Smart Atmos.

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***Abstract*—The creation of an IoT system of devices linked through Bluetooth in order to remotely control a humidifier and air purifier; adding the ability for them to sense the world around them and be actuated based off of these sensed readings.**

Keywords—IoT, air quality, humidity, retrofit

I. Introduction

Every winter people across the northern half of the country drag out their humidifiers to increase the moisture content in their homes. As the air outside becomes colder, the amount of water it can hold decreases. In a home, as that air warms, its capacity for water increases causing relative humidity to fall indoors. Humans don't feel absolute humidity, only relative, as that relatively unsaturated air pulls moisture instead from us. This leads, among another things, to discomfort. Another aspect of air quality to look at is PM2.5 content in a room, the "dustiness" of a room for lack of a better term. One final aspect of air quality we will consider are volatile compounds in the air, gases that are detrimental for humans to breathe, like acetone.

An issue with correcting these air quality conditions lies in the devices commonly used to for rectifying them. Most humidifiers and air purifiers that are commercially available on the lower end of the price range are dumb devices. That is, they lack the ability to sense the world around them; they simply have an on and an off, and sometimes multiple levels of operation (high, medium, low). This often leads to cases where the device is operating when it either does not need to be, or is even detrimental to keep running. Particulate and volatile compounds have an acceptable range for humans, after entering that range, further air purifier use is effectively just wasting energy and putting additional wear on the filter(s) used for removing contaminates. Too high a humidity can also have negative consequences, making humidifiers a large issue if they run for too long.

II. Motivation

This project is a selfish endeavor, in the sense that it isn't necessarily targeted specifically at wide spread usage. The idea began simply as having issues with low humidity in the winter myself. With humidifier added though, my room would begin to feel swampy, though no condensation formed. My mind was particularly captured on a visit home for the winter holidays, my parents had a humidifier running upstairs and that room was getting massive amounts of condensation on the windows to the point that it became a notable problem. The flipside to this was the rapid drop in humidity should the humidifier not run for an evening. Finally, one of my roommates in my apartment has highly sensitive allergies to both pollen and dust, leading to year-round irritation. I sought to make simple system that could be retrofitted to devices for myself, my family, and my friends to help in improving their cold-weather indoor air quality.

III. Background

Low humidity is defined indoors as below 30% relative humidity. Based on medical findings, low humidity leads to overall discomfort caused by the drying out of the lips leading to chapped lips, eyes leading to dry eyes [1], and skin which can exacerbate preexisting skin conditions such as eczema [2]. Mucous membranes dry out as well, which increases the spread of disease, as the mucous membranes are our body's first line of defense in terms of stopping pathogens.

High humidity is defined indoors as above 60% relative humidity. As moisture content reaches these levels, condensation can begin forming in your house. This can cause wood to rot, requiring costly repair, as well as aiding in the growth of mold and dust mites. Mold and dust mites each decrease the quality of air, particularly for those with asthma, mold allergies, or dust mite allergies. High humidity air also stagnates more easily, causing a feeling of increased difficulty breathing. This is brought upon as the higher moisture content of the air suspends small particulate matter for longer periods of time [3]. Diseases also have an easier time spreading in high humidity, fungi prefer humid environments and some viruses and bacteria spread through water vectors, think Covid-19 which spreads through water droplets.

PM2.5 is defined as fine particulate matter, smaller than or equal to 2.5 micrometers in size. This extremely small size allows the particulate to more deeply penetrate the lungs. Long-exposure to PM2.5 has been shown to significantly increases the odds of cardiopulmonary problems [4]. Even short-term exposure leads to health problems, every 10 $\mu g/m^3$ present increase asthma symptoms by 18% [5].

As for volatile compounds, health effects and healthy thresholds vary across each chemical compound. In general, too high an exposure amount leads to respiratory distress.

IV. IMPLEMENATION

First, let's outline the overarching architecture of the system.

