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BTP MED 411

SYSTEM DESIGN OF HVAC OF OFFICE SPACE FOR ENERGY & IAQ OPTIMIZATION

PRANAV REDDY
RAJAT VARSHNEY

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OVERVIEW

MOTIVATION

1. ENERGY CONSUMPTION - INCREASING EXPONENTIALLY. MORE USE OF HVAC SYSTEMS THAN EVER. HENCE ENERGY EFFICIENT MEASURES NEED TO BE ADAPTED
2. IAQ IS DEGRADED AT PEAK TIMES & EXCESSIVE LOAD. USER COMFORT, HEALTH IS COMPROMISED. COULD HAVE ADVERSE EFFECTS IN LONG RUN
3. EXHAUSTIVE THERMAL & CONTROL SIMULATION COMPLEMENTING EACH OTHER NEEDED TO IDENTIFY THE APPROPRIATE SYSTEM DESIGN & PARAMETERS
4. NEED FOR SELF LEARNING/ ADAPTIVE OPTIMIZATION ALGORITHMS - AI. WHICH WOULD REQUIRE MINIMAL HUMAN INPUT AND EFFORT

LITERATURE SURVEY

Several approaches have been taken for obtaining the optimal control of HVAC systems, each of which has a trade off in accuracy, information required to describe the thermal performance, the capability of the model to accommodate changing conditions, and the computational power required. We can briefly sort the literature into 3

- FEA/ CFD ANALYSIS OF THERMAL COMFORT, IAQ OPTIMIZATION BY STATISTICAL METHODS
- DEVELOPMENTS IN CONTROL SYSTEM OF HVAC, OPTIMIZATION USING CLOSED LOOP, PREDICTIVE MAINTENANCE
- ML/ AI ALGORITHMS USED EXCLUSIVELY OR INCORPORATED WITH MODERN CONTROL SYSTEMS FOR BETTER PERFORMANCE

A large number of papers have used the PMV model to predict thermal sensation. [1] offers insights into the same and also about the advances in computerisation & simulation that can can aid the process. [2] used random forest classification algorithm with CFD to develop an adaptive thermal comfort maintenance system. [4] also develops a CFD model to evaluate human comfort using indices PMV, PPD. Other literature in the area approached optimization by using statistical methods.

Fundamentals of air handling unit of the system - structure, components and basic control sequences have been explored in [5] and some parts of [6]. [6] further goes on to investigate advanced, adaptive control designs such as neural network controller, MIMO controller and reinforcement learning controller. [8] presents a comprehensive study of all major control systems that can chosen while [7] inspects multivariable control using PI system
Other papers in similar domain observed the conventional systems with classical and adaptive, optimal & predictive maintenance. They have shown how development of intelligent control systems have improved the efficiency.

