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A Fuzzy Inference System Prototype for Indoor Air and Temperature Quality Monitoring and Hazard Detection

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ABSTRACT. This paper demonstrates a monitoring system that helps guide the user to attain comfortable and safe room conditions. The monitoring system is divided in an Indoor Air and Temperature Quality ("Comfort") Monitoring System, and a Hazard Detection Unit. The concept behind this Monitoring System is to assist the user to get an idea of how different factors such as room temperature, humidity, airflow, and clothing affect human comfort. The same concept is also applied to the Hazard Detection Unit (HDU), where carbon monoxide, carbon dioxide, particulate matter, room size and room occupancy may affect the comfort and safety of the user. The Monitoring system is based on Fuzzy Logic programming and built using MATLAB® software. Two Fuzzy Inference Systems (FISs) independent of each other are developed. Each FIS is based on a Mamdani type of controller. One FIS is responsible for the Comfort Level and the other is for the Hazard Detection Unit (HDU). A Graphical User Interface (GUI) is also developed to couple the two Fuzzy Systems together and to provide the user with an interactive interface. Inputs and outputs are extensively tested through the GUI to observe the system performance.

Keywords: fuzzy logic control, fuzzy inference system, comfort systems, fuzzy thermal comfort, mamdani controller

1. Introduction

We currently live in an age where technological developments based on Artificial Intelligence and Intelligent Systems techniques are used in almost every field. One area that this technology can thrive in is climate control systems. Climate control systems used in buildings function much more efficiently if non-conventional techniques such as Fuzzy Logic are considered.

It is a well known fact that in North America we spend a vast amount of our times indoors or in some types of building structures. Hence, having an efficient exhaust system is essential to avert any type of chronic illnesses that may be caused by poor indoor air quality. The problem with closed environments such as basement units is the lack of air quality. Humidity in our living spaces can cause a severe problem to both our health and electronic components. Hazardous gases such as carbon monoxide and carbon dioxide are present in all indoor environments and can be maintained to adequate levels using proper ventilation. Many factors come into play in maintaining a comfortable environment. This paper presents a Fuzzy Logic controller (FLC) using MATLAB® that has the ability to monitor room temperature and humidity level while monitoring for harmful emissions and alerting the user. It is worth to mention that Thermal comfort level can be undecided when it comes to humans; each person has a different definition of comfort. It is an even more complicated, unreliable and expensive process if it involves traditional software modeling methods. Since human sensation of comfort is vague and subjecttive, Fuzzy Logic theory is well suited to describe it in a linguistic manner (Hossein, 2008).

A FLC acts as a nonlinear control system implementing human-based reasoning for computation of the control values (Caponetto et al., 2000). More precisely, an FLC, which is defined by a set of linguistic rules and fuzzy sets, is able to compute appropriate values for the actuators by taking into account information data coming from the actual system.

A common use of Fuzzy Inference Systems (FISs) discussed in the literature is their use as an excellent control system; in particular, for those systems where there is no model available. This characteristic is mainly due to the Fuzzy Logic ability to be highly adoptable and being able to be implemented and integrated with existing systems and various programming languages or platforms.

Several FISs as FLCs have recently been introduced for the regulation of climate variables such as temperature and humidity in artificially conditioned greenhouses. One of the main benefits obtained from these modern controllers is a minimized energy cost for heating. A similar methodology can be applied to the indoor air and temperature quality ("comfort") monitoring system to achieve several of its goals, inclu-

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ding reduced energy consumption. The primary goal of any modern Heating, ventilating and Air Conditioning (HVAC) systems is to maintain occupants' thermal comfort and energy efficiency.

The Fuzzy climate control and Fuzzy hazard detection systems proposed in this paper differ from other Fuzzy Logic systems (Hossein, 2008) in the literature and in the market by having the outputs controlled based on the user inputs rather than based on a Predicted Mean Vote (PMV) (Alcala, 2005). Human understanding on comfort is subjective and varies among indi- viduals. The development of a climate control system on the basis of the PMV would not seem to be addressing the indivi- dual needs. PMV was proposed by Fanger in 1970 and was used to predict the mean thermal sensation vote on a standard scale for a large group of people (Liang, 2005).

The PMV model is typically based on two sets of parameters, i.e., environmental and personal. Environmental parameters may include air temperature, radiant temperature, air velocity and relative humidity. Personal parameters include anything else that would create an atmosphere of discomfort such as activity level and clothing insulation. These factors must be measured or estimated and then the PMV index will be calculated.Similar models have been built for predicting indoor air quality. Simulations have been performed using a new airflow and pollutant transport model (Dounis, 1996), in these models; CO_2 concentration is used as the indoor-air quality (IAQ) index.

Besides the fact that the proposed system based on Fuzzy Logic serves a dual purpose, i.e., basic HVAC needs, and monitoring for harmful emissions. Our prototype also differs from other systems that are based on Fuzzy Logic by actually informing the user on the comfort condition of the room based on what is being inputted into the system.

