Development of Intelligent Controller for HVAC Damper Control

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Abstract- This paper shows the development of intelligent controller for Heating Ventilation and Air Conditioning (HVAC) systems. HVAC systems consumes about 50% of the total energy requirement of a commercial building, this is due to the lack of intelligent controllers in the conventional system that controls the unit. A conventional system can be converted into an energy efficient system using an intelligent control. An intelligent controller is used to calculate the cooling requirements based on various parameters that include room temperature, required temperature, time required to cool, occupancy, and heat load requirement of the area to be cooled. A controller was modelled in LabView with the help of a novel equation, which was formulated by using the parameters, simulations are carried out using various test conditions and parameter. With the use of artificial neural network, the heating and cooling requirements of an area is predicted and are supplied as per demand. The neural network model is trained with the data set obtained from the LabView CRIO controller, which improves the system efficiency and reduce energy wastage.

Keywords- HVAC system; Controller Design; Control System; LabView; Artificial Neural Network.

1. Introduction

Temperature comfort of the people inside the building. Improper ventilation, varied temperature and humidity causes poor “indoor environmental quality”. People spend most time indoors. Bad IAQ makes them less productive and more often unwell. Air quality depends on several parameters such as temperature, air density, humidity, CO2 concentration.

To assure a good indoor air quality, HVAC systems normally uses a control that keep up a fixed set point of fresh air ventilation. It is based on the designed occupancy, but due to its inefficiency, Demand Controlled Ventilation is used which uses CO2 sensors to manage the fresh air supply. It ensures that the indoor air quality (IAQ) is achieved or not. Since the main source for indoor air contamination are people, the change in CO2 concentration is a perfect way to check the number of occupants, which makes it possible to set the fresh air volume as per demand.

In many countries, the energy usage by buildings for HVAC is around half of the total energy usage. As the population keeps growing, the building services and comfort levels demand keeps on growing. HVAC systems are the largest energy consumers in a building and this has been increasing over the years, as comfort is considered the most important thing. The intelligent control strategies are considered to reduce the total energy usage by at least 30%. The saving of energy can also help to reduce the carbon dioxide concentration in the atmosphere caused by the use of fossil fuels in generators.

A sensor is required to identify the number of occupants(occupancy) in the room and depending on that the variable frequency drive is adjusted that varies the rpm of the blower in the AHU to maintain a certain CFM pushing the air at a certain speed creating a temperature difference hence cooling the room to the required temperature.

Equations are formulated to calculate the volume discharge and heat transfer by using input parameters like effective humidity, surrounding temperature, number of occupants and angle of opening of the two valve controllers connected at the two ends of the duct. Equations are also derived for controlling the intelligent controller in the HVAC model using LabView. Dimensions of a normal classroom was determined and have calculated the volume of the room so as to find the CFM and hence calculate the time taken to cool the room when the blower runs at a particular rpm decided by the given parameters decided by the sensor and the user input.

The objectives of this work are:

1) Enabling optimal airflow efficiency along with minimizing acoustic disturbance in a space.

2) Aim to minimizing the size and fit of the system and allow minimum power consumption.

3) Develop HVAC control strategies.

4) To develop a simulation model of the controller.

Heating Ventilation and Air Conditioning (HVAC) Systems

The main components of a HVAC system are: a) Air Handling Units (AHU) b) Ducts c) Area to be cooled or heated d) Variable Area Valve (VAV) e) Thermostat f) Furnace g) Evaporator coil h) Heat exchanger i) Blower motor j) Condensing unit k) Refrigerant Lines l) Vents

1. AHU: The AHU consists of a chiller unit or a heating unit, an air blower, a variable frequency drive. The chiller unit cools the air and the heating unit heats the air as per requirement. The blower blows the air from chiller unit or heating unit into the ducts for the distribution of the air. There is a variable frequency drive connected to the blower, which controls the CFM output of air from it.

2. VAV: The variable area valve controls flow of air going out from the AHU as well as the air coming back to it.

3. Thermostat: It is used to start the entire system. It decides whether cooling or heating should take place in the HVAC System and is programmable to the needs of residents.

