, temperature, relative humidity, carbon dioxide, and carbon monoxide[12].

2.13 ERGONOMICS

The study of ergonomics as a scientific field was originally designed to play a functional role in industry. With an understanding of how the human body works and how people behave, one can apply ergonomic design to achieve the optimal relationship between the worker and the work place.

The first documented study was published by Ramazzini in the early 1700s relating bad posture, poorly designed tools, and the consequential health effects on workers[15]. Since then, ergonomics has expanded its scope to the allocation of a wide variety of scientific and engineering fields. This includes, but is not limited to, the biological sciences (i.e. anatomy, physiology, epidemiology), mathematics, behavioral science, physics, chemistry, applied mechanics (i.e. statics, dynamics, fluids, thermodynamics), electrical engineering, and computer science[16].

The root of the word "ergonomics" is Greek in origin. It stems from ergon meaning work and nomikos meaning law. This term was first widely used in Europe and has slowly made its way into the US. Historically, the term "human factors" was used in the US and Canada to describe a larger scope of application which included consumer product design. However, with time ergonomics as a respectable scientific field has evolved, eliminating much of the controversy. Now the terms human factors and ergonomics are often used interchangeably, which was reflected in the changing of the Human Factors Society to the Human Factors and Ergonomics Society in 1993[16].

2.14 ERGONOMICS APPLICATIONS

The optimization of worker productivity coupled with a healthy environment is the ultimate goal of ergonomic research.

> "The two conflicting factors in this optimization process are workers' productivity and their health and well being. That is, while workers should perform their job in the most efficient manner possible, they must also be protected against undue physical, biological, and psychological strain that may occur as a result of performing the required tasks." [16]

There are four primary applications to ergonomic research [16]. They include:

1. modification or replacement of equipment
2. modification or replacement of work space/workplace layout

3. modification of work methods
4. controlling of the workplace environment, i.e. manipulation of heat/cold, noise light

Many jobs in our society require time to be spent in front of a human-systems interface requiring a mental workload. In the context of education, the primary goal for ergonomically applied principles associated with the classroom setting is the ease of information transfer. All applications of ergonomics ultimately feed into a dynamic relationship between the teacher, student, and classroom/learning materials.

The addition of multimedia in the classroom has become prevalent in recent years. Computers have revolutionized the way information is communicated. They have joined the classroom to supplement the use of overhead projectors and chalkboards.

Through the research performed by learning theorists, application #3 has resulted in changes in teaching methodology. One example is that of the use of small group work. Although we couldn't directly require a professor to teach in this manner (and in some cases group work is not appropriate) we can design the classroom to better accommodate and encourage this method of learning. Classroom design is for practical purposes ergonomic application #2 but can influence application #3 in education.

While teaching depends primarily on the capabilities of the professor, the environment in which the student learns plays a significant role in the learning process. Issues like an overheated or cold room can make learning difficult. Issues of comfort are not limited to room temperature.

The student must feel comfortable in the seats provided without having to reposition themselves in a manner awkward to their natural seating posture. The desks must be adequately sized for students. The student must be able to hear the professor and see the visual aids with the least possible strain on the neck and back. By relieving these obstacles, the focus in the classroom can remain on the actual mental workload of learning. The role of Occupational Ergonomics as a solution oriented branch of ergonomics. "Its goal is to optimize worker well-being and productivity by treatment of the work stressors" [16].

2.15 THE HUMAN BODY

A comprehensive understanding of how the human body works and moves is critical to the proper design of materials people interact with. What good is a comfortable chair if it's design is such that it is difficult to climb in and out of? Body movement is governed by what is called anthropometrics, which is the study of the lengths and motions of body parts. But before that can be discussed a review basics of human anatomy and physiology relevant to the study of ergonomics need to be established.

2.16 ANATOMICAL POSITIONS

Because the human body is a complex, 3 dimensional, compact network of bones and tissues, an organized system of reference is needed to describe the location of body parts in relation to each other. All reference planes and directional terms are made relative to the body when it is in anatomical position. Anatomical position refers to the body when it is standing erect, head facing forward, with the palms facing outward [17].

Three planes of reference describe the different cross sections of the human body. The midsagittal plane cuts the body into left and right sections. It runs through the middle of the body, which inherently excludes the legs (Figure 2.1). Tissue that is described to be medial is relatively closer to the midline formed by this plane. Tissue is considered lateral if it is relatively farther away from the midsagittal plane. However, a sagittal plane refers to the same plane parallel to this section, but it is not limited to the center of the body. A sagittal plane may include portions of an arm or leg [17].

The coronal plane (frontal plane) also runs lengthwise down the body and separates the body into front (anterior) and back (posterior) sections (see Figure 2.1). Anterior/Posterior refers to tissues relative to the front and back of the body. The kidneys are posterior to the intestine [17].

The skeletal system consists of bones (206) and connective tissue. There are four types of bone: long bone, short bone, flat bone, and irregular shaped. 106 of them are solely contained distally from the wrists and ankles. The 33 or 34 vertebrae that constitute the irregular shaped bones of the back are classified as 5 types. There are 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 or 5 coccygeal vertebrae whose number varies from person to person (see Figure 2.2).

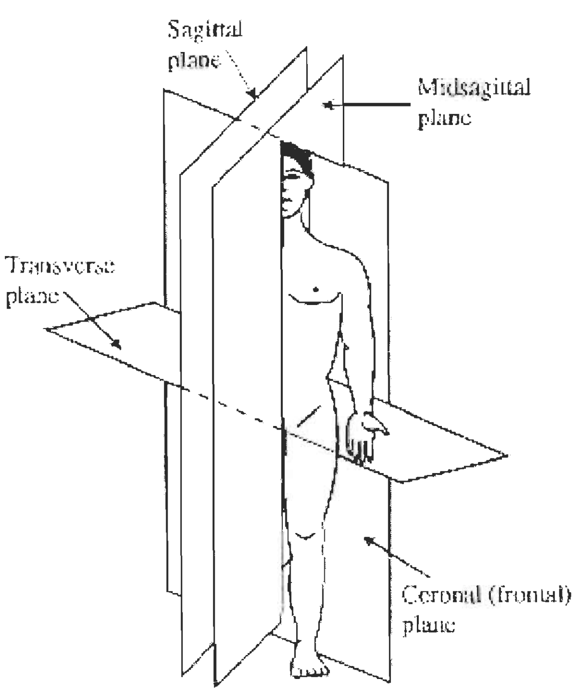

Figure 2.1: Human planes [17]

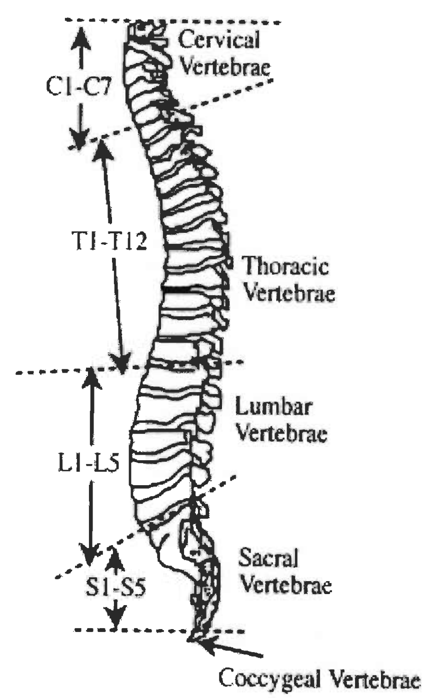

Figure 2.2: The spine [17]

The vertebrae of the sacral and coccygeal regions fuse after childhood forming the sacrum and the coccyx [18]. Vertebrae are connected by intervertebral discs. The disc's elastic properties allow motion and curvature of the spine due to the viscus fluid contained within them. Unfortunately the discs themselves do not receive blood flow. They need to obtain nutrients through diffusion. When pressure is put on a disc, fluid rushes out. When this pressure is relieved, the fluid now containing nutrients flows back in[18].

Curvatures of the spine constitute a substantial portion of deformities of the back. Scoliosis is a well-known abnormal curvature of the spine. It specifically pertains to a curvature that pushes vertebrae laterally outward, breaking the midsaggital plane. The non-epidemiological model of the spine has no lateral curvature.

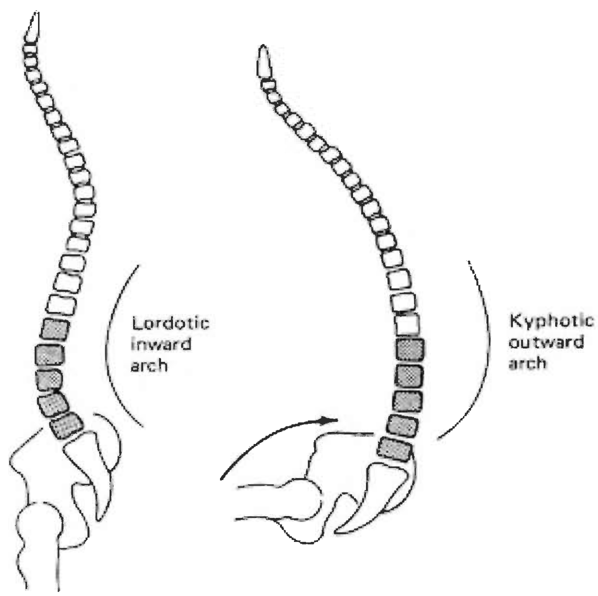

Figure 2.3: Lordotic and kyphotic curvatures [17]

Lordosis and kyphosis are curvatures of the spine that people are usually unfamiliar with. Lordosis is a natural front facing arch that according to a saggital plane points towards the anterior portion of the body. It is important to note that this is anatomically correct for the lumbar and cervical regions, and occurs to a small degree when standing.

However, medically lordosis refers to a pathological exaggeration of this curvature. Conversely, Kyphosis refers to the arching outward of the lumber spine, which effectively flattens the natural curvature [18]. This occurs when people are seated.

2.17 SEATING CONSIDERATIONS

Discomfort resulting from inadequately designed seating or poor work posture can decrease one's attention span, concentration level, learning ability, and work output. This issue has prompted efforts to design seating that is both ergonomically fit for people, and which promotes a supportive posture that reinforces the specific nature of its use.

2.18 BIOMECHANICAL ANALYSIS

The fields of biomechanics and ergonomics are concerned the physiological demands of people. As a result, research has been carried out to divulge the nature of body weight distributions and relative tensions acting on different parts of the human body. The tension (postural stress) acting on the intervertebral discs is thought to be higher when sitting than when standing [18]. Specifically, the intervertebral disc that lies between the 5th lumbar (L5) and the 1st sacral (S1) vertebrae has drawn much attention due to a strong likelihood for injury [16]. This stress is due mainly to tilting of the pelvis backwards, resulting in a torque that pushes against the natural lordosis of the lumbar region. A backrest designed to support the lower back will counteract the tendency for a kyphotic arch to form, allowing for a reduction in tension[19].

It is important to mention that even small changes from a symmetrical seating position can cause adverse and often unpredictable strains on the body with prolonged exposure[19]. It is a natural tendency for people to adjust their seating position. This is a healthy behavior, which stretches muscles, encourages blood flow to the legs and allows diffusion of nutrients into the intervertebral discs. However, a chair should provide proper support so that the user need not try to compensate for a poorly designed chair at the risk of injury.

Recommendations based on biomechanical evidence follow the goals to maximize proper balance of the trunk, minimize tensions in the back and promote comfort. For instance, it is suggested that the height of the chair should enable a person's feet to fully touch the ground with a 90^{o} bend in the knees [19]. If the seat height is too high, the thighs will compress resulting in a loss of blood flow, increased pressure on the buttocks, and possible ischemia[20]. The length of the seat should compare to about 2/3 the length of the user's thigh. If it is too long, then the user is forced forward, disabling the use of the backrest[20].

Desk chairs designed for long seating periods should have adjustable height and backrest controls. The difficulty arises with fixed seating when a design must fit a population of varying body shapes and sizes. Anthropometrical data on the lengths of arms, legs, seating heights, etc. is usually gathered to model the target population.

Different design philosophies pertaining to the way anthropometrical data is handled dictates design parameters [16]. The main design philosophies are as follows:

1. Designing for the average
2. Designing for the largest
3. Designing for the smallest
4. Designing for the majority

It would be unwise to design a chair to exclude smaller people from using it. The universal solution is to design chairs that can adapt to the user. Adjustable backrests and height adjustment are ideal features to satisfy ergonomic demands. In the case of fixed seating, where neither the backrest nor height can be manipulated, a design that will include the 95th percentile of the population is often used [16].

2.19 FUNCTIONAL REQUIREMENTS

When making decisions on the choice of seating, it is important to understand the needs associated with different types of learning facilities. The function of the room will dictate the seating arrangement and consequently, the type of seating used. At least 13 different types of functional seating arrangements have been documented [21].

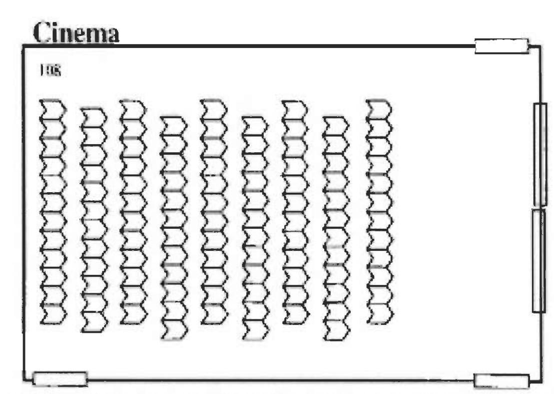

Figure 2.4: Cinema [21]

The "cinema" arrangement (Figure 2.4) is designed for large audiences and is ideal for lectures involving one-way communication, but discourages interaction and group work [21]. Good sight lines for large lecture halls depend on sloped floors and staggered seating, however the vertical viewing angle should not be greater than 15° [22]. Peripheral chalkboard sections should be angled to offer the best possible viewing angle for the students located on the far end of the room. It is recommended that the horizontal viewing angle be no steeper than 45° relative to the center-line, though slightly sharper angles are acceptable [22]. The furthest viewer should not be farther than "six screen height multiples from the projection screen", and the nearest viewer should not be much closer than two[22].

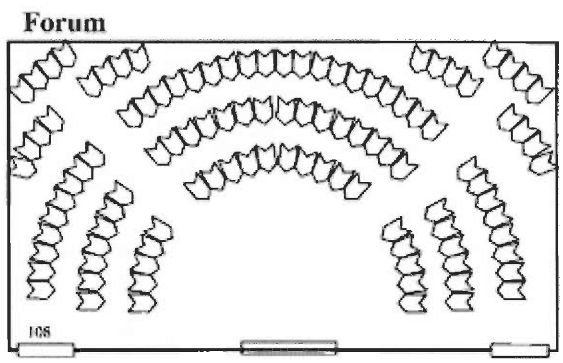

Figure 2.5: Forum seating design [21]

The "forum" arrangement (Figure 2.5) consists of a half circle. Verbal exchange between the presenter and the audience is encouraged. This is ideal for speeches and councils. However, the use of imaging equipment is compromised due to the steep viewing angle of the peripheral seating, which results in poor sight lines[21]. The "classroom" arrangement (Figure 2.6) as described by the technical services at Melbourne University to be ideal for teaching to small groups of students. Interaction between the professor and students is encouraged, but collaboration between students is not. Seating broken up by a middle isle or desks partitioned off in groups of 2-4 will mend the situation, allowing for dialogue between neighbors[21].

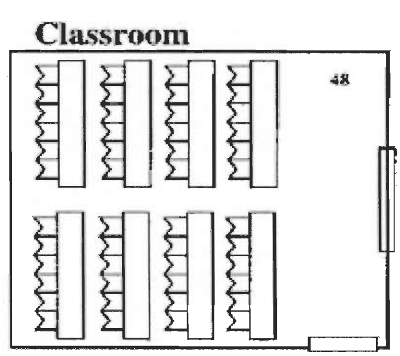

Figure 2.6: Classroom [21]

Seating capacity is a factor that dictates the type of seating used. Seating must be chosen appropriately according to the demands of the room and the nature of instruction. Seating arrangements must facilitate the optimal communication and interaction when appropriate.

High cost, ergonomically designed seating with special caster-wheel mounted legs allow for easy manipulation and optimal comfort. This is ideal for computer labs and collaborative classrooms, but wouldn't be functionally ideal for a large lecture hall. The recommended space allocation for this particular type chair it 15 square feet [23].

A successful design scheme for educational facilities acknowledges the relationship between design and function. Ergonomically designed seating is often employed for users expected to perform in front of a control interface or a computer for extended periods of time. Rooms designed for collaboration are likely to contain user adaptive seating as well to ensure comfort and support for extended seating periods. A large lecture hall is more likely to have fixed seating however, which offers less comfort for a larger portion of the audience, but designed with a more aggressive backrest for note taking.

2.20 ACOUSTICS

Intelligibility is the primary motivation behind acoustics research in classroom design. By following simple guidelines, an acoustically sound structure can be constructed allowing for optimal function and communication. If these guidelines are ignored however, the improper use of materials or poorly designed dimensions could result in an expensive problem to fix.

2.21 SOUND AND NOISE LEVEL MESUREMENT

Throughout the latter half of the century, there have been many different attempts to quantify sound and noise measurements. Many of these measurement protocols rely on taking measurements for extended periods of time to determine the duration, average, as well as peak noise pollution levels in residential and industrial environments.

It is difficult to objectively quantify sound due to its complex nature. The most widely accepted scheme for sound measurement is the decibel system. The decibel system was devised in a way that compares two sound pressures.

$$\textit{Decibel ratio} = 20 \cdot \log\left(\frac{P_1}{P_2}\right)$$

Equation 2.1: Decibel ratio [24]

Equal perceptual increases of sound rely on the same ratios of pressures, regardless of how loud or soft the sounds are[24]. The ratio of (.0002/.0004) dyn/cm^2 =1:2 pressure units= 6 dB perceptual increase at 0-6 dB, .001/.002 dyn/cm^2 =6dB perceptual increase at 14-20 dB.

A sound level meter bought today comes with at least two accepted weighting options for measurement, an A-weighted (L_A) and C-weighted (L_C) measurement [25]. A C-weighted noise measurement closely measures the sound pressure level (SPL) for frequencies between 50 and 5000 Hz. With primary sound (non-reverberant) a direct correlation can be made between SPL and energy, thus validating the use of a C-weighted measurement [26].

