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Applications of wireless sensors in monitoring Indoor Air Quality in the classroom environment

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Abstract: The focus of this research project was to investigate Indoor Air Quality monitoring technologies, government regulations and policies, and best practices to improve IAQ while minimizing the adverse effect of poor IAQ, specifically in the classroom environment. The investigation involved two parts: development of a cost effective indoor air quality prototype sensor unit and the deployment of the unit to monitor 5 different indoor locations. The data from the sample monitoring locations will then be compiled and analyzed. In addition, researching the literature was instrumental in establishing the parameters for testing the environment and conducting experiments. This provided valuable experiences which will be shared with both district teachers and students.

Background

With the heightened concern over indoor air quality (IAQ), the interest in monitoring the air quality and the cost of those monitoring systems has drastically increased. The most common types of inside monitoring are done with individually purchased units for the home (i.e. carbon monoxide & smoke detectors). Typically, professional gas sensor units cover a wide variety of gasses and measure them to very sensitive concentrations. The use of these units is constrained by high cost and they are generally used only when a problem has been reported. In order to have a more comprehensive picture of what is happening with IAQ, a more cost effective; early warning system needs to be developed.

Professional grade monitoring systems researched included PPM technologies wireless IAQ profile monitor. Each of these units can monitor 3 to 7 parameters via a wireless network. The manager PC connects to a mesh network via a special node which is capable of receiving and transmitting information to the IAQ profile monitors. The manager PC can view, run, and control the real time monitoring and data logging of air quality in a building at the click of a button. The PPM monitoring software enables the data gathered to be viewed graphically, produce reports with statistical data, and run schedules as well as alarm functions and notifications for more effective and economical building management.

Although the PPM monitoring system is a good idea, its major limiting factor is cost. This reduces expansion of the PPM monitoring system for the general public. Each network setup has to have a controller equipped with a zigbee wireless module antenna, and mounting stand which only comes configured for temperature and Rh. The base model costs $856.62 and each additional sensor function plus the installation is an additional cost. The maximum number of parameters is 6. The remote sensors which communicate with the controller unit are the same scenario. The remote sensor comes equipped for temperature and humidity and can be configured for up to 8 sensor functions. The base remote sensor costs $779.61 and can function as a stand-alone unit. "Having a product giving real time monitoring will give immediate warning of over exposure to toxic or harmful gases. [1] For maximum efficiency a network of these sensors would provide a more comprehensive picture of a large building's air quality, but the cost of such a venture could also be astronomical.

The primary professional grade monitoring system researched is the Gray Wolf Direct Sense IQ 610 monitoring system. This system is also the professional system which was available for comparison testing with our prototype sensor assembly.

The IQ610 monitoring system offers several mobile computing platforms making it relatively easy to use. This unit came equipped to measure TVOC, CO2, CO, Ozone, Temperature, %RH, and Dew Point for an initial cost of $7449, and the option for adding additional parameters are available. Customers have the option of buying their computing platform (i.e. pocket PC, ruggedized pocket PC or tablet PC) from Gray Wolf or provide their own laptop. Software to run the sensor is provided when purchased.

The Wolf Sense PC data transfer software allows readings logged on a mobile PC to be reviewed on desktop models. Readings can be easily exported to Excel. The other option is to use the Wolf Sense software to produce graphs from data with all pertinent documentation to produce a highly professional presentation directly from the monitoring system. Photos, graphs, and other files may be attached for additional documentation. The system is also available with an optional advanced report generator which eliminates the need for additional software and produces professional presentations of the data gathered.

The Gray Wolf IAQ 610 monitors make proactive IAQ surveys to be efficient and easy to conduct. It enables the user to optimize the balance between facility energy efficiency and occupant health and comfort. It also enables the user to identify potential IAQ issues before they become problems and allows for immediate response to complaints with high accuracy testing capabilities. The Gray Wolf IAQ610 is designed for both walk-thru and long term testing needs and is one of the most intuitive IAQ meters available on the market.[2]

Related Works

With the rapid development of wireless communication systems in all aspects of our lives, incorporating wireless sensor networks (WSN) for monitoring conditions in many applications has become an acceptable practice. The development and implementation of a wireless sensor network (WSN) has increased interest because it offers a wide range of applications. These applications include: monitoring energy usage, monitoring air quality conditions, monitoring health conditions, national security applications, detecting weather conditions, monitoring agriculture environments, assessing water quality parameters, and many other industrial settings.[3]

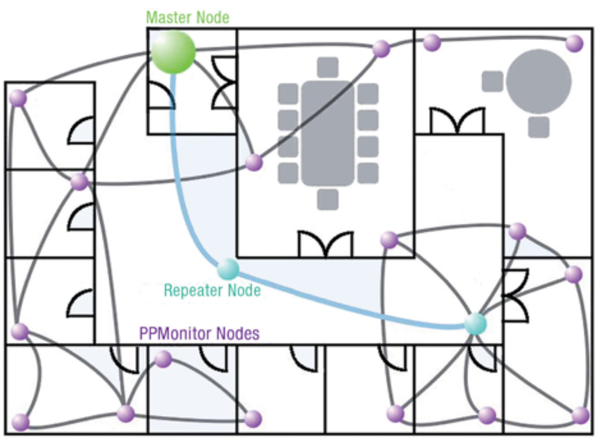


Figure 1 – How wireless units can be placed in any location to enable building wide analysis of IAQ

Wireless Sensor Networks

Wireless sensor network technology promises a wide range of applications from research to our daily lives. The benefits include reduced installation and system costs, increased flexibility, and simplification of deployment. Additional benefits include minimizing the need for battery replacement, adding weather proof containers which reduce maintenance, and enlarging coverage of large spatial areas. [5]

The challenges involved in monitoring natural, in-situ environmental systems have resulted in an increase interest in WSN's. It would allow the monitoring of remote or dangerous environments as well as providing hazard warnings for situations such as floods, earthquakes and inclement weather.

This project used an Arduino board in combination with an XBEE shield which allows the Arduino board to communicate wirelessly using Zigbee for our wireless sensor network (WSN). The WSN consists of three components: gateway, nodes, and software. The nodes interface with an indoor air quality (IAQ) sensor board that was specifically designed to mount on and interface through Arduino. These IAQ boards are capable of gathering data on dust, carbon dioxide, carbon monoxide, VOCs, temperature, and humidity. The gateway Arduino/Zigbee board gets its power through the USB connection to the host controller and sends information directly to this computer. The IAQ monitor nodes transmit gathered information wirelessly through Zigbee to the host, but require an external power source (i.e. battery) due to the lack of USB connectivity.

The IAQ sensor assembly and wireless transmission is based on the compatibility of the Arduino with the XBEE modules either from Max Stream or Digi, depending on which shield you incorporate into the design. The module can communicate up to 100 feet indoors or 300 feet outdoors (with line of sight). Possibilities for usage include using it as a serial/USB replacement or put it into a command mode and configure it for a variety of broadcast and mesh networking options. XBEE products are easy to use. They require no configuration or additional development and allow networks to be enabled in a minimum time frame. Programmable versions allow for further customization without the need of a separate processor. These modules do not form a risk to RF performance or security.