Here, a simple program based on Fuzzy Logic and user interface are developed to guide the user away from uncomfortable human conditions by notifying the user early if undesirable room conditions have been feed into the system. The program displays the room conditions and the expected “comfort” and hazard levels on a Graphical User Interface (GUI). The user can then judge as to what levels are ideal. Based on the information displayed in the GUI in terms of a comfort level, rules can be modified to suit the user’s definition of comfort, thus, making the system fully customizable towards the user.

The overall developed program is broken down into two different systems or units, based on two independent FISs. The first unit (FIS 1), an Indoor Air and Temperature Quality (“Comfort”) Monitoring System assists the user to get an idea of how different factors such as room temperature, humidity, airflow and clothing affect human comfort. The same concept is also applied to the second unit (FIS 2), Hazard Detection Unit (HDU), where carbon monoxide, carbon dioxide, particulate matter, room size and room occupancy may affect the comfort and safety of the user. Moreover, the GUI is developed to bring the two systems together. This interactive interface allows the user to test various inputs and outputs to observe how the system performs.

2. Background

HVAC systems are installed in most modern buildings, i.e. residential, commercial and industrial buildings to provide a comfortable environment. A comfortable environment can be defined as an environment that addresses human needs in terms of temperature, humidity and other environmental conditions. Temperature and relative humidity are essential factors in meeting physiological requirements. When temperature is above or below the comfort range, the environment disrupts person’s metabolic processes and disturbs his activeties. A well-designed, operated, and maintained HVAC system is essential for a habitable and functional building environment. Outdated, inappropriate, or misapplied systems result in comfort complaints, indoor air quality issues, control problems, and exorbitant utility costs. Moreover, many HVAC systems do not maintain an uniform temperature throughout the structure because those systems employ unsophisticated control systems (Alcala et al., 2004).

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHARE) has identified key parameters that influence thermal comfort. These are: Temperature, Relative Humidity, Air Velocity and Temperature (Hossein, 2008). Clothing insulation, room size and occupancy are factors that affect thermal comfort, but they are variable and usually not measurable using traditional methods.A HVAC system should achieve two main tasks: i) Dilute and remove emission from people, equipment and activities and to supply clean air. ii) Maintain a good thermal climate (Song and Johns, 1998).

Artificial Intelligence and Intelligence System techniques have several known advantages compared to the conventional control systems still being used. The comfort monitoring system presented in this paper is a control unit that can be easily incorporated into future HVAC systems. The monitoring units discussed in this paper try to address the above two main tasks. The comfort system handles the thermal comfort of the user, while the hazard detection unit addresses the air quality.

2.1. Modern Versus Conventional Control Systems

HVAC control systems can be categorized into three main groups: Traditional Controllers, Advanced Controllers, and Intelligent Controllers.

Traditional climate controllers are typically made up of On/Off control and proportional-integral-derivative controller (PID) controllers (Dounis et al., 1996). Traditional systems such as On/Off and PID controllers were an ideal option for control of HVAC systems due to their less complicated structure and the low development costs. However, these traditional control methods lack accuracy and quality. Such traditional systems were also less efficient and had high maintenance costs associated to them (Hossein, 2008). Traditional control systems use timers to activate the heating and cooling systems and most had to be controlled manually. If left unattended the fluctuation of power would cause uncomfortable conditions and a hike in your electricity bill. One major drawback of ON-OFF control systems in buildings is that the controlled variable swings continuously (Dounis et al., 1995). On/Off control provides only two plant outputs, maximum (on) or zero (off). The control sensor usually takes the form of an on/off thermostat; humidistat and pressure switch (Harrold, 1988). Another disadvantage with ON-OFF control in thermal comfort is its ability to control only one factor i.e. indoor temperature only, without taking into account other critical thermal comfort variables.

This paper demonstrates that by using fuzzy logic several important/relevant variables can be taken into account, such as temperature and humidity levels in order to yield thermal comfort.

Conventional PID as well as ON-OFF control systems have also been proved to be energy "inefficient" due to over-shooting and oscillations (Dounis et al., 1995). Over-shooting and oscillations are the result of a controlled variable that occurs when the reference signal is reached. Over-shootings and oscillations are known to be two of the main causes for energy waste.

Advanced controllers such as the Auto-tuning PID controller determine PID parameters without human intervention (Wang, 1999). This is done by utilizing Model-based algorithms in which the parameters of the PID controller are related to the parameters of a transfer function model of the plant (Dexter, 1990). The tuning procedure of a PID controller can be a time-consuming, expensive and difficult task compared to intelligent systems based on Fuzzy Logic (Pinella, 1986).

Intelligent controllers include Artificial Neural Networks controllers, and FISs used as FLCs. Since the HVAC systems are Multiple Input Multiple Output (MIMO), nonlinear and time-varying systems, intelligent controllers based on FISs (that is, based on human expert decision making) can be used to design systems that are essentially more reliable in the control of HVAC systems. Thus, Intelligent Systems based on FISs used as FLCrs can be programmed to be more energy efficient than traditional methods.

