ME 121

6 June 2022

Smart Building project

Smart building project

Abstract

Control of relative temperature and CO2 concentration in an indoor environment is important to maintain a comfortable environment and to reduce energy consumption and escape air overheating and the lack of “fresh” air inside the building. Using a LOW-cost microcontroller Feather nRF52480 Sence, Adafruit SCD30 NDIR CO2 Temperature and Humidity Sensor, 5VDC fan, PWN-controllable ventilation fan, a resistive heater and OLED display. I will do 5 different experiments. “1. Create a schematic, similar to Figure 1, that reflects how you set up your “smart building”. 2. Conduct tracer decay tests as described in Lecture 17 to measure the ventilation flowrate through your box for at least three DCV fan settings (LOW, MEDIUM, HIGH). 3. Conduct an experiment to characterize the K-constant (i.e. the heating rate of the box). of your smart building under two conditions: LOW or no ventilation and HIGH ventilation. 4. Program a control algorithm that includes setpoint based control of the heating and ventilation systems and run your smart building and demonstrate the system operation. 5. Report the results of your measurements of energy consumption of the three devices: heater, on/off fan, and DCV fan. “Extra credit: program a real-time energy tracker.

Introduction

Indoor temperature is important, because people inside buildings don't want to swear or feel bad. The main task for engineers is to make a comfortable environment for people inside. Controlling CO2 level is very important too. If we talk about CO2 concentration, as higher it is as bad people feel themselves, because organism need enough concentration of oxygen. Too HIGH CO2 level can build up and create health, productivity and comfort problems for people. That's why in almost all new buildings a good ventilation system is a necessary feature. It's also very important to make energy efficient buildings starting from environmentally friendly materials and ending with smart algorithms that minimize energy consumption.

High temperature and CO2 level is not a problem for real mechanical engineers! Solving problems with CO2 level is easy. We need to make it possible for buildings to get outside air and exhaust inside air away from the inside of buildings. Here are some examples of CO2 level means: 400-600 – excellent, 700-100 – fair, 1100 – 1500 mediocre and 1600 – 2100 – bad. We can also prevent HIGH temperature! We need to turn off heaters and/or turn on ventilation and air conditioning.

Methods

I created the box with length = 318 mm, width = 143 mm, height = 100 mm and volume = 4.5 L. To cheare a circuit for the Smart building project I used a LOW-cost microcontroller Feather nRF52480 Sence, Adafruit SCD30 NDIR CO2 Temperature and Humidity Sensor, 5VDC fan, PWN-controllable ventilation fan, a resistive heater and OLED display. Fans are powered by 5V 2A. SCD30 module and OLED are powered by 3.3V. The display is showing current energy consumption, temperature, CO2 concentration, status of fan, status of heater and time from the start of the program.

For the first experiment I drew by hand a schematic that reflects how I set up my "smart building"(Figure 1).