An A-weighted measurement takes into account the variable sensitivity of the human ear to different frequencies. Thus an A-weighted measurement closely measures what a human would actually experience when subjected to a particular noise. This weighting would account for the fact that the human ear is more sensitive to mid-range and high frequencies than to low frequency sound [26]. When taking a noise level measurement, the dominance of low frequencies can be quantified by subtracting the decibel readings of the C weighted measurement minus that of the A-weighted measurement [25].

$$LC - LA = \text{Dominance of low frequency sound}$$

Equation 2.2: Dominance of low frequency sound [24]

Audibility is the principle concern for the purposes of classroom design, therefore two types of data are of interest, (1) ambient background noise from air conditioning/ventilation systems, and (2) reverberation time. The former of the two is a straightforward measurement that is easily quantified experimentally, and can be scrutinized against standardized values [26].

A correlation can be made between the volume of airflow and the amount of un-damped noise that emanates from the ventilation system [27]. However, units made by different manufactures vary in quality and performance. As a result, air conditioning units are rated in terms of a preferred noise criterion (PNC) [27]. A unit with a PNC=15 will not produce more than 26 dB-A where as a PNC-40 would not produce more than 48 dB-A. A PNC-35, producing no more than 43.5 dB-A would fall under the Environmental Protection Agency's recommendations for a classroom space [25].

When making measurements it is important to note the weighting used (A or C), the distance to the point of origin (though with ambient noise it may be difficult to pinpoint) and location relative to the layout of the room. Taking measurements at different areas of the room- preferably where people will be seated- provides a thorough set of data [25].

A decibel meter may come with a peak level option that records the highest observed decibel reading for any given length of time. When using this setting it is important to clarify that it is a noise level measurement, where the duration of the intensity is not noted [26]. For the purposes of recording a relatively steady, low intensity sound similar to that of an air conditioning unit (~45dB-A), it will suffice to take a peak noise level reading. It is of little importance to take the measurement as a time-plotted value or a time-averaged value. These latter types of readings are considered to be noise exposure level measurements. They are often used in legislation to monitor residential neighborhoods and industry, and to gauge the difference between a loud noise of short duration (such as a plane passing overhead), and noise of a constitutive nature [27].

2.22 REVERBERATION

The phenomenon of sound transmission from one room to another is due to poor barriers between rooms. Misconceptions about the properties of sound absorbent materials can lead to this problem. Sound absorbent materials do not prevent noise transmission. The prevention of sound transmission from room to room is due to the properties of pre-existing walls that are not subject to manipulation for a classroom redesign project [28]. Although sound transmission to other parts of the building is an important factor to consider when constructing an educational facility, the focus of this discussion will be on sound conditioning, with deals with the treatment of sound within the room in question.

Reverberation is a complex phenomenon to deal with and requires more specialized equipment to measure and analyze than a simple noise level measurement[26]. However, for the purposes of classroom design it is of little importance to actually measure reverberation. Rather, it is sufficient to make approximations through calculation and to follow guidelines to minimize reverberation.

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Reverberation time (RT) is defined as the amount of time it takes for a sound to decrease in intensity one million fold. This is equivalent to a 60-dB drop, regardless of the initial intensity of the noise [28]. RT relies on the size and shape of the room, as well as the materials that make up the ceiling, walls, and floor. It is dependant on the absorption ability of the materials in the room as well as well as the frequency of sound-surface interaction, represented by the volume of the room [24].

RT can be calculated roughly using the Sabine formula, where V= volume of the classroom and A= total absorbance of all the surfaces combined.

$$\mathrm{RT} = 0.49 \cdot \frac{\mathrm{V}}{\mathrm{A}}$$

Equation 2.3: Reverberation time (measured in sabins) [24]

Total absorbance is actually a summation of the areas of the individual surfaces of the room (s) multiplied by the respective absorption coefficient of the material (α).

$$\mathrm{A} = \sum_{n}^{i} s_i \cdot \alpha_i$$

Equation 2.4: Total absorbance [24]

Reverberation time varies with frequency and low frequencies are much more likely to have longer RTs. A lecture hall of 100,000 cubic feet is likely to have a RT at 500Hz of 1 second when empty, making speech without the use of a microphone difficult [24]. This formula is sufficiently accurate for absorption coefficients that do not approach 1. One would expect that when a substance is 100% absorbent, the reverberation time would approach zero, however, the mathematical result of a perfectly absorbent material is equal to .49V divided by the surface area. This is an erroneous result [24].

A factor that would cause a margin of error between the predicted and actual measured value for frequencies above 1000Hz is that at high frequencies, absorption by the air becomes significant. Margins of error for low frequencies can result from the fact that the Sabine formula assumes homogenous sound pressures throughout the room [26]. It does not consider the potential for the generation of standing sound waves. When a wavelength is equal to, or a multiple of any of the three dimensions of a room, they can resonate between parallel walls, producing extended reverberation times [24].

2.25 SOUND ABSORBANT MATERIALS

A significant reverberation time may be desirable for concert halls to provide a stereophonic reception of a concert orchestra. This is not a desirable effect for the classroom setting however. "A short decay period favors speech intelligibility because each spoken syllable dies away in so short a period that successive syllables cannot mask it" [25]. When a sound is emitted in a room, it has three possible fates when it makes contact with the surrounding walls. It can be reflected back, absorbed, or transmitted through the wall. Rigid, flat, and smooth surfaces are likely to reflect a large portion of incident sound waves in a geometrically predictable way. Materials such as concrete, brick and other common building materials have these properties. Conversely, materials that are porous and flexible are likely to both transmit and absorb incident sound [27]. A pressure wave will hit and push up against a surface. If the matter is porous then the pressure wave will penetrate the surface and create friction between the molecules of air and that of the material. If the material is flexible in nature then much of the pressure wave will be converted into vibrational energy and eventually dissipate as heat [25].

The ability of a substance to absorb sound partially depends on its thickness. Creating a space between the hard wall and the decor is a common construction technique. The space created allows a place for sound to reflect back and forth internally, maximizing its potential to dissipate sound. This is often implemented in ceilings, where there already is space for the ventilation network [25].

An absorption coefficient tells you the proportion of sound that is absorbed over the total amount of incident sound. A coefficient of .2 will absorb 20% and reflect back 80% [25]. Materials are rated from zero to one and are specified as being tested either by a noise normal to the surface (90^O) or from all directions. It is important to note that absorption varies with frequency so that an absorbance value obtained for 5000 Hz may not accurately predict the absorbance at 500Hz. Comprehensive data on the absorption and transmission coefficients of acoustic materials can be obtained through the US Department of Health, Education, and Welfare [25].

Treatment of a room by sound absorbent materials can be quantitatively gauged by the noise level reduction (NR).

$$(a) \quad NR = 10 \cdot \log \frac{A}{A_0} \qquad\qquad (b) \quad NR = 10 \cdot \frac{RT}{RT_0}$$

Equation 2.5a: Absorption dependent noise level reduction [25]
Equation 2.5b: Reverberation time dependent noise level reduction [25]

NR is measured in decibels, A_0=the total absorption at frequency f before treatment, A=total absorption at frequency f after treatment, RT_0=reverberation time at frequency f before treatment, RT= reverberation time at frequency f after treatment. A ten-fold increase in total absorbance (measured in sabins) will produce a 10dB noise reduction, resulting in a ten-fold reduction in reverberation time [25].

2.26 DESIGNING ACCOMODATIONS for the DISABLED

Under the Rehabilitation Act Amendments of 1974, federally funded institutions and facilities were required to follow the guidelines instated for accommodating disabled persons. As of July 12, 1990, the Americans with Disabilities Act (ADA) expanded this requirement to all facilities and institutions. This includes places of adult education including private, non-federally funded schools, which falls under public accommodations title III[28]. WPI has recognized both laws and has established an extensive protocol to accommodate disabled students entering the institution.

There is interpretation integrated into the law. It is not clear-cut as to the exact technology needed to facilitate the optimal learning potential of the students in question. An important stipulation in the law is that the accommodations provided need not result in a harsh financial burden i.e. major renovations to an existing building, or expensive sophisticated interpretive software. It is left to the administration and faculty to decide what is most appropriate, though it is encouraged to employ experts like doctors, speech pathologists and audiologists to help in the process. WPI has set up extensive support services to facilitate proper aid to students, however, the student has the right to appeal to the Dean of Student Affairs for any accommodation they feel is insufficient for their needs[28].

43 million Americans are thought to be disabled in some way, 33 million of which having disabilities not associated with wheelchairs[27]. Many of these people suffer from communication related disorders including hearing, sight, and learning impairments. This means that adding ramps and guardrails is not sufficient to accommodate all disabled individuals.

Lecture halls are now required to provide listening devices for the hearing impaired and interpreters for completely deaf students. For newly built lecture halls, installment of a permanent sound augmentation device is strongly suggested. For existent buildings, portable devices are a cheaper option worth considering. WPI's existing policy provides adaptive equipment, use of a note taker, and use of an interpreter[28].

It is important for wheelchair-bound individuals to have a clear view of the presentation space. Recommendations for the allocation of seat space to suite wheelchair-bound individuals vary from 1% to 2%[20, 23]. The seats that would otherwise occupy that space should be removed, and the area chosen should be on the ground level in the front, towards the center of the room[20]. The clearance height for wheelchairs is 31", and most tables are 29" high, so tables intended for wheelchair accessibility should be obtained[23]. All ramps must not have a steeper incline than a one-foot rise for a twelve-foot run. When designing the entrances and turns, an angle sharper than 60^{o} is not acceptable [23]. Text enlargement software for the visually impaired is suggested (pg 42). WPI offers tape recording of lectures and taped texts to accommodate visually impaired students. A full description of Worcester Polytechnic Institute's policies can be found on their website.

CHAPTER 3 - METHODOLOGY

3.1 SURVEY DESIGN

The Classroom survey was conducted through an Internet website, http://www.wpi.edu/~thomas7/index.htm. An online survey was chosen for the ease of distribution. The WPI student body relies on the web for class registration and multiple other student activities. Internet literacy is an intimate feature at WPI, so participating should not have any technical difficulties accessing the website.

Frame technology was employed to help create a more appealing and easy to use interface.

Screen Shots of the Web Site

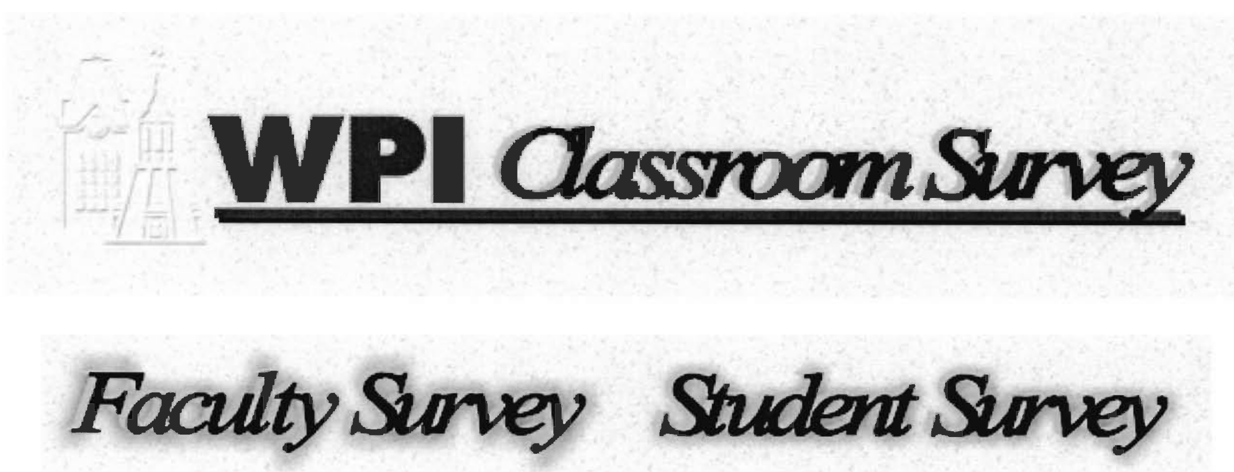
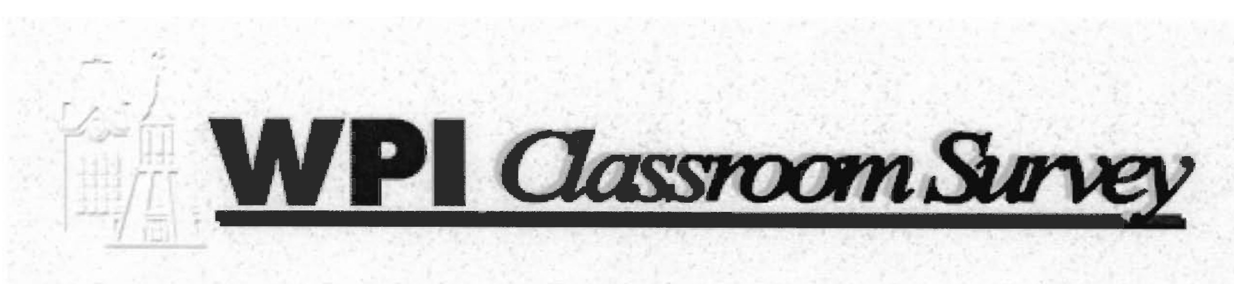


Figure 3.1: This is a screen shot of the website



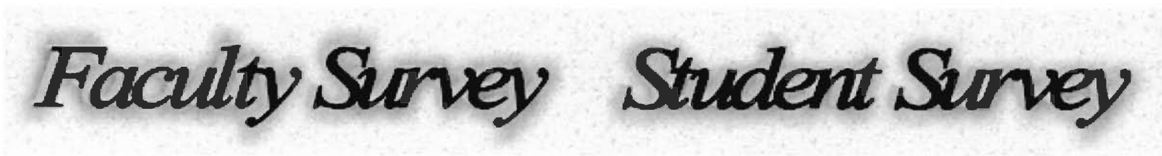


Figure 3.2: Example of student survey selected

The use of JAVA and JAVA script were supplement the user with instant feedback. The light-up effect was used to prompt the user to click on the correct department.

Recording and collecting data was simplified through server-side web programming. HTTP or Hyper Text Transfer Protocol was developed to let web browsers communicate with web servers and display web pages. Using HTTP web browsers direct the web servers to transfer data over the Internet. The common gateway interface or CGI lets HTTP interact with applications on the web server. This standard can be written in to applications to allow programs to be executed over the worldwide web. Scripts and other programs must be written to interact with this common web interface. The standard input and output of programs can be piped to the common gateway interface and then redirected over the Internet to a web browser.

To intercept the data from the common gateway interface a PERL script was written and tested. Form fields prompt the user to type in or check their answer. The form field results in conjunction with the common gateway interface provide the input for the PERL script.

This script called survey.cgi intercepted the information and parsed out the answers to the survey questions. Once the information was correctly parsed, titles associated with each answer were sent with an email message.

Multiple web technologies helped the user effortlessly coast through the survey process. The Worcester Polytechnic Institute Apache web server served out HTML to display the survey questions and to execute the PERL script responsible for handling the input from the common gateway interface.

The finalized question format entailed closed-ended questions with ordered choices, close-ended questions with unordered choices and open-ended questions. Each different question was carefully worded to deliver the best possible results.

Once the HTML is downloaded and the student survey page loads up in a web browser the introduction to the survey clearly instructs the user on how to answer the first set of questions.

The first round of survey questions required that closed-ended questions with ordered choices be used to establish a criterion for students to judge the classrooms on campus. The survey results for this section were considered useless for statistical analysis. The close-ended questions with ordered choices were used to establish the criteria for evaluation. Closed-ended questions were used to make the data compilation of the useless data as easy as possible. Computer compilation is suggested with closed-ended questions and the format works nicely with the web interface. The questions in the first section of the survey are as follows:

Please rank the following criteria in its importance to you to facilitate learning.

VU- Very Unimportant U - Unimportant

I - Important VI - Very Important

A classroom's appearance	VU ☐	U ☐	I ☐	VI ☐
The comfort of the seats and/or desks in the classroom	VU ☐	U ☐	I ☐	VI ☐

A classroom's equipment and multimedia support	VU ☐	U ☐	I ☐	VI ☐
The capability for working in groups	VU ☐	U ☐	I ☐	VI ☐
The number of seats in a classroom	VU ☐	U ☐	I ☐	VI ☐
How easy it is to hear the teacher or the multimedia in a classroom	VU ☐	U ☐	I ☐	VI ☐
How easy it is to see the blackboard or other visual aids in a classroom	VU ☐	U ☐	I ☐	VI ☐

Figure 3.3: First round of survey questions

The students are asked to rank the following criteria in its importance to facilitate learning. These seven questions quickly start the respondent thinking about the classrooms at Worcester Polytechnic Institute, the impact classroom had on their learning experience, and how they should judge those classrooms.

The eighth survey question is the most important question of the survey. This question asks the students to identify what they feel to be the most inadequate classroom at Worcester Polytechnic Institute. A closed-ended question with un-ordered choices was used to accomplish this. By following the link, "Click here for a listing of all classrooms at WPI" the students can consult a full classroom listing to refresh their memory. The question reads as follows:

Based on your ranking of these criteria, what is the worst classroom you have used at WPI? Enter classroom number here __________	Click here for a listing of all Classrooms at WPI.

The default text prompts the user to type in their answer in the space provided. The closed-ended format of this question lends itself to easy compilation and the unordered choices presents all classrooms to keep from leading the response.

"Throw-away" questions defined in the background, occupy the last section of the survey to ensure the proper submittal of the survey. The students are asked to recall a class they have had in the bad classroom. This question was used to identify demographics information about the response. The last question asks the respondent to supply their name for the contest. This allows the correspondent to choose to submit the information anonymously. The open-ended questions that make up the last section of the survey are as follows:

What course did you take in that classroom?

What's your name (Necessary for the contest)

At the bottom of the page the submit button reads, "Submit The Survey".

A confirmation page is created by the PERL script to give the user a sense of closure to the survey process. This confirmation page thanks the respondent for their time used taking our survey.

The questions in the survey were constructed to minimize measurement error by supplying clear guidelines for the responses. According to software design principles the entire survey process relates a feeling of the beginning, middle and end of the system.

One of our greatest advantages with the survey was the ease with which we obtained our population listing. WPI Computer Center supplied the whole student listing along with supplemental information. The full names of the students along with their telephone numbers, majors, class years, and finally their mailbox numbers were requested in the format of a Microsoft Word transmittal. The mailbox information would be used in the mailing. The student's class year and major were be compiled for demographics analysis. Telephone numbers were requested in case a follow-up interview would be needed in the future. Obtaining the exact student listing from the college ensures that coverage error would be minimized.

Choosing the sample group out of the population of the survey is tricky. The sampling group must be chosen to minimize the coverage error in the survey. Freshmen, participating in the survey would drastically increase the amount of measurement error because of their lack of experience with the classrooms on WPI's campus. For this reason, the freshmen class was excluded from the survey.

All students on the transmittal were assigned a reference number in the order that they appeared. A JAVA program randomly picked the students for the survey by their assigned reference numbers.