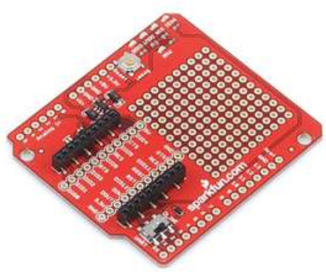


Figure 2
Arduino XBEE Shield Adaptor

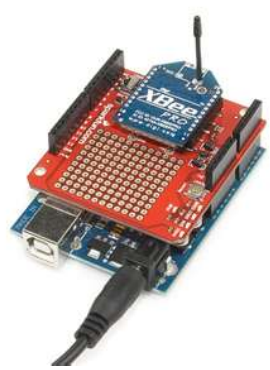


Figure 3
Arduino XBEE Shield Assembled

Figure 4
XBEE with Antenna

Introduction

In recent decades much research has gone into the concept of improving indoor air quality, specifically its importance as a public health issue. Research has shown that both short term and long term health conditions can be linked to the indoor characteristics of buildings. According to ASHRAE, "providing superior IAQ can improve health, work performance and school performance, as well as reduce health care costs, and consequently be a source of substantial economic benefit." [6]

Going back to the oil crisis of the 1970's, new construction of buildings strived for an energy efficient design. Buildings were designed and constructed to be air tight, meaning windows were sealed and ventilation units were turned down to minimal levels. This was done to reduce the energy used to cool or heat the air used in the building. While that was a useful concept for energy efficiency it had adverse effects on the indoor air quality. This issue has been remedied as of late, with a push for buildings to be energy efficient and maintain proper indoor air quality. "While some see energy efficiency and IAQ as contradictory goals, an integrated design can lead to high performing buildings that are both energy efficient and have good IAQ….Furthermore, as the world moves rapidly toward constructing high performance and sustainable buildings , it should be recognized that sustainable/net zero energy efforts will fail if they achieve energy targets but cause significant health or comfort problems for occupants or imped occupant performance in ways that inhibit the building from attaining the goals for with it was built" [6]

The procedure of monitoring indoor air quality was another aspect that we wanted to investigate. Most buildings have an established ventilation rate that the HVAC unit is expected to execute. This ventilation rate is based upon building size and the expected number of building occupants. Because of this stagnant monitoring technique the concept of carbon dioxide based demand controlled ventilation was introduced. "CO2 demand controlled ventilation is a real-time, occupancy-based ventilation approach that can offer significant energy savings over traditional fixed ventilation approaches, particularly where occupancy is intermittent or variable from design conditions." [7] This concept could potentially save companies significant amounts of money in energy costs, while increasing the health of the buildings occupants. "Excessive over-ventilation is avoided while still maintaining good IAQ and providing the required cfm-per-person outside air requirement specified by codes and standards. The authors have observed operational energy savings of $0.05 to $0.15 per square foot annually. [7] This monitoring technique is a monumental change from the previous method of using a fixed ventilation system and then taking IAQ measurement's after a problem has been reported. This sort of technique has led to the development of the condition known as sick building syndrome.

Sick building syndrome was introduced in the late 1980's, and was directly caused by poor indoor air quality. Sick building syndrome (SBS) can affect people in different ways, but should not be confused with specific building related illnesses. SBS symptoms will usually resolve themselves after the person leaves the room or building. Symptoms of SBS include fatigue, headaches, shortness of breath, loss of concentration, eye and throat irritation, and nausea. Common factors that lead to SBS are poor ventilation, airborne pollutants (dust and fungal spores), chemical pollutants, ozone, and high concentration of VOC's. Much work is being done to develop automated systems to monitor IAQ by measuring several different parameters to prevent SBS from becoming a factor in buildings.

An extension of this project was to examine the role that IAQ plays in educational environments. Several studies have researched the IAQ of schools, and the possible health effects it has on students. "The elevated indoor PM2.5 and BTEX concentrations in primary school classrooms, exceeding the ambient concentrations, raise concerns about possible adverse health effects on susceptible children." [8] Before acceptable levels can be established for classroom, certain values must be determined for the levels at which parameter can become detrimental to student health. "In order to set adequate threshold values and guidelines, detailed information on the health impact of specific PM2.5 composites is needed. The results suggest that local outdoor air concentrations measurements do not provide an accurate estimation of children's exposures to the identified air pollutants inside classrooms." [8]

Once all of the factors that influence indoor air quality have been investigated, we can begin to look into their effects on student attendance in schools, and consequently their performance. To better determine what effects poor air quality can have on students in schools, we must first look at what poor air quality in general can have on children. "Relatively little is known about the exact mechanisms underlying any health effects, although most pollutants affect the respiratory and cardiovascular systems. Even less is known about the effects of pollutants on children, although it is thought that children are more susceptible to the effects of pollution than adults because their bodies are developing and they have higher metabolic rates. For example, a child exposed to the same air pollution source as an adult would breathe in proportionately more air and suffer proportionately greater exposure." [9]

After determining the possible health effects that poor indoor air quality can have on student health, we can begin to think about its effect on student performance. It is difficult to determine the relationship between poor IAQ and student performance unless we can narrow it down to certain indicators. One such indicator that is referenced in research is absenteeism. Leaky roofs, problems with heating, ventilation and air conditioning systems, insufficient cleaning or excessive use of cleaning chemicals and other maintenance issues can trigger a host of health problems, including asthma and allergies, which increase absenteeism and reduce academic performance.[9] The Centers for Disease Control, or CDC, backs up this idea in a 2003 journal which states Asthma is a leading chronic illness among children and adolescents in the United States. It is also one of the leading causes of school absenteeism. On average, in a classroom of 30 children, about 3 are likely to have asthma. [10]

When it comes to improving indoor air quality, solutions can often be found by determining and treating the source. One such example would be the airborne bacterial contamination that occurs when large groups of students congregate. Research has shown that the application of a pulsed UV-rich light system to disinfect the contaminated air will cause a significant reduction in the levels of airborne bacterial population.[11]

The EPA has developed an IAQ Tools for Schools program which helps schools organize and implement a specific IAQ program. The program implements strategies including moisture management, integrated pest management, cleaning and maintenance, material selection and adequate ventilation which all help control environmental triggers in building occupants.[12] This program offers a cycle of continuous assessment, planning, and evaluation to help deliver positive indoor air quality results. The main idea being that if a proactive approach is taken vs. a retroactive approach, most issues can be avoided before any symptoms are felt by building occupants.