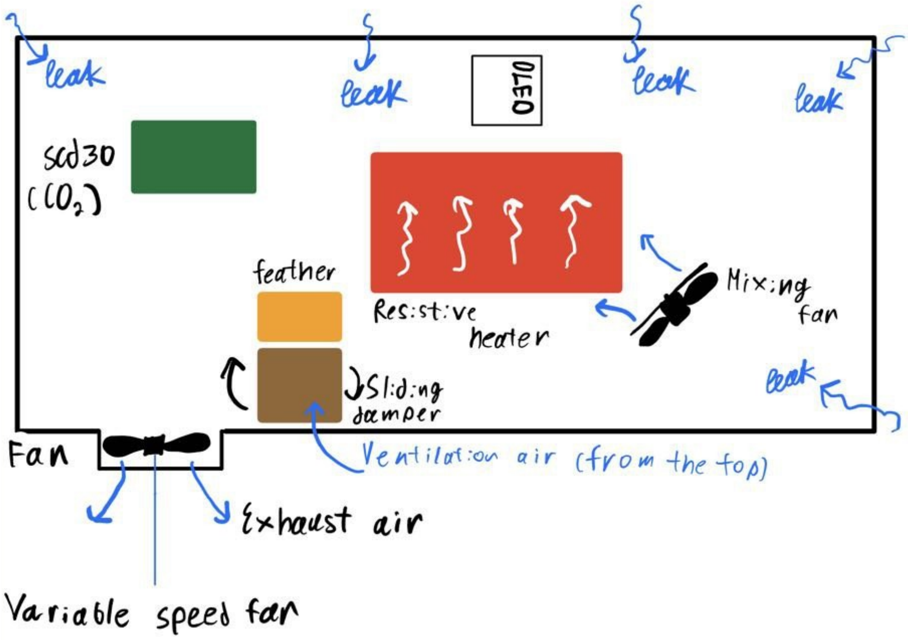


Figure 1: Schematic that reflects how I set up my "smart building"

For the second experiment I conducted a tracer decay test to measure the ventilation flowrate through my box for three PWM fan settings. I made a plot of CO_2 versus time for this experiment in HIGH ventilation mode(Figure 2). I also made a hand calculation of the flow rate Q from the slope of the curve fit(Figure 3). I also summarized my results in a table below(Table 1). In my opinion the value of Q is realistic. It's changing when the fan works faster, so it looks almost normal. What about anomalies in a HIGH mode experiment? I think that fan was so powerful that it opened my sliding damper a little and let fresh air come into my box much easier which increased the flow rate a lot. It's possible because my sliding damper is located on the top of the box and it's easy to push it inside or out of the box.

Table 1: Summary of ventilation experiments.

FAN settings	Calculated flowrate (L/min)
Low (analogWrite = 90)	0.11
Medium (analogWrite = 150)	0.37
High (analogWrite = 250)	3.03

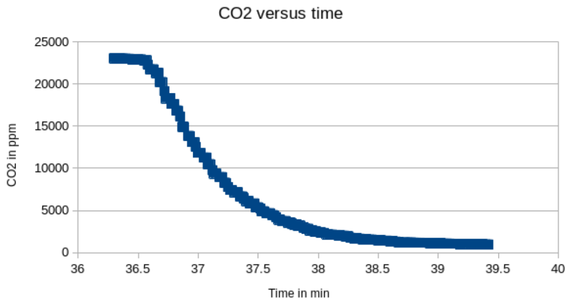


Figure 2: Plot of CO2 versus time in HIGH ventilation mode.