This paper demonstrates that by using Fuzzy Logic a control method can be developed to eliminate problems such as over-shooting and oscillations. This is accomplished by having a human-based reasoning method that makes decisive controls on the actuators by taking into account information coming from the actual system.

3. What is Fuzzy Logic?

Fuzzy logic is a useful tool for solving many real-world problems characterized by imprecise and uncertain information. FISs used as FLCs are “intelligent” devices that have potentially many applications in control engineering. They are used to control various consumer products that are out in the market. Normally, FLCs consist of a set of linguistic control rules based on fuzzy implications and the rule of inference. By providing an algorithm, they convert the linguistic control strategy based on expert knowledge into an automatic control strategy (Lee, 1992).

In contrast to the mathematical models or other expert systems, FLCs allow the representation of imprecise human knowledge with approximate terms and values, rather than forcing the use of precise statements and exact values; thus making them more robust, more compact and simpler (Dounis et al., 1996).

3.1. Fuzzy Logic Methodology

With Fuzzy Logic the first step is to understand and characterize the system behaviour by using knowledge and experience (Figure 1). The second step is to directly design the control algorithm using fuzzy rules, which describe the principles of the controller's regulation in terms of the relationship between its inputs and outputs. The last step is to simulate and debug the design. If the performance is not satisfactory we only need to modify some fuzzy rules and retry (Zimmerman, 1990).

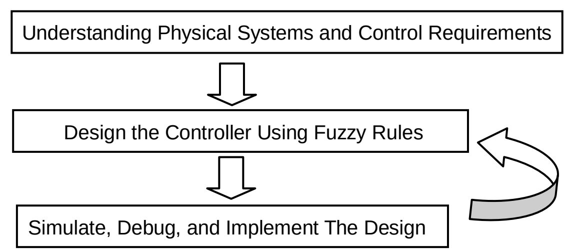

Figure 1. Fuzzy logic methodology.

3.2. Advantages of Fuzzy Design

Fuzzy Logic-based methodology substantially simplifies the design loop. This leads to the following significant advantages: Simplified design complexity; Reduced design development cycle; Reduced hardware costs; Simplified implementation; Better alternative solution to Non-Linear Control; Improved control performance (Zimmerman, 1990).

3.3. Fuzzy Logic Control Theory

The basic configuration of a FIS / FLC comprises of four principle components (Figure 2): a Fuzzification process, a Knowledge Base, Decision-making Logic, and a De-fuzzification process.

The Fuzzification process involves the following functions: a) Measure the values of input variables; b) Perform a scale mapping that transfers the range of values of input variables into corresponding universes of discourse; c) Perform the function of fuzzification that converts input data into suitable linguistic values, which may be viewed as labels of fuzzy sets. For example, if someone needs to give an judgment about temperature, they may simply say "hot", "warm", "cool", "cold", "slightly cool" etc. A fuzzy set is used to interpret that linguistic value. To make things discrete, it is assumed that each perception is rated by a number in set of $X = \{0, 0.1, 0.2, 0.3, \ldots, 1\}$. The linguistic value 'hot' is then defined to be the fuzzy set of rates living in the universe X (Feriadi and Hien, 2003).

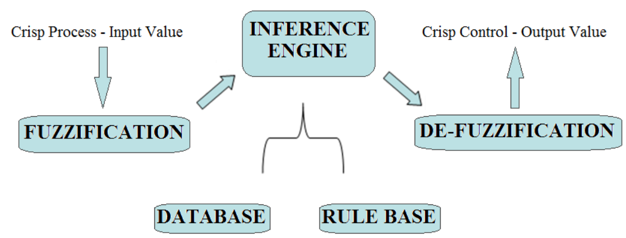

Figure 2. Basic FIS/FLC configuration.

The Knowledge Database comprises knowledge of the application domain and the attendant control goals. It consists of a "database" and a "linguistic (fuzzy) control rule base". The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules (Zimmerman, 1990). The Decision-Making Logic is the core of an FLC. It has the capability of simulating human decision-making based on fuzzy concepts, implication and the rules of inference in Fuzzy Logic.

The Defuzzification process performs the following functions: a) Scale mapping, which converts the range of values of output variables into the corresponding universe of discourse; b) Defuzzification, which yields a non-fuzzy control action from an inferred control action; A defuzzifier converts an inferred fuzzy control action into a crisp one (Zimmerman, 1990). The method adopted in this model is Centre of Area (COA) Defuzzification Technique. This method is also known as centre of gravity or centroid defuzzification. This is the most widely used technique and is proven to be reliable in this study.

The degree to which crisp value belongs to a given fuzzy set is represented by function known as a membership function (MF). The MF is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1 (Feriadi and Hien, 2003). Many different types of MF curves are available for these applications such as triangular, trapezoidal, Gaussian distribution curve etc.

4. Methodology

HVAC systems are considered to be highly nonlinear with disturbances and uncertainties (Hong, 2006). The nonlinear characteristics and the interrelated variables such as; temperature and humidity makes the HVAC systems mathematical modeling a difficult task. (Mirinejad, 2008).