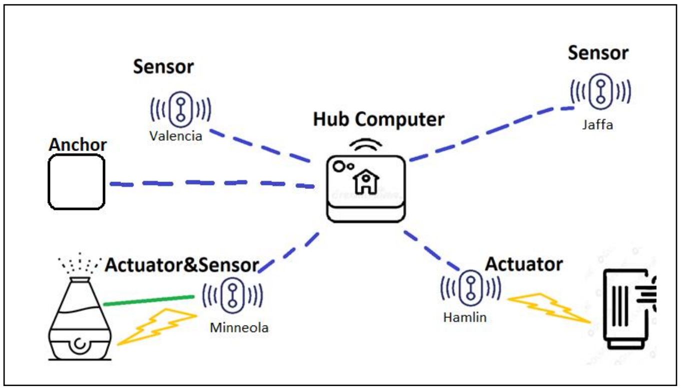


Figure 1 Overall System Architecture

The system is composed of a low-cost humidifier and a low-cost air purifier, four microcontrollers, and a central computing hub that the microcontrollers connect to. The central computing hub used is an Asus ZenBook 15 laptop, though this could easily be swapped out for something like a Raspberry Pi, so long as the replacement has way to connect to Bluetooth devices and the ability to be a master in the Bluetooth master-slave model. There is also any other sort of device capable of Bluetooth connectivity present, the anchor. For the purposes of this implementation, a Bose portable Bluetooth speaker was used, though the speaker functionality does not matter, just that it is Bluetooth equipped.

Microcontrollers Valencia and Jaffa act as the main sensoring function of the system. Each is a Teensy 4.0 and is equip with a DHT11 module for humidity sensing and a MQ-135 for volatile compound detection. Jaffa is also equipped with a Keystone KS0196, used for sensing PM2.5 (Valencia would have one, but the module is prohibtably expensive to purchase more than one).

Microcontrollers Minneola and Hamlin are responsible for actuating power to the humidifier and the air purifier respectively. This is done through the SRD-05VDC-SL-C relay. Unfortunately the process for attaching the relay to the humidifier and air purifier is destructive, though thankfully minimal, as the power cords must be cut and have the relay mounted in the middle <PLEASE USE CAUTION WHEN WORKING WITH WALL POWER>.

Minneola also has some sensing function, it has an XKC-Y25-V, a contactless liquid level sensor and a photoresistor. The contactless liquid level sensor is used to detect when the liquid level is nearly empty. The photoresistor is attached to the back of the XKC-Y25-V over the LED. This LED relays the on/off of the XKC-Y25-V, as the sensor returned a binary value; there was either liquid present at the level or there wasn't.

Figure 2 XKC-Y25-V, note the red LED that the photoresistor will be affix over

Upon the detecting a low water level, the system turns off the humidifier to prevent the device from burning itself out should the water tank completely empty. An e-mail will be sent to the user, stating that the water tank is low.

All microcontrollers are powered by basic breadboard 3.3v/5v power supplies. Each of the four microcontroller possesses an HR-06 Bluetooth module. This allows each device to communicate with the central computer hub. Valencia, Jaffa, and Minneola push their sensed outcomes to the hub, then the hub pushes out a message to Minneola or Hamlin if it is necessary to switch the power of either respective device.

Every minute, the hub checks to see if it can connect to the anchor. If so, it proceeds to check the sensor readings; if not, it shuts down the actuated devices until the anchor able to connect. This is a proof-of-concept geofencing feature, the humidifier and air purifier don't need to run while the user is not present.

When the hub proceeds to sensor reading, it first reads the two humidity sensors and averages them. If greater than 45% humidity, the humidifier is shut off; and if less than 40% humidity, then humidifier is turned on. This is in the middle of the healthy humidity range. The accepted range ensures that the humidifier is not rapidly turned on and off, hovering over a single value.

The hub then reads from the PM2.5 and volatile compound PPMs, the PPMs are averaged from both microcontrollers. Those three values (one PM2.5 and two PPM) are actually each themselves an average of reading taken between hub readings, as the sensors are very prone to fluctuation on any given individual reading, averaging multiple readings before passing to the hub ensure some level of stability from the cheaper quality sensors.

The sensor readings are averaged at the hub to determine an overall reading of the levels across the room, as a sensor close to the humidifier will report higher humidity than the entire room is experiencing for instance.