Design Challenges

- Size & configuration of circuit board to attach to Arduino One unit
- CO sensor is a round configuration & needs an adaptor to fit the circuit board
- Heat from VOC & CO sensor interfering with Temperature Sensor
- Preheat time for VOC & CO sensors
- Accuracy of our design versus Grey Wolf
- Mobility of Unit (Lab View on laptops & wireless options)
- Developing testing criteria
- Integration of Arduino and LabVIEW software

The Arduino compatible board that was ordered for assembly purposes is 2 inches by 2.25 inches, which severely limits how many components can be used and the positioning of the components. We were only able to mount two sensors on each board for testing, and the dust sensor could not be secured to the circuit board because it measures 1.75 inches by 1.25 inches. Another issue is warm up periods, the CO2 sensor needs a minimum of 48 hours while the VOC sensor needs 7 days.

To allow for the use of 4 sensors at the same time we used a Syntax bare prototype board that measures 3.25 inches by 3.75 inches. CO sensor and its resistor were mounted in the upper left hand corner and the VOC sensor along with its resistor was mounted in the upper right hand corner. Since these two components put out a significant amount of heat the temperature sensor was mounted in the lower right hand corner of the board and facing away from the CO & VOC sensors. This configuration was to prevent the heat given off by the sensors from interfering with accuracy of measuring room temperature. The dust sensor was mounted in the center of the board with its capacitor and resistor being located in the lower left hand corner. The needed connectors were located to the left and right of the dust sensor in a configuration to make it compatible for insertion into the Arduino One board. We also added an additional 8 pin connector to each side as a ground and power bank to make testing easier.

When the Syntax prototype board was plugged into the Arduino One board the bottom of the Syntax board was resting on the top of the aluminum housing for the USB connector on the Arduino board. To prevent the possibility of shorting out any portion of the circuitry the USB connector was insulated with a small piece of a 3/8 inch wide rubber band. The piece of the rubber band was secured with a small amount of clear silicon.

The bottom of the dust sensor did not have a way to secure it to the prototype board, therefore we used a small amount of clear silicon to mount it on the Syntax board. There was also an issue with the stranded wire for the dust sensor connector not plugging into the ground and voltage bank connectors. To aid in our testing, a small piece of solid core wire was soldered to the end so we could easily connect or disconnect the wiring as needed. The solder joints were insulated with a 1 inch long piece of heat shrink to prevent shorting.

The CO sensor is round and the pins are in a rounded configuration. The pins on the CO sensor are very rigid, so we were unable to bend the leads to fit the square sensor configuration of the holes in the Syntax prototype board. In order to use the sensor, a solid core copper wire was wrapped onto the pins leaving enough length to allow mounting to the Syntax prototype board. The copper wire was soldered to the CO sensor leads to insure connectivity, and then soldered to the board during assembly. This current mounting solution seems to have solved the issue during testing. To add the wireless ability an xbee shield was added along with a module to allow communication with the arduino board. The module then sends the gathered information from the sensors to another xbee module that is programmed as a gateway device.

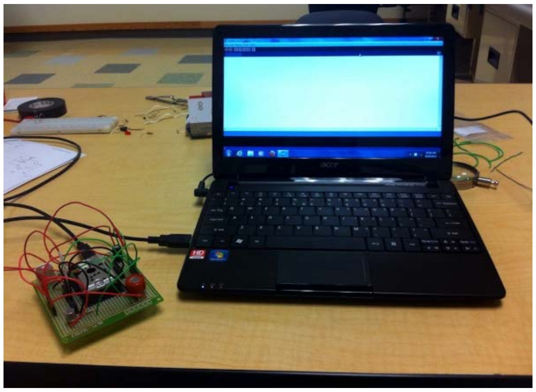


Figure 5 – Hardwired IAQ prototype set to take data

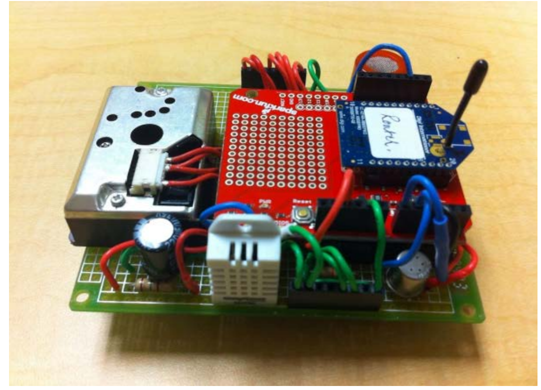


Figure 6 – Wireless IAQ prototype

Materials and Methods

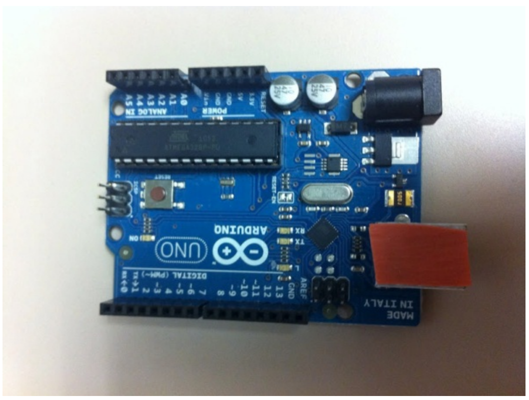


Figure 7-Arduino Board

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as Pulse Width Modualation outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable of power it with a AC-to-DC adapter or battery to get started. In layman's terms: The Arduno Uno acts like the mother board of a computer for our project sensor board.

Sensors

Figure 8 - Relative Humidity and Temperature Sensor

RHT03 Digital Relative Humidity and Temperature Sensor

Output Signal	Digital Signal via MaxDetect 1-wire bus	
Sensing Element	Polymer humidity capacity	
Operating Range	Humidity 0-100%RH;	Temperature -40~80Celsius
Accuracy	Humidity +-2%RH;	Temperature +-0.5Celsius
Sensitivity	Humidity 0.1%RH	Temperature 0.1 Celsius

Figure 9- VOC sensor

VOC sensor – TGS 2602

Detection Range	1~30 ppb
Sensitivity	.15~.5 ppb

Figure 10-MQ-7 Gas Sensor

MQ-7 Gas Sensor for the detection of Carbon Monoxide

Method	Electrochemical
Range	0 to 100ppm
Operating Temperature	-20Celsius to 50Celsius

Figure 11 – Dust Sensor

Compact Optical Dust Sensor

Method	An infrared emitting diode and a phototransistor are arranged diagonally. It detects the reflected light of dust in the air. The presence of dust can be detected by the photometry of one pulse.
Operating Temperature-	10°C ~ 65°C
Sensitivity:	0.5V/(0.1mg/m3)
Voltage - Output:	3.4V
Voltage - Supply:	4.5 V ~ 5.5 V

Lab Experiment

1. Readings were taking from 5 different locations:

Location 1: B242 Lecture Room
Location 2: B239 Teacher Lab
Location 3: Copy Room
Location 4: Staff Kitchen
Location 5: Terrarium

2. Each location was monitored using our IAQ prototype and an Acer netbook.
3. We set the Arduino program to take measurements every 5 minutes, and rotated between locations every 24 hours
4. The GrayWolf unit was set next to our prototype and set to take measurements in the same 5 minute increments for comparison purposes
5. Temperature, Relative Humidity, VOC's, CO, and dust were measured each time with our prototype, while Temperature, Relative Humidity, VOC's, CO and CO_2 were measured each time with the GrayWolf unit.
6. We then analyzed the data to identify certain trends based upon each location.