3.2 SAMPLING ERROR

The WPI undergraduate student body numbers under 2,500. A 95% confidence with a plus or minus ten percent sampling error can be tolerated for this type of experiment. In conducting a survey, the common knowledge and experiences, or lack there of, by the survey pool must be taken into consideration. This assumed knowledge and experience of the students translates into the "split" of the population. The split is a study of the ratio of the survey pool that has the assumed knowledge compared to those who do not. The standard splits are 50\50 and 80\20. To ensure the validity of our survey, the students who are chosen to be in the survey pool consisted of sophomores, juniors, and seniors only. The freshmen were omitted from this survey due to their lack of classroom experience. Not having the freshmen in our survey, allows us to assume a more favorable split of 80\20 [1.] For these criteria, sixty completed useable surveys are needed [1]. A 50% response rate validates that the survey results accurately represents the opinions of the population. To predict a fifty percent return rate, at least one hundred to one hundred and fifty surveys must be sent out.

To boost the response rate a "carrot" or prize for participating should be used. In the notification letters of our survey, we publicized a contest to win a Nintendo 64 game console. After completing the survey the students were asked to enter their name for contest. Making the students input their name to be entered in the contest made it necessary for the students to read the survey and fill everything out. Another incentive to participate in the survey is making the respondents believe that they are contributing to an important cause.

In the initial letters sent to the students, we tried to gain their interest in participating by explaining the legacy they could leave by improving the classrooms of Worcester Polytechnic Institute. The personalized letter mailed out to all the recipients of the survey is as follows:

INSERT STUDENT NAME HERE,

Congratulations, you've been selected to partake in an on-line survey regarding classrooms on campus. For your participation in the survey you will be eligible to WIN A NEON NINTENDO 64 CONSOLE AND CONTROLLERS! Although participation is voluntary, this will allow your voice to be heard regarding the state of WPI's teaching facilities. The process is simple. On Wednesday, November 15th, you will receive an e-mail containing the Internet address of your survey. Copy the URL of the survey into an Internet browser of your choice, such as Netscape or Internet Explorer.

The survey will take approximately three minutes to finish. Once the survey is completed, you will automatically be entered into a drawing to win a new neon Nintendo 64 console and controllers. The chances of winning may be good as one in sixty, but no less than one in one hundred.

This is a rare opportunity to tell the WPI administration how you feel about the classrooms where your valuable learning time is spent. Not only that, but your reply could affect the lives of students in the years to come.

Thank You (Ink signature placed here)

The second letter shown below was emailed to all the recipients of the survey. The email contained the URL for the survey. The email is as follows:

Dear Participants (Student's Name Here),

Congratulations! You've been selected to participate in an online survey. For your participation in the survey you will be eligible to WIN A NINTENDO 64 CONSOLE AND CONTROLLERS. This is a rare opportunity to tell the WPI administration how you feel about the classrooms where your valuable learning time is spent. Your reply could affect the learning of students in years to come. Just copy the following URL of the survey into an Internet Browser: http://www.wpi.edu/~thomas7

Thanks,

Tom Plunkett

Follow-up emails were sent out a week after this one thanking those who participated in the survey and asking those who did not participate to please return a survey.

3.3 FOLLOW UP FACULTY INTERVIEWS AND STUDENT INTERVIEWS

In addition to the student survey, a faculty interview and a student interview was conducted. The faculty interviews focused on the professors at Worcester Polytechnic Institute that teach in the troubled classrooms pinpointed as the worst by the surveyed students. The sample group for the student interview consisted of the students that named AK 116 or OH 107 as the classroom on campus most in need of change. In the interview process the faculty and students will be asked the following questions:

1. Short project introduction to introduce us.
2. What classrooms do you think are in need of change at WPI?
3. Would you like to comment on the classroom's appearance?
4. Do you have any comments on the seats and desks in the classroom?
5. Is there anything you would like to comment on about the multimedia support in the classroom?
6. Do you have any comments on the classroom's ability to facilitating group work?
7. Would you like to comment on the scheduling of the class or the amount of students put in the classroom? Was the number of students too many for the classroom, just the right amount, or not enough students for the space provided?
8. Would you like to comment on the audio systems of either OH 107 or AK 116?
9. Would you like to comment on the student's ability to see the blackboards or other visual aids?
10. Do you have any other comments about AK 116 or OH 107 that you would like to add?

Thank you for your time

3.4 LIGHT QUALITY MEASUREMENTS

Taking notes and filling out the lighting checklist developed a lighting profile for each classroom. Notes were taken describing the light fixture locations, the type of lighting in that fixture, and how that lighting was controlled. When measuring each zone, acquisitions should be taken at desktop level, facing the chalkboard or projection screen. Measurements were made for the following: overhead projection, slide projection, and video and data projection. The time and ASA settings on the meter were set to 1 second and 100 ASA respectively. The lighting checklists were completed for OH 107, AK116, and SL115. SL115 was used a control to evaluate the lighting measurements made in AK116 and OH107. This classroom was used as the control because it was recently remodeled, it is similar in size to the classrooms under evaluation. SL115 is updated with the most current lighting heuristics.

3.5 INDOOR AIR QUALITY MEASURMENTS

To produce an indoor air quality profile, measurements of the carbon monoxide, carbon dioxide, temperature, and humidity levels need to be taken. Air quality measurements were recorded during the days that the classroom occupancy was at its highest.

Based on this data the indoor air quality measurements were taken on Thursday in room 107 and Friday in room 116.

In the preceding situation the origin of the problem is usually a faulty HVAC system. To take these measurements the following equipment was used:

1. Q – Trak™ IAQ Monitor with Carbon Monoxide sensor.
2. TrakPro Data Analysis Software Version 3.05
3. CO_2 monitor calibration tanks, a laptop computer, an extension cord, and a power strip.

The Q-Trak™ IAQ Monitor with carbon monoxide sensor, TrakPro Data Analysis Software, and the CO_2 monitor calibration tanks were obtained from the Environmental and Occupational Safety Manager, Dave Messier. The CO_2 sensor on the monitor was calibrated according to the standard operating procedure given by TSI incorporated, the maker of the Q – Trak IAQ monitor

[13]. The Q – Trak was then connected to the computer via the computer interface cable. The TrakPro Data Analysis software was then installed on the laptop, obtained at the Instructional Media Center at WPI, and adapted to the Q-Trak monitor according to its standard operating procedure, which is also appended. When the software was properly installed, the apparatus was set up in the classroom prior to the first class of the day. The apparatus was situated in the middle of the classroom seating area. This was done to receive an average measurement of the room at the level that the students and professors breathe. The software was set to real time and measurements were made once every minute.

Measurements were taken throughout the day to obtain accurate data of the raise of the CO_2 concentration. Control measurements were also taken outside after the classroom data was acquired, to establish a baseline according to what the initial air quality the HVAC system used at its intake.

3.6 NOISE LEVEL MEASUREMENT

Careful consideration of noise management is a chief priority in the design process. Background noise level measurements were taken from rooms OH107, AK116, and SL115 to assess the current status of noise generated primarily from the air-conditioning and ventilation units. AK116 and OH107 were investigated because the student survey indicated them as the worst classrooms on campus. The interviews with professors and students at WPI both indicated the classrooms acoustics were inadequate. SL115 was used as a control, because of it comparable size and usage. SL115 was renovated with current acoustic heuristics.

Measurements were taken with a Sper Scientific Digital Sound Meter model #840029. The sound meter was calibrated prior to use using the internal calibration system. The “A” weighting option was selected to best simulate actual human perception. The range selector was set to look for decibel readings 30-80 dB.

Eight locations were designated for observation in OH107, nine for AK116, and nine for SL115. Observation locations were chosen and recorded according to a grid that allowed readings to be obtained from the front, middle, back, as well as the left, middle, and right side of the seating areas.

Data acquisition involved a 360^{o} rotation of the device at each location, where two peak level measurements were recorded in succession for each observation location. To ensure that each measurement was independent from the last, the reading on the LCD display was reset in between each acquisition.

3.7 QUALITATIVE ASSESSMENT of REVERBERATION

Reverberation time is complex property of rooms and requires expensive equipment to measure. It is beyond the scope of this project to try to quantify reverberation. However, a qualitative comparison between rooms is a useful way to determine whether the acoustical properties of the room are sufficient or poor.

The method used will follow the guidelines of an "echo test" where reverberation is assessed by the echo produced in response to a trigger sound[25]. The initial sound is required to have a sharp impulse to allow for easy differentiation between the primary and reverberant sound. A ruler was raised four inches above the surface of the overhead projection table in each room. The experiment was repeated three times for each room and recorded on audiotape, which for each acquisition was placed in the front center of the room facing the back. The recordings were carefully reviewed and judgment was based solely on the reverberation decay signature, not by the loudness of the initial noise.

3.8 SUMMARY

The student survey was done to find out what classroom on campus the students thought was the worst. Interviews were conducted to find out what was wrong with these classrooms. Measurements and experiments were conducted following our methodology to investigate what the students and professors indicated as problems.

CHAPTER 4 - RESULTS

4.1 SURVEY RESULTS

Coverage error is error introduced to a survey by not reaching a diverse group that accurately models the population. If a singular demographic returned the survey the correspondents possess a like characteristic that would skew the survey results. To minimize coverage error we randomly mailed the student body. Our coverage error can be investigated by analyzing the demographic information.

4.2 NO RESPONSE DEMOGRAPHICS

Non-response error is introduced to a survey when the survey is sent to a large amount of people in a population where only a small proportion returns useable results. To validate our results we must obtain a 60% response rate[1]. In our survey we tried to minimize the non-response error by administering the survey on the Internet. We received 69 responses to the survey. Seven were anonymous and could not yield demographic information, thought their data could be used for other purposes. Five surveys were duplicates bringing the usable survey count down to 64 out of 100. This gives us a response rate of 64%. This rate is higher than the maximum expected response rate of 60% for the methods used [1].

Figures 4.1 through 4.3 display the demographics of students that did not reply to the survey. Figure 4.4 represents the students that did not respond organized by their major

Figures 4.5 through 4.7 display the demographics of the students that replied to the survey. The demographics data was organized by class year to reveal trends in the coverage of the survey. Figure 4.8 represents the students that responded by their major. There are no apparent trends in this data. No apparent trends in the demographic data indicate that the survey was evenly distributed to all the sophomores, juniors, seniors and super seniors at WPI. This validates our data minimizing our coverage error over the school.

Our results of the survey are as follows:

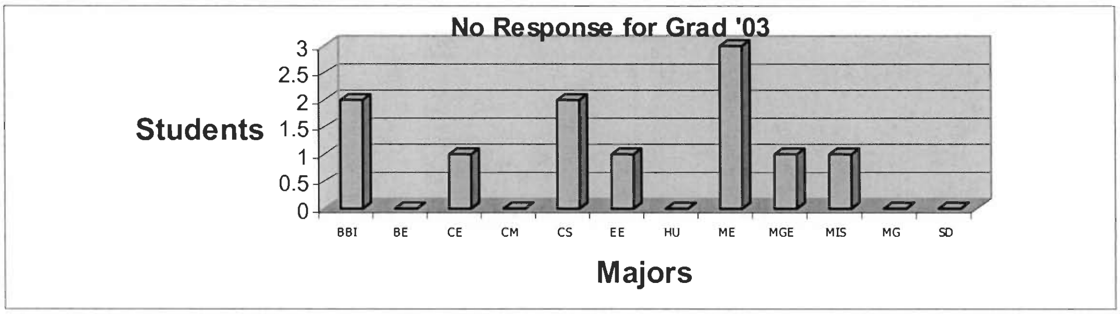


Figure 4.1: No response demographic for the graduating class of 01'

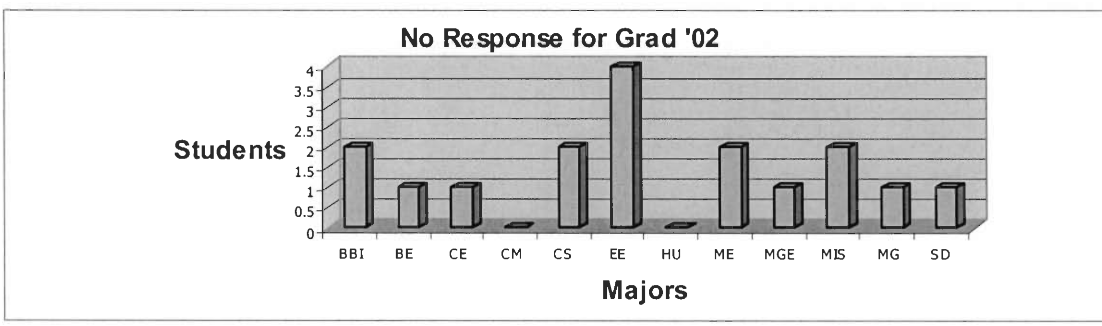


Figure 4.2: No response demographic for the graduating class of 02'

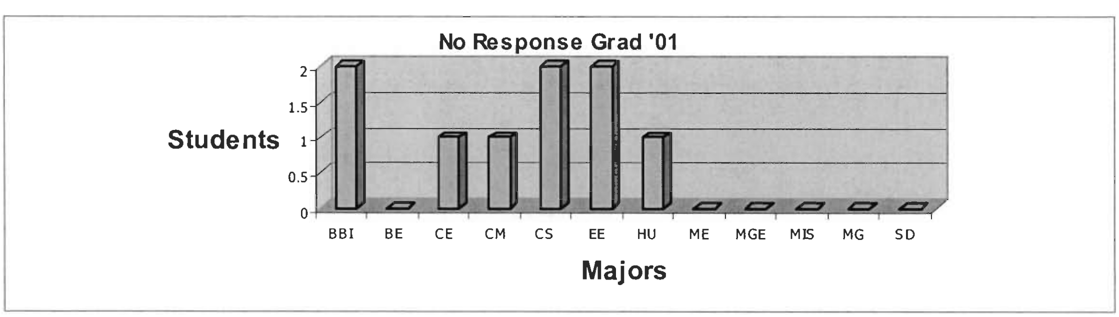


Figure 4.3: No response demographic for the graduating class of 03'

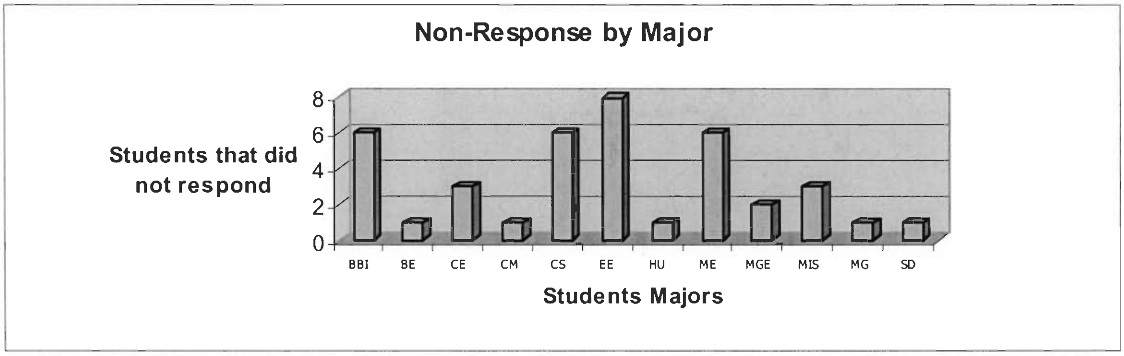


Figure 4.4: No response by major

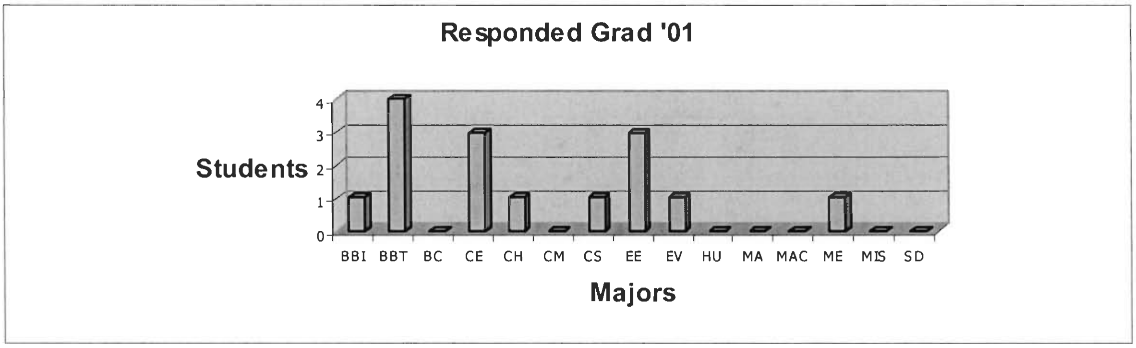


Figure 4.5: Response demographic for the graduating class of 01'

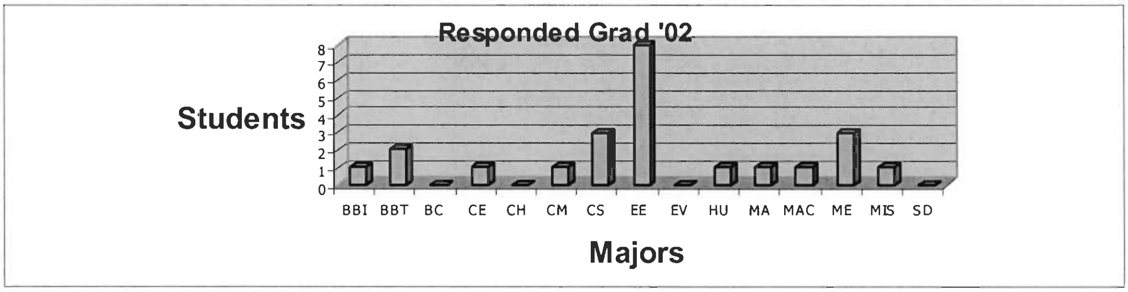


Figure 4.6: Response demographic for the graduating class of 02'

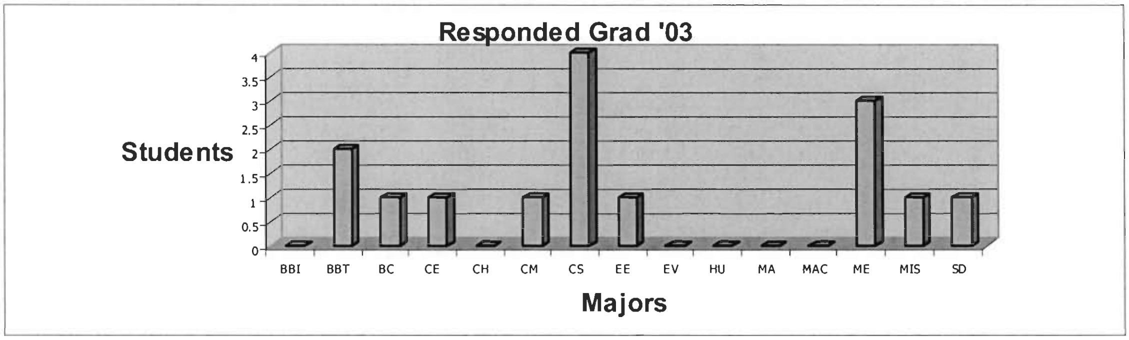


Figure 4.7: Response demographic for the graduating class of 03'

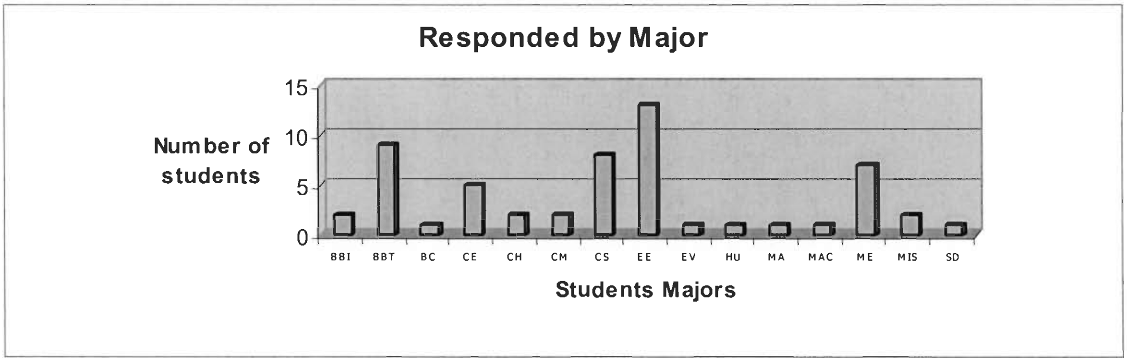


Figure 4.8: Response by major

Figures 4.9 displays all the classrooms that received a vote as a classroom that was disliked. AK 116 and OH107 take well over fifty percent of the votes. The survey clearly indicated OH107 and AK 116 as the classrooms the students would like to see renovated.

