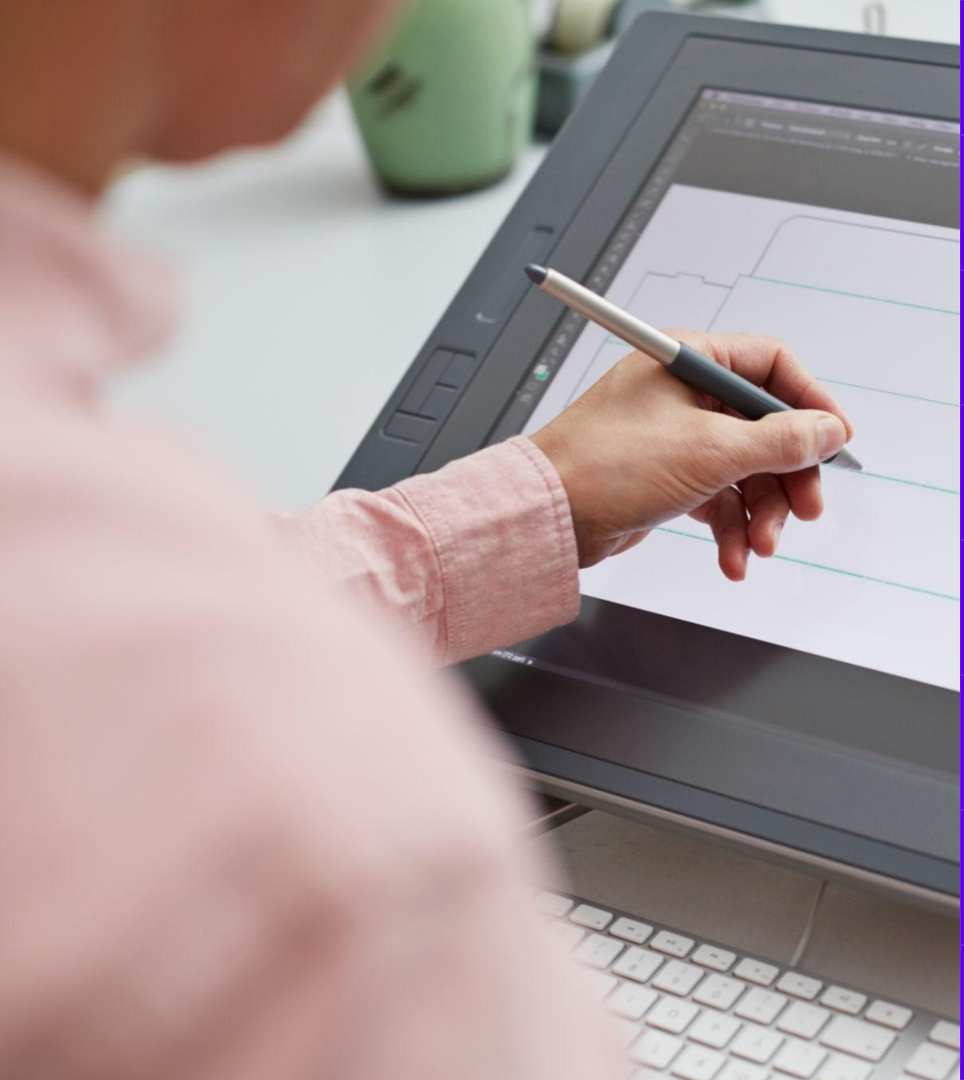


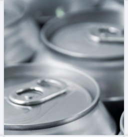
Fuzzy Logic in HVAC Systems

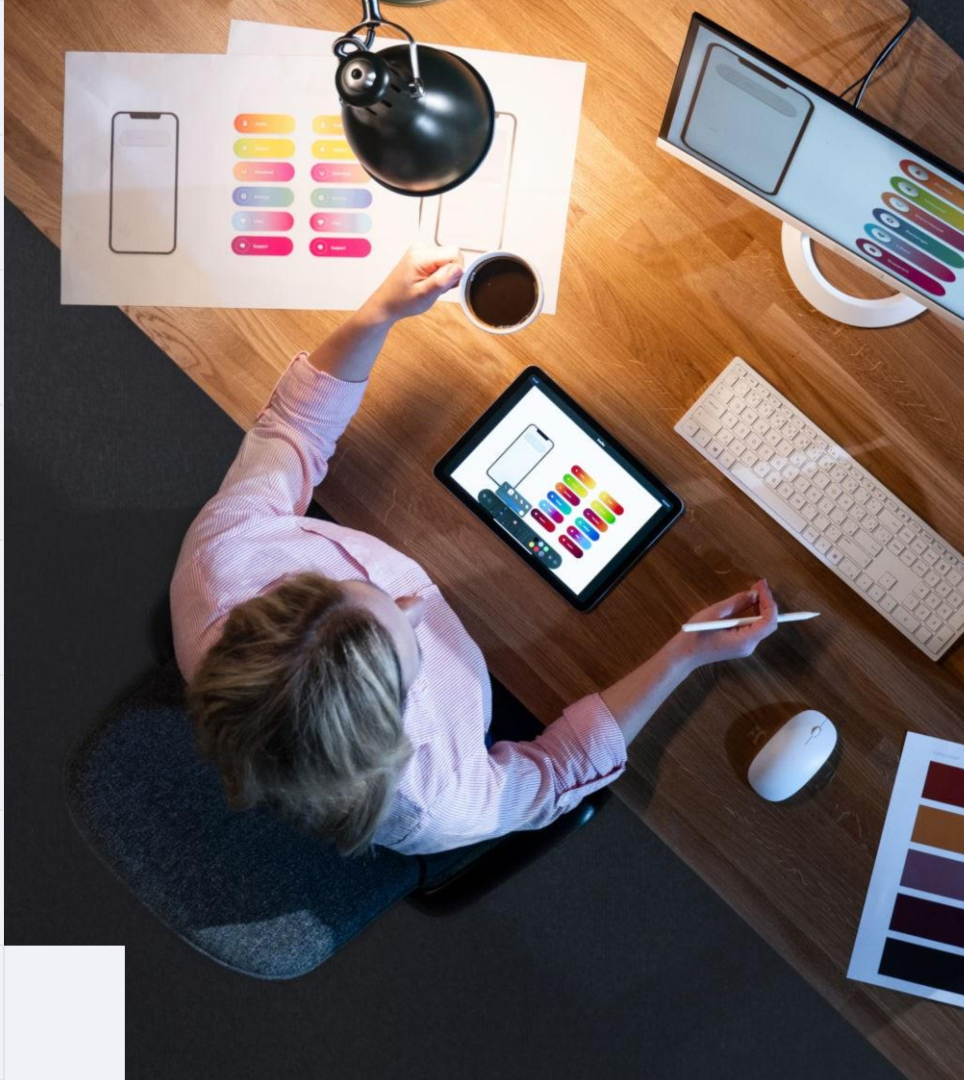
Troy Kleger

An Introduction

The purpose of this project is to showcase a simple fuzzy logic system which can be used to control the temperature and humidity in an environment.