After the initial experiment was complete we began setting certain thresholds, or levels at which a reading could reach before it was noticed. The threshold we decided to experiment with was VOC, specifically at what point does a certain smell become noticeable and then correlating that to a VOC reading. The last section of our experiment was to investigate ways of improving indoor air quality last variable that we looked at was the addition of plants to the teacher lab, and what affect that would have on the CO_2 levels.

Discussion of Results

Temperature and Humidity

Both of these are related to the comfort of the individuals inside of the building, but can also be related to the levels of biological contaminants in the building. The warmer a building is and the higher the relative humidity, the more conducive it is to the growth of biological factors. We found that the building is maintained at 22.8 degrees Celsius with a relative humidity of 47.8%. During weekends and holidays the buildings average temperature and relative humidity remained the same.

Carbon Dioxide

Carbon Dioxide levels are an excellent indicator of how adequate the buildings ventilation rates are. Looking at the data we found that the levels are typically below 800 ppm, with levels only exceeding that threshold when labs are at their full capacity. For example, with the teacher lab at full capacity the CO_2 levels reached a maximum of 900ppm but when occupants took a break for lunch the levels dropped back below the threshold of 800 ppm. In the terrarium sample we saw levels drop below 550 ppm and reach a max of only 650ppm. This was expected due to the low population, openness of the area, and the reduced population of occupants.

TVOC- Total Volatile Organic Compounds

The kitchen location gave us the best representation of VOC data. When the sensor was set up in the morning, the aroma of coffee was noticeable in the air. This was supported in the data by a high VOC reading in the morning that slowly decreased until 11:30. At 11:30 the readings spiked again, which can be explained by building occupants preparing their lunch that once again produced an aroma. After lunch the readings dropped and leveled out with no significant events.

Carbon Monoxide

Carbon Monoxide is produced mainly by the incomplete combustion of fuel, such as coal or gas. Low levels of carbon monoxide found inside can most likely be attributed to air entering from outside the building through fresh air intakes. Looking through our data we found that the buildings CO levels are well within acceptable IAQ levels.

