Design

The Air Quality Detection system consist of two sections, as shown in Diagram 1. In the first section, the output air pollutant index (API) is determined by the readings of particulate matter 2.5 (PM2.5), total volatile organic compounds (TVOC), carbon monoxide (CO) and nitrogen dioxide (NO2) detected. Concurrently, the output thermal comfort index (TCI) is determined by room temperature and humidity. In the second section, both API and TCI are used to determine the indoor air quality (IAQ) level. This controller utilizes the Mamdani Fuzzy Inference System. When the input variable is passed into the system, the crisp value will be changed into a fuzzy value through the fuzzification process. This process is achieved based on the membership functions. Next, rules are evaluated in parallel and generate the fuzzy output. The outputs of all rules are then aggregated into a single fuzzy set and the fuzzy value is finally converted to crisp output using the centroid defuzzification method.

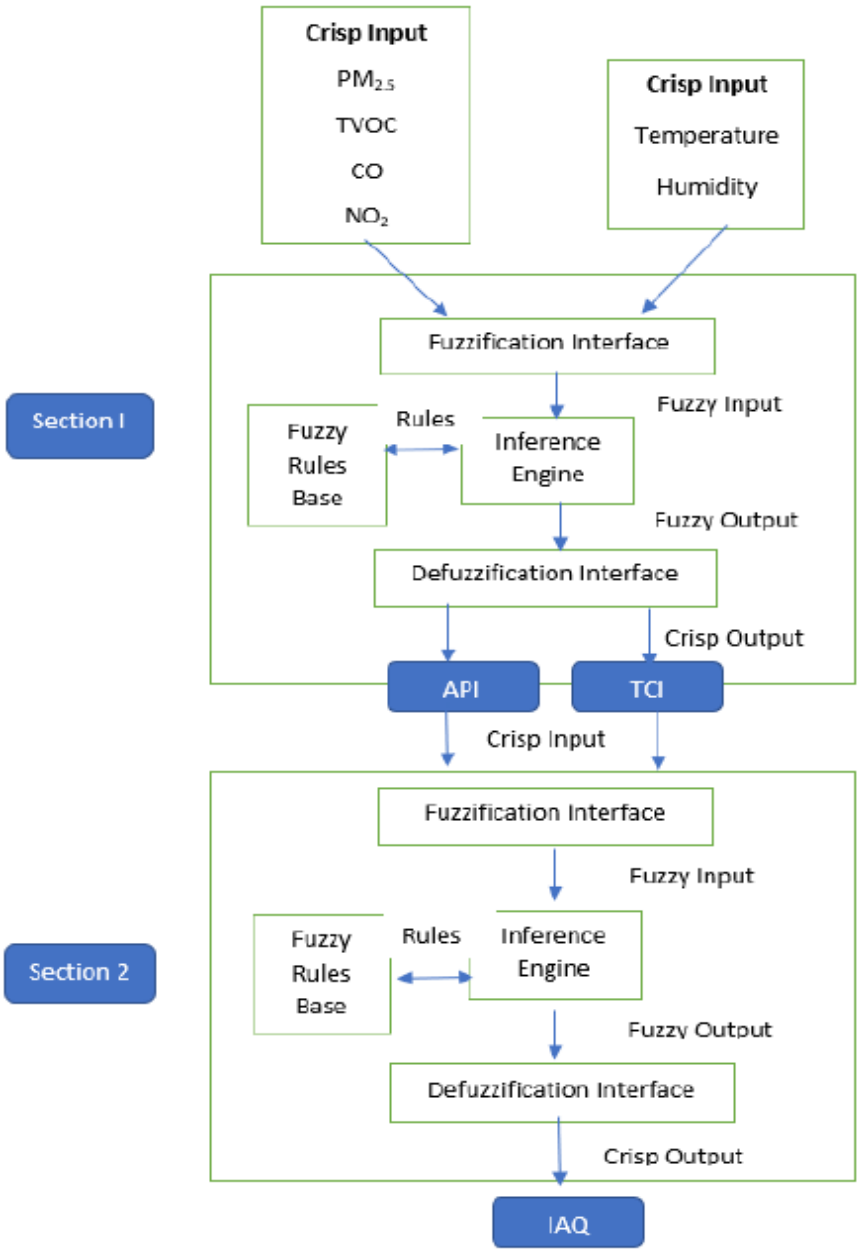

Diagram 1 Solution flowchart of the Air Quality Detection controller.