The mission

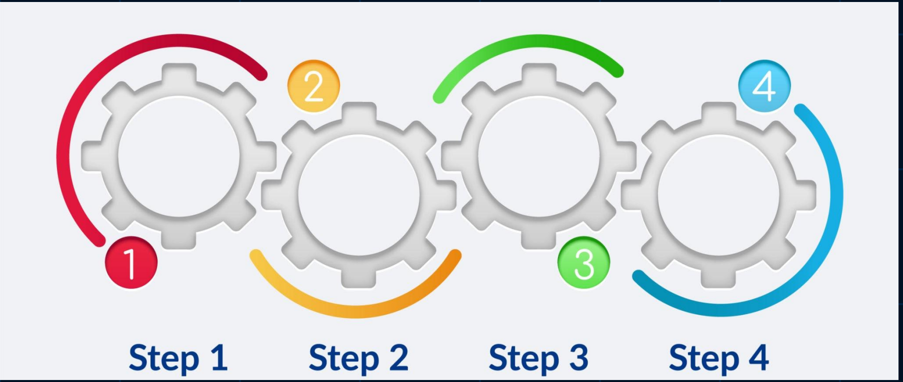




- Maximize Comfort
- Minimize Energy Consumption

The System

1. Input values into the fuzzy logic
2. Compute with fuzzy logic
3. Simulate the environment with equations and the output from the fuzzy logic