4. Furnace: It is used for heating applications. It heats the air inside the AHU and by burning fuels.

5. Evaporator Coil: It is used during the summer to chill the air in HVAC system. It is placed besides the furnace.

6. Heat Exchanger: It heats the air which is pulled in and is made to flow in the room. It works on contrary to evaporator coil

7. Blower Motor: After the air in the heat exchanger reaches a set temperature, an electric blower motor starts the fan that forces the warm air into the room's ductwork, through the air vents, into all the rooms in the building. Combustion ends before the blower motor stops working, so all the warm air produced in the heat exchanger and ductwork will get to the rooms of the building before the motor shuts down and waits for the next heating cycle.

8. Condensing Unit: The condensing unit is used to cool the hot air present in the building. It is placed outside the building and connected to the evaporator. There is a gas used in the condenser which is used for the heat transfer. The gas can be vaporized and liquidized with less amount of heat and chillness respectively. Therefore, it can absorb the heat from the room and help in cooling process.

9. Refrigerant Lines: These are used for the transportation of the refrigerant gas between condenser and evaporator. They are made of either copper or aluminum to withstand extreme weather conditions.

Fig 1. Schematic diagram of an HVAC system

10. Ducts: The duct connects the AHU to the area to be cooled or heated. The ducts run throughout the building to deliver air to each room.

11. Vents: They are cut into ducts to allow the air to flow into the room. They are designed to direct the airflow in certain direction into the room.

Fig 1. shows the schematic diagram of an HVAC system. For efficient working of the system the total area to be cooled are divided into several zones based on cooling required. For this, a controller is needed with which the air conditioning required for each room can be determined. An intelligent controller can be used to obtain this with ease and least effort.

Major classification of HVAC systems is based on location of the equipment, that is, whether the whole building is to be cooled using a centralized unit or dividing the whole building into several units and treating them as decentralized units. So, the major types are:

i) Centralized system - A central HVAC system serves one or more thermal zones, and its major equipment is located outside the served zone(s) in a central location whether inside, on top, or adjacent to the building. The centralized system is further classified into all air systems and water related systems. All-air systems can be sub-classified based on the zones as single zone and multi-zone and the airflow rate for each zone as constant air volume and variable air volume, terminal reheat, and dual duct.

ii) Decentralized system - This type of system is considered as a local HVAC system where each equipment serving its zone without crossing boundaries to other adjacent zones.

Types of Local HVAC Systems:

a) Single-Split System
b) Multi-Split System
c) VRF or VRV System
d) VAV or CAV System
e) Ductless Split Systems
f) Packaged Systems
g) Geothermal HVAC Systems

This paper focuses on the VAV or CAV system. Variable air volume also called as constant air volume (CAV) systems are using a single-duct supply and a return system with changing airflow (VAV) or constant airflow (CAV) to maintain temperatures between respective limit. An illustration of the VAV system is shown in Fig 2.

2.Proposed HVAC Control System

HVAC requires a control system to regulate heating and cooling operations of the system. A sensing device is usually used to compare the actual state with a targeted state. Thermal comfort is the condition in which an individual feels satisfied with the thermal environment and is evaluated by distinctive examination. It is important so

Fig 2. VAV System in HVAC system

that a person doesn't feel too cold or too warm. Thermal comfort is needed for enhancing or balancing health and well-being as well as productivity of a person. A lack of thermal comfort causes stress among building occupants.

To achieve thermal comfort in our selected room/class, a thermal sensor is subjected to detect the room temperature or the temperature difference between the outside environment and the class environment. Along with the temperature sensor, another sensor is placed to check or detect the occupancy count or the number of occupants in the room. The time required to cool or heat the room is also taken as an input. Controlling the opening and closing of the damper flap can control the movement of cold or hot air into the area that is to be air conditioned. Control of the angle of the damper flap is achieved by control of these parameters that is, when the temperature of the room, required temperature, number of occupants and time to cool is set into the system, the flap/damper angle is adjusted by the system according to the need and the cfm required to cool the room for that situation is also adjusted.

The equation for the calculation of flap angle was formulated using duct air flow equation, total heat load of the area to be cooled, and the input parameters.

The duct air flow equation is:

$$V=V_{r}/(A_{d}*t) \quad (1)$$

where,
V= air flow velocity
V_r = Volume of the room.
A_d = Area of cross section of the duct.
t = time required to cool the room.