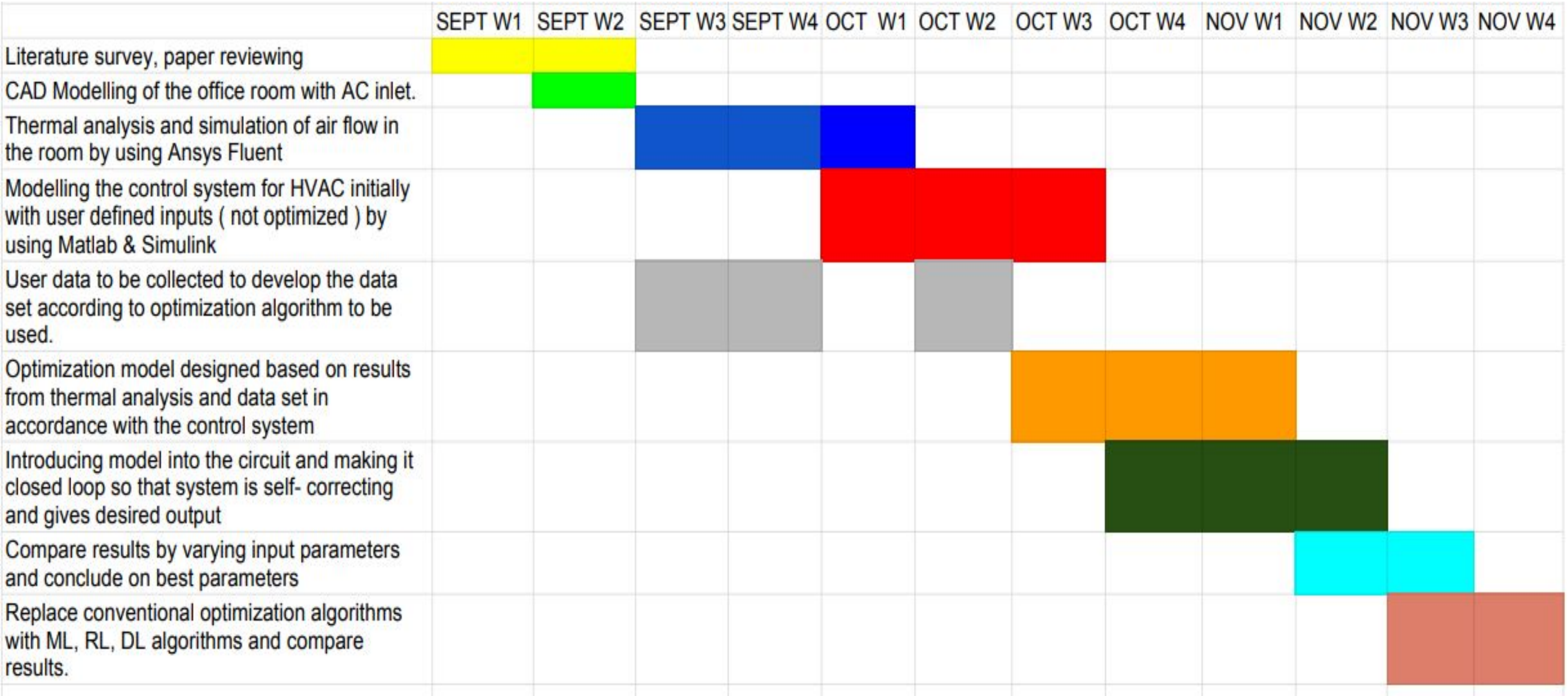
[11] & [12] discuss the results of applying genetic algorithm to optimize HVAC systems. [13] and many other papers similar to it have used machine learning & deep learning algorithms for prediction of thermal comfort and automatic tuning of systems for optimized energy consumption and improved user satisfaction.

OBJECTIVE

After a detailed study of literature & problems concerning the issue, the primary goals of an intelligent HVAC system should be high air quality & Energy savings. Also the comfort conditions should be combined with an energy saving control strategy embedded with an appropriate optimization technique

1. TO DESIGN AND SIMULATE AN OFFICE ROOM AND ANALYSE THE RESULTS
2. TO DEVELOP A 2 - ZONE THERMAL MODEL AND COUPLE IT WITH IAQ MODEL
3. EXAMINE THE SUITABLE CONTROL METHOD AND IMPLEMENT IT ON THE MODEL
4. ANALYZE RESULTS OF AND USE OPTIMIZATION ALGORITHMS TO IMPROVE