The concept of the rules design in this controller is based on the United Nations Environment Programme (UNEP). As the authoritative advocate for the global environment since 1972, UNEP (2023) stated that the greater the density of air pollutants, the higher the Air Quality Index. Four types of air pollutants are included in the air quality detection system. The respective concentrations and risk levels set by the authority are as presented in section I. In addition to that, according to the Department of Occupational Safety and Health, indoor air quality can affect a person's health, comfort and ability to work, the contributing factors can include but not limited to temperature, humidity, bacteria or exposure to other chemicals. However, as mentioned in section I, the range of temperature and humidity on moderate level is deemed to be 'good', whereas low level of both variables are deemed to be riskier to one's health. Other than that, the risk level of each variable increases as the respective concentration level increases. Therefore, while adapting a more conservative approach, the rules are set based on the condition in which as long as the concentration of one of the variables increases, the respective output risk level will also increase.

As shown in table 1 to table 3, a total of 12 rules have been defined for the entire system in which the first section consists of 8 rules and second section consists of 4 rules.

Rules

In the first section, 8 rules are set as follows:

PM2.5	**TVOC**	**CO**	**NO2**	**API**
Low	Low	Low	Low	good
Moderate	Moderate	Moderate	Moderate	moderate
High	High	High	High	unhealthy
Very high	Very high	Very high	Very high	hazardous

Table 1: Rule table of PM2.5, TVOC, CO, NO2 and API

Rule 1: If PM2.5 is low OR TVOC is low OR CO is low OR NO2 is low THEN API is good.

Rule 2: If PM2.5 is moderate OR TVOC is moderate OR CO is moderate OR NO2 is moderate THEN API is moderate.

Rule 3: If PM2.5 is high OR TVOC is high OR CO is high OR NO2 is high THEN API is unhealthy.

Rule 4: If PM2.5 is very high OR TVOC is very high OR CO is very high OR NO2 is very high THEN API is hazardous.

Temperature	Humidity	TCI
Low	Low	unhealthy
Moderate	Moderate	good
High	High	moderate
Very high	Very high	hazardous

Table 2: Rule table of Temperature, Humidity and TCI

Rule 5: If temperature is low OR humidity is low THEN TCI is unhealthy.

Rule 6: If temperature is moderate OR humidity is moderate THEN TCI is good.

Rule 7: If temperature is high OR humidity is high THEN TCI is moderate.

Rule 8: If temperature is very high OR humidity is very high THEN TCI is hazardous.

API	TCI	IAQ
Good	Good	excellent
Moderate	Moderate	good
Unhealthy	Unhealthy	unhealthy
Hazardous	Hazardous	hazardous

Table 3: Rule table of API, TCI and IAQ

Rule 9: If API is good OR TCI is good THEN IAQ is excellent.

Rule 10: If API is moderate OR TCI is moderate THEN IAQ is good.

Rule 11: If API is unhealthy OR TCI is unhealthy THEN IAQ is unhealthy.

Rule 12: If API is hazardous OR TCI is hazardous THEN IAQ is hazardous.

Fuzzy Membership Functions

Due to its simplicity, Triangular fuzzy membership function is used in this fuzzy controller design. Lofti A.Zadeh who introduced fuzzy sets used to believe that simple and intuitively clear methods work the best in almost all condition. When utilizing this method, both formulas and intuition are being relied on (Kreinovich et al. 2018). The triangular fuzzy membership function is defined by three parameters, in which one parameter defines the height and two parameters define the base of the triangle. Therefore, it works better for variables which consists of narrow range of values.