The flap angle equation is:

$$ɵ =\{[[T_R-T_r*1090]+[(n-1)*500]]*0.64\}/t \quad (2)$$

Where,
ɵ = Angle at which variable area valves are opened
T_R =Room temperature
T_r= Required temperature
n =Number of occupants
t= time required to cool the volume of the room

The heat load requirement of a room varies with its total effective volume and occupancy. Therefore, a room with a volume of 155ft3 was taken for the system. Each degree change produces a heat load of 1090 Btu and each occupant add 500 Btu's each.

The room is capable of accommodating a maximum of 50 occupants, but in the flap angle equation, the value of the number of occupants varies from 1 to 10. This is because tonnage of blower is changed using a variable frequency drive. The CFM output of the blower is increased by 200 after every 10th occupant and for the 11th occupant, the 'n' value is set to 1. That is:

if n < = 10 then CFM = 600
if n < 21 then CFM = 800, n = n - 10
if n < 31 then CFM = 1000, n = n - 20
if n < 41 then CFM = 1200, n = n - 30
if n < 51 then CFM = 1400, n = n – 40

Fig 3. The Process Flow Chart of the Proposed HVAC Control System

Fig 3. Shows how the parameters are taken and the sequence in which each calculations and functions that are taking place in the control system. Damper Control Simulation Using LabView

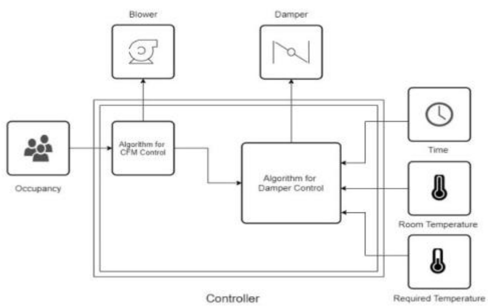

Fig 4. Schematic Diagram of the HVAC Control System

The schematic diagram of the HVAC Control System in the Fig 4 shows the arrangement and flow of control in the controller. The controller has two parts. One part does CFM selector and the other controls the damper. The occupancy value first reaches the CFM selector, where the required CFM value is calculated and send to the blower. The occupancy value is also modified in the CFM selector. This modified occupancy value is sent to the damper controller. Required time to cool the room, room temperature and required room temperature are the other parameters that are given to the damper controller. The damper control algorithm arrives at an optimal angle for the given room condition. The angle found is then send to the damper.

Fig 5 and 6 shows the block diagram and front panel of simulation respectively which was done in LabView. Based on the simulations done, three case studies were done to analyze the result obtained.

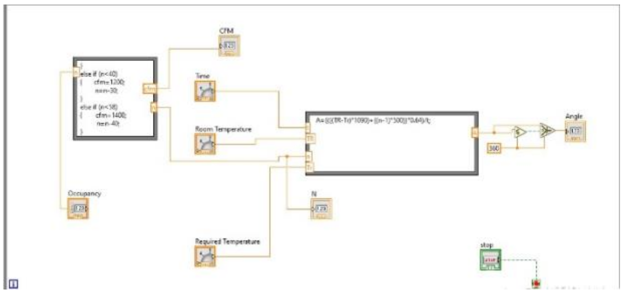

Fig 5. Shows the Block Diagram of the Controller in LabView

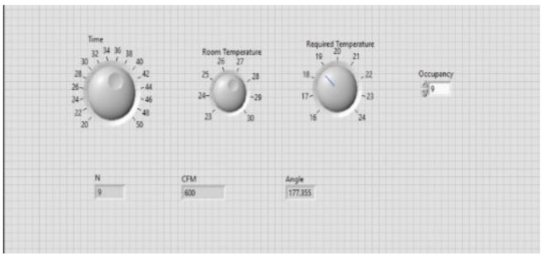

Fig 6. Shows the Front Panel of LabView

Case study 1: Occupancy and Required Temperature are constant

In case study 1, occupancy and required temperature are kept constant. All the other parameters are changed and the flap angle is calculated using equation (2). The performance curve is also obtained.

Table 1 Performance of the Controller When Occupancy and Required Temperature are Kept Constant

Sl no	Time requir to cool	Room temperature	Required temperature	Room occupancy	Blower CFM	Angle of flapper
1	20	26	23	15	800	170
2	20	25	23	15	800	134
3	20	24	23	15	800	98
4	30	26	23	15	800	112
5	30	25	23	15	800	89
6	30	24	23	15	800	65
7	40	26	23	15	800	84
8	40	25	23	15	800	68
9	40	24	23	15	800	50
10	45	26	23	15	800	75

Case study 2: Occupancy varies and Required Temperature is constant

In case study 2, required temperature is kept constant. All the other parameters are changed and the flap angle is calculated using equation (2). The performance curve is also obtained.