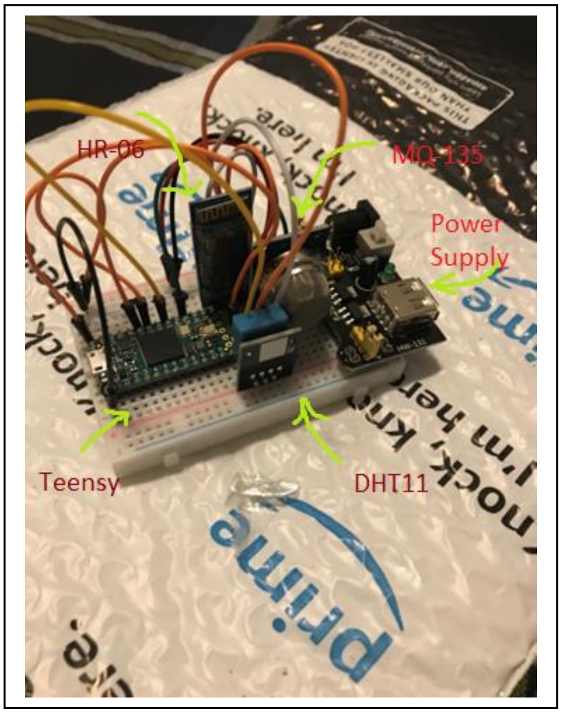


Figure 3 Sensor Array, Valencia

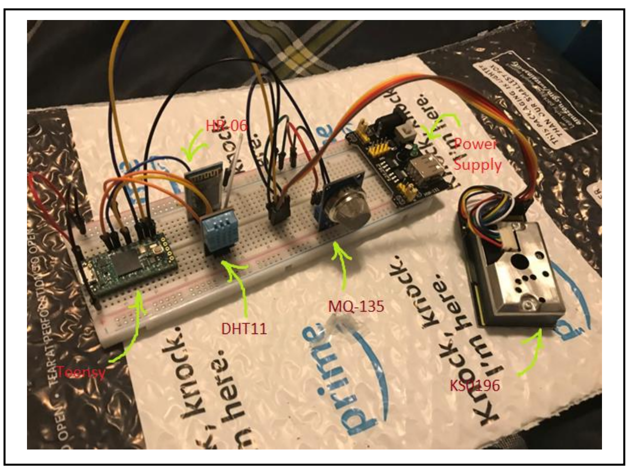


Figure 4 Sensor Array, Jaffa

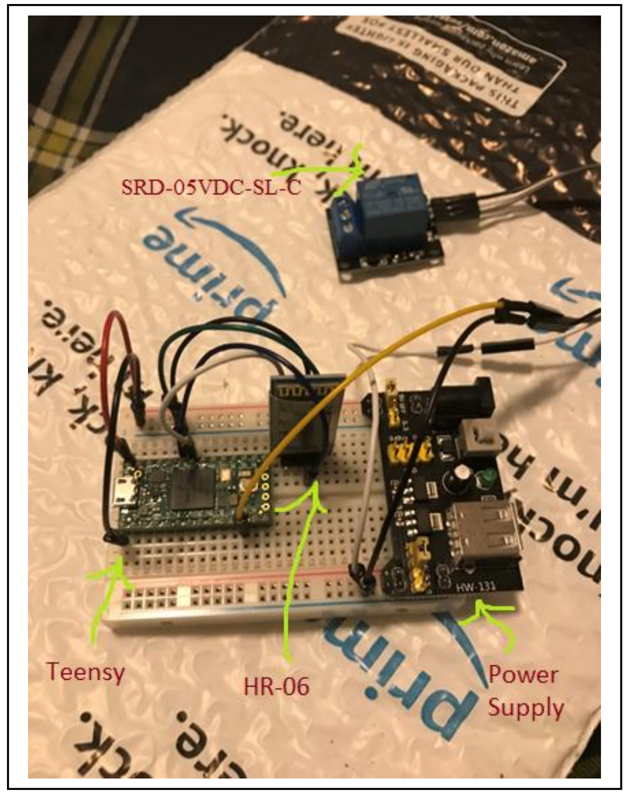


Figure 5 Actuator, Hamlin (relay not attached to air purifier)