As shown in table 4, each input variables are classified into 4 classes low, moderate, high and very high. The fuzzy membership of these variables is shown in figures 1 to 6 respectively.

Level	**$PM_{2.5}$ ($\mu g/m^3$)**	**TVOC ($\mu g/m^3$)**	**CO (ppm)**	**NO2 [µg/m3**	**Temperature (^oC)**	**Humidity (%)**
Low	0-25	0-300	0-10	0-40	-15-20	0-40
Moderate	20-50	240-1000	8-30	32-80	16-24	32-60
High	40-100	800-3000	24-50	64-120	19-32	48-80
Very High	80-300	2400-10000	40-90	96- 200	26-40	64-100

Table 4 Fuzzy Classification of Factors Contributing to Air Quality and Thermal Comfort Indices

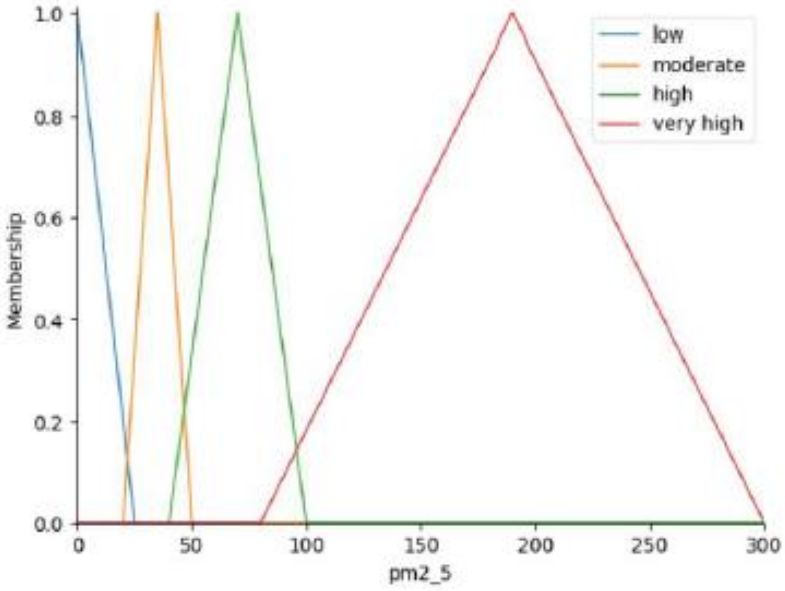

Figure 1 Fuzzy membership function for $PM_{2.5}$

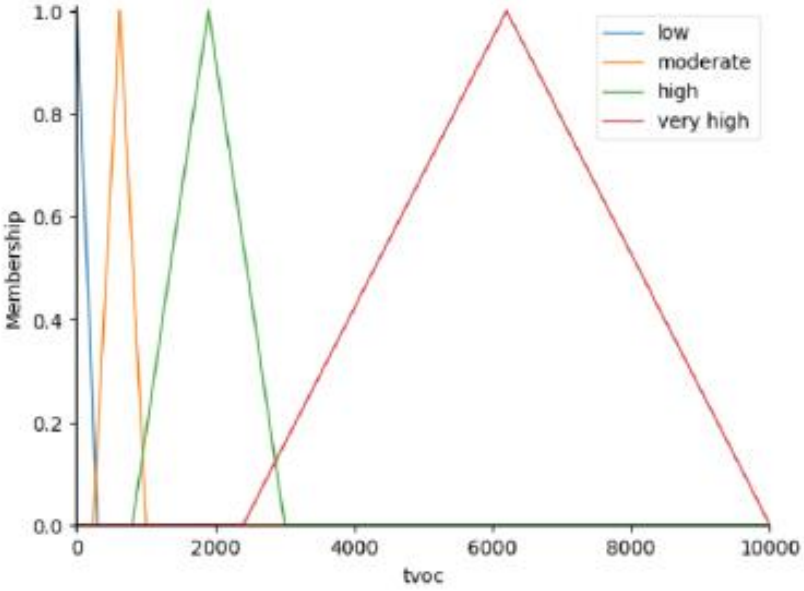

Figure 2 Fuzzy membership function for TVOC

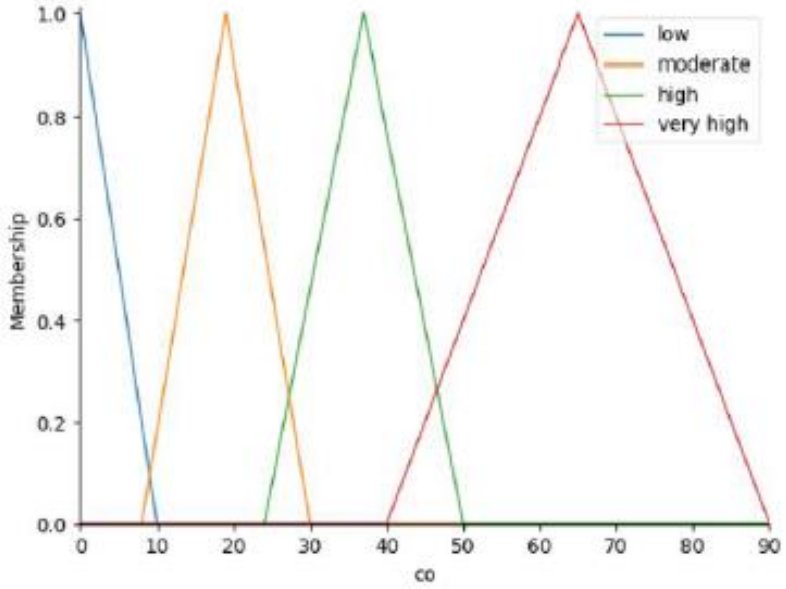

Figure 3 Fuzzy membership function for CO

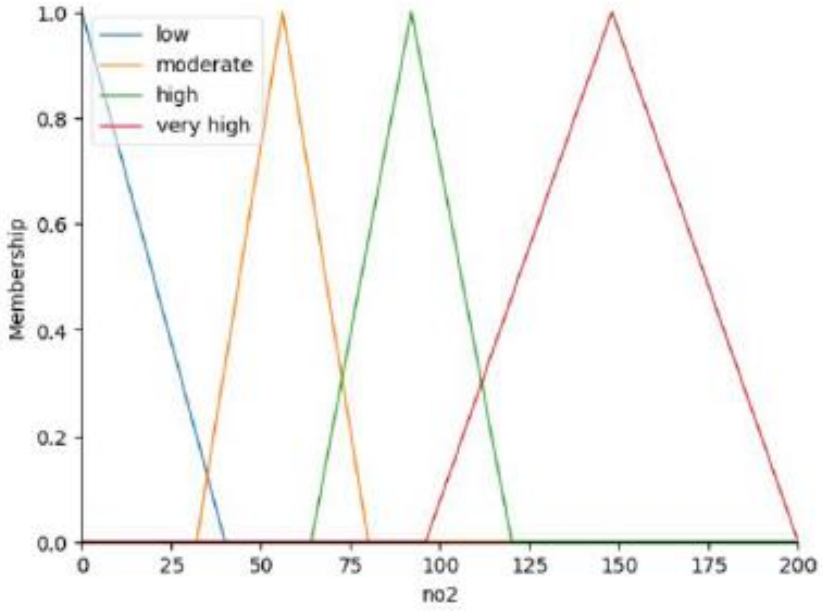

Figure 4 Fuzzy membership function for NO_2