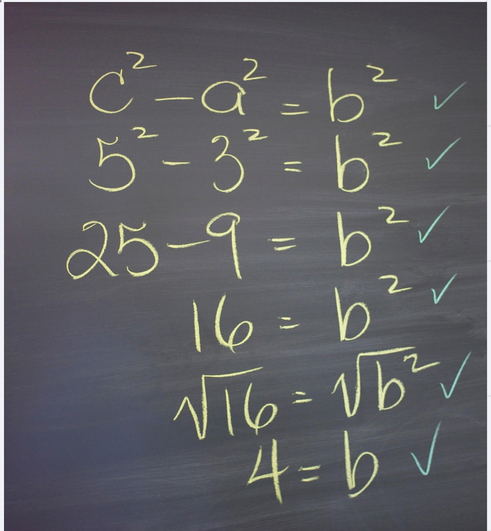
Environment Model

The Room

- 8 x 8 x 3 m roo
- 192 m^3

The Equations

- Fourier's Law of Conduction
- Heat Transfer



$$k = 0.002 W/mK$$

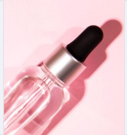
$$L = 0.2m$$

$$Area = 256m^2$$

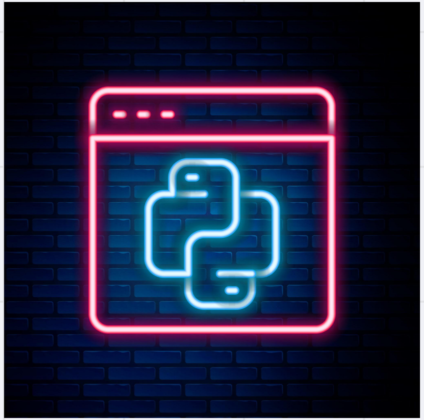
$$Q_{loss} = \frac{kA(T_{in} - T_{out})}{L}$$

$$P_{net} = P_{ACHeater} - Q_{loss}$$

$$\Delta T = \frac{P_{net} \cdot s}{m_{air} c_p}$$



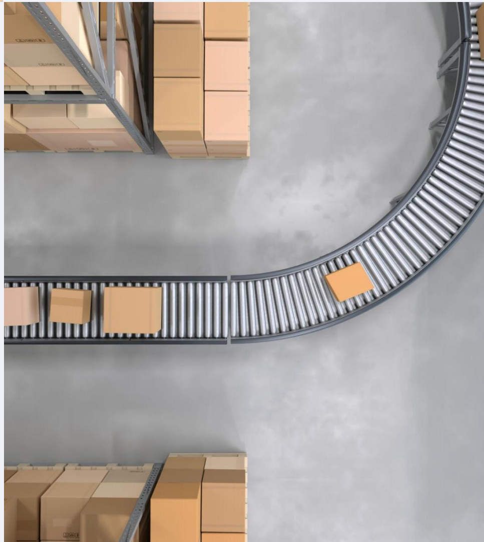
Coding Environment



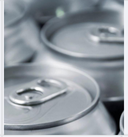
Additional Libraries

- Numpy
- Matplotlib
- Scipy

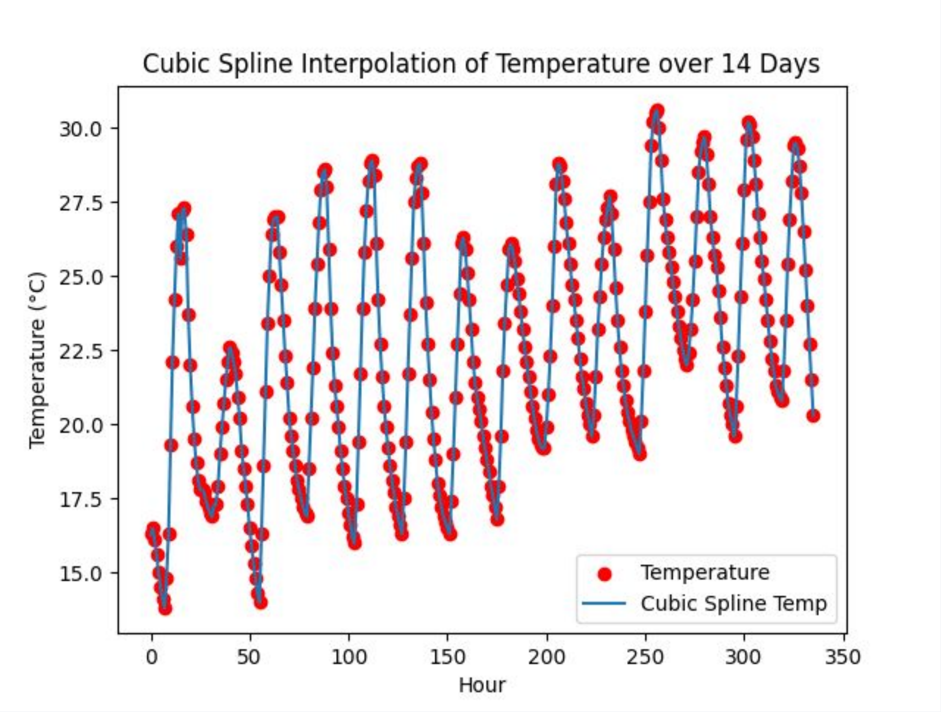
skfuzzy is the library used for the fuzzy logic.