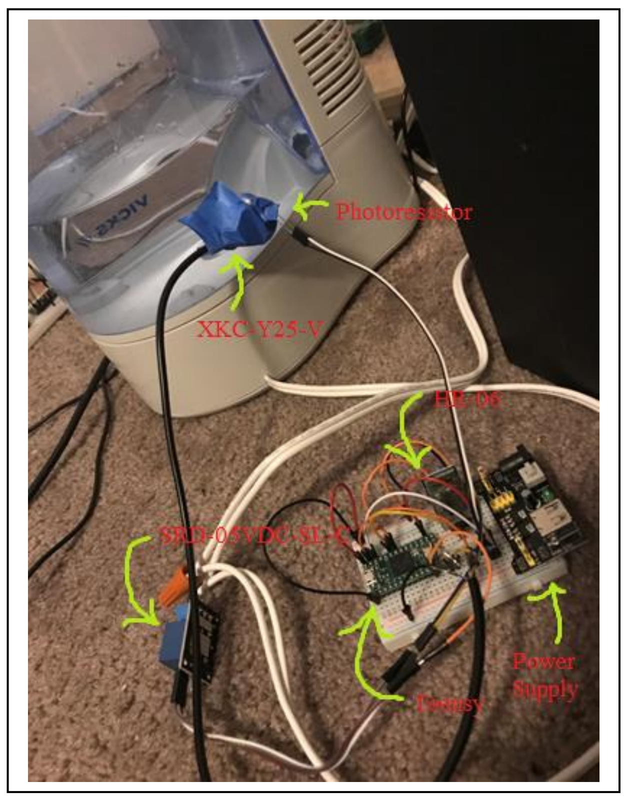


Figure 6 Actuator/Sensor Array, Minneola

V. Experimentation

A. Humidity Test

The first test run was to see how well the system could manage humidity. Minneola and Valencia were used. The test was run in my bedroom, measuring 15’5”x12’0”. The door was generally kept closed unless necessary. The test ran for just shy of nine hours. Outside the temperature was in the mid-80sF, with a relative humidity fluctuating between 40% and 43%. The range of humidity to stay between was 50% and 55%. Air conditioning was on, bring cool dry air into the room occasionally. The sensors were read by the hub once every minute.

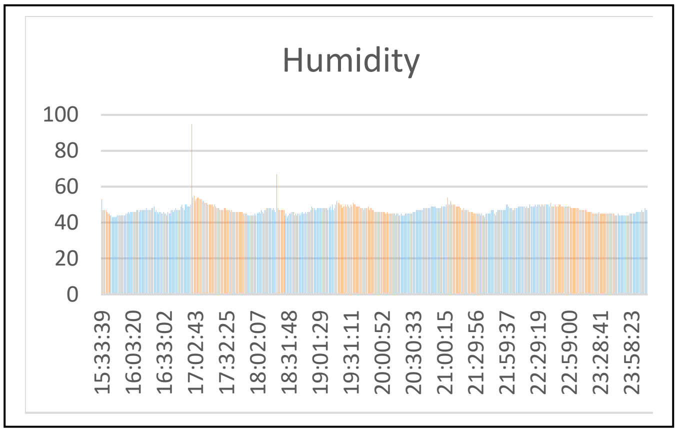


Figure 7 Humidifier is off when graph is orange, on when blue

The spike in the graph at 17:02:43 was someone breathing on the humidity gauge to double check that it was functional before the test progressed too far. The spike at 18:31:48 is believed to simply be a fault with the sensor. From this we can see that the humidifier successfully kept the relative humidity in the set range, and the humidifier was only on for roughly 60% of the time. As this humidifier being used has a one-gallon tank, and consumes 5% of its tank per hour, it would be expected for the device without sensing capabilities to consume roughly 0.44 gallons; the test only saw 0.26 gallons consumed. As an aside, ground truth for the experiment was provided by several humidor humidity gauges, the DHT11’s measurements were comparable to those humidity gauges.

B. PM2.5 Test

As a device to measure PM2.5 is quite expensive, I had no ground truth to make sure the KS0196 was consistent. To establish if there was consistency or not, the burning oil test used. The burning oil test took place in my kitchen, and saw me put canola oil into a wok on my stove and heat it to its smoke-point (roughly 400 degrees F if you’re interested). The oil would be allowed to continue to heat and produce smoke until the smoke detector would alarm, at which point the air was allowed to clear. The process when then repeated four more times. Jaffa was the only microcontroller used for this test, and was generally located on the countertop closest the stove. A reading was taken once every minute.