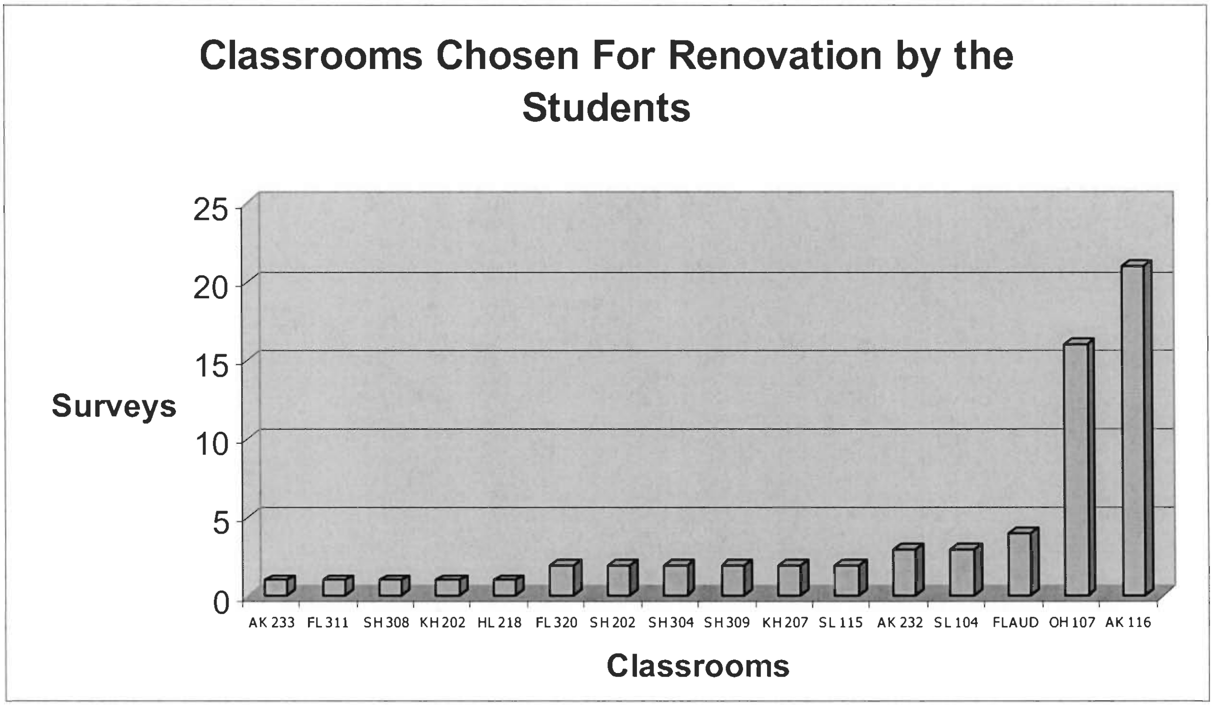


Figure 4.9: Votes per classroom

4.3 INTERVIEW RESULTS

Students and facility were interviewed to support our findings and to dig for classroom defects. Eleven students and three faculty members were interviewed. The results can be grouped into four different topics for both rooms. The first topic commented on was the lighting in both classrooms. The students and faculty indicated that the acoustics were a major problem in the classrooms. The temperature in both classrooms was indicated as uncomfortable for one reason or another. Lastly, miscellaneous comments were received for each classroom.

For AK 116 and OH 107 Tables 4.1 and 4.2 display the comments received by the students and professors.

TABLE 4.1: AK116 INTERVIEW RESULTS

AK 116

Lighting	Acoustics	Temperature	Miscellaneous
Poor lighting	Difficult to hear if professor doesn't talk very loud	Cold in the winter	Colors somehow just seem too drab
Very poor chalkboards	Poor sound quality	Too hot	Very steep
Poor lighting	Cant hear	Too hot	Professors are unfamiliar with the control systems
Poor lighting	Microphone needs work		The seats smell
Cant see screen			Equipment is old

Table 4.2: OH 107 Interview results

OH 107

Lighting	Acoustics	Temperature	Miscellaneous
Poor lighting	Difficult to hear if professor doesn't talk very loud	Cold in the winter	Smells
Very poor chalkboards	Poor sound quality	Too hot in the summer.	Very steep
Use of visual aids is harder to see	Noisy from construction	Hot in the summer	Colors stink
Is dark	Cant hear	Cold in the winter	Equipment is old
			Insufficient disabled access

Both classrooms received results that pointed to the same defects. These defects included the lighting, acoustics, temperature, and the seating. There was only one deviation between what the professors commented and what the students said. All the professors interviewed reported not liking the stage in AK 116, where as the students did not comment on the matter.

4.4 LIGHTING RESULTS

Measurements made in SL115 were considered as the control measurements for the other classrooms because of its similarity in size, and its recent renovation. The following data provided on SL115 supplies the information needed for the control profile.

SL115: SL115 has recess lighting equipped with sharp cutoff luminaries that allow for a brightly lit presentation area with minimal lighting spill onto the audience. There is track lighting above the presentation area with halogen spotlights, useful for visual aids and presentations. When using any type of projection equipment all the overhead lighting can be shut off to ensure the best view of the projected image, without loosing the ability to take notes. This is accomplished with the aid of stairway lighting and ¼ shell wall mounted soft halogen lighting.

To attain uniformity and sufficient brightness during lectures there are two types of overhead lighting above the students. The overhead lighting is considered standard fluorescent down-lighting with small clear ballasts covers. Clear ballast covers would normally create relatively sharp direct lighting. This problem is averted with the addition of the up-lighting situated above the down-lighting ballasts, facing the ceiling. This technique used in SL 115 adds indirect lighting. The indirect lighting provides uniform lighting for the students.

The lighting is controlled at three lighting panels located between the entrance and the chalkboard. The first panel is for the up-lighting, the second panel is used for the down-lighting. The final panel controls the recess lighting, track lighting, wall mounted lighting, and the stairway lighting.

OH107: OH107 is equipped with track lighting in sharp cutoff luminaries. The track lighting in OH 107 was installed at a much greater height than in SL115. The track lighting is facing the audience, not the presentation area. The presentation area therefore doesn't have any type of specialized lighting. The rest of the lighting in the room is the standard fluorescent lighting in rectangular ballasts. Six banks of fluorescent lights equivalent to 12 bulbs had gone out above the student seating area. This resulted in non-uniform lighting in the classroom.

Figure 4.10 shows the comparison of the light meter measurements of OH107, AK116, and SL115 when the classrooms are fully lit. The student seating area in OH107 is on average 2 full exposure value units less than SL115 as shown in Figure 4.10. Measurements of OH 107 light settings appropriate for video, data, and overhead projections are compared to control measurements given in Figure 4.11. This shows that the brightness at the board or projection screen is well above SL 115 measurement.

Figure 4.10 shows the levels of light measured in OH107 at the specified locations throughout the room. The lighting in the room was set as if some type of projection was being shown in the class. These light measurements were compared to those taken in SL115 under the similar conditions. In Figure 4.11 the possible projection setting for OH107, denoted by "OH107 2" is higher in exposure value by 1 EV unit on the projection screen. This implies that "washout" occurs. The second possible setting, "OH107 2", is higher in exposure value than the control by 2EV units indicating "washout".

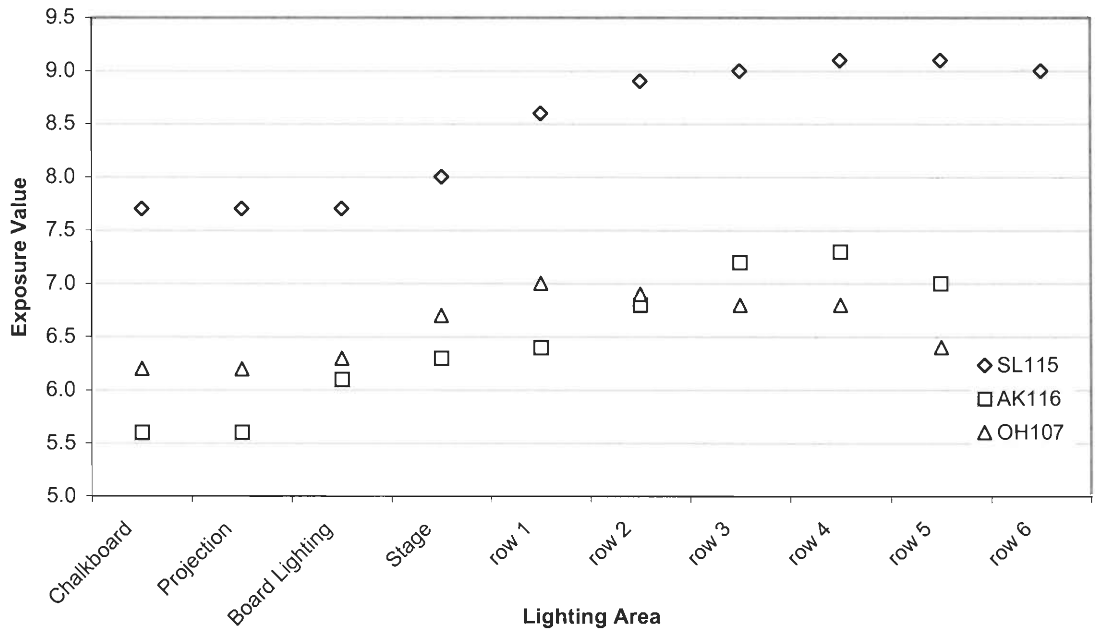


Figure 4.10: Fully lit lecture hall versus the control measurements

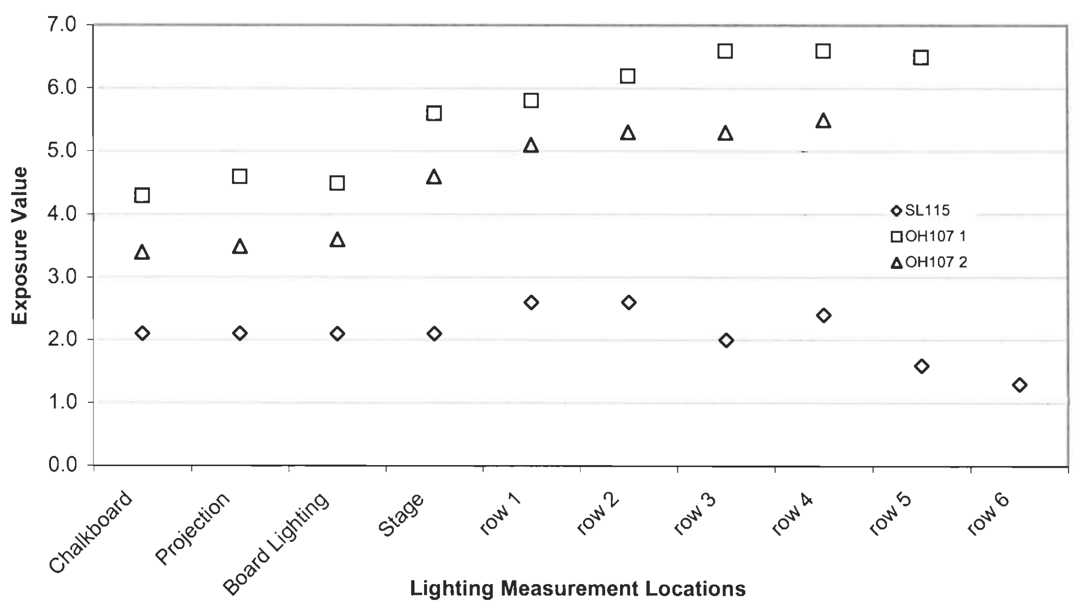


Figure 4.11: Light measurements all possible projection settings for OH107

Another sign that the lighting is poor in this classroom is the total number of lights in the classroom compared to SL115, shown in Table 4.3.

Table 4.3: Difference in the total number of lights

Classroom	*Total # of Lights*	*Difference From Control*
SL 115	240	___
AK116	192	48
OH107	118	122

Olin Hall has 122 lights less than SL115 as shown above in the Table 4.3.

The lighting in AK116 is inherently different from SL115 and OH107. The lighting banks are placed parallel in between the HVAC air ducts running along the ceiling. In SL115 and OH107 the HVAC air ducts do not obstruct the lighting fixtures because they are embedded directly in the ceiling. The lighting fixtures were not placed parallel to the front of the classroom because they were prevented by the exposed HVAC system air ducts. Lighting should run parallel to the front of the classroom to best benefit the student. Louvers were used to compensate for the lighting fixtures running perpendicular to the front of the classroom. These louvers were hung from the ceiling parallel to the front of the classroom to redirect the lighting. To compensate for this situation single fluorescent lights were placed along the ductwork.

The lighting in the front of the classroom at the chalkboard comprises of a string of 5 banks of deeply recessed fluorescent lighting. This keeps the chalkboards well illuminated and minimizes the spill of light from the front of the class onto the student seating area. There is also a string of 4 banks of recessed fluorescent lights directly above the raised stage at the front of the classroom. There are no spotlights in this classroom and very minimal indirect lighting. Figure

4.10 illustrates what the lighting in this classroom is like when all the lights are on. Figure 4.12 shows that AK116 has the worst presentation area and overall classroom lighting. Measurements of the possible lighting settings for use during classroom projections of video, data, or overhead are shown in Figure 4.12. The third setting, "AK116 3", seems to be the best for projection, but it produces non-uniform classroom lighting. The "AK116 1" and "AK116 2" settings are clearly too bright causing "washout" or conditions too dim for students to take notes. This is shown by in Figure 4.12.

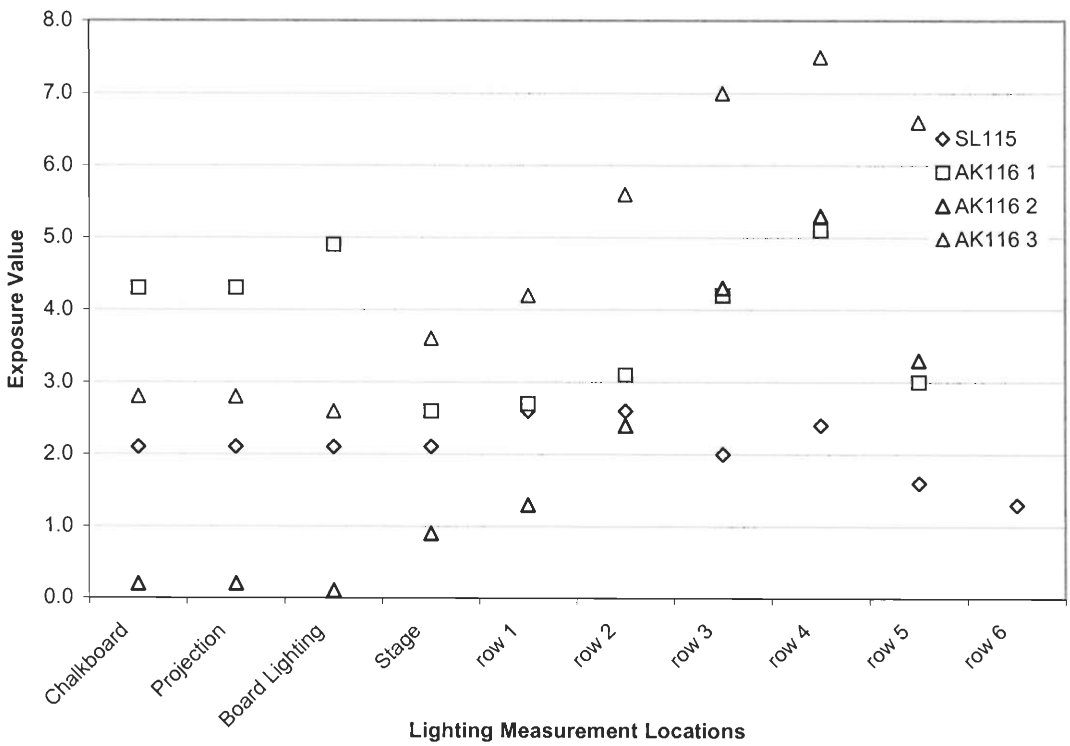


Figure 4.12: Light measurements of all possible projection settings for AK116

Two light switches and one lighting panel control the lighting of AK116. None of the switches are marked on the lighting panel, and the on/off positions are not specified by the typical up and down designation. A switch located at the entrance of the room turns on the back seven banks of lights for each of the four columns of lights situated across the room. Another switch is located beside the stage at the other entrance and turns on the first two lighting banks in the same four columns of lights. The lighting panel is located below the chalkboard.

4.5 INDOOR AIR QUALITY RESULTS

Measurements of the carbon dioxide, carbon monoxide, temperature, and humidity levels were taken from OH 107 and AK 116. These measurements were acquired and stored using the TrakPro software. The data was exported from the software.