ESTIMATED TIMELINE

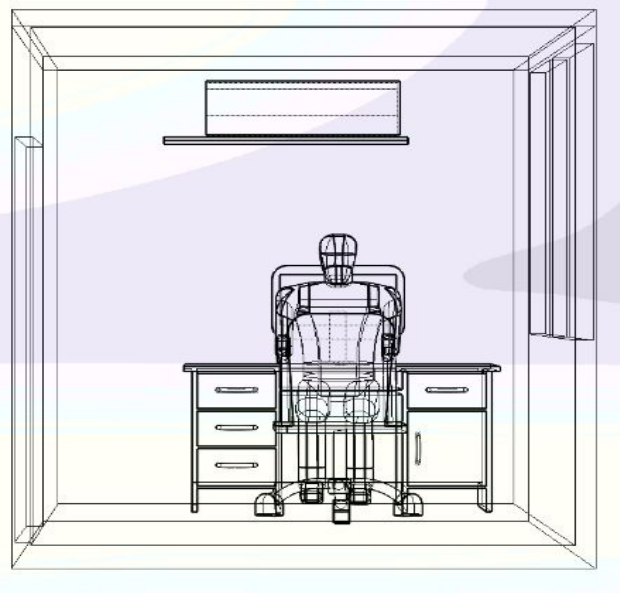


SYSTEM DESCRIPTION

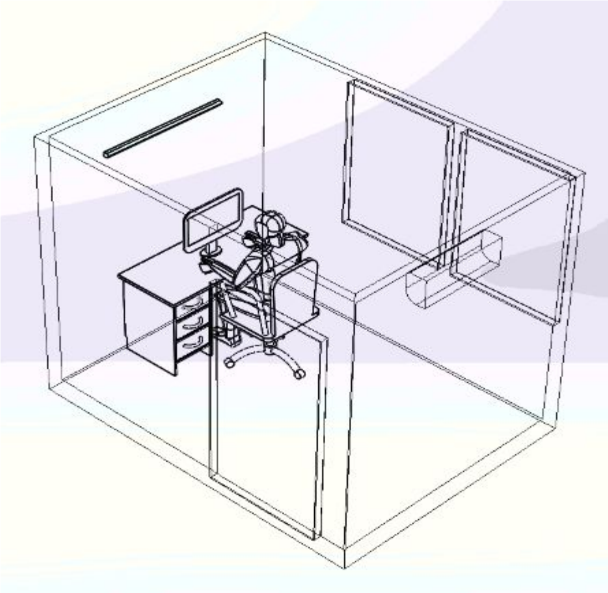
CAD MODEL

A standard office room (8x10x8 ft^3) has been modelled with the help of solidworks.

Front View



Right View



Isometric View

CFD Model

The CAD model is simulated with the help of Ansys.
Cavity modelling is used for analysing the air flow and Solid modelling for the thermal.
In the simulation RNG k-ε turbulence model was used to predict the air flow and thermal condition of the office space.

Equations that has to solved are continuity, momentum and energy equation.

Continuity equation:

$$\frac{\partial p}{\partial t} + \nabla . (\rho \, \vec{v}) = 0 \qquad (Eq\ 1)$$

where

t = time (s)

$\vec{v}$ = air velocity at measurement position (m/s)

ρ = air density (kg/m3)

Cont.

Momentum equation:

$$\frac{\partial}{\partial t}(\rho\,\vec{v}) + \nabla.(\rho\,\vec{v}\vec{v}) = -\nabla P + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} \qquad (Eq\ 2)$$

where

P = static pressure (Pa)

$\bar{\bar{\tau}}$ = stress tensor (Pa)

$\rho\vec{g}$ = gravitational body force

Energy equation:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{v}(\rho E + p)\right) = \nabla\left(\rho k_{eff}\nabla T - h + (\overline{\overline{\tau_{eff}}}.\vec{v})\right) \qquad (Eq3)$$

$$E = h - \frac{p}{\rho} + \frac{v^2}{c} \qquad (Eq\ 4)$$

Cont.

where

E	= total energy (J)
h	= enthalpy (J)
k_{eff}	= effective conductivity (W/m k)
T	= air temperature (K)
$\overline{\overline{\tau_{eff}}}$	= deviatoric stress tensor (Pa)

Solver used to solve these equations is Fluent.
SIMPLE method is used for the coupling of pressure and velocity.

CAVITY MODELLING APPROACH

In this type of modelling we only consider the air part and the rest is taken as cavity. This type of approach is good to study the flow of air (fluid) as it is computationally faster and cheap. It has its limitations, we can't add a heat source and we can't consider properties of different bodies.

Model was meshed into small size elements. The surface of AC inlet is meshed into 0.2 cm while the rest of the domain will be into 1cm. Orthogonal quality is maintained greater 0.5.