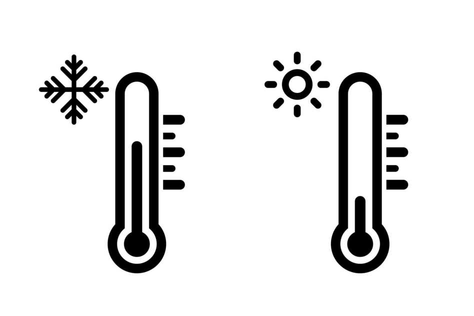
Data



- 14-day hourly forecast for Macon, GA starting on October 11, 2025
- Used temperature and humidity
- A cubic spline was made for each of the fields to allow data reading at any time between measured points
- Data sourced by an api call from weatherapi.com
  - http://api.weatherapi.com/v1/forecast.json?key=**REDACTED**&q=31207&days=14&aqi=yes&alerts=yes

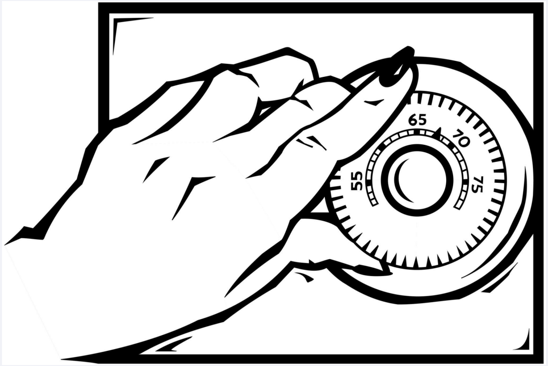


Fuzzy Logic Inputs



Temperature (℃)

Change in Temperature (Δ℃)



Humidity (%)

- The initial change in temperature should be set to 0
- The initial temperature and humidity can be anything as the system will pull it to a reasonable number regardless*
    - Not currently working for the humidity as the value goes to 0 always as of now

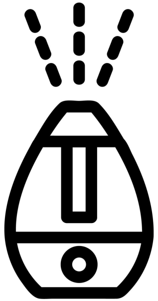
Fuzzy Logic Outputs

AC/Heater Power (%)

- Negative values represent AC and positive values represent Heater
- This method works due to the way the temperature equation in the environment model works

Humidifier/Dehumidifier Power (%)

- Negative values represent Dehumidifier and Positive values represent Humidifier



Fuzzy Sets

AC/Heater Power
- Cooling
- Off
- Heating

Temperature
- Freezing
- Cold
- Warm
- Hot

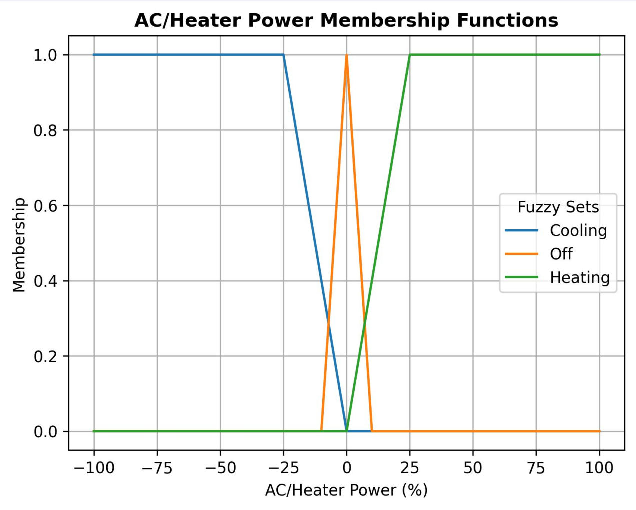
Humidifier/Dehumidifier
- Dehumidifying
- Off
- Humidifying