Data

Gray wolf   Prototype

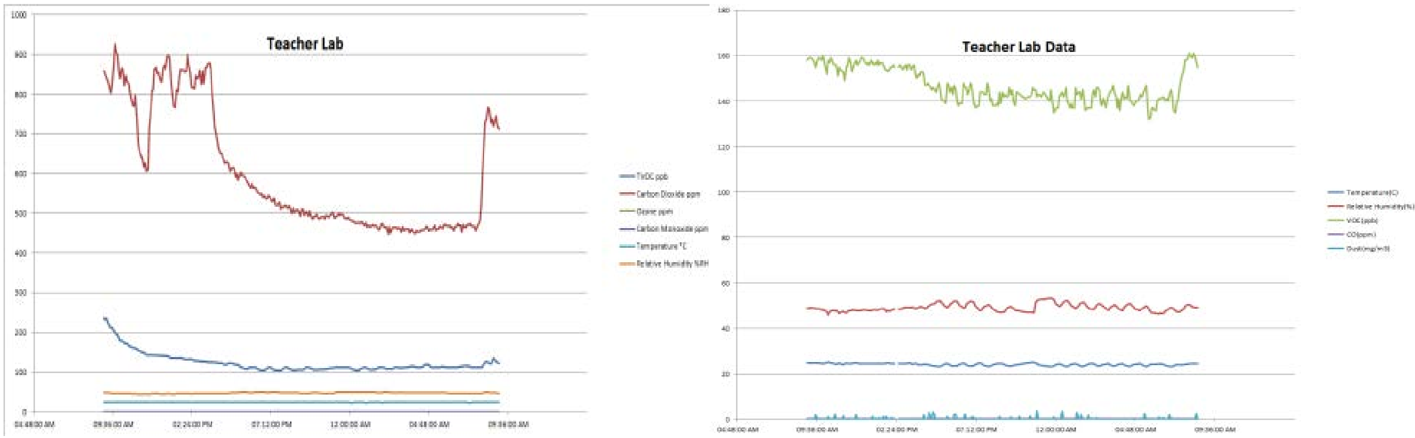


Figure 12 – Teacher lab comparison

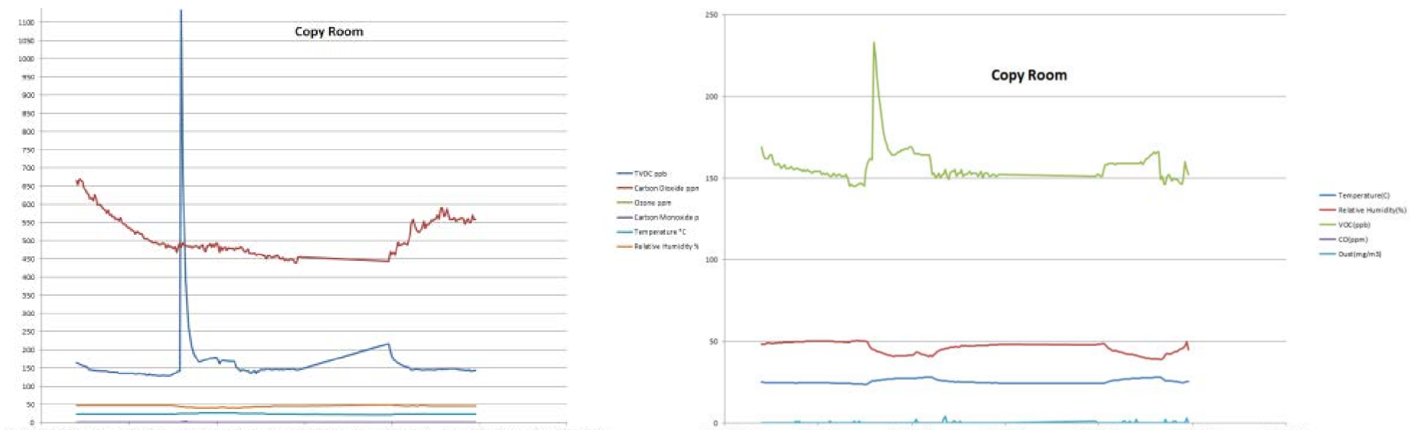


Figure 13 – Copy Room Comparison

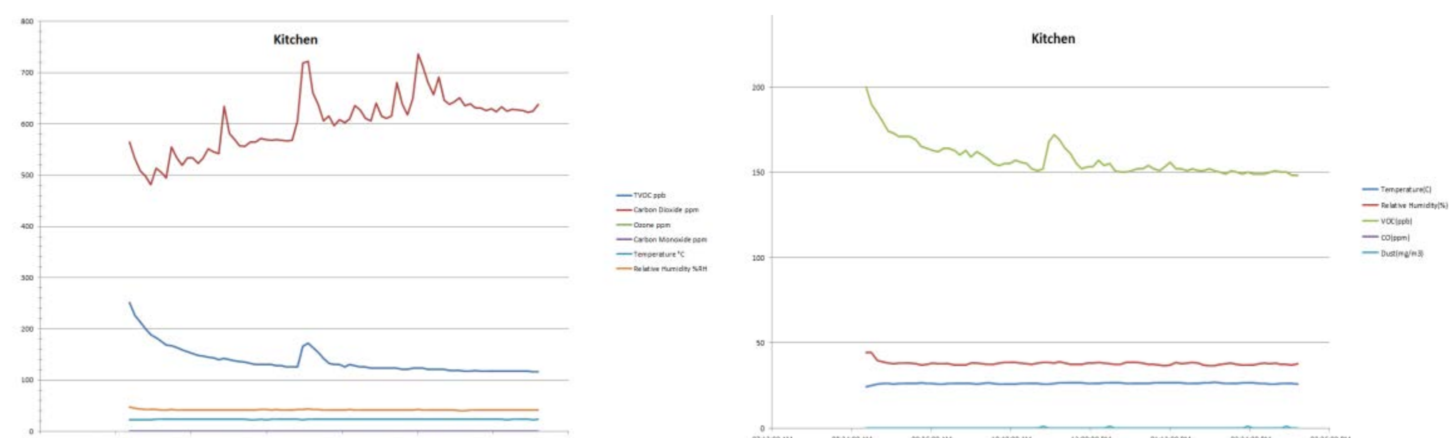


Figure 14 – Kitchen Comparison

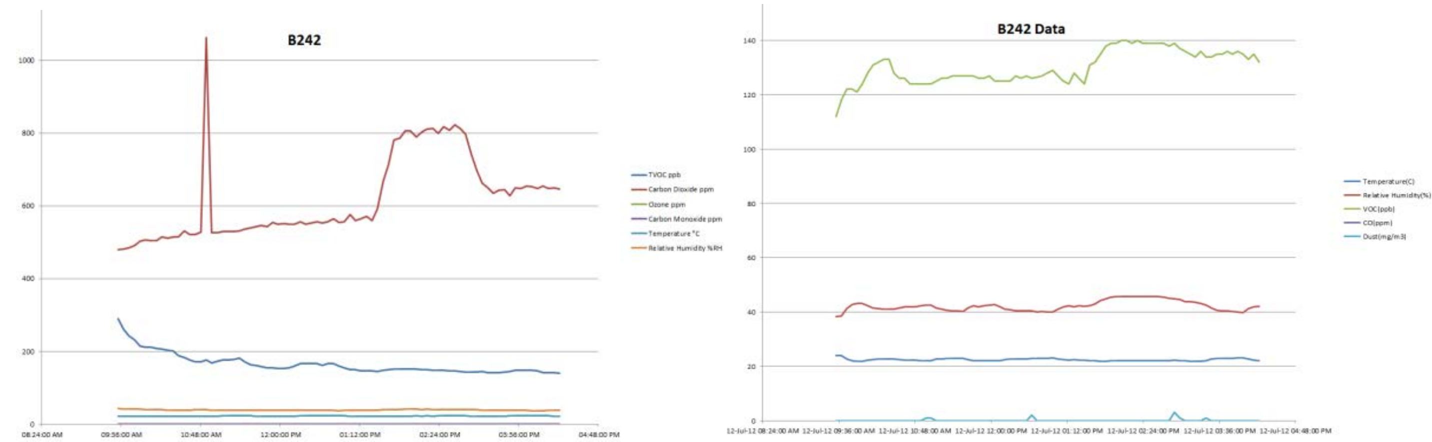


Figure 15-B242 Lecture Room Comparison

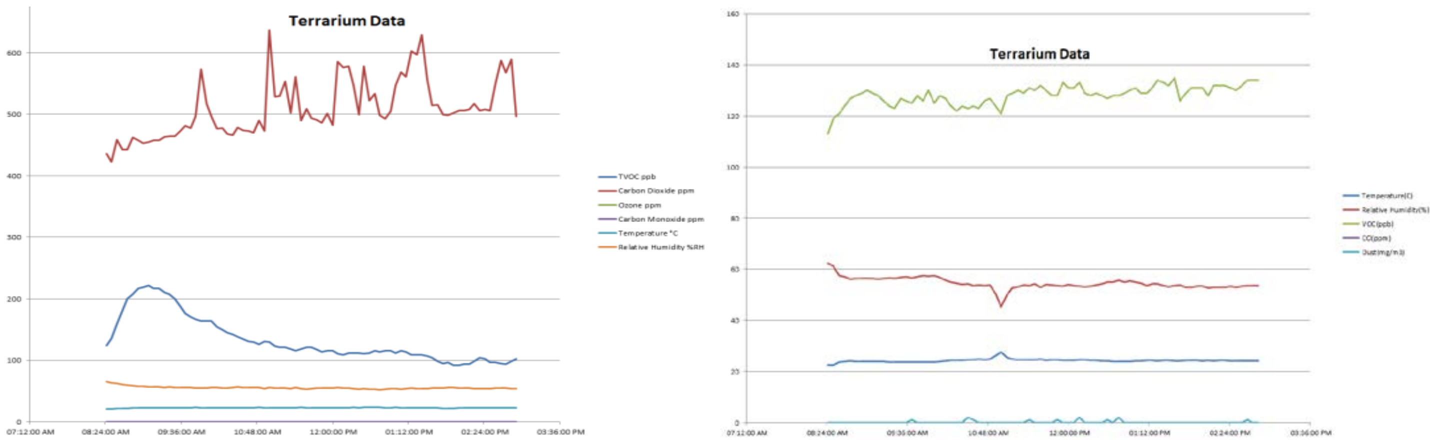


Figure 16- Terrarium Comparison

Results of VOC Threshold Experiment

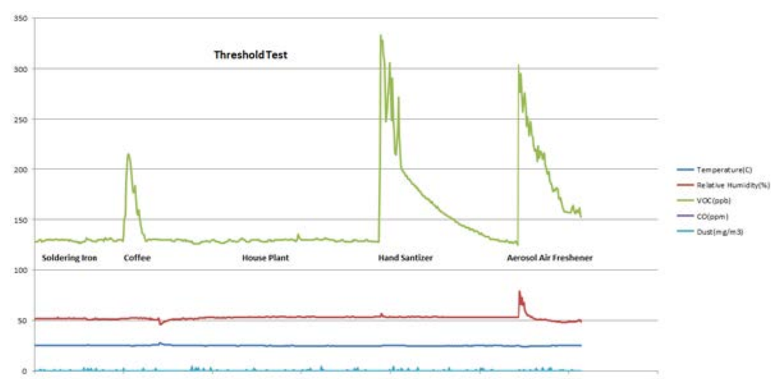


Figure 17 – Results of different VOC samples

For our threshold test we experimented with four different parameters, fumes from a soldering iron, coffee, hand sanitizer, and aerosol air freshener. The prototype was set to record data every 30 seconds. We were specifically looking at what readings were produced and at what point the fumes became noticeable to the room occupants. The standard VOC reading for the room was 130 ppb, so all of our tests were based from there. Our first sample came from soldering iron fumes. The fumes had no effect on the VOC content of the room, therefore registered no change in our data. Next, a hot cup of coffee was placed on the same table the sensor was located on. Within the first minute the sensor registered a VOC reading of 150ppb, before climbing all the way to 215ppb. Over the next 15 minutes the coffee fumes dissipated and our readings dropped back to the base 130ppb level. Knowing that plants can naturally release VOC's, we added a common house plant, aloe vera, to our list of samples. Placing the prototype sensor directly next to the plant for two and a half hours produced no detectable response from our VOC sensor. An extension to our project could be to test different plant species for a longer sampling period to see if any change in VOC can be found. For the next sample 3 tablespoons of hand sanitizer was placed next to the sensor. The readings immediately jumped to 333 ppb before slowly declining over the next hour. This sample provided the highest reading for VOC content for any of our threshold tests. The last sample came from an aerosol air freshener. The air freshener was applied to the room that the sensor was located in. Once again the readings jumped immediately, but only to 304 ppb. Apart from the VOC, this sample also caused a change in the relative humidity causing a spike that brought it near 80%. Over the next hour the readings then slowly returned to their normal values. While the data was being recorded, we also noted at what point each aroma became noticeable. Based upon the data, a reading of at least 200 ppb is needed for a VOC to be detected by an individual inside the building. It should be noted that VOC's are present, even if they are not detected by occupants.

Effects of plants on Carbon Dioxide levels

Six plants were added to the teacher's lab to test what effect plants have on the CO2 concentration of an area. The plants were placed around the room at a height of around 4.5 feet. The plants used were: aloe vera, pothos, 2 crotons, and a fern. The GrayWolf senor was then used to monitor the location for 24 hours so the results could then be compared to the original teacher lab data. The comparison shows that the plants lowered the CO2 concentration by around 85ppm. The room's population was kept the same as the original sampling, along with the location of the sensor. This data supports the idea that plants are a viable option for improving indoor air quality.