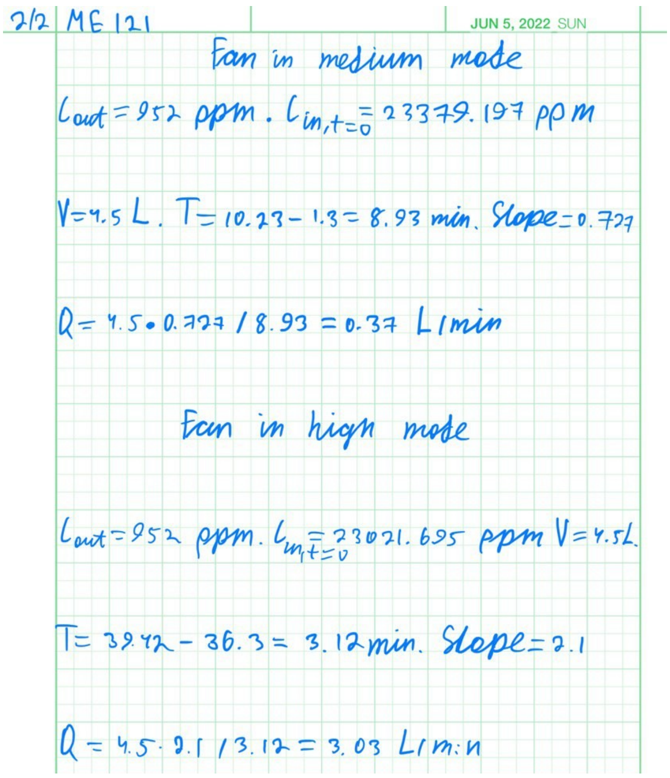


Figure 3: Hand calculation of the flow rate Q from the slope of the curve fit

K-constant experiments. I performed a K constant experiment by measuring temperature through time using my SCD30 sensor under two conditions: with LOW ventilation and with HIGH ventilation. I simply set up the box with constant conditions, turn the heater on, and record the change in temperature through time. I included a chart of both K-constant experiments shown on a single plot(Figure 4 and 5). This is formula for LOW fan mode → f(x) = 0.101868697743206 * x + 29.399730812818. This is formula for HIGH fan mode → f(X) = 0.018546516803771 * x + 28.8811516287064. Unfortunately, my apartment is very hot. Standard temperature is higher than 28 *C. Heater which I used doesn't allow me to make experiments bigger than increasing 2-3 degrees. Because of that my calculations are not accurate. Anyway, I got results. If the fan is in HIGH ventilation mode the temperature can't be higher than 29.5 because of very active cooling. Additionally, we can see on plots that fan in HIGH ventilation mode decreases temperature growth ~ 10 times! This is a very good result.

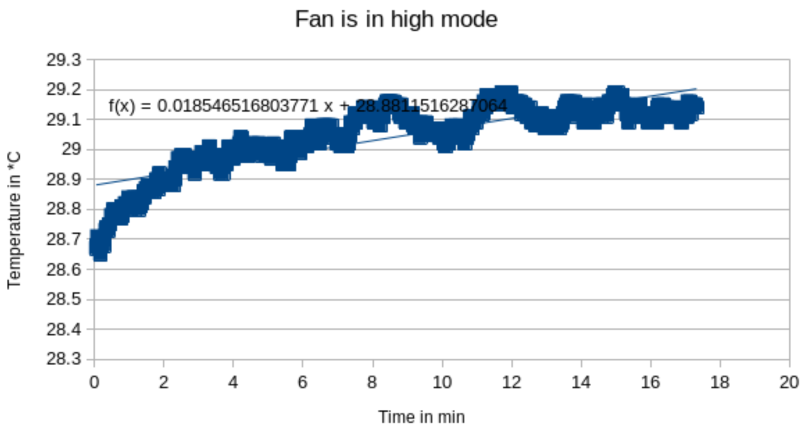


Figure 4: A chart of K-constant experiment. Fan is in HIGH mode.

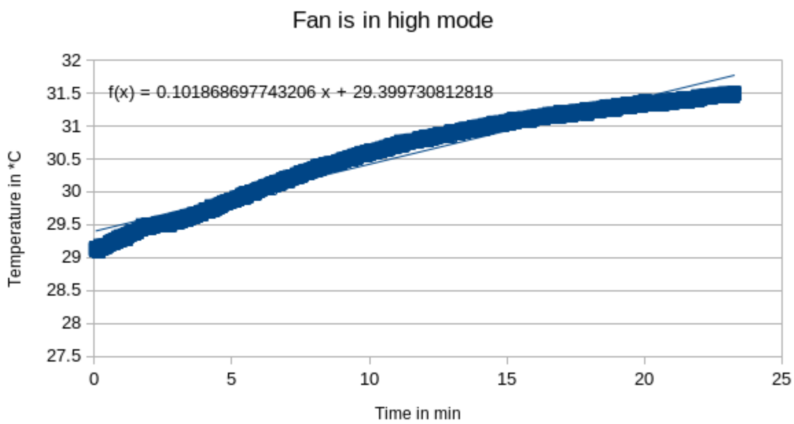


Figure 5: A chart of K-constant experiment. Fan is in LOW mode.