In this paper, the thermal comfort and indoor air quality are selected as two of the main parameters that influence the occupants' comfort. Thermal comfort depends upon temperature, humidity, air movement, and a lot to do with the individuals clothing. Indoor Air Quality is mainly influenced by the concentration of pollutants in the controlled space (Batterman and Peng, 1995). The CO_2 concentration (measured in ppm) is the most representative controlled variable to measure the indoor air quality, as it reflects the presence of occupants as well as various sources of pollutants in the building (Dounis et al., 1996). Other parameters specifically used in this paper for indoor air quality are carbon monoxide, room size, room occupancy and particulate matter.

4.1. Indoor Air and Temperature Quality ("Comfort") Monitoring System

To identify the FLC variables, various parameters may be considered depending on the HVAC system, sensors and actuators. For the purpose of this paper, specific variables have been chosen for the two units. The design of the "Comfort" Monitoring system in this paper uses room temperature, humidity, room air flow, and clothing as input.

Room Temperature's ranging from 10 to 30 °C was used mainly because any values outside this range would be considered uncomfortable for human conditions. US Environmental Protection Agency cites the ASHRAE Standard 55-1992 Thermal Environmental Conditions for Human Occupancy, which recommends keeping relative humidity between 30% and 60%. At high humidity levels, sweating is less effective so we feel hotter. Dry air feels colder at room temperature leading to discomfort, lowering productivity and demanding for more heating. When relative humidity is ideal, temperatures in buildings can be lowered without causing discomfort to people in them.

Room Airflow in this case is simply the amount of air fluidity that is present in the room. In other words, it indicates whether the room is stuffy or has flowing air (draft). The level of clothing is a very important factor when considering human comfort because it insulates the body. Very heavy clothing will retain more body heat; lighter clothing will of course retain less heat. In conjunction with temperature and air flow, relative humidity affects comfort; conditions of 20 to 60% relative humidity at temperatures between 20 and 25 °C are usually judged comfortable (Health Canada, 2007).

4.2. Hazard Detection System

If we take into account that the building and the HVAC system are properly designed and functioning well, we can assume that human occupants are the main source of pollution. This section of the paper identifies carbon dioxide, carbon monoxide, particulate matter, room occupancy and room size as variables for the hazard detection unit. The unit uses the following variables feed by the user or identified by the sensors to decide if the concentrations are favourable to the user.

Since carbon dioxide (CO_2) concentration is a reliable index of the pollution emitted by occupants, it has been selected as an indoor air quality index for this paper. Based on health considerations, the acceptable long-term exposure range (ALTER) for carbon dioxide in residential indoor air is ≤ 3,500 ppm (Health Canada, 2007). One of the most acutely toxic indoor air contaminants is carbon monoxide (CO), a colorless, odourless gas that is a by-product of incomplete combustion of fossil fuels. Common sources of carbon monoxide in closed environments are tobacco smoke, space heaters using fossil fuels, defective central heating furnaces and automobile exhaust. By depriving the brain of oxygen, high levels of carbon monoxide can lead to nausea, unconsciousness and death. The acceptable short-term exposure ranges (ASTER) for carbon monoxide in residential indoor air is ≤ 25 ppm - one-hour average concentration (Health Canada, 2007).

Airborne particulate matter is a mixture of physically and chemically diverse substances. The size range of concern when human health effects and indoor air quality are considered is from 0.1 to 10 µm in aerodynamic diameter, particles smaller than this generally being exhaled. Above 15 µm, most particles are too large to be inhaled. The acceptable exposure ranges for fine particulate matter (≤ 2.5 µm mass median aerodynamic diameter -MMAD) in residential indoor air is ASTER: ≤ 100 µg/m^3 - one-hour average concentration (Health Canada, 2007). Room Occupancy is another important factor when it comes to air quality. The more people there are in a room, thermal, humidity and carbon dioxide levels will increase due to metabolic activities. The size of the room is also very important as it determines how these different systems work together. The larger the room means there is enough room for air diffusion. Smaller rooms would lead to a much more concentrated type environment. Thus, the larger the room, the HVAC would not have to work as hard as it would for a small room size.

COMFORT LEVEL	
Temperature	10 ° C - 30 ° C
Humidity	30 % RH - 90 % RH
Air Movement	Draft - Stuffy
Clothing Thickness	Thick - Lighter

HAZARD DETECTION UNIT	
Room size	Small - Larger
Room Occupancy	Few - Many
Carbon Dioxide	0 - 100 PPM
Carbon Monoxide	0 -8000 PPM
Particulate Matter	0 - 100 ug/m^3

Figure 3. Inputs & ranges of developed FISs.

4.3. Inputs and Outputs of the FISs

Figure 3 summaries the inputs and outputs of the variables and defines the individual variable boundary for each of the developed FISs.

4.4. Design of the Fuzzy System Using Matlab

The use of MATLAB®, as a tool for mathematical programming, is actually increasing in a large number of fields. In the field of buildings and HVAC, the number of users of MATLAB® has increased. The tool is suitable for many applications in this field, such as energy consumption, control strategies, hydraulic and air flow studies, IAQ, comfort, and sizing problems (Riederer, 2005).