Figure 18 - Teacher lab without plants

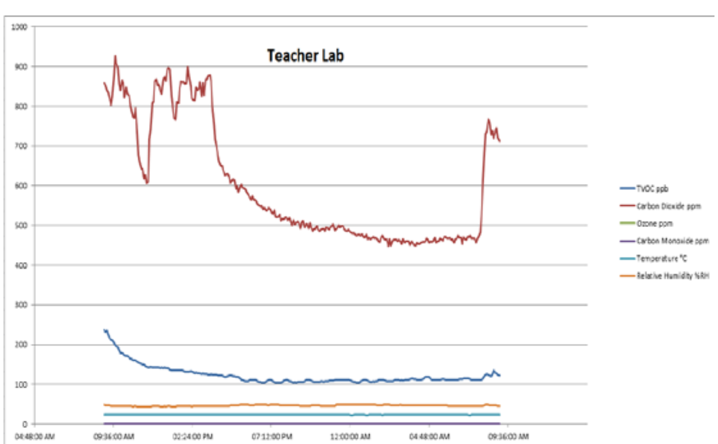
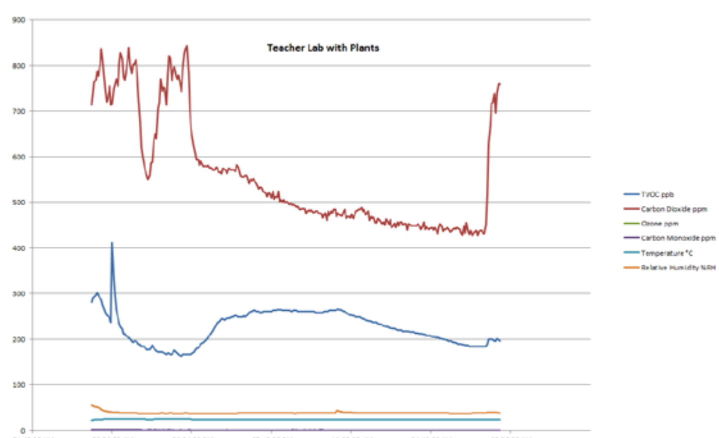


Figure 19 - Teacher lab with plants



Conclusion

Potential hazardous gasses in the work place are a critical issue. Too often, these gasses are undetected until the employee becomes ill or a foul odor is reported by building occupants. By the time this occurs, occupants will have suffered exposure to poor air quality. The next step is to test the building with an expensive sensor unit to determine the source of the problem. Indoor air quality needs to have a cost effective early warning system to warn building occupants before the air they breathe becomes a health threat.

Continuous cost effective monitoring of indoor air quality as part of a proactive plan will help limit the need for expensive testing as a reactive solution. Real time monitoring enables immediate warnings of the presence of harmful gases in the air, thus protecting students. Analyzing data over time allows for a more efficient management of resources and energy. The use of monitoring technology should be applied to indoor air quality in the same way that it is used for monitoring outdoor air quality.

Based on the results generated by analyses, we found that the GrayWolf unit was much more sensitive than our prototype. This was consistent with the fact that our prototype is designed for applications such as early detection or education use, not scientific research.

Further Work

Continual work still needs to be done integrating the Arduino software into the LabView system. This will allow for a more presentable graphical system, along with certain system alerts that can be installed. These alerts will be based upon the thresholds found for each parameter tested. The CO_2 and O_3 sensors also need to be added to the prototype board once those sensors become available. Last, a complete wireless system with multiple nodes will be developed to monitor several locations. These nodes will report back to a central gateway to give a holistic view of the area being monitored.

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Indoor Air Quality Match Up

Pollutant	Major Indoor Sources
Environmental Tobacco Smoke	Cigarettes, cigars, and pipes
Carbon Monoxide	Unvented or malfunctioning gas appliances, wood stoves, and tobacco smoke
Nitrogen Oxides	Unvented or malfunctioning gas appliances
Organic Chemicals	Aerosol sprays, solvents, glues, cleaning agents, pesticides, paints, moth repellents, air fresheners, drycleaned clothing, and treated water
Formaldehyde	Pressed wood products such as plywood and particleboard; furnishings; wallpaper; durable press fabrics
Respirable Particles	Cigarettes, wood stoves, fireplaces, aerosol sprays, and house dust
Biological Agents (Bacteria, Viruses, Fungi, Animal Dander, Mites)	House dust; pets; bedding; poorly maintained air conditioners, humidifiers and dehumidifiers; wet or moist structures; furnishings
Asbestos	Damaged or deteriorating insulation, fireproofing, and acoustical materials
Lead	Sanding or open-flame burning of lead paint; house dust
Radon	Soil under buildings, some earth-derived construction materials, and groundwater