Control algorithm. I programmed a control algorithm that includes setpoints for demand controlled ventilation operation of my ventilation fan to three speed settings(HIGH, MEDIUM, LOW). I programmed a control algorithm that includes on/off control of my heating system. I selected my setpoint based on the temperature of the box absent the heater and my experiments to determine the K-constant of my box. I ran an experiment that demonstrates the implemented control algorithm and discusses results and how they do follow expectations. The fan was set to turn to “HIGH” when CO2 > 2000 or the temperature was > 31.5 degrees C. The heater was set to keep 31 degrees C. Results are below(Figure 6):

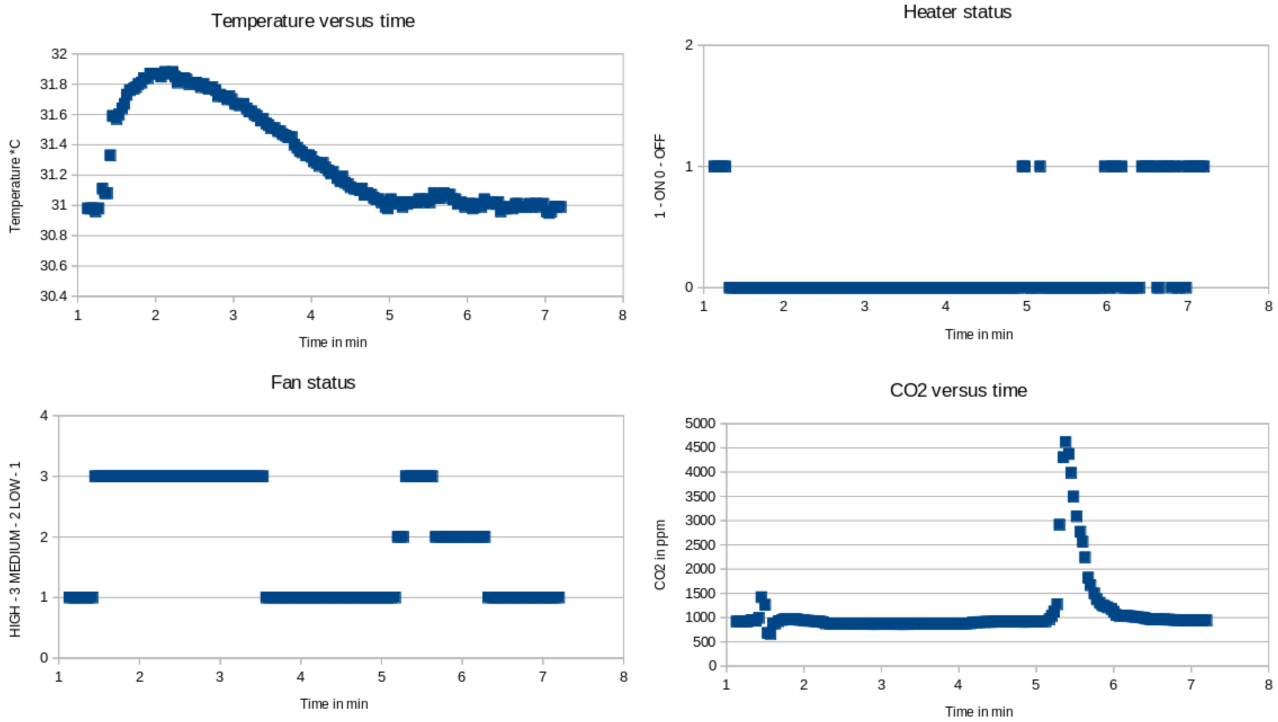


Figure 6: Heater and fan control algorithm.

Energy Tracking. I attached a picture of the voltage and current measurement through one of the tree devices in my box. I also included hand calculations that show how power is calculated from these measurements(Figure 7). I summarized results in a table below(Table 2):

Table 2: Summary of power consumption experiments

Device	Current draw (A)	Voltage drop (V)	Calculated power consumption (W)

On/off fan	0.09	5.12	0.4608
Resistive heater	0.49	3.84	1.8816
Fan is in HIGH mode	0.08	4.85	0.388
Fan is in MEDIUM mode	0.03	4.56	0.1368
Fan is in LOW mode	0.01	4.35	0.0435

```
heater = 3.84 V * 0.49 A = 1.8816
FAN dc =  5.12 V * 0.09 A = 0.4608
LOW = 4.35 V * 0.01 A = 0.0435
MEDIUM = 4.56 V * 0.03 A = 0.1368
HIGH = 4.85 V * 0.08 A = 0.388
```

Figure 7: Hand calculations that show how power is calculated from these measurements.