The purpose of this paper is to produce a unit to satisfy the thermal comfort and air quality demands for the users' environment. To accomplish this goal, and as a proof of principle, FIS 1 and FIS 2 (Figure 4) were built using MATLAB® version 7.0 and the Fuzzy Logic Tool Box. Using information from distinguished international journals and publications, a knowledge base was created to assist in the building of the rules and membership functions for each FIS. FIS 1 was developed for the comfort level, and FIS 2 for hazard detection. The comfort level had 30 rules, and the hazard detection unit had 35 rules. The rules were constructed manually for this particular portion of the project, mainly for testing purposes. However these rules can be easily calibrated based on expert opinion to fine tune the system when combined with actual sensors.

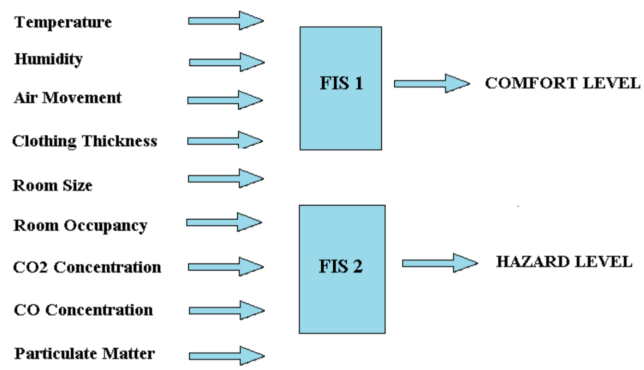

Figure 4. Structure of two different FISs.

Information for temperature, humidity, carbon dioxide, carbon monoxide and particulate matter are manually feed for this version of the control system. However; once the sensors are installed, the inputs from those variables would be solely based on sensor inputs rather than manual input unless specified by the user. The only manual inputs would be regarding clothing, room size and occupancy and the ideal temperature that user would like to set. The FIS as a FLC then provides relevant instructions to the actuators to carry out the required tasks in the two units (Figure 5).

Here, Gaussian membership functions types were used to establish the input and output variables of the two systems. The input values for simulation were selected so that all regions are covered by membership distribution functions. Through trial and error it was noted that the addition of more rules did not yield a better control feature. Conflicting rules actually caused the systems unstable, hence they were not included.

4.5. Simulation

Simulation is part of the process of modeling and forecasting the behaviour of a system. The task of simulation is to reproduce the developed progress of a system in the most suitable way. Simulation also plays an important role when designing FISs. Since the early design process of the developed

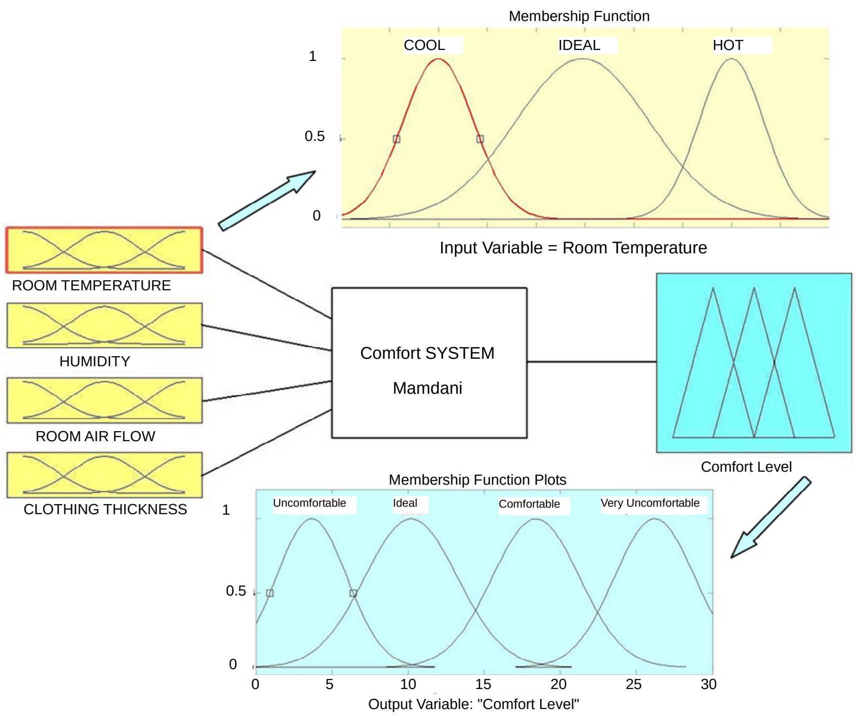

Figure 5. "Comfort" level output of FIS 1.