Abstract- indoor air quality (IAQ) can contribute to the safety, health and comfort of the people. Since indoor exposure to air contaminants penetrating from the indoor air contaminant sources depends on a number of parameters such as the ventilation rate, the geometric characteristics of the indoor environment, the indoor removal mechanisms and the concentration of air contaminants released, the implementation of smart sensor network is a promising solution to ensure good indoor air quality.
This paper focuses on the application of

Student Activity: Monitoring Indoor Air Quality in the Classroom Environment

OBJECTIVE:

- To develop an understanding of the components of indoor air quality and the factors that influence them
- To understand how WSN's function, and to utilize it in a monitoring capacity
- To analyze and interpret data recorded from the IAQ prototype and software
- To evaluate what changes need to be made to the indoor system to improve the IAQ

Materials:

A. Electronics

- Student Laptops
- Indoor Air Quality Prototype Monitoring System, containing the 5 different air quality senors (Temperature/relative humidity, Carbon monoxide, Carbon Dioxide, VOC, and dust.)
- Arduino Board
- Arduino software installed on student laptops
- USB cable to connect Arduino board to laptops

In this activity you will:

- Take readings from 4 separate classrooms:
  - The first classroom will be a math, history, or an english room
  - The second classroom will be an art or chemistry room
  - The third will be the copy room , or any place where large amounts of printing is done
  - The last will be a room with a large congregation of plants
- Set up the prototype unit in each location for 1 day, set to take readings every 5 minutes
- Students will then analyze the data, looking for specific trends
- Students will determine the cause of particular trends, and if necessary evaluate possible solutions for the outcome

Introduction:

Indoor air quality (IAQ) is a term which refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ can be affected by gases (including carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria) or any mass or energy stressor that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings. Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modeling of air flow inside buildings.

Student Activity: Monitoring Indoor Air Quality in the Classroom Environment

Procedure:

A. Data Collection

1. Introduce students to the prototype unit, explaining what each piece is and what each sensors function is.
2. Have students determine testing locations, making sure that one will serve as your control, the second is a chemistry or art room, the third is a copy room or room where printing is done, and the 4th contains several plants.
3. In their journal students will predict readings for each location and provide justification for each prediction.
4. Place the sensor and laptop in the first testing room and set the unit to take readings every 5 minutes. After 24 hours retrieve the unit and repeat the procedure for the subsequent locations.
5. After all the readings have been taken, students are to compile a graph of each location, and begin looking for certain trends in the data.

B. Air Quality Journal

Quantitative Data:

1. Set up data tables in your journal – one for each parameter measured

Qualitative Data:

1. Set up an observation section in your journal.
2. Record daily activities and all steps taken when working with the system.
3. Record your observations on each location (number of people in the room, what the people are doing, number of window/doors, etc).
4. Record all daily observations in your journal.

C. Graphs:

1. Graph the results of your testing for each location. Students should have a graph for each parameter vs. time for each location.
2. Compare temperature and relative humidity to the other parameters to see if there is any correlation.
3. Interpret each data graph and relate it to your overall set up.

D. Assessment Questions:

1. Describe your IAQ set up. Explain how this affected your experiment.
2. List the parameters that you tested for. List the source of each and the possible effects if the levels are outside of the acceptable range.
3. What are some of the hazards/side effects of poor indoor air quality, specifically in a classroom?
4. What did adding plants to the room do to your readings?
5. What are some possible solutions for improving indoor air quality?
6. What was the most difficult part in attaining a balance between energy efficient buildings but maintain good IAQ?
7. Reflection questions: What was the most interesting thing that happened during this project? What is the one thing you will remember about this project? What would you change about this project for next year?

Student Activity: 3D Design of Indoor Air Quality Monitoring System & Monitoring of a Classroom Environment

OBJECTIVE:

- To develop an understanding of the components of indoor air quality and the factors that influence them
- To understand how a Wireless Sensor Network operates, and how to utilize it in a monitoring capacity
- To analyze the Indoor Air Quality Design Sensor System for design flaws
- To evaluate the Indoor Air Quality Design Sensor System

Materials:

A. Electronics
- Student Laptops
- Indoor Air Quality Prototype Monitoring System, containing the 5 different air quality senors (Temperature/relative humidity, Carbon monoxide, Carbon Dioxide, VOC, and dust.)
- Arduino Board
- Inventor 3D Design Suite & LabView software installed on student laptops
- USB cable to connect Arduino board to laptops

In this activity you will:

- Construct Virtual Design of Sensor Assembly
    - The first level is to layout the prototype board in Inventor software
    - The second level is to add individual sensor circuits to the prototype board in Inventor 3D Drawing
    - The third level will be to add the Arduino control unit to the Inventor 3D Drawing
    - The last step will be to monitor a room with a large congregation of people to demonstrate the sensor network board function
- Set up the prototype unit a location for 1 day, set to take readings every 5 minutes
- Students will then analyze the data, looking for specific trends
- Students will determine the cause of particular trends, and if necessary evaluate a possible solutions for the outcome
- Students will determine if design flaws are present

Introduction:

Indoor air quality (IAQ) is a term which refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ can be affected by gases (including carbon monoxide, radon, and volatile organic compounds), particulates, microbial contaminants (mold, bacteria) or any mass or energy stressor that can induce adverse health conditions. Source control, filtration and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings. Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modeling of air flow inside buildings. Designing cost efficient, user friendly models for public use is important to maintain IAQ and to develop standards.

Procedure:

A. Data Collection

1. Introduce students to the prototype unit, explaining what each piece is and what each sensors function is
2. Have students construction techniques for sensor function demonstrations
3. In their journal students will define 3D Drafting techniques for prototype assembly and testing variables
4. In their journal students will predict IAQ readings for a specific testing room location
5. Place the sensor and laptop in the testing room and set the unit to take readings every 5 minutes. After 24 hours retrieve the unit and repeat the procedure for the subsequent locations.
6. After all the readings have been taken, students are to compile a graph

7. **Optional**: Have students determine multiple testing locations, making sure that one will serve as your control, the second is a chemistry or art room, the third is a copy room or room where printing is done, and the 4^{th} contains several plants

B. Air Quality Journal

Quantitative Data:

1. Document design variables in student journal
2. Set up data tables in student journal – one for each parameter measured

Qualitative Data:

1. Set up an observation section in student journal.
2. Record daily activities and all steps taken when designing and working with the IAQ system.
3. Record your observations on assembly data and how design differences could affect sensor measurements
4. Record sensor data from observation location (number of people in the room, what the people are doing, number of window/doors, etc).
5. Document all observations in student journal.