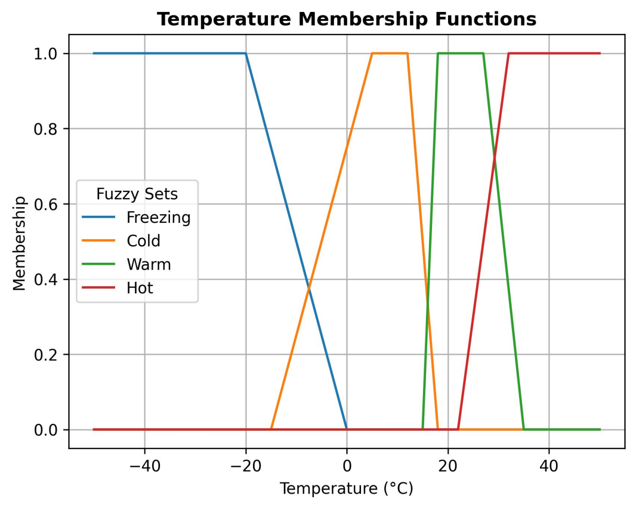
Humidity
- Dry
- Comfortable
- Humid

Delta Temperature
- Decreasing
- Stable
- Increasing

Membership Functions

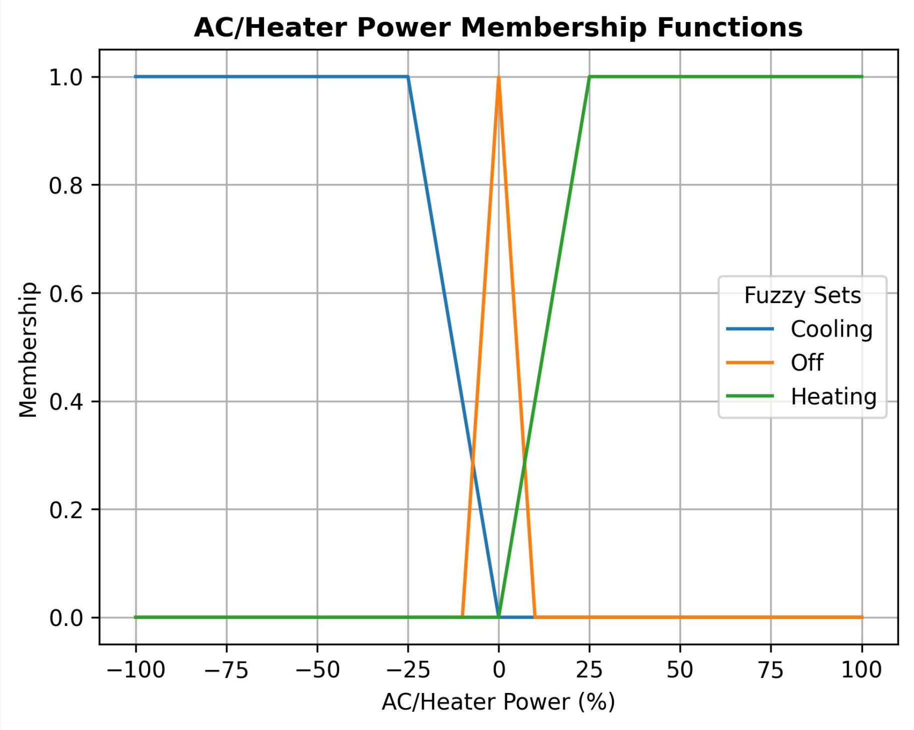
- Triangular and trapezoidal membership functions were used
- 3 fuzzy sets for all variables except temperature, which has a 4th
- The resulting temperature gets held around 20℃, which is within the max of the Warm fuzzy set
- Every fuzzy set's function is a numpy array. This lets us do "1 – arr" to flip the membership function vertically





Membership Function Issues

- The AC/Heater power membership functions were troublesome
    - This has to do with the small gap between the peaks of the fuzzy sets and the fact that typically these systems are typically binary on/off instead of variable power



Fuzzy Rules

- Two types of rules are used in the simulation
  - Single and multivariable
- The single variable rules are very simple and self explanatory
- The multivariable rules as of now exist for inputs temperature and delta temperature
  - The output for all of these is AC/Heater Power

Parameters

Step Size: 300 seconds

This is the amount of time that each call to the environment simulator is supposed to make.

Max AC/Heater Power: 3000 W

If the AC/Heater Power is 100%, the heater is on with 3000W, and the AC is off. If the AC/Heater Power is 50%, the heater is on with 50% and the AC is off.

Simulation Time: 72 hours

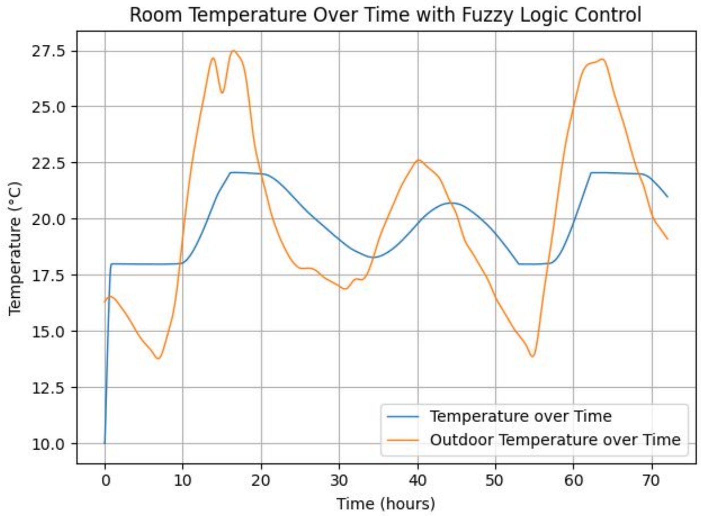
Must be in $[0, 14 \cdot 24]$
The 14*24 is since the project has data for every hour for 14 days. The time picked mainly depends on the time you want to wait for the simulation.