Figure 4.13 shows the data collected from the carbon dioxide readings in room 107. The outside CO_2 reading was measured at 419 ppm, which is slightly higher than a poor outdoor air quality minimum level of 400 ppm. This shows that the air upon intake to the HVAC system is polluted. The initial CO_2 reading in the room before any occupants had arrived was between 650 ppm and 700 ppm. This reading should be close to the outdoor measurement; instead it was 250 ppm to 300 ppm higher than the outdoor measurement. A difference in these readings indicates a malfunctioning or inadequate HVAC system.

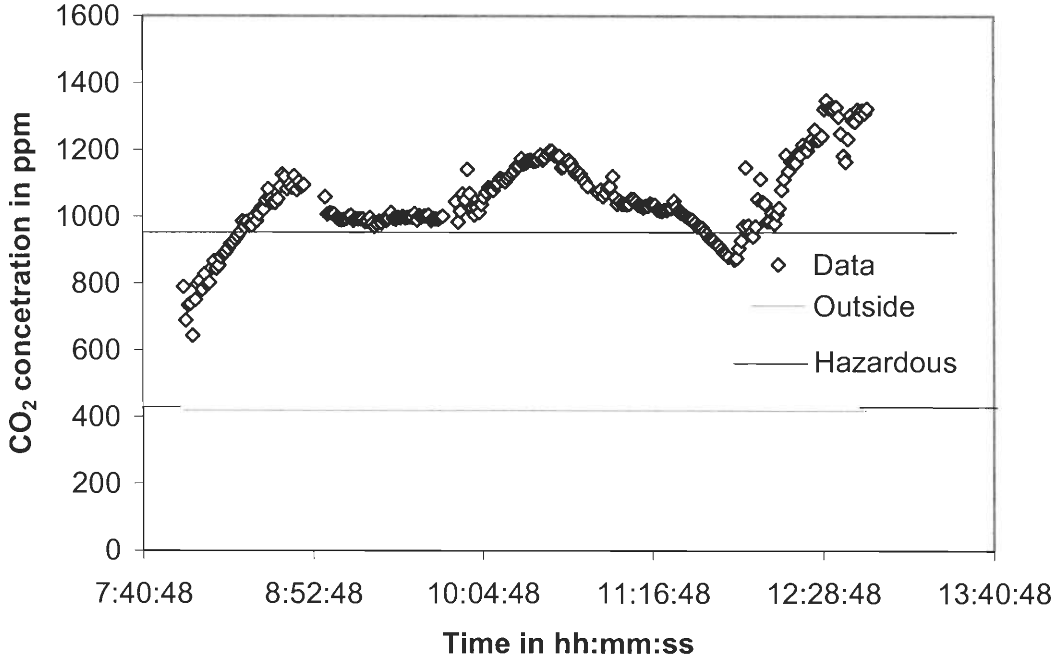


Figure 4.13: OH107 CO_2 concentration vs. time

The CO_2 began to rise drastically during the first hour. The CO_2 level still rose above the healthy indoor air quality standard of 1000 ppm. The peak measurement of 1348 ppm was recorded in the last hour of data acquisition. The build-up of CO_2 to a concentration 348 ppm higher than the EPA's recommended standard is a clear indication of poor indoor air quality. This is depicted in Figure 4.13 as the CO_2 concentration rising above the EPA's "Hazardous" air quality line. Concentrations of CO_2 above this line are considered hazardous by the EPA standards. The hazard is not the CO_2 concentration, which will by itself make people feel fatigued. The hazard lies within the indication of a poorly ventilated room. Poor ventilation, as stated in the background, can lead to a build up of much more serious contaminants in the air, resulting in the health problems stated in the background. Do to the severity of these results, they were reported to Dave Messier, the Environmental and Occupational Safety Manager at WPI.

The temperature in OH 107 was well managed and stayed within the comfort range as shown in Figure 4.14. The relative humidity shown in Figure 4.15 was consistently 22% to 23%. This level of relative humidity does not fall within the recommended comfort range of 30% to 60%. The relative humidity is directly related to the temperature comfort range. If the relative humidity is lower in the room than recommended, the occupants will feel colder. This means that the temperature must be increased or the relative humidity must be increased. It is preferable to keep the temperature the same and change the relative humidity so that it falls within the comfort range.

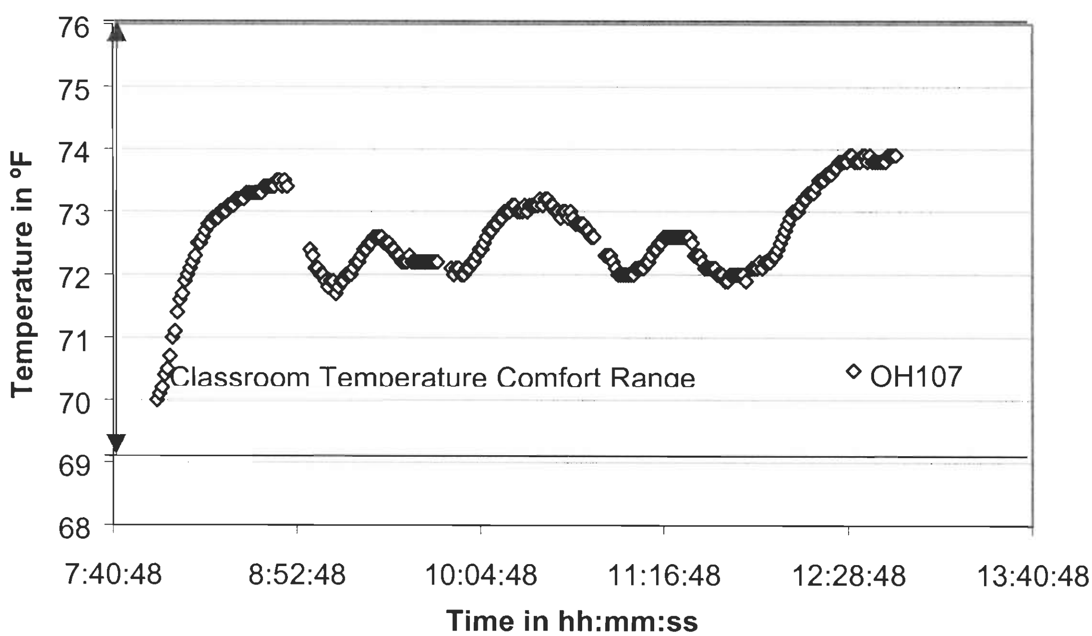


Figure 4.14: OH107 Temperature versus time

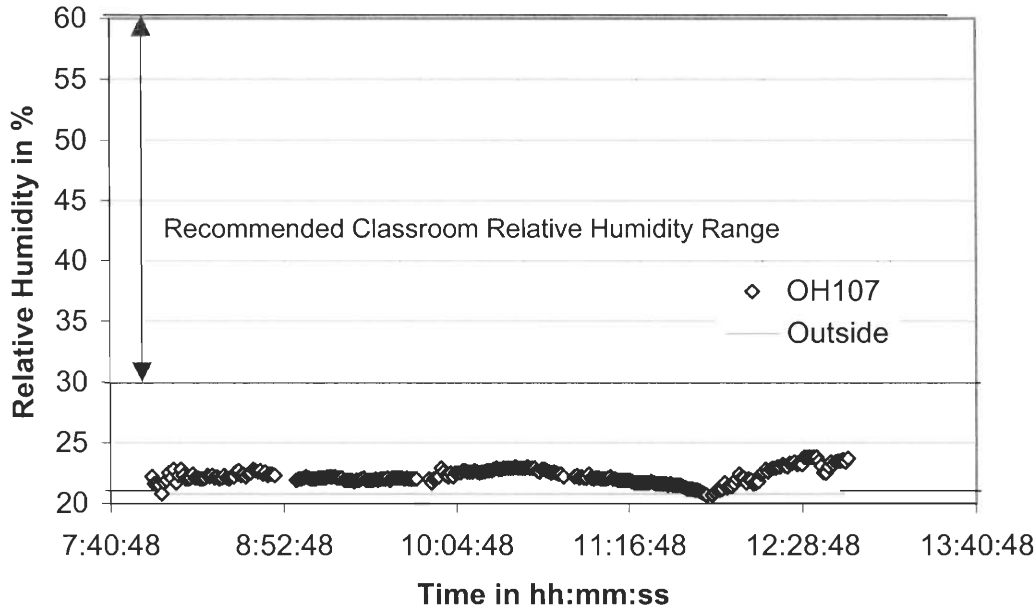


Figure 4.15: Relative humidity versus time

It is important to note that the Professor of the first class propped open the door to the classroom and opened two of the windows in the back of the lecture hall. This was done to alleviate the discomfort from the temperature and stuffiness already present in the lecture hall. As more of the students arrived in the lecture hall, two more of the windows were opened later that afternoon. Opening the windows and the doors are a direct effect of the discomfort of the occupants of this room. These actions indicate problems with the HVAC system.

The CO_2 readings for AK116 are shown in Figure 4.16. The average outdoor CO_2 measurement was 360 ppm. The CO_2 measurement was below the hazardous outdoor level of 400 ppm and therefore not initially a contaminant to the indoor air quality. The initial CO_2 measurement of 730 ppm was well above the outdoor CO_2, which indicates a malfunctioning or inadequate HVAC system for this building. The peak CO_2 reading for the day was 994 ppm, which falls just below the hazardous level. This is due largely to the fact that the windows and the door were open.

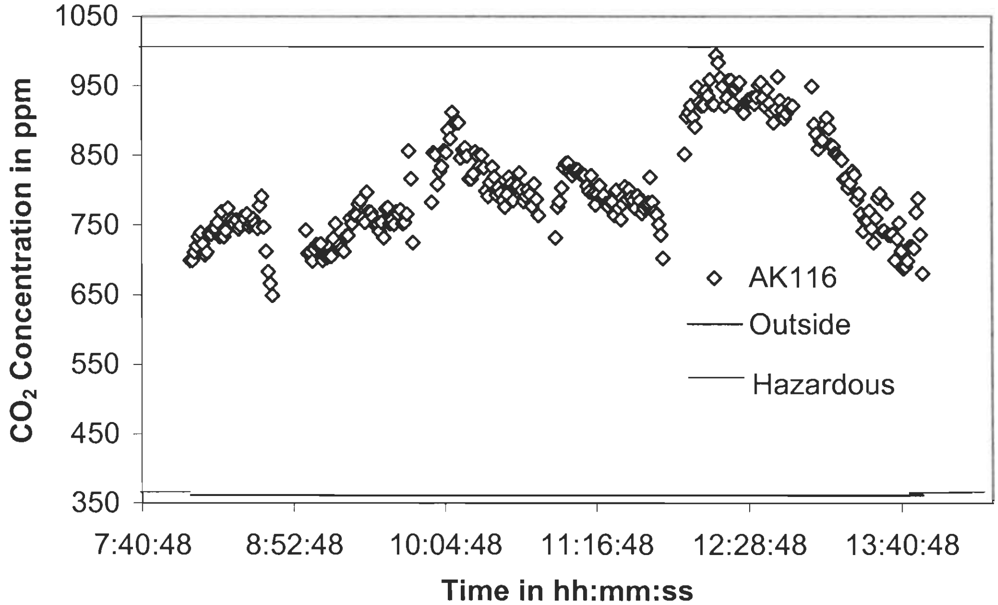


Figure 4.16: AK116 CO2 concentration versus time

Even with the windows open letting in cold air at 44.5ºF, the temperature exceeded the recommended standard with an average of 80ºF (see Figure 4.17). This temperature exceeded the comfort zone by 5ºF. The relative humidity was around 20%, with seemingly little or no HVAC influence. This is shown in Figure 4.18.

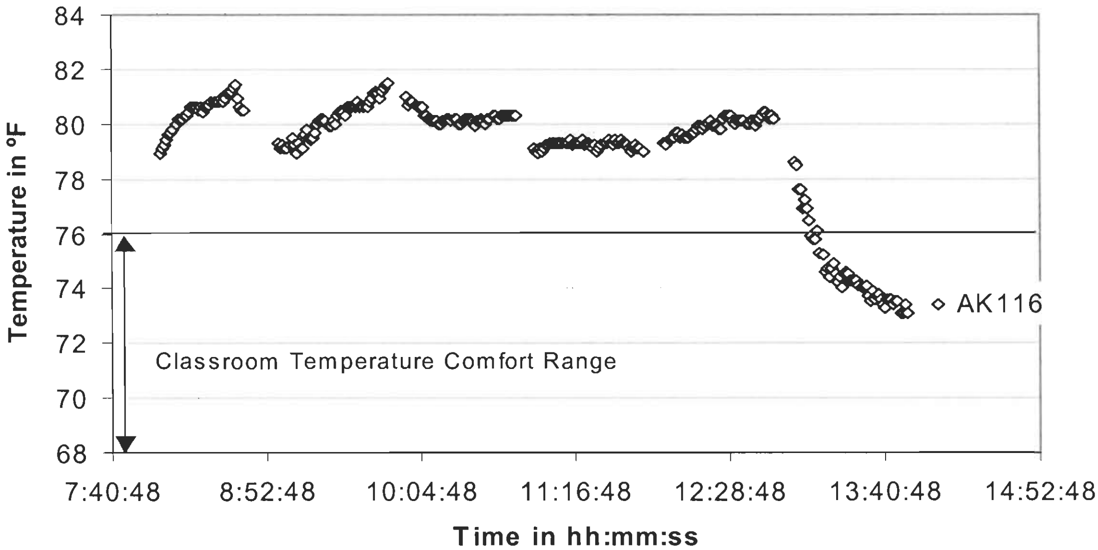


Figure 4.17: AK116 temperature versus time

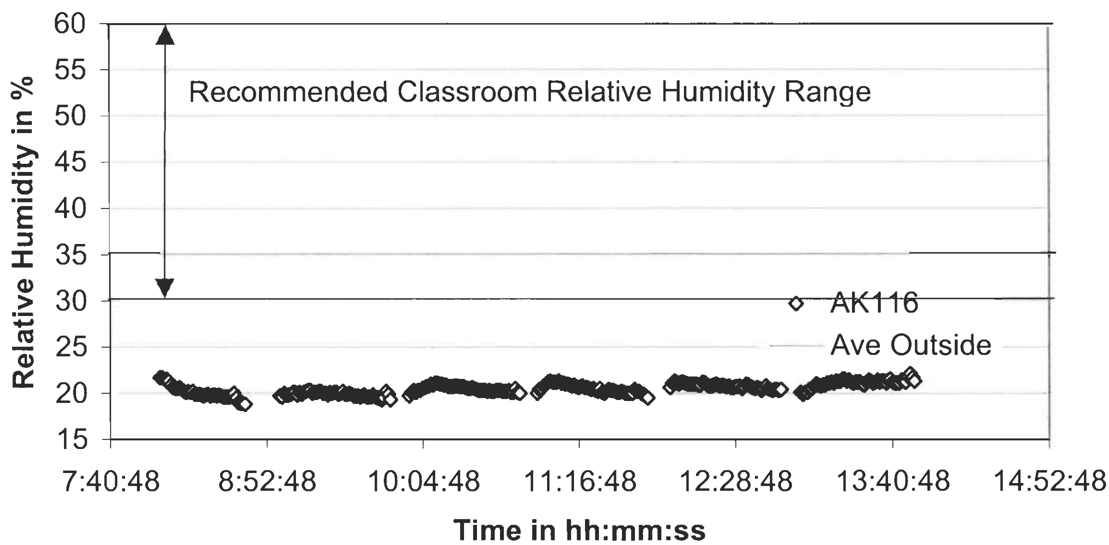


Figure 4.18: AK116 Relative humidity versus time

On a reassuring note, the carbon monoxide levels in both classrooms were at normal healthy levels. Graphs were not constructed for the carbon monoxide levels since they were at trace amounts of 1 or 2 ppm. All the measurements were taken only on the days that were stated. None of these measurements were replicated for any of the classrooms.

4.6 ACOUSTICAL MEASUREMENT RESULTS

The two classrooms determined to be the least liked by students, AK116 and OH107, were both fingered for having poor acoustics. Subsequently, they were tested for excessive noise levels. SL115 having been recently renovated was measured for excessive noise to serve as a control.

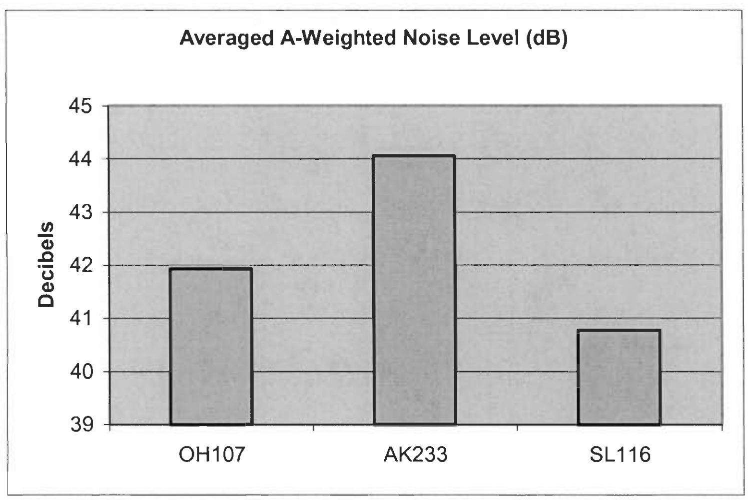


Figure 4.19: Average noise level per room

The noise level measurement data was treated in two respects. The first analysis included averaging the 16 measurements taken OH107, and the 18 from both SL115 and AK116 to produce comparative data in terms of an average noise level per classroom. The average noise levels for the three rooms measured, OH107, AK116, and SL115, were 41.9, 44.1, and 40.8 respectively (see Figure 4.19). The average noise level for OH107 was slightly over one decibel greater than the control, where as AK116 was over three decibels higher.

The second analysis involved averaging the two measurements for every allocation position. This allows for an internal comparison of data to determine the distribution of noise within a specified classroom. The graphing style selected is a 3-D perspective that clearly represents the relative noise levels. (See Figure 4.20).

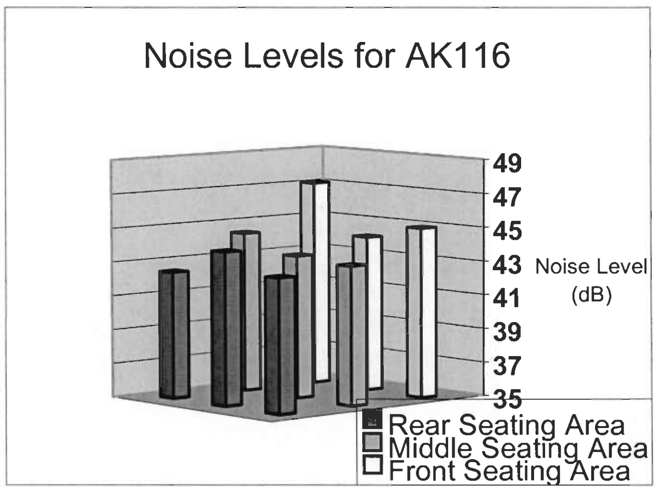


Figure 4.20: Noise levels for AK116

The second analysis involved averaging the two measurements taken from each acquisition point and plotting the values such that these positions can be represented. This allows for an internal comparison of data to determine the distribution of noise within a specified classroom. The graphing style selected is a 3-D perspective that clearly represents the relative noise levels. The average noise levels for all three classrooms fell under the EPA's recommendation of less than 45dB. However, the area surrounding the left front of AK116 produced values above 45 dB. This was attributed to a relatively loud noise emanating from a closet approximately 12 feet in front of the point of data acquisition.