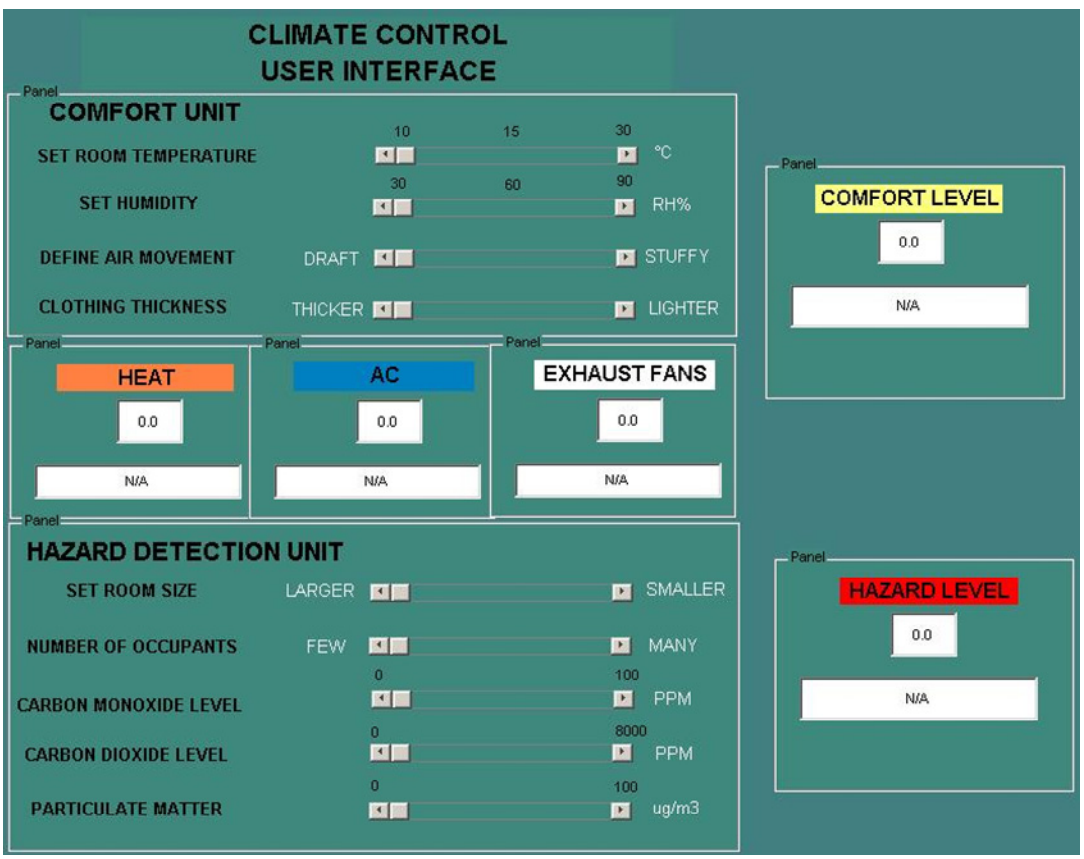

Figure 6. Graphical user interface (GUI).

fuzzy control system cannot be directly connect to the controlled systems, a simulation environment is used instead. The simulation process is used to design and tune the fuzzy control system to verify the functionality of the system. In this paper, the MATLAB Graphical User Interface Development Environment (GUIDE) is used in order to accomplish the simulation process.

Using GUIDE, it is feasible to simulate different scenarios to demonstrate how the program will operate under different conditions. This is done by comparing it to known and expected conditions. Once satisfactory results have been obtained, the new control strategies can be updated to the newly modified control system, thus validating the decisions made by the Fuzzy Logic Control system. Modifications are done by adjusting the membership functions and adding additional rules to include all potential conditions.

Through GUIDE, a simple yet effective GUI is developed for real-time visualization, testing and validation of the program (Figure 6). Even though FISs 1 and 2 are independent of each other, the developed GUI brings the two FISs together and provides the user with an interactive interface. When different room conditions are set by the user, the GUI shows in real time not only the "Comfort" and Hazard Level, but also the activity of the HVAC system. The idea behind the GUI is to give the user an understanding of how comfort and hazardous environments can be maintained through the guidance of an interactive interface. The system inputs can then be easily tested through the GUI to see if the system (by observing its outputs) behaves as expected.

COMFORT LEVEL	
Temperature	20 ° C
Humidity	50 % RH
Air Movement	Brief Draft
Clothing Thickness	More Lighter

HAZARD DETECTION UNIT	
Room size	Smaller
Room Occupancy	Many
Carbon Dioxide	85 PPM
Carbon Monoxide	7500 PPM
Particulate Matter	180 ug/m^3

Figure 7. Inputs to demonstration.

5. Demonstration

The climate control program is run in a MATLAB software environment through the help of a GUI. All the different conditions are manually feed. However, in a real world application the inputs would be feed from monitoring sensors that gives the system real time conditions. No physical prototype has been built; however, as a proof of principle a MATLAB simulated environment considering "real" conditions has been constructed for testing purposes. The original focus of this program using Fuzzy Logic is to stray away from conventional thinking or programming that uses historical data as a means of measure. However, once hooked up to sensors, real-time data can be collected or logged, and this data can be easily used further down the road for monitoring indoor air quality.