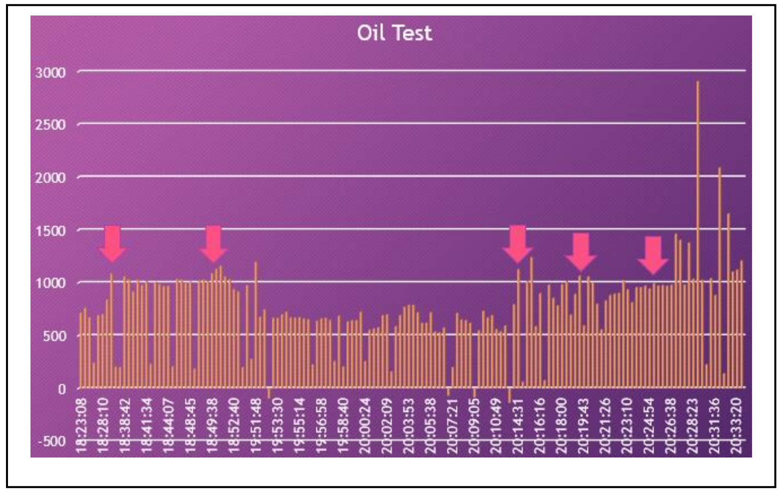
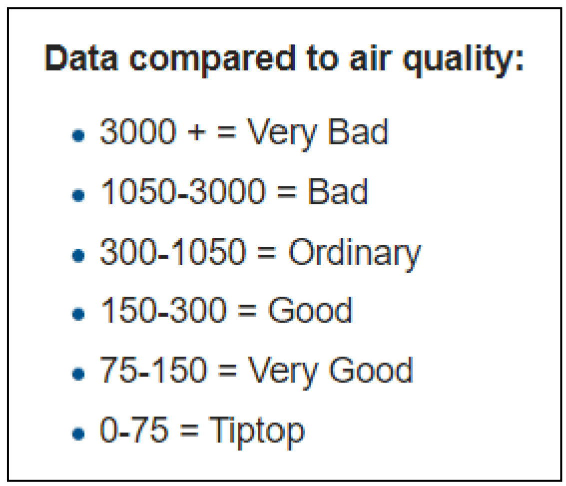


Figure 8 Arrows are located at the points in time where the smoke detector alarmed

The KS0196 consistently read around 1000 each time the smoke detector alarmed, which is exactly what we were looking for! A few things to note, the y-axis of the graph is unitless, the documentation for KS0196 does not include any form of PM2.5 unit, the only metric to gauge the value on is the following chart that they provided:


Data compared to air quality:

- 3000 + = Very Bad
- 1050-3000 = Bad
- 300-1050 = Ordinary
- 150-300 = Good
- 75-150 = Very Good
- 0-75 = Tiptop

Figure 9 Not the most portable measurement system, but it works well enough

The few negative values on the graph are faults in the sensor. Finally, that large spike at 20:28:23 was Jaffa being held up to the ceiling of the room instead of the countertop. Though anecdotal, I can safely say that the air quality at the height of the ceiling, as smoke rises, was definitively “Bad”, borderline “Very Bad”, so the provided measurement system appears accurate (enough) as well.

C. Volatile Compound Test

Just as with the PM2.5 sensor, there was no affordable and available volatile compounds sensor to check the consistency of the MQ-135 sensor. As such the acetone test was run. This consisted of moving Jaffa toward and away from a dollop of acetone placed on a block of PLA. A reading occurred every twenty seconds.

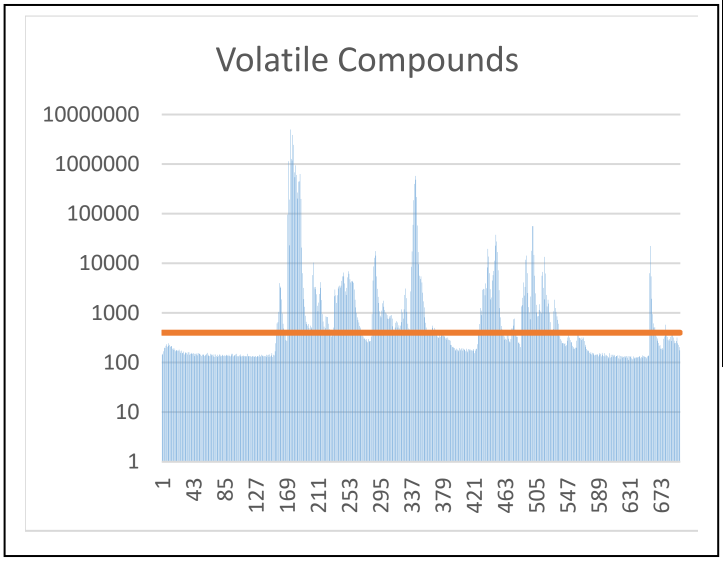


Figure 10 The orange line is at 400PPM, the upper limit at which humans can first detect acetone

The massive spike at 169 occurred when the device was right next to, nearly touching, the acetone. Though rudimentary, using the human olfactory nerve as a ground truth, at the distance where acetone could first be detected by sense of smell, the MQ-135 read right around 400PPM. This suggests to me that the MQ-135 is accurate enough for the purposes of this project.