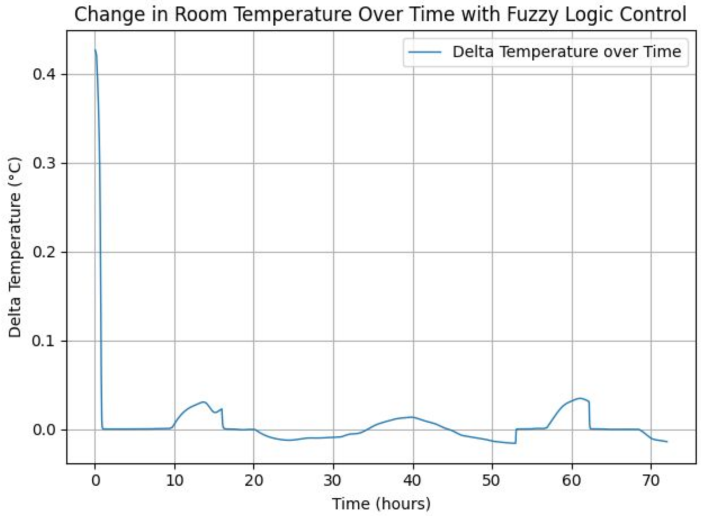
Starting Conditions

- ΔTemp = 0
- Temp = 10℃
- Humidity = 50%

Temperature Results

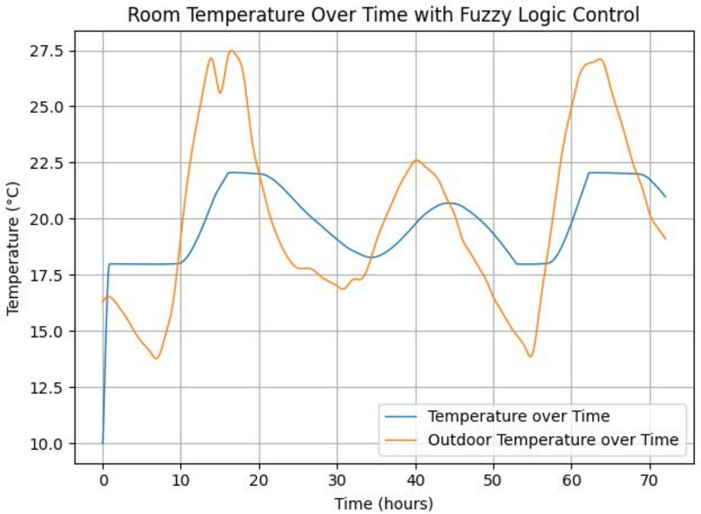
- Temperature held within 17.5℃ and 22.5℃
  - Middle of this range is 20℃. The temperature is always close to this value once it initially gets there.
- The peaks and valleys in the temperature and come a little bit after the same peak or valley occurs in the outdoor temperature.
  - Change in temperature does the same thing
- After the temperature gets to about 18℃ it does a smooth turn into a mostly flat line until the outdoor temperature passes it.

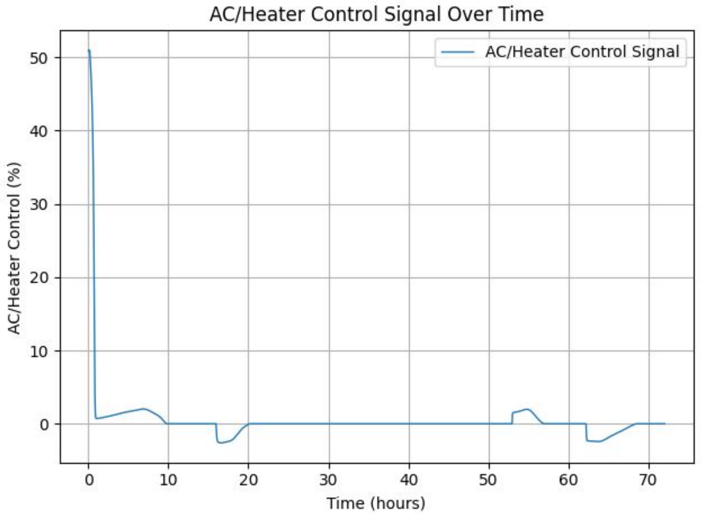




AC/Heater Power Results

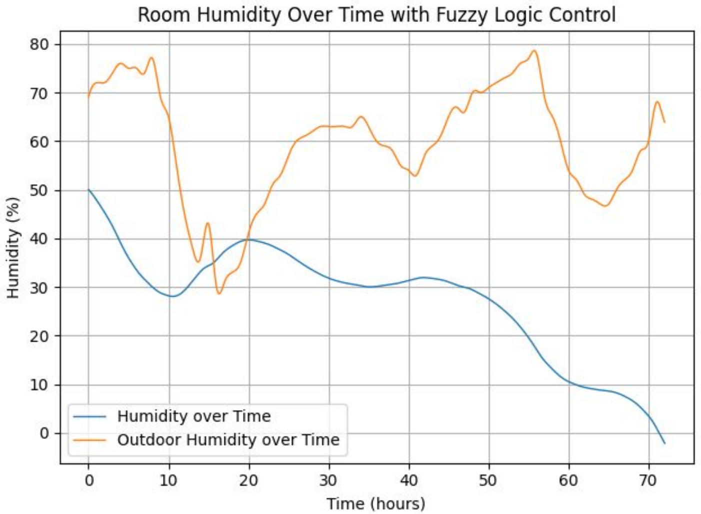
- Initially the power is high to quickly make up most of the temperature difference of the inside compared to its desired temperature
- The AC/Heater is not on most of the time. It is only turning on when the indoor temperature strays too far from its desired temperature.
  - Sharp turns in temperature occur when the temperature is too far from the desired temp and when the AC/Heater Power stops being 0%.
- The AC/Heater Power goes back to 0% when the indoor and outdoor temps are equal.