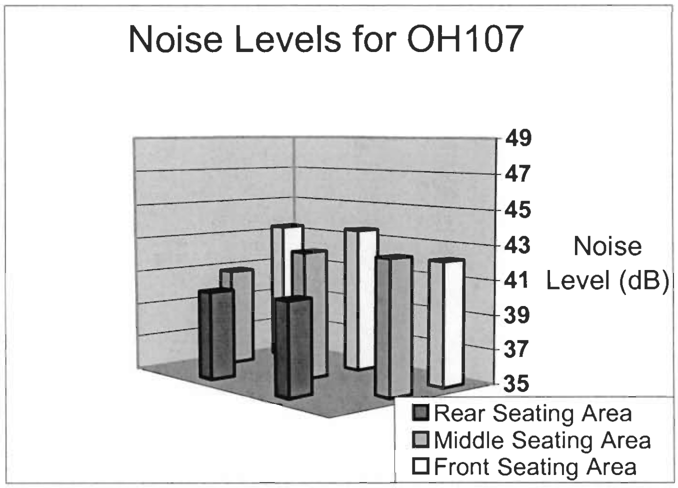


Figure 4.21: Noise levels for OH 107

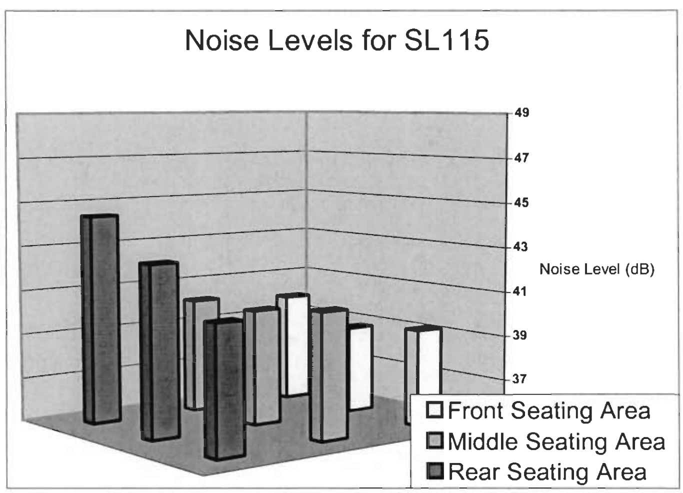


Figure 4.22: Noise levels for SL115

A similar scenario occurred with the control, where an AC ventilation fan towards the left rear ceiling of the room was noted to be overactive (Figure 4.20). This accounts for the unusually high readings observed in that section as compared to a rather consistently low noise background for the rest of the room.

OH107 reveled to have background noise levels in accordance with EPA recommendations (see Figure 4.21). However, a qualitative assessment of the echo produced as compared to AK116 and SL115 indicated the room to be highly reverberant. The other two lecture halls did not appear to have a substantial echo. It is known that the capacity for human beings to differentiate between primary and echoed sound requires a delay of 70 milli-seconds. That is equivalent to a difference of 70 feet traveled by the primary sound and that of the reverberant sound [25].

This poorly damped reverberation is most likely due to the acoustical properties of the materials that constitute a substantial portion of the room's surface area. OH107 is different from the other two rooms in that there are no cushions on the seating and that the floor is not carpeted. The seating in OH107 is made of wood that is designed to reflect sound towards the front wall of the lecture hall. The surfaces of the lecture hall are mainly rigid and non-absorbent. Therefore it is no surprise that OH107 is highly reverberant. OH107 (V=35,000 ft^3) is larger than SL115 (V=28,000 ft^3) so it is expected to have a slightly longer reverberation time by volume alone, but AK116 is even larger (V=39,000 ft^3) and didn't have a substantially long echo.

CHAPTER 5 - CONCLUSIONS

5.1 LIGHTING CONCLUSIONS AND RECOMMENDATIONS

The overall classroom lighting is clearly deficient for both AK 116 and OH 107. This is primarily due the following findings.

6. Not enough lights in the classroom.
7. The positioning of the lighting fixtures.
8. The misuse of the lighting fixtures.
9. Classroom architecture.
10. Poor central lighting controls.

Both lecture halls have high ceilings. On these ceilings are ceiling mounted fluorescent lights with off white plastic covers. These plastic covers inhibit the lighting from illuminating sufficiently. It is recommended that the classrooms should be equipped with hanging fluorescent lights in clear electronic dimmable ballasts, which facilitates up-lighting and down-lighting. The hanging lighting would be especially useful in AK 116 to avoid the obstructive ductwork. This would also make the louvers unnecessary because the lighting direction wouldn't need to be changed.

There should be stairway and quarter-shell wall mounted, soft fluorescent lighting for use during presentations and video, data, and overhead projection. Combining the use of the stairway lighting and wall-mounted lighting will provide sufficient illumination for students to enter or exit the room, and to take notes. To add the correct type of lighting and increase illumination, spotlights or directional track lighting coupled with halogen recess lights will provide sufficient chalkboard and visual-aid lighting for OH107 and AK116. In Olin Hall 107 the lighting in the front of the room could be improved by hanging a slanted drop ceiling like that in SL 115. The slanted drop ceiling would increase the reflection of light from the seating section onto the chalkboard and presentation area.

A few simple steps could fix the lighting control. First, all light switches in the room should be labeled. Second, the lighting switch at each entrance should control the lights above the student seating area and the presentation area. Third, there should be a lighting panel on the side of the chalkboard (also labeled) separating the down, up, recess, track, wall, and stairway lighting. It is recommended that a dimmer switch or dial on this panel have settings based upon the classroom exercise and labeled accordingly. This dial should be connected to all the lighting in the room so that for each setting all of the lights will adjust. The settings could be designated as lecture, visual aids, video/data projection, and overhead projection. The lighting system should be connected to the multimedia system to make presentation more automated.

Connections to the multimedia system will allow for the projection screen to drop while the lights adjust. If the podium remains in the redesign proposal for the classrooms in question, they should be outfitted with a master lighting control to centralize the lighting system.

5.2 IAQ CONCLUSIONS AND RECOMMENDATIONS

The indoor air quality level of the rooms was objectively evaluated and compared to the standards for indoor air quality established by the EPA and the ASHRAE. The resulting data from these measurements indicated poor indoor air quality for both AK 116 and OH 107 as compared to the EPA standards.

It was determined that the carbon dioxide level in AK 116 had the potential to create uncomfortable conditions inhibiting learning. The high carbon dioxide levels in both classrooms indicate poor ventilation. The HVAC system did not alter the relative humidity in the classroom based upon the data.

In OH 107 the carbon dioxide level was determined to be well above the initial hazardous level. The students were uncomfortable due to the temperature in this room, which was above the comfort level set by the EPA. The relative humidity level measured inside the classroom showed the same levels as the outdoor readings taken. The HVAC system is clearly shown an inability to manage the ventilation, temperature, and relative humidity.

Performing the following tasks will assist in the justification that the HVAC monitoring company, the system itself, or both, need to be replaced. This cannot be assessed solely on the results found in this report, since they were not replicated. It is recommended that further information on the HVAC system should be acquired from the monitoring company. WPI or a third party should collect air quality measurements in Olin Hall and Atwater Kent. This data should then be compared to that of the monitoring company to evaluate their role in the poor operation of the HVAC systems.

The HVAC systems for Olin Hall and Atwater Kent should be replaced with a higher-grade system to handle the load necessary to omit air quality as a source of discomfort. As it is our professional obligation, the poor indoor air quality finding of this report were submitted to the Environmental and Occupational Safety Manager, Dave Messier and the HVAC system monitoring company.

5.3 ACOUSTICAL RECOMMENDATIONS

Olin Hall 107 needs complete refurbishing with acoustical materials. To improve the classroom the wood paneling must be replaced with carpeting for the floors and the walls. The projection booth should probably be removed, though data on the frequency of its use needs to be obtained. If it is determined that professors find it useful, then a new one can be built with wall carpeting to prevent reflection of sound back in the direction of the front (parallel) wall.

The seating needs to be replaced with cushioned seats, which will have higher absorption coefficients than the wooden ones that are in place now. A room full of students will increase the current absorption of the room, however it is unacceptable for a lecture hall to need a large attendance in order to obtain favorable audible conditions.

Compared to Olin Hall 107, Atwater Kent 116 needs less acoustical refurbishing. Sound absorbent material needs to be installed in the back and right sides of the lecture hall where brick walls currently exist. The left wall constitutes a surface that buffers the space between the room and the load-bearing wall. This desirable effect increases sound absorption. The wall is discretely askew to prevent the left and right walls from being exactly parallel, preventing excessive sound reflection. A ceiling should be added in to prevent noise pollution from the HVAC system.

Salisbury Labs 116 is well equipped with sound insulation. It has an imperceptible reverberation time. The floor and walls are carpeted, the seating is cushioned, and the ceiling is sound absorbent. The vent previously mentioned is the only source of excessive noise, though overall the ambient noise is minimal

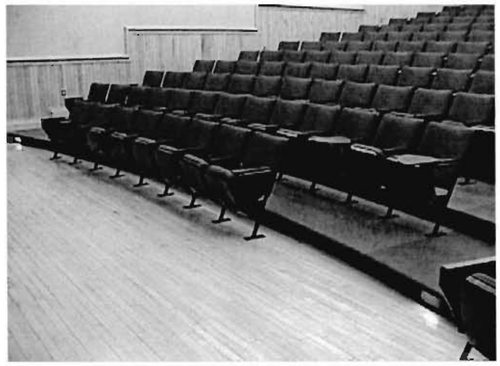


Figure 5.1: Wheelchair designated area – SL 115

SL115 provides both handicap access and space set-aside in the front center of the room for two wheelchair-bound students see Figure 5.1.

Figure 5.2: Front seating area of OH107

Olin Hall has been recently equipped with a ramp and automatic doors entering the floor of OH 107. However, the room itself is not well equipped to satisfy the needs of wheelchair-bound students. There is no seating space allocated for handicapped individuals. It is important that space be set aside in the front and center of the room. The only space available now is the isles, which would constitute a fire hazard. Seating students in the periphery would result in unacceptable sight lines, and placing students in the open space located close to the professor is likely to separate and alienate the student from the rest of the class (see Figure 5.2).

There is no permanent listening aid installed in any of the three rooms analyzed, though WPI's policy includes the personal distribution of such a device to the hearing impaired.

Atwater Kent 116 does not provide wheelchair access to the front of the room. The entrance to the front of the classroom leads to a stairwell and a fire exit with an alarm. It would be unfair to a wheelchair-bound student if they were forced to enroll in a class in AK116. It would also be unfair and unlawful for WPI to be forced into spending millions of dollars to install an elevator that gains access to the specified area. Simply taking the alarm off the door would not be adequate since the exit leads to a steep incline, making it difficult to go anywhere beyond that point in a wheelchair. I'm afraid that the only solution for wheelchair-bound students is to be taught in a lecture hall that provides appropriate accommodations. If the student feels OK with sitting in the back of the room, then there is space that seems to have been set-aside for this purpose. Otherwise they should complain about the conditions and force the class to move to a different room.

5.4 SEATING

Although the seating in AK116 is cushioned, the students complained about it. The seats are not entirely supportive. The cushioning is old, causing it to readily buckle under the pressure of my hand. This seating does not provide adequate lower back support. The seating needs to be reupholstered for this reason, if not replaced. Studies have shown that students prefer large writing surfaces. The writing surface provided by the drop-down tablet arm in AK116 placed second of the three rooms with 104 sq. in, but falls short of the recommended area of 130 sq. in [23].

Figure 5.3: Example of seating in AK116

AK116 is equipped with a podium that although houses a computer, blocks the view of the chalkboard for some students (see Figure 5.4). Even though only a few students have inhibited views, the professor is likely to be discouraged from using that side of the chalkboard altogether. The solution is to station the podium farther to the right side of the room, beyond the sight lines of students.

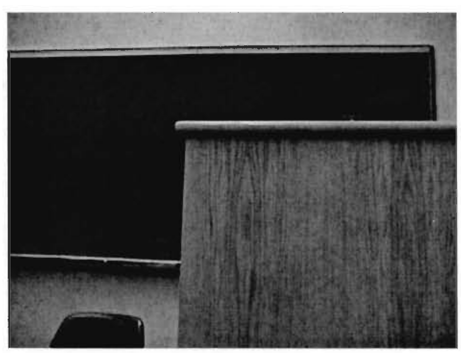


Figure 5.4: Podium blocking chalkboard

The stage that is present in the front needs to be removed. It serves no purpose but to (1) inhibit students from seating closer to an "oversized" professor, (2) discourage the volunteering of students to solve problems on the board, and (3) encourage the psychological separation of the professor over the students.

The square footage of Olin Hall that contains seats is approximated to consist of 2/3 of the 52'x50' room. Mathematically it is (52')*(50'-(50'/3))=1733 ft^2. This allows approximately 116 seats for students if redesigned using these chairs. This is unfeasible for the purposes of a large lecture hall considering that the lecture hall now seats 208 and that the loss of about 90 seats would result. Also, this arrangement would not be cost effective to fulfill the needs of a large lecture hall. Most lecture classes are usually no longer then one hour in duration which is not considered long term, so to spend exorbitant amounts of money on seats designed for long term seating would be excessive.

The seating in OH107 needs to be replaced. The writing surface provides the most space out of the three classrooms to write on (132 in^2), but doesn't allow the flexibility of a fold down tablet arm. The seating surface is hard, and because of which, proper posture is not encouraged. Conversely, an unhealthy slouching posture results, which ultimately leads to discomfort as well (see Figure 5.5).

Figure 5.5: Example of seating in OH107

The seating in SL115 is rather comfortable. The cushions are firm and provide lower back support (see Figure 5.6). The writing surface, however, is insufficient. The tablet arm provides about 80 in^2 of writing space. This can be improved by replacing the tablets themselves. Otherwise, this room is very well adapted for the anthropometrical differences in people.

Figure 5.6: Example of seating in SL115

5.5 FINAL CONCLUSIONS

This research was conducted to provide WPI administration with evidence intended to support or refute the current plans of future classroom renovation. Data was collected to determine the classrooms most in need of renovation. Current plans to renovate OH107 are supported by our research.

This yielded OH107 as one of the most in need of redesigning. The student body of WPI was surveyed and a portion of the students and faculty were interviewed to gain further information on specific design flaws. OH107 is considered by the project group to be a lecture hall of high need of renovation.

AK116 was also determined to be in need of renovation. The student survey indicated this classroom as the most in need of renovation. Subsequent evaluation of the data collected from the interviews and site evaluation indicates that renovation of this classroom is of second priority to that of OH107.

Further information needs to be collected on various attributes of both classrooms. A cost analysis needs to be preformed to determine the feasibility of the proposed renovations.

More definitive data needs to be collected on the exact flaws of the HVAC system. CAD drawings are a needed supplement to our recommendations for classroom renovation.

A committee has been formed to plan the renovation of Olin Hall. This project and its findings will be submitted to a member of the renovation committee at WPI to aid in the reconstruction of OH107.

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APPENDIX

TABLE OF CONTENTS

I SURVEY DATA

Appendix 1

Results from the first set of closed ended questions.

Appearance														
VU =										1				
U =												1	1	
I =			1	1	1	1	1	1	1	1				
VI =	1	1												1
Comfort														
VU =														
U =														
I =					1			1			1			1
VI =	1	1	1	1		1	1		1	1		1	1	
Equipment														
VU =														
U =														1
I =			1			1	1				1	1		
VI =	1	1		1	1			1	1	1			1	
Groups														
VU =														
U =				1										1
I =					1		1	1	1	1		1	1	
VI =	1	1	1			1					1			
Seats														
VU =														
U =						1		1						1
I =				1			1			1		1	1	
VI =	1	1	1		1				1		1			
Hear														
VU =														
U =														
I =														1
VI =	1	1	1	1	1	1	1	1	1	1	1	1	1	
See														
VU =														
U =														
I =	1				1									
VI =		1	1	1		1	1	1	1	1	1	1	1	1

Appearance																		
VU =																		
U =		1		1	1	1					1	1		1			1	
I =	1		1				1	1	1	1			1		1	1		1
VI =																		
Comfort																		
VU =																		
U =																		
I =				1	1	1	1				1	1						
VI =	1	1	1					1	1	1			1	1	1	1	1	1
Equipment																		
VU =																		
U =																		
I =		1		1			1		1	1	1	1	1	1	1	1		1
VI =	1		1		1	1		1									1	
Groups																		
VU =												1		1				
U =		1		1				1							1			1
I =	1						1		1	1	1		1			1		
VI =			1		1	1											1	
Seats																		
VU =															1			
U =												1	1					1
I =	1	1	1	1	1	1	1	1	1	1				1		1	1	
VI =											1							
Hear																		
VU =																		
U =																		
I =														1				1
VI =	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	
See																		
VU =																		
U =																		
I =														1				
VI =	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1

Appearance																	
VU =																	
U =							1										
I =	1	1	1	1	1	1		1	1	1		1		1	1	1	1
VI =											1		1				
Comfort																	
VU =																	
U =																	
I =					1	1	1					1		1	1	1	1
VI =	1	1	1	1				1	1	1	1		1				
Equipment																	
VU =																	
U =																	
I =	1					1				1	1			1	1		
VI =		1	1	1	1		1	1	1			1	1			1	1
Groups																	
VU =	1																
U =							1			1							
I =		1	1	1	1	1		1			1	1		1	1	1	
VI =									1				1				1
Seats																	
VU =									1								
U =		1	1			1		1									
I =					1					1		1	1	1	1	1	
VI =	1			1			1				1						1
Hear																	
VU =																	
U =																	
I =														1			
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See																	
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U =																	
I =														1			
VI =	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1

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VI =					1									7
Comfort														0
VU =														0
U =														0
I =		1		1		1			1			1		25
VI =	1		1		1		1	1		1	1		1	41
Equipment														0
VU =												1		1
U =			1											3
I =						1			1	1			1	29
VI =	1	1		1	1		1	1			1			33
Groups														0
VU =												1		4
U =			1					1					1	13
I =	1				1	1	1		1	1	1			35
VI =		1		1										14
Seats														0
VU =														2
U =							1	1	1					15
I =	1	1	1			1				1		1	1	34
VI =				1	1						1			15
Hear														0
VU =												1		1
U =														0
I =														4
VI =	1	1	1	1	1	1	1	1	1	1	1		1	61
See														0
VU =												1		1
U =														0
I =														4
VI =	1	1	1	1	1	1	1	1	1	1	1		1	61