D. *System Test*

This was a roughly five-hour test, again in my bedroom, door closed. For this test the entire system would be used: Jaffa, Minneola, Valencia, and Hamlin. Outside was low-60sF, with a relative humidity of 33%. The range for this test was 40% to 45% relative humidity, as this was still in the healthy range and the starting humidity was lower than the standalone humidity test. Upper limit of PM2.5 was set to 900 and 400PPM for volatile compounds, if either limit was breached the air purifier was kicked on. Sensors were sampled every minute.

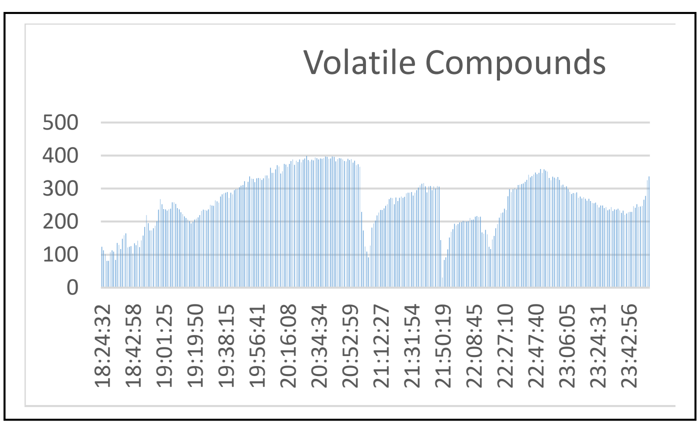


Figure 11 Volatile compounds never reached levels to activate the air purifier

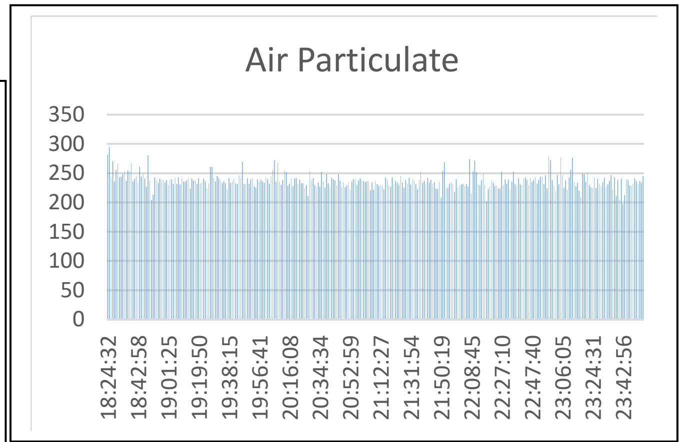


Figure 12 PM2.5 never reached levels to activate the air purifier

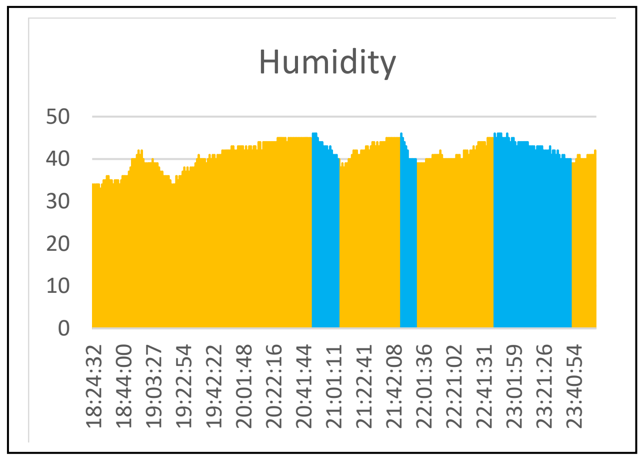


Figure 13 Orange is humidifier on, blue is humidifier off

Next to no change was occurring on the air particulate level, which makes sense as no dust was being stirred up, no cooking was occurring, and the room was semi-sealed. Volatile compounds would build then fall off. I believe each fall off was the door being opened, giving the opportunity for every day, off-gassed compounds to be wafted out and replaced with cleaner air. The humidifier spent the first two hours building up from the initial humidity to that upper limit of 45%. This led to the humidifier being off for only 22% of the time, not much compared to the standalone humidity test. This test would have generally been more useful, had more time been available to proceed with a longer span of study, but it at a minimum demonstrates that all parts of the system are able to function together, which had yet to be trialed until this point.