Case study 3: All input parameters varies (Comfort Mode)

In case study 3, all the parameters are varying and the flap angle is calculated using equation (2). The performance curve is also obtained.

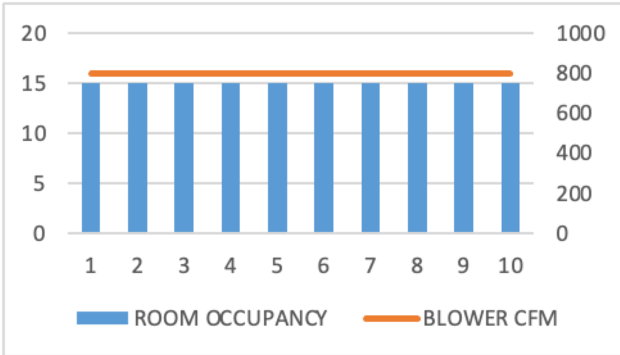

Fig 7. Occupancy vs Blower CFM Curve

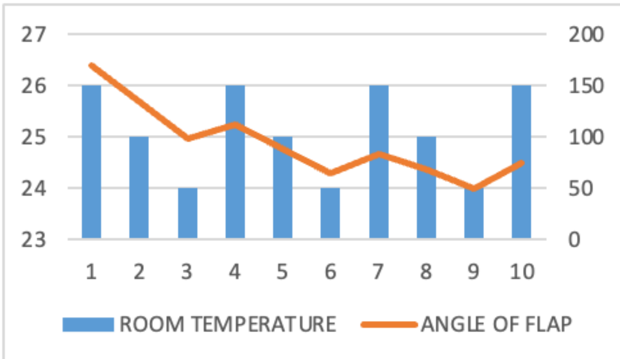

Fig 8. Room Temperature vs Flap Angle Curve

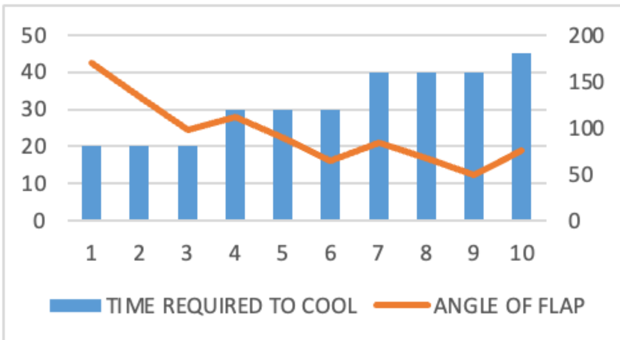

Fig 9. Time Required to Cool vs Flap Angle Curve

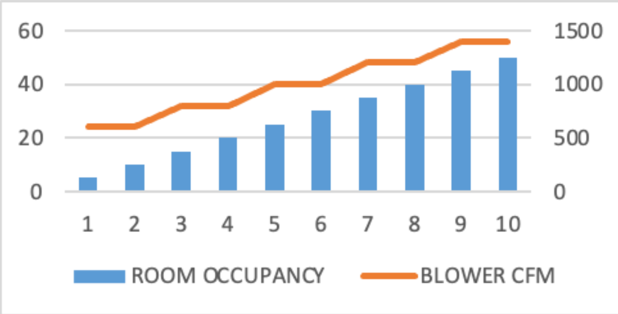

Fig 10. Occupancy vs Blower CFM Curve

Fig 11. Room Temperature vs Flap Angle Curve

Table 2 Performance of the Controller When Required Temperature is Kept Constant

Time req. To co	Room temp	Req. Temp	Room occ.	Blower cfm	Angle of flap
20	24	23	5	600	100
20	25	23	10	600	214
25	25	23	15	800	107
25	26	23	20	800	199
30	26	23	25	1000	113
30	27	23	30	1000	189
35	27	23	35	1200	116
35	28	23	40	1200	182
40	28	23	45	1400	119
40	29	23	50	1400	178