Worst	Class held in that classroom.
AK 116	programming language concepts, algorithms, paradigms
SH 202	Advanced Calc, Boundary Value Problems
OH 107	= Chemistry 1
OH 107	Physics I
AK 232	System Dynamics
SH 309	Calculus
OH 107	physics 1 & 2
AK 116	= CE3020, MA1023, MA2611
AK 232	Introduction to Literature
KH 207	Cross-Cultural Psychology
OH 107	CS 3013, PH 1110, PH 1120
SL 104	BB 1030, Zoology
FLAUD	Organic Chem I-II, Calc IV, Microbiology
OH 107	Physics
HL 218	Statistics I
AK 116	EE 3601
OH 107	PH1140, MA2071, ES2001
OH 107	PH1010, PH1020, ES2001
FLAUD	MA102
AK 116	CS1005/2005
AK 116	Calculus 2, Calculus4, CS1005, Chem 1, EE3601
OH 107	physics & chem
OH 107	physics 1-4
SL 115	CS2011
AK 116	EE 3601
AK 116	CS1005, MA2611
AK 116	AK116: Stats, Organic Chem AK 232: Cross-Cultural psych
AK 116	CS3041
AK 116	CH4110
SH 308	Calculus III Conference
AK 116	Organic Chemistry
OH 107	CS 3013, PH 1110, PH 1120
AK 233	Microeconomics
KH 207	Spanish
SH 202	Calculus II
AK 116	Chemistry
AK 232	Introduction to Sociological Concepts and Analysis
OH 107	PH1110 and PH1120
OH 107	PH 1110, 1120
AK 116	CS2223,EE2011
OH 107	physics
OH 107	Physics
AK 116	CS2136 Calc4 CS2012 CS3041
SH 304	Calc 1,2, 4
OH 107	Physics
FL 320	CE3061
KH 202	MG2720,MG3720,MG4720
AK 116	Algorithms
AK 116	Algorithms CS2223
OH 107 - duplicate	ES2001 duplicate
AK 116	Statistics

Worst	**Class held in that classroom.**
SH 304	calc 1 to 4 and differential equations
AK 116	Organic Chemistry
FL 311	History
AK 116 - duplicate	Chemistry duplicate
AK 116	Statistics
FLAUD	Calc 3
FL320	Foundation of Computer Science
FLAUD	CS1005
OH 107	Physics 1110, PH1120 and Biochem 2
OH 107	Physics
OH 107	PH1010, CS3013
SL104	ES3004
SL 115	Biology
SH309 - duplicate	Calc 1 2 3
SL104	Zoology, genetics

II LIGHTING MEASUREMENT DATA

Lighting Checklist

Building Name __Salisbury Labs______ Completed By ____Mike Titus____

Address ____100 Institute Rd. Worcester_ Classroom ____SL 115

Planning # of Lighting Banks	# of Lights/Bank	Type	Operational	Description
18	2	Energy Saving Halogen	all	3 rows of 6 recess lighting banks with cutoff luminaires positioned over the presentation area
1	6	halogen spot lights	all	1 row of track lighting shining toward the chalkboard
24	96	fluorescent	all	hanging banks with small clear ballasts - downlighting
24	96	fluorescent	all	hanging banks with small clear ballasts on top on the downlighting facing up- uplighting
30	30	soft fluorescent	all	stairway lighting at the back of each of stair
10	10	soft fluorescent	all	1/4 shell wall mount uplighting (like movie theater)
107	**240**	**Total**		

Light Swith Panels	Control # switches	Location	Labeled	Comments
	4	between the board and the entrance	uplighting	
	4	between the board and the entrance	downlighting	
	4	between the board and the entrance	indiviually	labeled, track, wall, stairs, recess

Measurements at various settings

Comment Location	All lights on EV	Uplighting/Downlighting Off EV	Recess, Up, Down Off EV	Recess, Up,Down, Track EV
Chalkboard/projection	7.7	6.8	5.7	2.1
Track	7.7	6.4	3.4	2.1
Recess	8.0	6.2	2.7	2.1
1	8.6	5.7	2.9	2.6
2	8.9	4.9	2.7	2.6
3	9.0	4.0	2.7	2.0
4	9.1	3.1	2.5	2.4

Lighting Checklist

Building Name __Atwater Kent___
Address ____100 Institute Rd. Worcester_

By ____Mike Titus____
Classroom ____AK116__

Planning # of Lighting Banks	# of Lights/Bank	Type	Operational	Description
5	20	fluorescent	4 out	1 row of fluorescent lighting running along the chalkboard
4	16	fluorescent	all	1 row lighting the presentation area
36	144	fluorescent	all	4 columns of 9 banks going straight back over the seats
12	12	fluorescent	all	6 columns of 2 banks running parallel to and in between the 4 other columns
57	**192**	**Total**		

Light Swith Panels	Control # switches	Location	Labeled	Comments
	1	at entrance	no	controls the back 7banks in the large 4 fluorescent columns
	1	at the entrance beside the chalkboard	no	controls the first 2 banks in the 4column set of fluorescent lighting
	5	under chalkboard	no	controls the 6 columns between the main ones,4-stage lighting,5-chalkboard lighting

Measurements at various settings

Comment **Location**	All lights on **EV**	back 7 banks off **EV**	9 banks, stage off **EV**	9 bank, stage, board off **EV**	front 2 bank, stage, board off **EV**
Chalkboard/projection	5.6	5.5	4.3	0.2	2.8
Board lighting	6.1	6.1	4.9	0.1	2.6
Stage	6.3	6.3	2.6	0.9	3.6
1	6.4	6.0	2.7	1.3	4.2
4	6.8	6.0	3.1	2.4	5.6
7	7.2	5.4	4.2	4.3	7.0
10	7.3	5.3	5.1	5.3	7.5
13	7.0	3.3	3.0	3.3	6.6

Lighting Checklist

Building Name __Olin Hall
Address ____100 Institute Rd. Worcester_

By ____Mike Titus____
Classroom ____OH 107_____

Planning # of Lighting Banks	# of Lights/Bank	Type	Operational	Description
6	12	fluorescent	2 out	1 row of fluorescent lighting running along the chalkboard
10	20	fluorescent	all	1 row lighting the presentation area
1	6	halogen spot lights	2 out	2 of the spot lights that didn't work were facing the chalkboard while the rest faced the students
40	80	fluorescent	4 out	lights touching the ceiling in flat rectangular ballast with off white plastic covers
57	**118**	**Total**		

Light Swith Panels	Control # switches	Location	Labeled	Comments
	4	at entrance	no	controlled the front middle and rear fluorescent lighting banks, had a broken dimmer switch
	4	at Podium	1-rear, 2-middle, 3-front, 4-spot	

Measurements at various settings

Comment **Location**	All lights on **EV**	Spot lights off **EV**	Spot & Front Off **EV**	Spot,Front, Middle Off **EV**
Chalkboard	6.2	6..2	4.3	3.4
Projection	6.2	6.3	4.6	3.5
1	6.3	6.3	4.5	3.6
2	6.7	6.7	5.6	4.6
3	7.0	6.7	5.8	5.1
4	6.9	6.7	6.2	5.3
5	6.8	6.7	6.6	5.3
6	6.8	6.7	6.6	5.5
7	6.4	6.5	6.5	4.1

III AIR QUALITY DATA

Newell Hall Time hh:mm:ss	CO_2 ppm	Temperature °F	Relative Humidity %	CO ppm
8:03:40	699	78.9	21.7	2
8:04:40	699	79.1	21.7	2
8:05:40	711	79.2	21.5	2
8:06:40	720	79.4	21.5	2
8:07:40	733	79.6	21.3	2
8:08:40	739	79.7	20.9	2
8:09:40	723	79.8	20.6	2
8:10:40	707	80	20.5	2
8:11:40	711	80.2	20.5	2
8:12:40	738	80.1	20.6	2
8:13:40	737	80.2	20.4	2
8:14:40	745	80.3	20.2	2
8:15:40	745	80.3	20.1	2
8:16:40	754	80.4	20.2	2
8:17:40	733	80.6	20.1	2
8:18:40	769	80.6	20.2	2
8:19:40	733	80.6	19.9	2
8:20:40	742	80.6	19.9	2
8:21:40	774	80.5	19.9	2
8:22:40	754	80.6	19.8	2
8:23:40	758	80.4	19.7	2
8:24:40	751	80.6	19.8	2
8:25:40	757	80.7	19.9	2
8:26:40	744	80.7	19.7	2
8:27:40	749	80.8	19.8	2
8:28:40	762	80.8	19.8	2
8:29:40	759	80.8	19.7	2
8:30:40	766	80.8	19.8	2
8:31:40	748	80.9	19.7	2
8:32:40	752	80.8	19.6	2
8:33:40	759	80.9	19.6	2
8:34:40	752	81.1	19.6	2
8:35:40	745	81.2	19.6	2
8:36:40	778	81.2	19.8	2
8:37:40	791	81.3	20	2
8:38:40	747	81.4	19.5	2
8:39:40	712	80.9	19	2
8:40:40	683	80.6	18.9	2
8:41:40	666	80.5	18.9	2
8:42:40	649	80.5	18.8	2

8:58:43	743	79.3	19.7	2
8:59:43	709	79.1	19.6	2
9:00:43	711	79.2	20	2
9:01:43	698	79.1	19.8	2
9:02:43	715	79.1	19.8	2
9:03:43	722	79.2	19.9	2
9:04:43	720	79.5	20.1	2
9:05:43	723	79.2	20.1	2
9:06:43	699	78.9	19.8	2
9:07:43	706	79.3	20.1	2
9:08:43	703	79.1	19.9	2
9:09:43	706	79.1	20.1	2
9:10:43	705	79.6	20.2	2
9:11:43	731	79.8	20.3	2
9:12:43	752	79.5	20.3	2
9:13:43	718	79.4	20	2
9:14:43	721	79.5	20.1	2
9:15:43	716	79.7	20.1	2
9:16:43	712	80	20.2	2
9:17:43	734	80.1	20.2	2
9:18:43	735	80.2	20	2
9:19:43	760	80.2	20	2
9:20:43	752	80.1	19.8	2
9:21:43	765	79.9	20.1	2
9:22:43	764	79.9	20	2
9:23:43	780	80.1	20.1	2
9:24:43	785	80	20.1	2
9:25:43	759	80.3	19.9	2
9:26:43	754	80.4	20	2
9:27:43	797	80.5	20.2	2
9:28:43	769	80.4	19.9	2
9:29:43	768	80.3	19.9	2
9:30:43	761	80.6	20	2
9:31:43	750	80.6	19.9	2
9:32:43	752	80.6	19.7	2
9:33:43	741	80.7	19.7	2
9:34:43	754	80.6	19.7	2
9:35:43	732	80.8	19.6	2
9:36:43	773	80.6	19.7	2
9:37:43	775	80.7	19.8	2
9:38:43	752	80.6	19.6	2
9:39:43	757	80.6	19.6	2
9:40:43	751	80.8	19.6	2

9:41:43	769	80.9	19.8	2
9:42:43	766	81.1	19.6	2
9:43:43	772	81.2	19.5	2
9:44:43	752	81.1	19.4	2
9:45:43	754	80.9	19.3	2
9:46:43	766	81.2	19.5	2
9:47:43	856	81.3	20.2	2
9:48:43	816	81.4	19.9	2
9:49:43	725	81.5	19.3	2
9:58:27	783	81	19.7	2
9:59:27	854	80.7	20.1	2
10:00:27	851	80.8	20.3	2
10:01:27	808	80.8	20.1	2
10:02:27	827	80.7	20.3	2
10:03:27	834	80.6	20.3	2
10:04:27	857	80.6	20.5	2
10:05:27	854	80.6	20.6	2
10:06:27	887	80.3	20.7	2
10:07:27	874	80.3	20.8	2
10:08:27	912	80.2	21	2
10:09:27	897	80.1	20.9	2
10:10:27	897	80.1	21.1	2
10:11:27	897	80.1	21.1	2
10:12:27	846	80.1	21	2
10:13:27	858	80	21	2
10:14:27	861	80	20.9	2
10:15:27	849	80.1	20.9	2
10:16:27	816	80.1	20.7	2
10:17:27	816	80.2	20.7	2
10:18:27	824	80.2	20.7	2
10:19:27	855	80.1	20.8	2
10:20:27	849	80.2	20.8	2
10:21:27	834	80.2	20.7	2
10:22:27	850	80	20.7	2
10:23:27	832	80	20.7	2
10:24:27	799	80.1	20.6	2
10:25:27	791	80.2	20.5	2
10:26:27	811	80.2	20.5	2
10:27:27	833	80.2	20.6	2
10:28:27	819	80.2	20.5	2
10:29:27	793	80.1	20.4	2
10:30:27	804	79.9	20.3	2
10:31:27	796	80.1	20.3	2

10:32:27	785	80.1	20.3	2
10:33:27	776	80.2	20.3	2
10:34:27	794	80.1	20.2	2
10:35:27	819	80	20.3	2
10:36:27	809	80.2	20.2	2
10:37:27	785	80.2	20.2	2
10:38:27	805	80.3	20.3	2
10:39:27	807	80.3	20.3	2
10:40:27	825	80.2	20.3	2
10:41:27	800	80.2	20.2	2
10:42:27	784	80.3	20.2	2
10:43:27	791	80.3	20.2	2
10:44:27	801	80.3	20.3	2
10:45:27	794	80.3	20.1	2
10:46:27	777	80.3	20.1	2
10:47:27	809	80.3	20.5	2
10:48:27	787	80.3	20.1	2
10:49:27	764	80.3	20	2
10:57:34	732	79.1	20	2
10:58:34	776	79	20.4	2
10:59:34	784	78.9	20.5	2
11:00:34	803	79.1	20.8	2
11:01:34	832	79	21	2
11:02:34	838	79.1	21.2	2
11:03:34	839	79.2	21.3	2
11:04:34	827	79.2	21.2	2
11:05:34	821	79.3	21.2	2
11:06:34	828	79.3	21.2	2
11:07:34	830	79.3	21.3	2
11:08:34	829	79.3	21.1	2
11:09:34	823	79.3	21.1	2
11:10:34	821	79.3	21	2
11:11:34	821	79.3	21	2
11:12:34	806	79.3	20.9	2
11:13:34	798	79.3	20.8	2
11:14:34	821	79.4	20.9	2
11:15:34	795	79.2	20.7	2
11:16:34	779	79.3	20.6	2
11:17:34	794	79.3	20.7	2
11:18:34	807	79.3	20.8	2
11:19:34	790	79.3	20.6	2
11:20:34	793	79.4	20.6	2
11:21:34	781	79.2	20.5	2

11:22:34	777	79.3	20.4	2
11:23:34	784	79.3	20.5	2
11:24:34	784	79.2	20.3	2
11:25:34	764	79.1	20.2	2
11:26:34	800	79.2	20.5	2
11:27:34	774	79	20.1	1
11:28:34	758	79.1	20	1
11:29:34	780	79.2	20.2	1
11:30:34	805	79.3	20.4	1
11:31:34	787	79.3	20.3	1
11:32:34	801	79.4	20.3	1
11:33:34	790	79.3	20.2	1
11:34:34	785	79.2	20.1	1
11:35:34	774	79.4	20.1	1
11:36:34	792	79.3	20.2	1
11:37:34	785	79.3	20.1	1
11:38:34	767	79.4	20	1
11:39:34	774	79.3	20	1
11:40:34	779	79.2	20	1
11:41:34	782	79.2	20	1
11:42:34	819	79.1	20.4	1
11:43:34	783	79	20.2	1
11:44:34	769	79.1	20.2	1
11:45:34	765	79.2	20	1
11:46:34	751	79.1	19.9	1
11:47:34	736	79.1	19.7	1
11:48:34	702	79	19.5	1
11:58:54	852	79.3	20.6	1
11:59:54	906	79.2	21.1	1
12:00:54	912	79.4	21.3	1
12:01:54	922	79.5	21.2	1
12:02:54	905	79.5	21	1
12:03:54	891	79.7	21.2	1
12:04:54	948	79.7	21.2	1
12:05:54	926	79.5	21.1	1
12:06:54	921	79.6	21	1
12:07:54	922	79.5	21	1
12:08:54	943	79.5	21	1
12:09:54	936	79.5	21	1
12:10:54	959	79.6	21	1
12:11:54	924	79.6	20.9	1
12:12:54	923	79.7	20.9	1
12:13:54	994	79.8	21.2	1

12:14:54	983	79.9	21.1	1
12:15:54	961	79.9	20.9	1
12:16:54	949	79.8	20.8	1
12:17:54	921	79.9	20.8	1
12:18:54	933	80	20.9	1
12:19:54	958	80.1	21	1
12:20:54	958	79.9	20.9	1
12:21:54	926	79.9	20.8	1
12:22:54	946	79.9	20.9	1
12:23:54	953	79.8	20.8	1
12:24:54	955	79.8	20.7	1
12:25:54	915	80.2	20.8	1
12:26:54	911	80.3	20.6	1
12:27:54	926	80.3	20.6	1
12:28:54	930	80.3	20.7	1
12:29:54	931	80.3	20.7	1
12:30:54	933	80.1	20.8	1
12:31:54	924	80	20.5	1
12:32:54	934	80.1	20.7	1
12:33:54	951	80.1	21	1
12:34:54	955	80.1	20.9	1
12:35:54	933	80.1	20.7	1
12:36:54	920	80	20.6	1
12:37:54	945	80	20.5	1
12:38:54	925	80.1	20.6	1
12:39:54	912	80.1	20.5	1
12:40:54	897	79.9	20.3	1
12:41:54	916	80.1	20.5	1
12:42:54	963	80.2	20.8	1
12:43:54	929	80.3	20.5	1
12:44:54	915	80.4	20.4	1
12:45:54	903	80.4	20.3	1
12:46:54	910	80.3	20.4	1
12:47:54	924	80.2	20.4	1
12:48:54	918	80.3	20.3	1
12:49:54	921	80.2	20.4	1
12:58:57	949	78.6	20.1	1
12:59:57	895	78.5	19.9	1
13:00:57	881	77.6	20.1	1
13:01:57	859	77.6	20.1	1
13:02:57	871	76.9	20.4	1
13:03:57	872	77.2	20.5	1
13:04:57	894	76.9	20.8	1