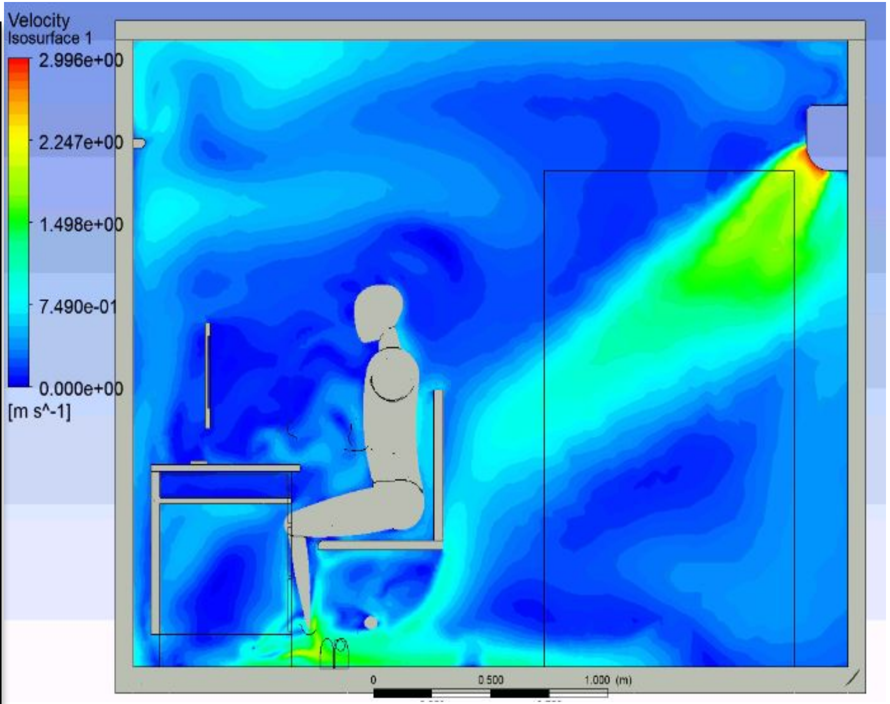
Parameters:

- Steady-state analysis
- Discharge velocity from air conditioner is taken as 3m/s
- Operating pressure is taken as 1 atm.
- Convergence criteria is set to be less than 10^{-3}.

Results

STREAMLINES

VELOCITY DISTRIBUTION



SOLID MODELLING APPROACH

In this, we consider all bodies along with air. It is good to study the heat interaction between bodies.

MATERIAL PROPERTY TABLE

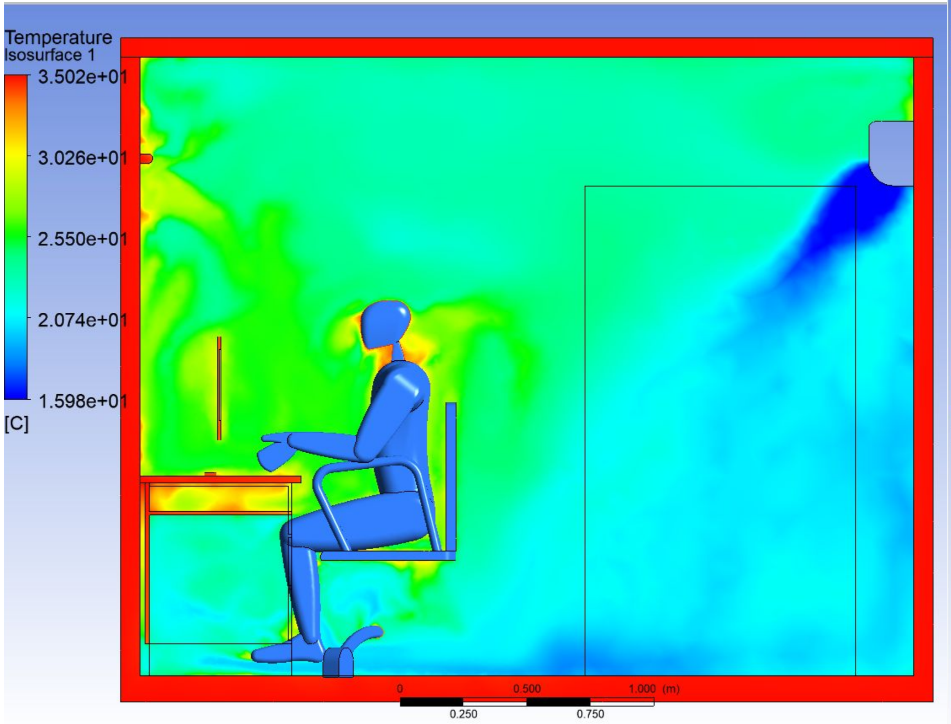
Material	Bodies	Density (kg/m^3)	Specific Heat Capacity (j/kg-k)	Thermal Conductivity(w/m-k)
Plastic	pc, tubelight	950	1900	0.5
Quartz glass	windows	2230	840	1.4
wood	table,chair	700	2310	0.173
Human	man	985	3600	0.5
Concrete	walls	2500	900	0.93