Bonus credit. I provided interesting and useful features. 1. I made a self cleaning function before start. This is cool because at the start of the experiment your CO_2 concentration and temperature will be in normal condition because the “smart building” turned on the fan to HIGH mode for 15 seconds(Figure 8). Additionally, the user can say which CO_2 concentration is maximum directly from the Serial port(Figure 8)! The OLED display was an optional feature but I added it(Figure 9)! So, I wish I could receive bonus credit for the OLED display too. I also did an energy tracker that updates in real time the energy consumed by my smart building(Figure 8)!

```
SHT31 test
Adafruit SCD30 test!
SCD30 Found!
Measurement Interval: 2 seconds

Prepairing the box for experiments! Please, wait 15 second!
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
The box is ready! :)
Which CO2 concentration is maximum?

Energy consumption W= 2.73 Energy used W= 0.96 Temp= 31.69 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 1003.869 Time min= 0.35

Energy consumption W= 2.73 Energy used W= 1.09 Temp= 31.73 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 1001.307 Time min= 0.40

Energy consumption W= 2.73 Energy used W= 1.18 Temp= 31.72 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 999.713 Time min= 0.43

Energy consumption W= 2.73 Energy used W= 1.27 Temp= 31.74 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 997.261 Time min= 0.47

Energy consumption W= 2.73 Energy used W= 1.37 Temp= 31.77 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 993.740 Time min= 0.50

Energy consumption W= 2.73 Energy used W= 1.46 Temp= 31.77 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 990.800 Time min= 0.53

Energy consumption W= 2.73 Energy used W= 1.59 Temp= 31.80 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 988.026 Time min= 0.58

Energy consumption W= 2.73 Energy used W= 1.68 Temp= 31.81 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 984.177 Time min= 0.62

Energy consumption W= 2.73 Energy used W= 1.77 Temp= 31.83 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 978.244 Time min= 0.65

Energy consumption W= 2.73 Energy used W= 1.87 Temp= 31.80 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 976.657 Time min= 0.68

Energy consumption W= 2.73 Energy used W= 1.96 Temp= 31.85 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 974.870 Time min= 0.72

Energy consumption W= 2.73 Energy used W= 2.05 Temp= 31.84 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 971.367 Time min= 0.75

Energy consumption W= 2.73 Energy used W= 2.18 Temp= 31.87 FAN STATUS= 3 HEATER STATUS= 1 CO2 ppm= 967.967 Time min= 0.80
```

Figure 8: Extra bonus features!

Figure 9: OLED display is working!