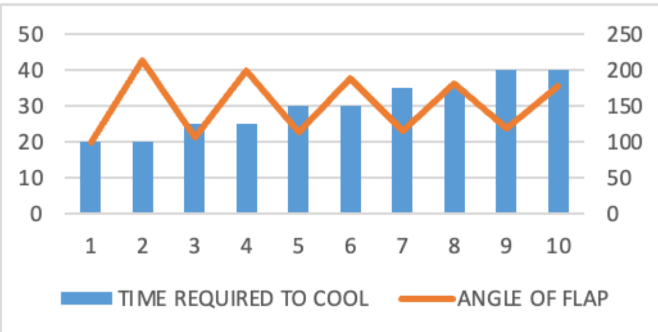

Fig 12. Time Required to Cool vs Flap Angle Curve

Table 3 Performance of the Controller When All the Parameters Are Changed

Time req. cool	Room temp	Req Temp	Room occ.	Blower cfm	Angle flap
20	24	24	5	600	65
24	25	24	10	600	150
28	25	23	15	800	96
30	26	23	20	800	166
35	26	22	25	1000	116
20	27	22	30	1000	319
24	27	21	35	1200	229
28	28	21	40	1200	276
30	28	20	45	1400	229
35	29	20	50	1400	262

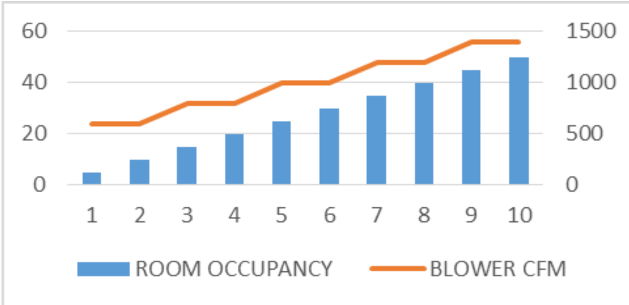

Fig 13. Occupancy vs Blower CFM Curve

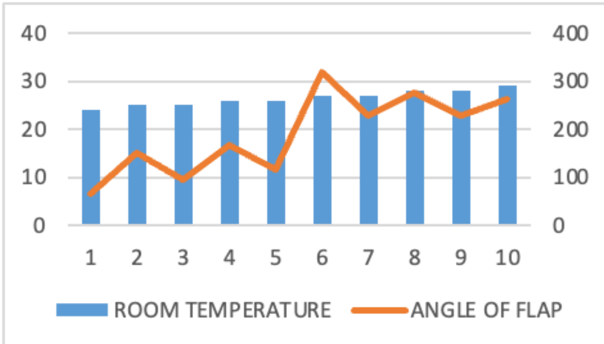

Fig 14. Room Temperature vs Flap Angle Curve

3.Development of a Neural Network

Neural Network contains a set of functions with weighted connections between them which may be adjusted ("trained") until a desired output is achieved by automatic optimization. Elements of the network structure itself also can be a part of training. NNs are often trained entirely from simulation data, measured data, or a mixture. The NN which is employed during this project is trained using the info set which is collected from the controller designed in LabView. The neural network uses feed forward architecture for classification of parameters. Levenberg–Marquardt algorithm is employed to train and predict NN. The block diagram of the neural network made in MATLAB is given in Fig 17. The block diagram of the model architecture is given in Fig 19.