Analysis Parameters

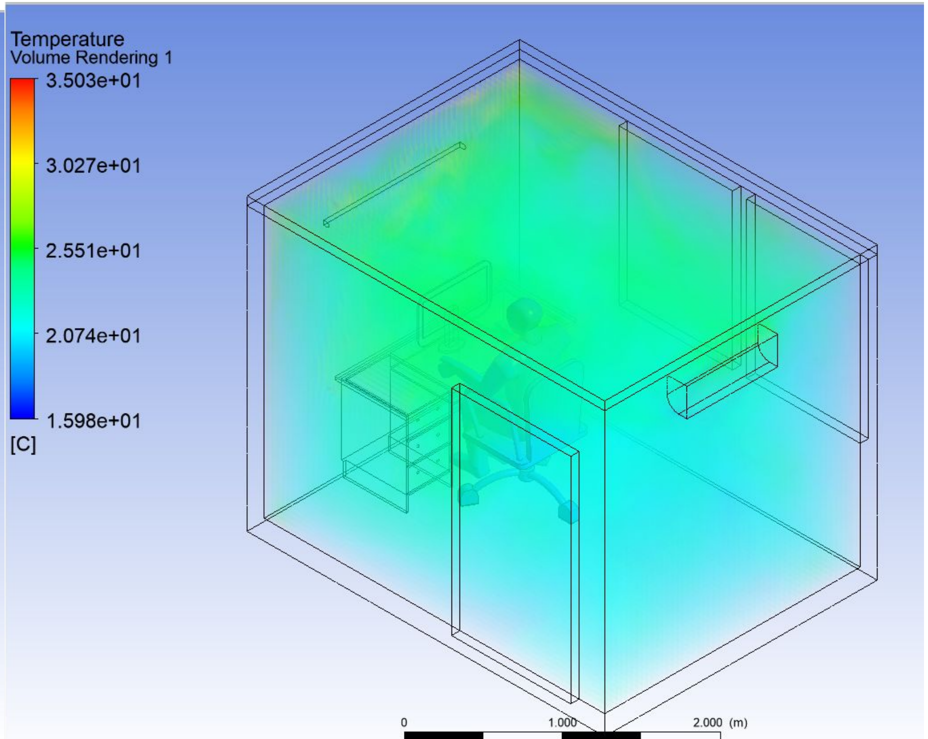
- Operating Pressure is 1 atm.
- Room walls are considered as insulated.
- Human, PC, and LED light are considered as heat-emitting bodies.
- Human - 30W, PC - 50 W, LED - 20 W
- Via system coupling boundary condition is applied on all interfaces.
- Convergence criteria is taken less than 10^{-6} for energy equation while others are set less than 10^{-3}.
- Initial room temperature is 35 ^{o}C in summers and 2 ^{o}C in winters
- Discharge air from air conditioner is taken as 16 ^{o}C in summers and 28 ^{o}C in winters.