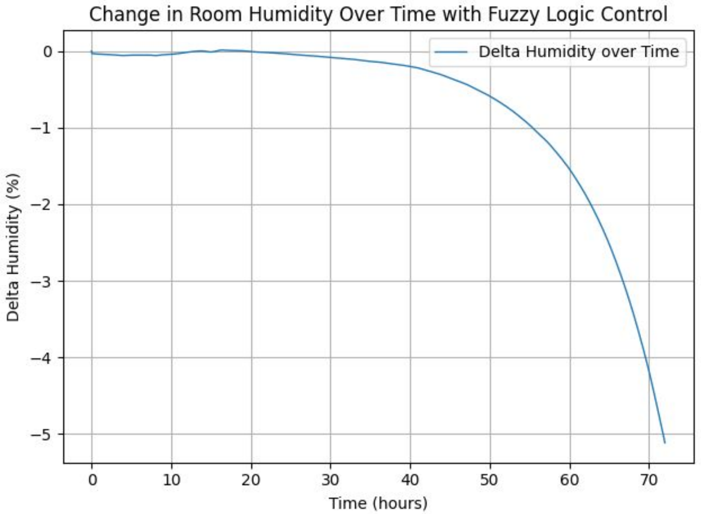




Humidity Results

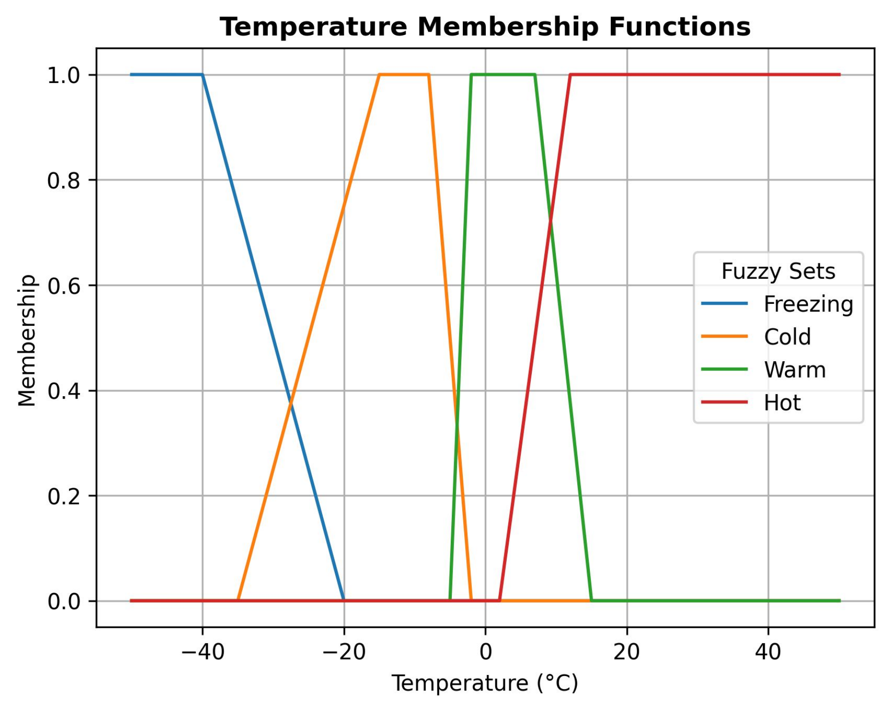
- Obviously, these results are very poor and do not resemble what would happen at all. I have tried the following with no luck
  - Implementing a “Change in Humidity” variable as a fuzzy input similar to “Change in Temperature”
  - Changing the simple formula used for calculating the next humidity
  - Tweaking membership functions for humidity and humidifier/dehumidifier power
- With a proper environment simulation I should be able to solve this issue