VI. Results

A. *Power Consumption*

The largest factor to examine in evaluating the value of the system is power consumption, does the actual power consumption of the system make up for the lower down time of the devices. Using a Kuman KW47-US electricity usage monitor, the humidifier and the air purifier were measured on their own. The humidifier consumes 273.3w, while the air purifier consumes 6.4w. With Valencia and Minneola in use with the humidifier, 276.6w is consumed when the humidifier is on, and 4.7w is consumed when the humidifier is off. With Jaffa and Hamlin in use with the air purifier, 11.8w is consumed when the air purifier is on, and 5w is consumed when the air purifier is off. The hub, my laptop, consumes 17.8w when plugged in.

A few things to note when looked at this. First, there are three common types of humidifiers available: vaporizers, ultrasonic, and passive evaporative. The humidifier used in this system is a vaporizer. These are by far the most energy intensive of the three, but it comes with two upsides deemed worthwhile. Of the three, vaporizers are the only that produces a warm mist, the other two types are considered cool mist humidifiers. This is due to the vaporizer style actually bringing water to a boil to add water vapor to the air. I personally find this quite pleasant as an additional source of heat, even if small, in the colder months. In fact, cool mist style will in fact bring down the temperature of a room ever so slightly, as the latent heat of vaporization required for any liquid to enter a gaseous form (and thus increase relative humidity) will take energy, in the form of heat, out of the room if energy is not actively provided by a heating element.

Another pro of vaporizers links directly with air quality. Passive evaporators are the least energy intense as they employ only a fan to increase airflow across the wick that draws water up from the tank. The wick is used to the increase surface area of water exposed to air, speeding evaporation. Passive evaporators' biggest downfall comes from this wick, as if not changed regularly, are excellent breeding grounds for mold; the fan(s) then facilitate in the spreading of mold spores, decreasing air quality. Vaporizers kill any molds that happen to grow internally, reaching a hot enough temperature to kill.

Ultrasonic humidifiers, similarly to passive evaporative, use far less power than a vaporizer. They employ the rapid vibration of an ultrasonic speaker to eject fine water droplets from the device, which due to high surface-area-to-volume ratio, evaporate relatively quickly. Unfortunately, these water droplets are useful for the transportation and spreading of molds if they begin to grow in the water tank. If hard water is used in an ultrasonic humidifier, those dissolved minerals will be carried along by the water droplets, either leaving mineral build up on surfaces in your home or being aspirated, lowing air quality. Vaporizers and passive evaporators do not share this problem, as by evaporating the water in the device, the mineral content in left behind, contained to the machine for easy regular cleaning to remove it.

Because of the factors given, a vaporizer is preferable for a system centered on air quality, even if more energy intensive. This high energy demand justifiers the additional draw of the microcontrollers and hub, as they are minimal compared to the active draw of the humidifier being always on.

The air purifier is far less justified, the power consumption of the device is roughly equivalent to the power needed for the microcontrollers and hub. This finding could also be due to the air purifier in use being on the small-scale of air purifiers, testing the wattage of another air purifier shows a device-only consumption of 24w. Even with this larger air purifier the extra energy used by the system is hard to justify. This makes sense as air purifiers generally only need to power a fan or two, used to draw and push into and out of the filter. It would take along the scale of the Nuwave OxyPure air purifier, very much on the larger side of consumer air purifiers and which can consume 100w, to fully justify the existence of the system.

The microcontrollers could also be further optimized in order to make the addition of the smart air purifier modifications more reasonable. As the system currently stands, there is plenty of room for decreasing energy consumption. The clock speed of the Teensy 4.0 could be turned down, or the microcontroller could be replaced entirely for a lower power controller. The HR-06, which uses Bluetooth 2.0, could be swapped out for a more expensive module that uses Bluetooth Low Energy (BLE). Finally, voltage control could be used to turn of sensor module until the hub requests a reading.