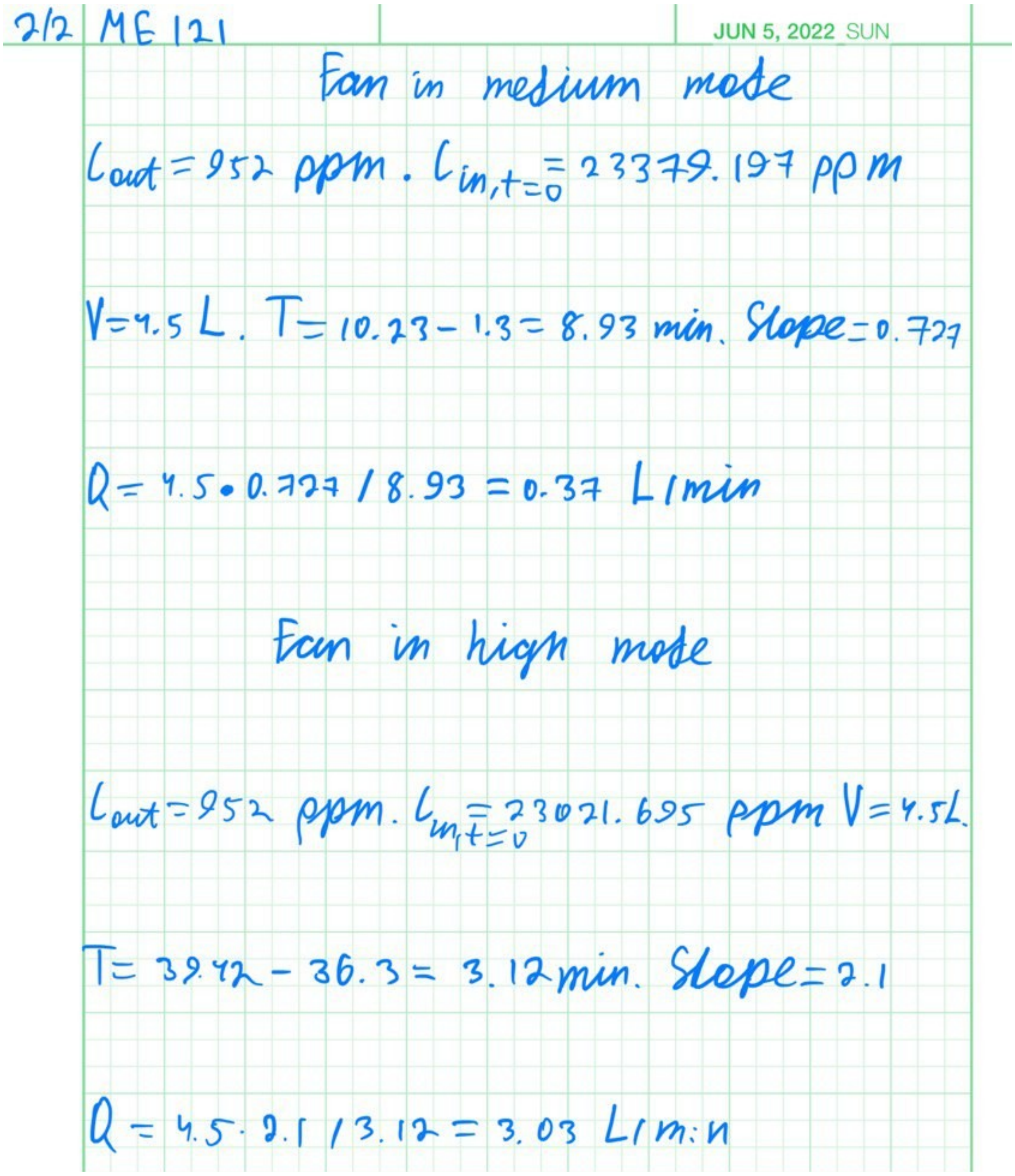
Results

I successfully did all the functions that I wanted to do. My “smart” box controls the co2 level and temperature. Moreover, the display in real time is showing current temperature in calcium, status of heater, status of fan, how much energy used, how much energy is using, CO2 level and time from the start.

Conclusion

According to the experiments above, I can make the conclusion that the arduino sketch and box works as designed and it shows very good results, because all experiments showed realistic results. Algorithm works correctly. Fan use high mode than co2 level is above co2max value + deadband, medium than co2 level less than co2max + deadband and higher than co2normal, low mode in other scenarios. Heater and fan trying to keep the temperature which the user writes in the code. Energy consumption is calculated in real time. Everything is done. I am absolutely satisfied with this project work.

Appendix



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Fan in medium mode

$C_{out} = 952$ ppm. $C_{in,t=0} = 23379.197$ ppm

$V = 4.5$ L. $T = 10.23 - 1.3 = 8.93$ min. Slope $= 0.727$

$Q = 4.5 \cdot 0.727 / 8.93 = 0.37$ L/min

Fan in high mode

$C_{out} = 952$ ppm. $C_{in,t=0} = 23021.695$ ppm $V = 4.5L$.

$T = 39.42 - 36.3 = 3.12$ min. Slope $= 2.1$

$Q = 4.5 \cdot 2.1 / 3.12 = 3.03$ L/min

Figure 3: Hand calculation of the flow rate Q from the slope of the curve fit