13:05:57	904	76.5	21	1
13:06:57	889	75.9	20.9	1
13:07:57	865	75.8	20.8	1
13:08:57	863	75.8	20.9	1
13:09:57	853	76.1	20.9	1
13:10:57	850	75.3	21.1	1
13:11:57	846	75.2	21.1	1
13:12:57	843	74.6	21.2	1
13:13:57	816	74.7	21.1	1
13:14:57	817	74.4	21.3	1
13:15:57	803	74.7	21.3	1
13:16:57	810	74.9	21.3	1
13:17:57	827	74.5	21.5	1
13:18:57	822	74.2	21.5	1
13:19:57	786	74.4	21.3	1
13:20:57	795	74	21.4	1
13:21:57	766	74.5	21.2	1
13:22:57	741	74.6	21.1	1
13:23:57	757	74.5	21.2	1
13:24:57	756	74.3	21.2	1
13:25:57	770	74.3	21.2	1
13:26:57	745	74.3	21	1
13:27:57	725	74.3	20.9	1
13:28:57	760	74.1	21.2	1
13:29:57	789	74	21.4	1
13:30:57	795	74	21.3	1
13:31:57	741	74.1	21.1	1
13:32:57	742	73.7	21.2	1
13:33:57	781	73.5	21.4	1
13:34:57	736	73.9	21.2	1
13:35:57	735	73.6	21.3	1
13:36:57	737	73.7	21.3	1
13:37:57	699	73.8	21.1	1
13:38:57	730	73.6	21.4	1
13:39:57	753	73.4	21.5	1
13:40:57	713	73.3	21.2	1
13:41:57	687	73.6	21.1	1
13:42:57	690	73.6	21.1	1
13:43:57	698	73.6	21.1	1
13:44:57	719	73.4	21.4	1
13:45:57	719	73.5	21.3	1
13:46:57	716	73.5	21.2	1
13:47:57	768	73.1	21.8	1

13:48:57	788	73.1	22.1	1
13:49:57	736	73.4	21.7	1
13:50:57	680	73.1	21.3	1

Time Hour	CO_{2min} ppm	$Temperature_{min}$ °F	Relative $Humidity_{min}$ %	CO_{min} ppm
8am	8:42:40	8:03:40	8:42:40	8:03:40
	649	78.9	18.8	2
9am	9:01:43	9:06:43	9:45:43	8:58:43
	698	78.9	19.3	2
10am	10:49:27	10:30:27	9:58:27	9:58:27
	764	79.9	19.7	2
11am	11:48:34	10:59:34	11:48:34	11:27:34
	702	78.9	19.5	1
12pm	11:58:54	11:59:54	12:40:54	11:58:54
	852	79.2	20.3	1
1pm	13:50:57	13:47:57	12:59:57	12:58:57
	680	73.1	19.9	1

	CO_{2max} ppm	$Temperature_{max}$ °F	Relative $Humidity_{max}$ %	CO_{max} ppm
8am	8:37:40	8:38:40	8:03:40	8:03:40
	791	81.4	21.7	2
9am	9:47:43	9:49:43	9:11:43	8:58:43
	856	81.5	20.3	2
10am	10:08:27	9:58:27	10:10:27	9:58:27
	912	81	21.1	2
11am	11:03:34	11:14:34	11:03:34	10:57:34
	839	79.4	21.3	2
12pm	12:13:54	12:44:54	12:00:54	11:58:54
	994	80.4	21.3	1
1pm	12:58:57	12:58:57	13:48:57	12:58:57
	949	78.6	22.1	1

	CO_{2ave} ppm	$Temperature_{ave}$ °F	Relative $Humidity_{ave}$ %	CO_{ave} ppm
8am	737	80.4	20.1	2
9am	746	80.2	19.9	2
10am	825	80.3	20.5	2
11am	791	79.2	20.5	2
12pm	930	79.9	20.8	1
1pm	788	74.7	21.1	1

Control: Outside

Time hh:mm:ss	CO_2 ppm	Temperature °F	Relative Humidity %	CO ppm
15:22:39	367	45.4	31.7	0
15:23:39	364	45	33.9	0
15:24:39	358	43.9	36.3	0
15:25:39	356	43.5	38.4	0

Outside Newell

CO_{2ave} ppm	$Temperature_{ave}$ °F	Relative $Humidity_{ave}$ %	CO_{ave} ppm
361	44.5	35.1	0
361			

Hazardous / Recommended

CO_2 ppm	Temperature °F	Relative Humidity %	CO ppm
\bove of equal to 100(	outside of 68 - 76 range	outside of 30 - 60 range	less than 3 or4

Olin Hall

Time hh:mm:ss	CO_2 ppm	Temperature ºF	Relative Humidity %	CO ppm
7:57:56	789	70	22.2	2
7:58:56	689	70.1	21.6	2
7:59:56	734	70.2	21.7	2
8:00:56	739	70.4	21.5	2
8:01:56	644	70.5	20.8	2
8:02:56	750	70.7	21.7	2
8:03:56	797	71	21.9	2
8:04:56	807	71.1	22.5	2
8:05:56	781	71.4	22.1	2
8:06:56	828	71.6	22.8	2
8:07:56	797	71.7	21.7	2
8:08:56	802	71.9	22.3	2
8:09:56	845	72	22.8	2
8:10:56	866	72.1	22.3	2
8:11:56	844	72.2	22	2
8:12:56	854	72.3	22	2
8:13:56	878	72.5	22.1	2
8:14:56	888	72.5	22.4	2
8:15:56	893	72.6	22.1	2
8:16:56	903	72.7	22.1	2
8:17:56	918	72.8	22	2
8:18:56	922	72.8	22	2
8:19:56	932	72.9	22.1	2
8:20:56	942	72.9	22.3	2
8:21:56	952	72.9	22.2	2
8:22:56	986	73	22.3	2
8:23:56	969	73	22.1	2
8:24:56	985	73	22.2	2
8:25:56	972	73.1	22	2
8:26:56	972	73.1	22.1	2
8:27:56	1000	73.1	22.3	2
8:28:56	987	73.2	22.1	2
8:29:56	1007	73.2	22	2
8:30:56	1026	73.2	22.2	2
8:31:56	1021	73.2	22.2	2
8:32:56	1049	73.3	22.6	2
8:33:56	1083	73.3	22.7	2
8:34:56	1052	73.3	22.3	2
8:35:56	1042	73.3	22.4	2
8:36:56	1041	73.3	22.2	2

8:37:56	1053	73.3	22.4	2
8:38:56	1089	73.3	22.5	2
8:39:56	1127	73.4	22.8	2
8:40:56	1119	73.4	22.7	2
8:41:56	1083	73.4	22.6	2
8:42:56	1097	73.4	22.7	2
8:43:56	1086	73.4	22.4	2
8:44:56	1122	73.5	22.6	2
8:45:56	1080	73.5	22.3	2
8:46:56	1105	73.4	22.4	2
8:47:56	1089	73.5	22.4	2
8:48:56	1095	73.4	22.3	2
8:57:58	1059	72.4	21.9	2
8:58:58	1007	72.3	22	2
8:59:58	1011	72.1	22	2
9:00:58	1009	72.1	22.1	2
9:01:58	1007	72	22.2	2
9:02:58	995	72	22.1	2
9:03:58	991	71.9	22	2
9:04:58	990	71.8	22	2
9:05:58	991	71.9	22	2
9:06:58	994	71.9	22.1	2
9:07:58	1000	71.7	22.1	2
9:08:58	1003	71.8	22.1	2
9:09:58	988	71.9	22.1	2
9:10:58	994	71.9	22.2	2
9:11:58	993	72	22.2	2
9:12:58	993	72	22.2	2
9:13:58	993	72	22.2	2
9:14:58	984	72.1	22.1	2
9:15:58	985	72.2	22.1	2
9:16:58	996	72.2	22.1	2
9:17:58	979	72.3	21.9	1
9:18:58	970	72.4	21.9	2
9:19:58	977	72.4	21.9	2
9:20:58	986	72.5	21.9	2
9:21:58	980	72.5	21.8	1
9:22:58	990	72.6	21.9	2
9:23:58	988	72.6	21.9	1
9:24:58	994	72.6	22	1
9:25:58	1012	72.6	22.1	2
9:26:58	994	72.5	21.9	1
9:27:58	992	72.5	21.9	1

9:28:58	996	72.5	21.9	1
9:29:58	995	72.4	21.9	2
9:30:58	1000	72.4	22	1
9:31:58	995	72.3	21.9	1
9:32:58	997	72.3	22	1
9:33:58	998	72.2	22	1
9:34:58	997	72.2	22	1
9:35:58	1009	72.2	22.1	1
9:36:58	989	72.3	21.9	1
9:37:58	1002	72.2	22.1	1
9:38:58	998	72.2	22.1	1
9:39:58	1001	72.2	22.1	1
9:40:58	1001	72.2	22.1	1
9:41:58	1004	72.2	22.1	1
9:42:58	988	72.2	22	1
9:43:58	994	72.2	22.1	1
9:44:58	993	72.2	22	1
9:45:58	992	72.2	22	1
9:46:58	996	72.2	22	1
9:47:58	1000	72.2	22	1
9:53:24	1044	72.1	22	1
9:54:24	983	72	21.7	1
9:55:24	1016	72.1	22	1
9:56:24	1067	72.1	22.1	1
9:57:24	1049	72	22.2	1
9:58:24	1141	72	22.9	1
9:59:24	1068	72.1	22.6	1
10:00:24	1025	72.1	22.3	1
10:01:24	1004	72.2	22.2	1
10:02:24	1027	72.2	22.5	1
10:03:24	1012	72.3	22.2	1
10:04:24	1036	72.4	22.5	1
10:05:24	1057	72.4	22.5	1
10:06:24	1072	72.5	22.5	1
10:07:24	1086	72.6	22.7	1
10:08:24	1084	72.7	22.7	1
10:09:24	1078	72.7	22.6	1
10:10:24	1095	72.8	22.6	1
10:11:24	1100	72.8	22.6	1
10:12:24	1114	72.9	22.7	1
10:13:24	1111	72.9	22.6	1
10:14:24	1104	73	22.5	1
10:15:24	1113	73	22.6	1

10:16:24	1122	73	22.6	1
10:17:24	1130	73.1	22.7	1
10:18:24	1137	73.1	22.7	1
10:19:24	1151	73	22.7	1
10:20:24	1152	73	22.8	1
10:21:24	1174	73	22.9	1
10:22:24	1157	73.1	22.8	1
10:23:24	1161	73	22.8	1
10:24:24	1168	73.1	22.9	1
10:25:24	1169	73.1	22.9	1
10:26:24	1166	73.1	22.9	1
10:27:24	1167	73.1	22.9	1
10:28:24	1169	73.2	22.9	1
10:29:24	1184	73.1	23	1
10:30:24	1170	73.2	22.9	1
10:31:24	1176	73.2	22.9	1
10:32:24	1187	73.1	22.9	1
10:33:24	1196	73.1	22.9	1
10:34:24	1196	73	23	1
10:35:24	1182	73	22.9	1
10:36:24	1181	72.9	22.9	1
10:37:24	1180	73	22.9	1
10:38:24	1146	73	22.7	1
10:39:24	1150	72.9	22.6	1
10:40:24	1165	73	22.8	1
10:41:24	1169	72.9	22.8	1
10:42:24	1160	72.8	22.7	1
10:43:24	1142	72.8	22.6	1
10:44:24	1129	72.8	22.5	1
10:45:24	1133	72.8	22.6	1
10:46:24	1127	72.7	22.5	1
10:47:24	1112	72.7	22.4	1
10:48:24	1103	72.6	22.4	1
10:49:24	1090	72.6	22.2	1
10:54:00	1070	72.3	22.2	1
10:55:00	1080	72.3	22.3	1
10:56:00	1060	72.3	22.1	1
10:57:00	1070	72.2	22.2	1
10:58:00	1086	72.1	22.1	1
10:59:00	1089	72	22.1	1
11:00:00	1120	72	22.4	1
11:01:00	1058	72	22.1	1
11:02:00	1037	72	22	1

11:03:00	1046	72	22.1	1
11:04:00	1038	72	22.1	1
11:05:00	1038	72	22	1
11:06:00	1036	72.1	22	1
11:07:00	1037	72.1	22	1
11:08:00	1052	72.1	22.1	1
11:09:00	1051	72.1	22.2	1
11:10:00	1043	72.2	22	1
11:11:00	1034	72.2	22	1
11:12:00	1032	72.3	21.9	1
11:13:00	1026	72.4	21.9	1
11:14:00	1031	72.4	21.9	1
11:15:00	1031	72.5	21.9	1
11:16:00	1039	72.5	21.9	1
11:17:00	1035	72.6	21.9	1
11:18:00	1034	72.6	21.8	1
11:19:00	1020	72.6	21.7	1
11:20:00	1017	72.6	21.7	1
11:21:00	1016	72.6	21.7	1
11:22:00	1019	72.6	21.7	1
11:23:00	1018	72.6	21.7	1
11:24:00	1025	72.6	21.7	1
11:25:00	1024	72.6	21.7	1
11:26:00	1046	72.6	21.8	1
11:27:00	1028	72.6	21.7	1
11:28:00	1016	72.5	21.6	1
11:29:00	1010	72.3	21.6	1
11:30:00	1007	72.3	21.6	1
11:31:00	1001	72.3	21.6	1
11:32:00	995	72.2	21.6	1
11:33:00	992	72.1	21.5	1
11:34:00	989	72.1	21.6	1
11:35:00	980	72.1	21.5	1
11:36:00	970	72.1	21.5	1
11:37:00	969	72.1	21.5	1
11:38:00	965	72	21.5	1
11:39:00	955	72	21.4	1
11:40:00	947	72	21.3	1
11:41:00	934	71.9	21.2	1
11:42:00	928	71.9	21.2	1
11:43:00	926	72	21.2	1
11:44:00	916	72	21.1	1
11:45:00	912	72	21.1	1

11:46:00	902	72	21	1
11:47:00	892	72	20.9	1
11:48:00	886	72	20.8	1
11:49:00	879	71.9	20.7	1
11:51:28	871	72.1	20.7	1
11:52:28	875	72.1	20.9	1
11:53:28	904	72.1	21.1	1
11:54:28	927	72.2	21.1	1
11:55:28	971	72.1	21.2	1
11:56:28	1147	72.2	21.7	1
11:57:28	972	72.2	21.3	1
11:58:28	951	72.2	21.4	1
11:59:28	940	72.3	21.4	1
12:00:28	970	72.3	21.6	1
12:01:28	1052	72.4	22	1
12:02:28	1112	72.5	22.4	1
12:03:28	1043	72.6	22.1	1
12:04:28	1039	72.7	22.1	1
12:05:28	985	72.8	21.7	1
12:06:28	987	72.9	22	1
12:07:28	1011	73	21.9	1
12:08:28	978	73	21.6	1
12:09:28	1007	73	21.7	1
12:10:28	1025	73.1	21.8	1
12:11:28	1080	73.2	22.4	1
12:12:28	1111	73.2	22.6	1
12:13:28	1184	73.3	22.8	1
12:14:28	1136	73.3	22.6	1
12:15:28	1165	73.3	22.8	1
12:16:28	1161	73.4	22.9	1
12:17:28	1160	73.5	22.9	1
12:18:28	1190	73.5	23	1
12:19:28	1184	73.5	23	1
12:20:28	1215	73.6	23.2	1
12:21:28	1203	73.6	23.1	1
12:22:28	1198	73.6	23	1
12:23:28	1218	73.7	23.3	1
12:24:28	1232	73.7	23.3	1
12:25:28	1260	73.8	23.4	1
12:26:28	1229	73.8	23.2	1
12:27:28	1231	73.8	23.3	1
12:28:28	1241	73.8	23.2	1
12:29:28	1322	73.9	23.8	1

12:30:28	1348	73.9	23.8	1
12:31:28	1324	73.8	23.8	1
12:32:28	1322	73.8	23.8	1
12:33:28	1320	73.8	23.8	1
12:34:28	1328	73.9	23.8	1
12:35:28	1299	73.9	23.5	1
12:36:28	1248	73.8	23.1	1
12:37:28	1182	73.9	22.5	1
12:38:28	1164	73.8	22.5	1
12:39:28	1232	73.8	23	1
12:40:28	1304	73.8	23.4	1
12:41:28	1288	73.8	23.2	1
12:42:28	1284	73.8	23.4	1
12:43:28	1320	73.8	23.5	1
12:44:28	1301	73.9	23.5	0
12:45:28	1318	73.9	23.6	1
12:46:28	1310	73.9	23.4	1
12:47:28	1323	73.9	23.7	1

Time Hour	CO_{2min} ppm	$Temperature_{min}$ °F	Relative $Humidity_{min}$ %	CO_{min} ppm
8am	8:01:56	7:57:56	8:01:56	7:57:56
	644	70	20.8	2
9am	9:18:58	9:07:58	9:21:58	9:17:58
	970	71.7	21.8	1
10am	9:54:24	9:54:24	9:54:24	9:53:24
	983	72	21.7	1
11am	11:49:00	11:41:00	11:49:00	10:54:00
	879	71.9	20.7	1
12pm	11:51:28	11:51:28	11:51:28	12:44:28
	871	72.1	20.7	0

	CO_{2max} ppm	$Temperature_{max}$ °F	Relative $Humidity_{max}$ %	CO_{max} ppm
8am	8:39:56	8:44:56	8:06:56	7:57:56
	1127	73.5	22.8	2
9am	8:57:58	9:22:58	9:01:58	8:57:58
	1059	72.6	22.2	2
10am	10:33:24	10:28:24	10:29:24	9:53:24
	1196	73.2	23	1
11am	11:00:00	11:17:00	11:00:00	10:54:00
	1120	72.6	22.4	1
12pm	12:30:28	12:29:28	12:29:28	11:51:28
	1348	73.9	23.8	1

8am	945	72.5	22.2	2
9am	996	72.2	22	2
10am	1119	72.8	22.6	1
11am	1008	72.2	21.7	1
12pm	1153	73.3	22.6	1

Control: Outside

Time hh:mm:ss	CO_2 ppm	Temperature °F	Relative Humidity %	CO ppm
13:05:20	557	57.2	14.8	1
13:06:20	436	54.8	14.9	1
13:07:20	415	50.1	16.3	0
13:08:20	410	44.9	18.2	0
13:09:20	402	42	20.4	0
13:10:20	393	42.6	22.6	0
13:11:20	386	41.7	25.2	0
13:12:20	398	43.7	26.5	0
13:13:20	377	44.8	28	0

Outside Olin

CO_{2ave} ppm	$Temperature_{ave}$ °F	$Relative\ Humidity_{ave}$ %	CO_{ave} ppm
419	46.9	20.8	0
419			

Hazardous

CO_2 ppm	Temperature °F	Relative Humidity %	CO ppm
Above of equal to 1000	outside of 68 - 76 range	outside of 30 - 60 range	less than 3 or4