A demonstration of the monitoring system is discussed below. The "Comfort" and Hazard Detection Units' input values shown in Figure 7 indicate actual input values entered into the monitoring system displayed on the GUI in Figure 6. Using information collected by the user (knowledge base), Fuzzy Logic works to decide which ranges constitute as ideal conditions. Once these "comfort" settings have been entered into the fuzzification process, the inference engine decides on a solution and then the de-fuzzification interface turns this conclusion into a crisp decision that controls the different actuators to achieve the users input or ideal conditions.

With the above given conditions, the FISs / FLCs decide that the comfort level falls within its defined "comfortable range" (Figure 8). However, a high hazard level is indicated on the GUI due to the high concentrations of pollutants and harsh room condi- tions (small room with high occupancy). Hence, the exhaust fans are switched on to "High" to help reduce any build up of hazardous gases. The air conditioning unit is also activated to help reduce the heat level that may have build up with harsh room conditions.

6. Conclusions

The Appendix presents several other simulation runs of the program under other diverse environmental conditions Problems related to developing an ideal controller for a HVAC systems may include: variable and nonlinear factors, interaction between climatic parameters, variation in system parameters and the difficulty of accurate modeling of the system (Hamdi, 1998). The main advantage of intelligent controllers such as FLCs compared to conventional control is that no mathematical modeling is required for the design of the controller. Fuzzy controllers are simply designed based on the human expert knowledge of the system.

The FISs developed for this project are based on a Mamdani Controller type. Two FISs independent of each other have been built: a "Comfort" Level FIS and a Hazard Detection Unit FIS. A GUI has also been developed to bring the two Fuzzy Logic Control systems together and provide the user with an interactive interface.

The system proposed in this paper is an alternative to the systems currently on the market. It is important to mention that Fuzzy Logic has several benefits over conventional systems. This paper demonstrates that a monitoring system has the ability to guide the user to attain comfortable and safe room conditions. It is based on a program that has been built using a Fuzzy-based methodology that substantially simplified the design loop. The proposed methodology helps achieve the following significant advantages: simplified design complexity, reduced design development cycle, simplified implementation, alternative solution to Non-Linear Control, and improved control performance.

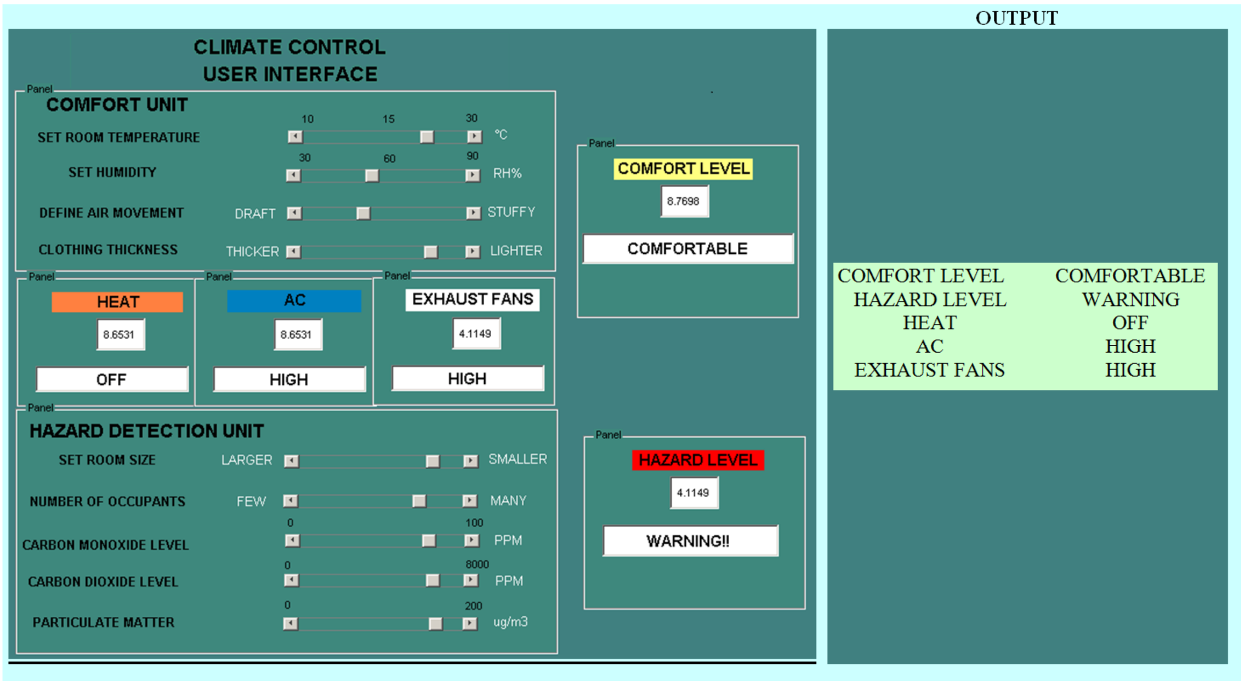

Figure 8. System outputs.