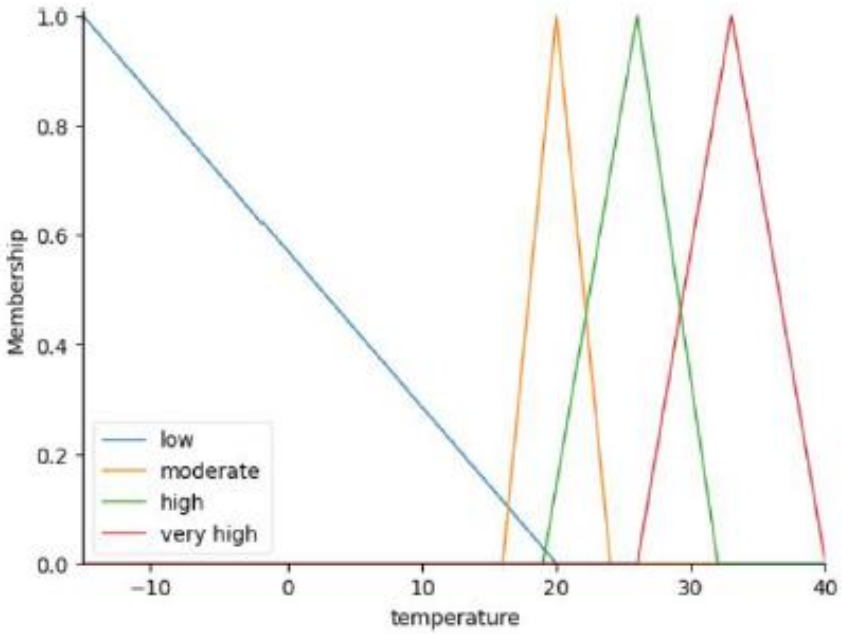

Figure 5 Fuzzy membership function for temperature

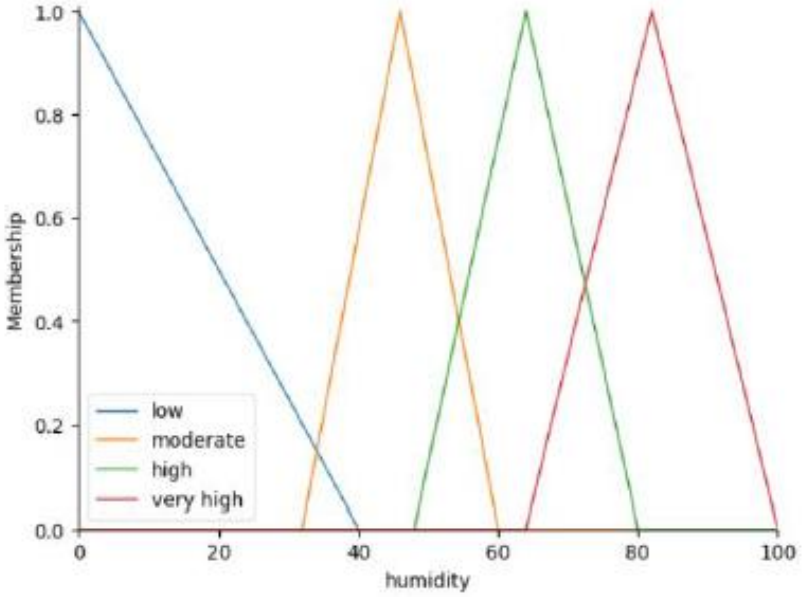

Figure 6 Fuzzy membership function for humidity

As shown in table 5, both API and TCI variables are classified into 4 classes good, moderate, unhealthy and hazardous. The fuzzy membership function for both variables are shown in figures 7 and 8 respectively.

Level	API	TCI
Good	0-4	0-4
Moderate	3.2-6	3.2-6
Unhealthy	4.8-8	4.8-8
Hazardous	6.4-10	6.4-10