C. Graphs:

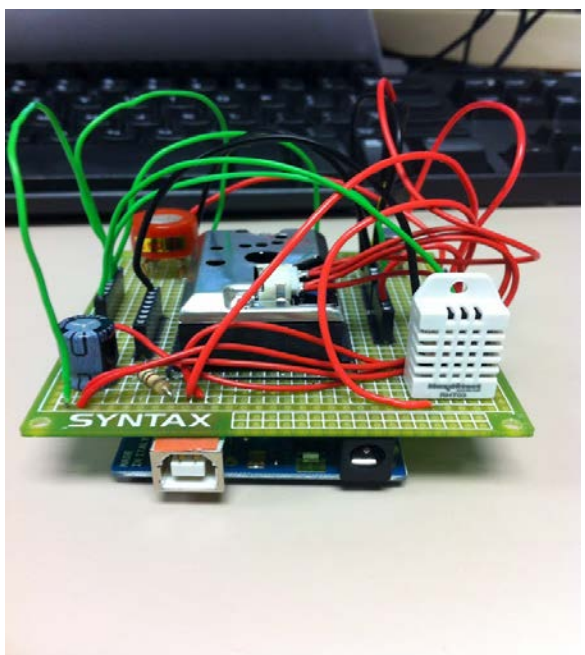
1. Graph the results of your testing for each location. Students should have a graph for each parameter vs. time for each location.
2. Compare temperature and relative humidity to the other parameters to see if there is any correlation.
3. Interpret each data graph and related to your overall set up.

E. Assessment Questions:

1. Describe your 3D IAQ design for prototype board.
2. Explain how to construct a 3D design layout for the sensor prototype.
3. Explain how making a 3D design can prevent design flaws.
4. Describe your IAQ set up. Explain how this affected your experiment.
5. List the parameters that you tested for. List the source of each and the possible effects if the levels are outside of the acceptable range.
6. What are some of the hazards/side effects of poor indoor air quality, specifically in a classroom?
7. What did adding plants to the room do to your readings?
8. What are some possible solutions for improving indoor air quality?
9. What was the most difficult part in attaining a balance between an energy efficient building but maintain good IAQ?
10. Reflection questions: What was the most interesting thing that happened during this project? What is the one thing you will remember about this project? What would you change about this project for next year?

RET: Research Experiences for Teachers
In Sensor Networks
Summer Internship 2012
University of North Texas (UNT)
NSF - 1132585

An Investigation Into Indoor air quality
5 E Lesson Plans



Georgette Jordan, Dallas ISD
Blaine Chamberlain, Carrollton-Farmers Branch ISD

Lesson Objective(s):

1. The students will design and build an experimental indoor air quality monitoring system.
2. They will monitor the following factors: CO, CO_2, VOC, temperature, O_3, humidity and dust/particulate matter.
3. Students will understand how human influence affects each of the factors being monitored and explore ways we can improve indoor air quality.

This system is designed to be an inexpensive way for teachers to introduce indoor air quality into the classroom.

Target Grade Level: High School Science, grades 9-12

Science TEKS:

Biology, Chemistry, Integrated Physics and Chemistry

- (B) Introduction: 4. - Science and Social Ethics. Scientific decision making is a way of answering questions about the natural world. Students should be able to distinguish between scientific decision making methods and ethical and social decisions that involve science
- (C) Knowledge and skills: 2.F - Collect and organize qualitative and quantitative data and make measurements with accuracy and precision using tools

Environmental Systems

- (C) Knowledge and skills: 9.A-E & H-L

Materials Needed:

A. Electronics
   a. Student Laptops
   b. Indoor Air Quality Prototype Monitoring System, containing the 5 different air quality senors (Temperature/relative humidity, Carbon monoxide, Carbon Dioxide, VOC, and dust.)
   c. Arduino Board
   d. LabView software installed on student laptops
   e. USB cable to connect Arduino board to laptops

Engagement:

A. Video: Indoor Air Pollution http://www.youtube.com/watch?v=bSCOnFLTzGQ
B. 60 minutes indoor air quality video http://www.youtube.com/watch?feature=endscreen&NR=1&v=5z6Y-I-LJsU
C. Protect yourself from indoor air pollutants http://www.youtube.com/watch?v=GrwbVBKEqZg

Exploration:

A. Student directed questions:
   1. How does indoor air quality affect a person's health?
   2. What are some examples of the pollutants you might find inside your home?
   3. How might you combat the causes of poor indoor air quality?
   4. What type of plants would be most effective for improving indoor air quality?

B. Students will research sources of poor indoor air quality:
   1. Have students complete the IAQ match up, students will cut out the pollutants and causes and then work in groups to match the pollutant with its correct cause
   2. After the matchup is complete, students need to discuss possible solutions to each of the pollutants listed.

C. Use at least 2 higher order thinking questions to solicit STUDENT explanations and help them to justify their explanations:
   a. Why do you think CO_2 levels fluctuate during the day?
   b. Develop a plan that would lower CO_2 in your school
   c. Justify the expense required to balance an energy efficient building while maintaining acceptable indoor air quality.

Elaboration:

A. Students will develop a more sophisticated understanding of the concept by completing the student activity

B. Scientific terminology to be introduced and to enhance/connect to students' observations:
   a. Carbon Monoxide
   b. Carbon Dioxide
   c. Relative Humidity
   d. Volatile Organic Compounds (VOC's)
   e. HVAC – Heating, Ventilation and Air Conditioning Unit
   f. IPM-Integrated Pest Management

C. Application of this scientific knowledge in our daily lives:
   a. What repercussions would improving IAQ have on the student body?
   b. What is the relationship between IAQ and student performance?

Evaluation:

1. How will students demonstrate that they have achieved the lesson objective?
   a. Monitor 4 different locations during the school year using the prototype system
   b. Keep a detailed lab journal
   c. Complete a formal lab report
   d. Lab report must include analysis of the data, and explanations for any trends that are identified
   e. Submit possible ways to improve IAQ based upon findings

2. Questions
   a. What evidence did you find that occupant population is directly related to CO_2 levels?
   b. What do you think a reasonable threshold should be for carbon dioxide based upon your schools findings?
   c. Identify different emission sources that might affect VOC.
   d. How would you explain the relationship between days with outdoor air warnings and the readings you recorded inside?

Background for Teacher*:*

Resources:

http://www.arb.ca.gov/research/indoor/healtheffects1table1.htm

http://www.alencorp.com/articles/indoor-air-quality-overview.asp

http://www.epa.gov/iaq/ia-intro.html

http://www.ppm-technology.com/downloads/PPMonitor%20Wireless%20Mesh%20Proposal.pdf

Tech Fest Activity: Indoor Air Quality

OBJECTIVE:

- To develop an understanding of the components of indoor air quality and the factors that influence them

Materials:

- Indoor air quality prototype sensor
- 1 can of each: aerosol air freshener, canned air (used for cleaning electronics), fart in a can (fart spray), and any flavor of axe body spray.

Activity

- Participants will hypothesize what parameters will change by spraying the different samples

Questions

- What is indoor air quality? Why is it different than outdoor air quality?
- What do you predict will happen when each sample is sprayed in the air?
- What would you do you improve indoor air quality?

Tech Fest Activity: Indoor Air Quality

What is indoor air quality? What factors do you think would influence indoor air quality?

Which spray caused the biggest change in indoor air quality? What value changed the most?

What would you do to improve the indoor air quality in your house?