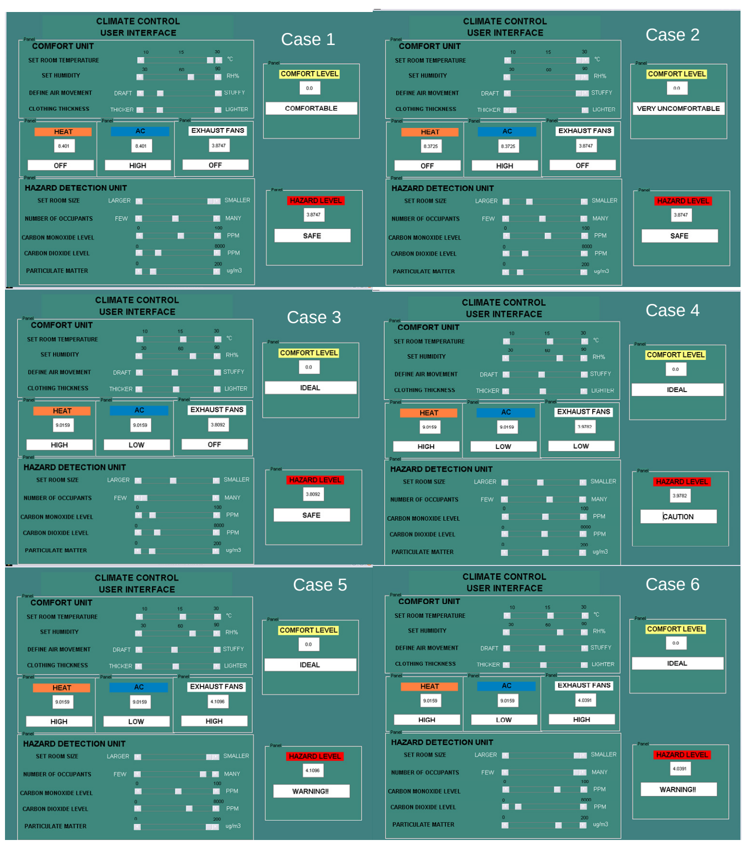

Figure A1. Six cases.

The monitoring system consists of a "Comfort" Monitoring System, and a Hazard Detection Unit. The following include some of the advantages of this system: minimized energy cost due to elimination of over heating and over cooling; automated HVAC unit; modification of programming capability to adapt to various buildings or environments using a fuzzy logic controller; "Comfort" and hazardous situations can be modified by altering or adding values to the rule set in the controller.

Though no actual physical prototype has been built to test the model in an actual environment; a proof of principle reliable software model in a MATLAB environment has been tested and proved successful in terms of the outputs achieved through many different and diverse "real" conditions set as inputs. During the many simulation runs, the inputs were manually entered by the user rather than through sensors, however; a fully functioning system would have sensors integrated into the system for data input. This system can be integrated into any HVAC system because Fuzzy Logic is highly adoptable and can be implemented and integrated with existing systems and programming languages or platforms.

Appendix

This Appendix contains a set of actual screenshots from the GUI of the Climate Control Unit (Figure A1). They represent simulation runs of the program under different environmental conditions. The purpose of the simulation runs is to basically give the user an idea of the functionality of the program and to display how different and diverse inputs affected the output.

Case 1

Case one focuses solely on the "Comfort" unit. Room temperature is close to 30 °C while the clothing thickness is heavy. The Fuzzy logic system computes this information and turns the Air Conditioning (AC) to "High" while shutting down the heat. The Fuzzy logic system interprets this information and outputs the comfort level as "Comfortable".

Case 2

Case two also focuses solely on the "Comfort" unit. Room temperature is close to 30 °C with no air movement, high humidity and heavy clothing. The Fuzzy logic system computes this information and turns the Air Conditioning (AC) to "High" while shutting down the heat. The Fuzzy logic system interprets this information and outputs the comfort level as "Very Uncomfortable".

Case 3

Case three also focuses on the "Comfort" unit and hazard detection unit. Room temperature is around 15°C with medium air movement, 70% humidity and medium thickness clothing. The Fuzzy logic system computes this information and turns the Air Conditioning (AC) to "Low" while turning the heat to high. The Fuzzy logic system interprets this information and outputs the comfort level as "Ideal". There are low threats from carbon monoxide, carbon dioxide or particulate matter, hence the Fuzzy logic interprets this system to be "Safe"

Case 4

Case four focuses on the hazard detection unit. Carbon Monoxide, Carbon Dioxide and Particulate Matter are all medium threat. The Fuzzy logic system computes this information and turns the Exhaust to "Low". The Fuzzy logic system interprets this information and outputs the hazard detection unit to as "Caution".

Case 5

Case five also focuses on the hazard detection unit. Carbon Monoxide, Carbon Dioxide and Particulate Matter have a medium-high threat. The Fuzzy logic system computes this information and turns the Exhaust to "High". The Fuzzy logic system interprets this information and outputs the hazard detection unit to as "Warning".

Case 6

Case six also focuses on the hazard detection unit. Carbon Monoxide, Carbon Dioxide and Particulate Matter are a high threat. The Fuzzy logic system computes this information and turns the Exhaust to "High". The Fuzzy logic system interprets this information and outputs the hazard detection unit to as "Warning".

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