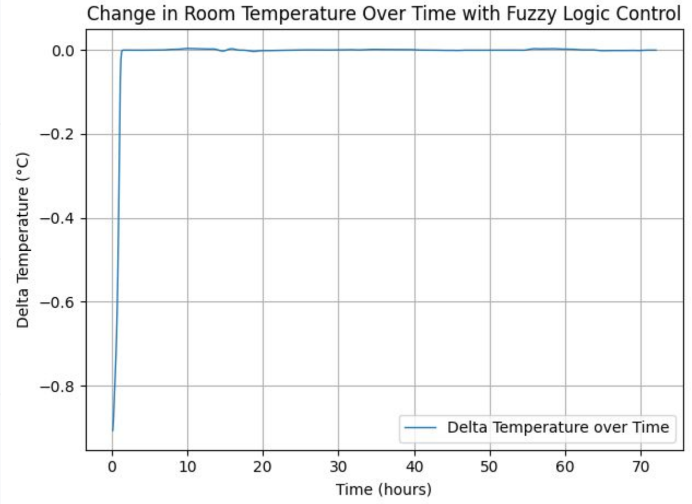


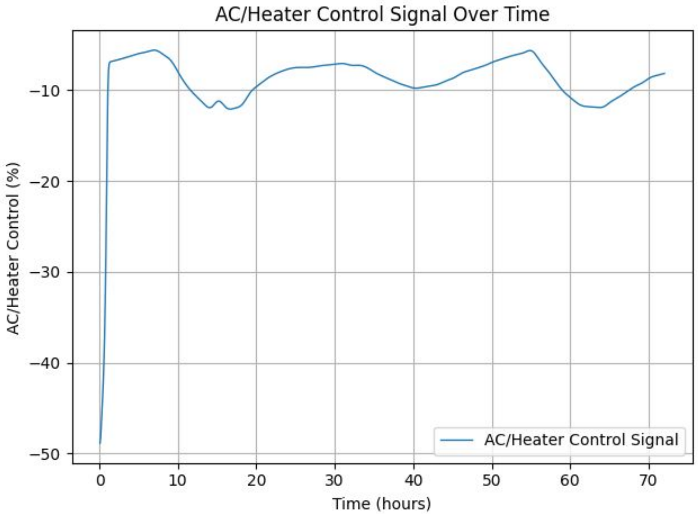
Shifting Temperature

- I decided to do another run of the simulation with everything the exact same except the temperature membership function
- I shifted every point in the temperature membership functions left by 20℃
    - This maintains overall structure while shifting everything

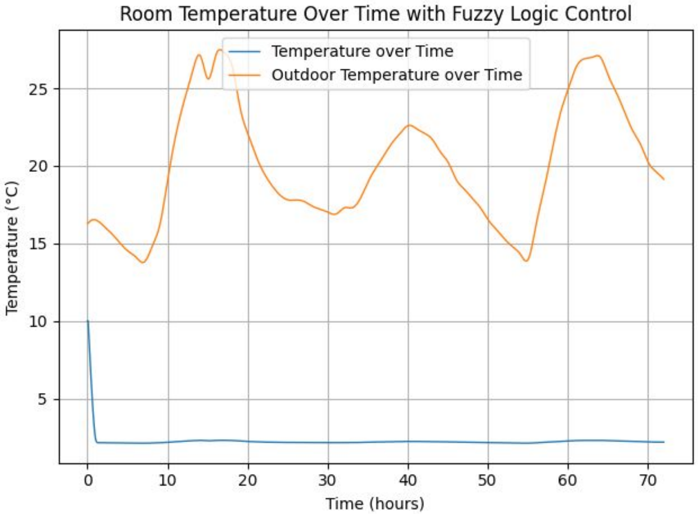


Shifted Results





- I decided to do another run of the simulation with everything the exact same except the temperature membership function
- I shifted every point in the temperature membership functions left by 20℃
    - This maintains overall structure while shifting everything
- As you can see, the temperature is holding at a specific value. In this case 0℃, which gives the temperature set “warm” a membership of 1



Next Steps

Environment Simulation

Using proper HVAC simulation software would allow me to get more accurate temperatures and humidities. Additionally, I could likely pull other features from the simulation to integrate with new variables

More Variables

Adding more variables (input and output) can make the system more robust, giving better results. The ideas thus far are delta humidity, room occupancy, and air pressure.

Tuning Membership Functions

There is always room for small improvements in the system. Tweaking the membership functions causes changes in the calculations for the outputs. I do not believe there currently exists a way to perfectly optimize the membership functions.

More Rules

More rules increases complexity and possibly accuracy. The new rules can be made

- Using already existing input variables only
- Using new inputs only
- Using a mix of new and existing inputs

Thank You!


SEED PACKETS
HERBS
WILD FLOWERS
Vegetables
SEEDS
Seed Type:
SALAD LEAVES
Date Collected:
SEPTEMBER
Collected From:
PAK CHOI
SEEDS
SUNFLOWER
SEPTEMBER
TITAN
JAN
FEB
MAR
JUN
OCT
NOV