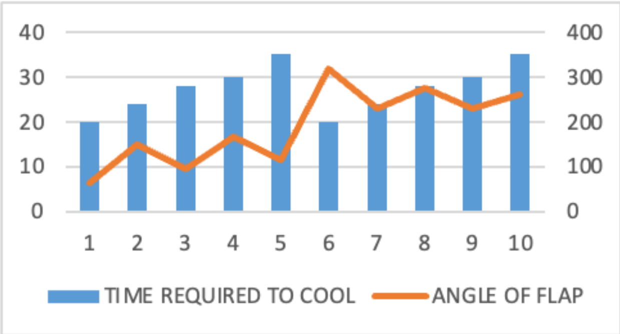

Fig 15. Time Required to Cool vs Flap Angle Curve

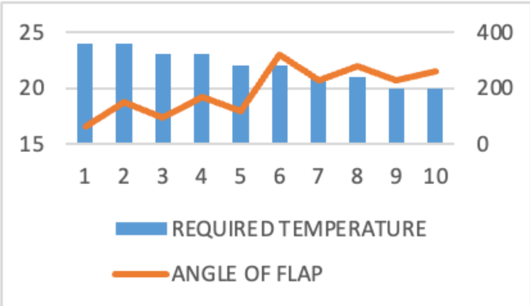

Fig16. Required Temperature vs Flap Angle Curve

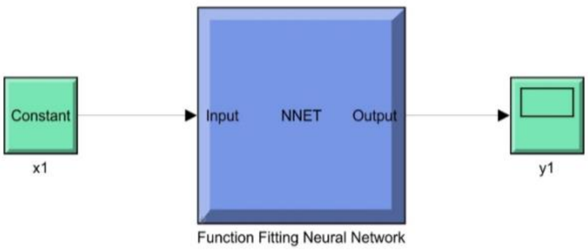

Fig17. Block Diagram OF Neural Network

3.1.Feed Forward Architecture

A feedforward neural network may be a biologically inspired classification algorithm. It consists of a (possibly large) number of straightforward neuron-like processing units, organized in layers. Every unit during a layer is connected with all the units within the previous layer. These connections aren't all equal: each connection may have a special strength or weight. The weights on these organized layers encode the knowledge of a network. Often the units during a neural network also are called nodes. The Neural Fitting app in MATLAB are often used to select data, create and train a network, and evaluate its performance using mean square error and regression analysis. A Neural network is modelled for the calculation of flap angle from the input parameters.2-layer feed forward architecture is employed .16 neurons are used, during which 15 are hidden. Feed-forward architecture model is shown in Fig 18.

Fig 18. Feed Forward Architecture [17]

Fig 19. Block Diagram OF Feed Forward Architecture

3.2.Levenberg-Marquardt Algorithm

It is used to solve non-linear method of least squares problems. These minimization problems arise especially within the least-squares curve fitting. The Levenberg–Marquardt algorithm is an iterative procedure. It is very fast when training neural networks. The State Diagram for The Levenberg-Marquardt Algorithm is shown in Fig 20.

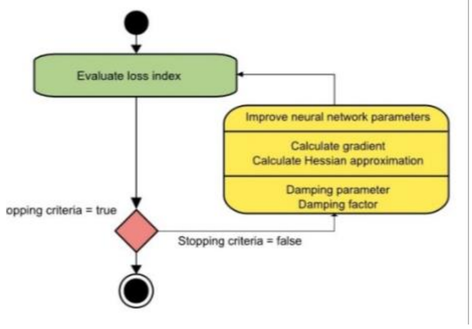

Fig 20. State Diagram for the Levenberg-Marquardt Algorithm

3.3.Training Results

The training results after the modelling of the artificial neutral network can be seen in Fig 21 and 22. The best validation performance of the model was obtained at epoch 22. Least value of mean squared error is considered the best validation performance. Fig 21 gives the Error Value over Epochs Curve and Fig 22 gives Curve Fitting. Table IV shows the comparison of calculated and predicted values of flap angle by the NN model.

Fig 21. Error Value over Epochs Curve

Fig 22. Curve Fitting for training andtarget

Table 4 Comparison of Calculated and Predicted Values of Flap angle by the NN Model

sl no	Calculated value of angle	Predicted value angle	Difference	% of error
1	129.5515	128.8313	0.7202	0.5590256
2	203.4824	203.4599	0.0225	0.0110587
3	345.92	346.2032	-0.2832	-0.0818017
4	156.2667	156.874	-0.6073	-0.387126
5	206.2	206.3967	-0.1967	-0.0953019
6	139.52	139.4075	0.1125	0.0806987
7	70.99535	69.40627	1.58908	2.2895338
8	95.4	93.86197	1.53803	1.6386083
9	95.00444	97.50494	-2.5005	-2.5644855
10	152.6857	148.8327	3.853	2.5888128

4. Conclusion

The working of different types of HVAC system was studied and the operation of different components of the system was analyzed. Several types of control techniques were also studied. Flow-charts of HVAC control systems was developed, the input and output parameters were studied and a controller was designed using different equations. A controller was designed in LabView such that it takes different parameters from the room and control the air flow rate into the room which can regulate the cooling or heating required by the room and different case studies where done based on the result. A rough model of an HVAC system was modeled in MATLAB with which the working of a damper in a duct was observed. An artificial neural network was developed and trained with the data set that was derived from the LabView simulation. The model was able to predict the value of flap angle of damper with minimum error. Therefore, an intelligent controller for an HVAC system was developed that is capable of automated damper control and enhanced indoor comfort.

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