Table 5 Fuzzy Classification of API and TCI

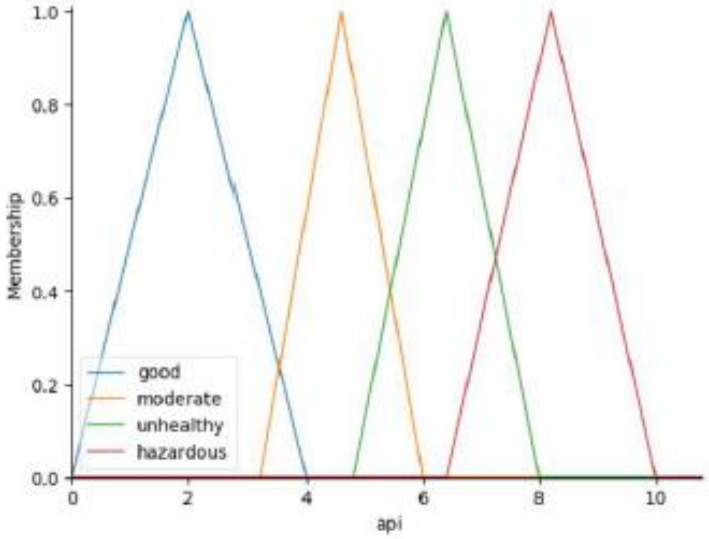

Figure 7 Fuzzy membership function for API

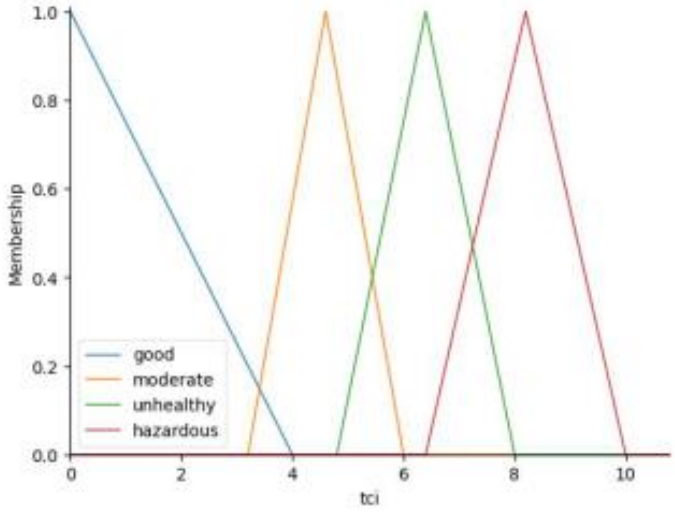

Figure 8 Fuzzy membership function for TCI

As shown in table 6, IAQ variable is classified into 4 classes excellent, good unhealthy and hazardous. The respective fuzzy membership function is shown in figure 9.

Output Status	IAQ
Excellent	0-4
Good	3.2-6
Unhealthy	4.8-8
Hazardous	6.4-10

Table 6 Fuzzy Classification of IAQ

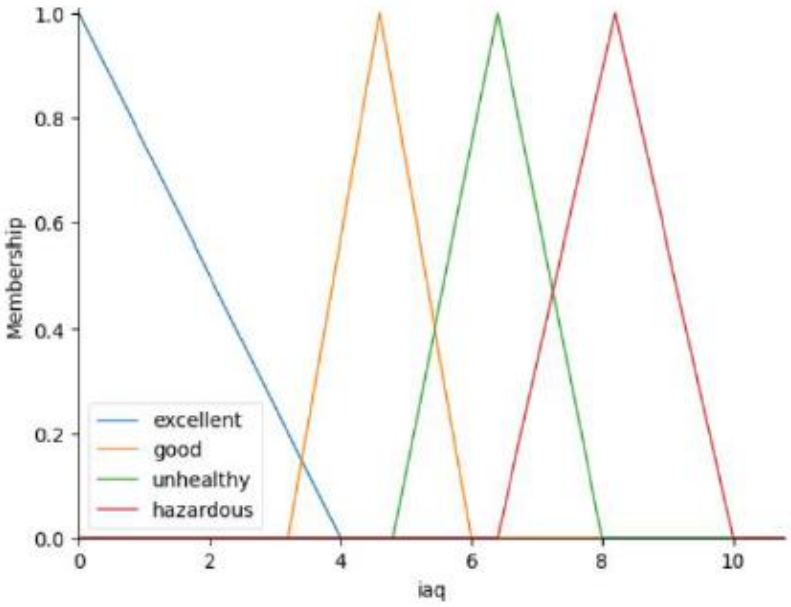

Figure 9 Fuzzy membership function for IAQ