The hub could be replaced to reduce system energy consumption. Even replacement to a Raspberry Pi 4 would cut energy needed for the hub by more than two thirds, from 17.8w to 5.5w. And a Raspberry Pi 4 is most likely still more computational power than needed, a lower electricity consuming hub is probably out there.

All this to say, as the system stands in its current implementation, the smart modification to the humidifier makes sense from a power saving point of view, while the air purifier is better of just being run consistently as the sensors on their own use just barely less power than the device itself. This could of course be improved in future iterations of the Smart Atmos. system.

VII. Limitations

There were three large limitations present when working on this project.

Financially, there were some items that would have been nice to have but were out of reach because of their price or because of the accumulated bill from this project. A nicer PM2.5 sensor, a legitimate accurate air quality sensing device for a ground truth, a beefier air purifier with a HEPA and charcoal filter, etc. It is for financial reasons that some components were used, though less than ideal, such as the Teensy 4.0, as they were already in my possession and worked well enough to deal with their downsides.

Documentation-wise, some components were a massive time sink to get operational because they lacked much in the way of documentation. The KS1096 PM2.5 sensor is a great example of this, the documentation of which is borrowed code from a random individuals GitHub. I never would have known that to get a sensor reading, you must turn on the internal IR LED (which detects particulate based off how that light scatters off of the dust) for a very specific amount that the manufacturer and/or seller does not give to you. Fortunately, I found out this vital information for the functioning of the sensor through an Amazon review from a disgruntled buyer. This review also informed that to turn on the LED, you set its pin on the microcontroller to LOW and HIGH for off, the opposite of every single LED or common module in use. And the manufacturer doesn't tell you!

Getting proper documentation for Bluetooth libraries is also not as simple as I assumed it would be entering the project. Most languages it seems have some degree of Bluetooth library, but the documentation is generally lacking to the point that probably individuals are better off writing their own Bluetooth libraries for most languages. Fortunately, Python Serial is straight forward and has enough documentation to be usable by a Bluetooth novice, such as myself.

Speaking of being a novice, the final limitation going into this project was my own lack of knowledge in working with electronics. Before this project the extent of my experience was using my Teensy to turn an LED on and off, that was about it. Having to learn on the fly while attempting to implement certainly slowed things down, much more than anticipated.

VIII. Future Work

Some future things that could be implemented or iterated upon in future versions of the Smart Atmos. system:

- Optimizing microcontroller and sensor energy consumption
- Port the code from a Windows laptop to Raspberry Pi or another microcomputer
- Run long term full system tests to further evaluate
- Replace the PM2.5 sensor with one that has a more usable metric of measurement
- Implementing GPS, wi-fi, or Bluetooth geofencing. Apply machine learning to this geofencing to learn a user's schedule and preempt return to home to have the air quality ready for them when they arrive
- Build an app to control the system hub over wi-fi/the internet
- Add a dehumidifier for summer time air quality control
- Integrate the system into a home's HVAC system through the thermostat's wiring to heating, cooling, and fan control.
- Modify humidifier and/or air purifier hardware to gain more fine grain control over operation rather than simply on and off. This might be useful for a zone control setup
- Zone control setup, multiple humidifiers and/or air purifiers throughout a home or building and a dozen or more sensors to try and balance the entire internal volume of air at roughly the same quality throughout

IX. Acknowledgements

Pratik Musale, for suggesting the use of a contactless liquid level sensor. I had no idea this existed in a modular form factor and would have otherwise destructively put a hole in my humidifiers tank in order to add a water contact sensor for reading the tank level.

Alexander Pujols, my friend and roommate, who saved me many hours of debugging and problem solving by aiding me in realizing that I was trying to read an analog value using a pin that I had not set to read analog and instead defaulted to digit. It would have been genuinely been dozens of hours to try and find a fix, and I'm honestly not 100% convinced I every would have noticed it without chatting about the project and Teensy microcontrollers with him.

X. Conclusion

This project is a success in my eyes. The goal was to create a system that can manage indoor air quality through a minorly destructor retrofitting process and manage the system wirelessly, and it can do just that! The broader question of should it be done, at this moment and iteration, is yes for vaporizing humidifiers, no for any other device unless very large.

XI. References

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