Results

Temperature Contour Plot

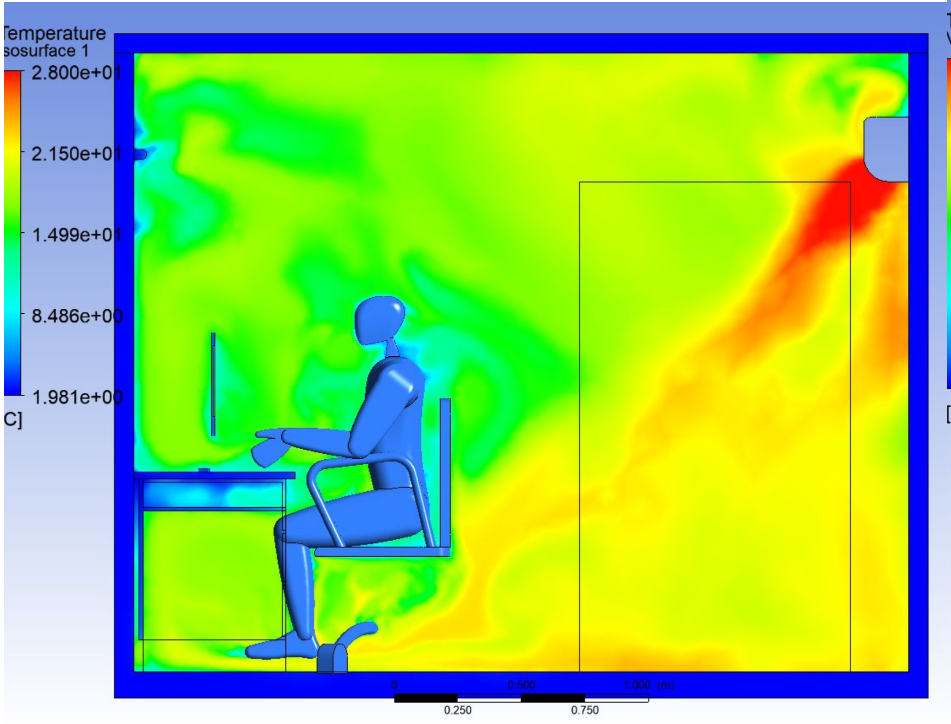


Room Air Temperature

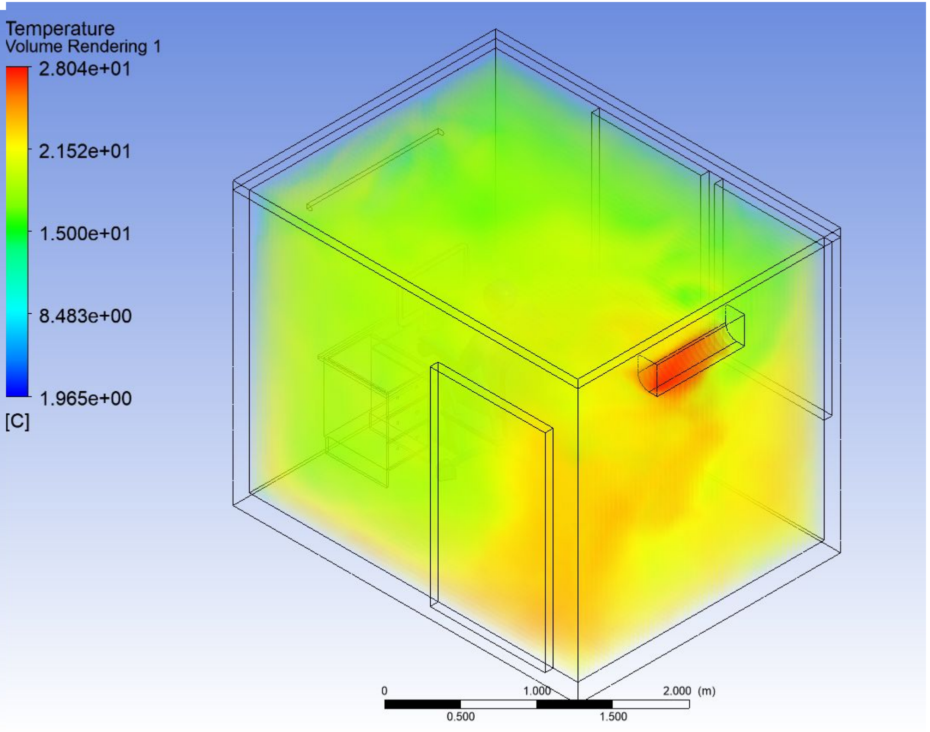


AC as heater

Temperature Contour Plot



Room Air Temperature

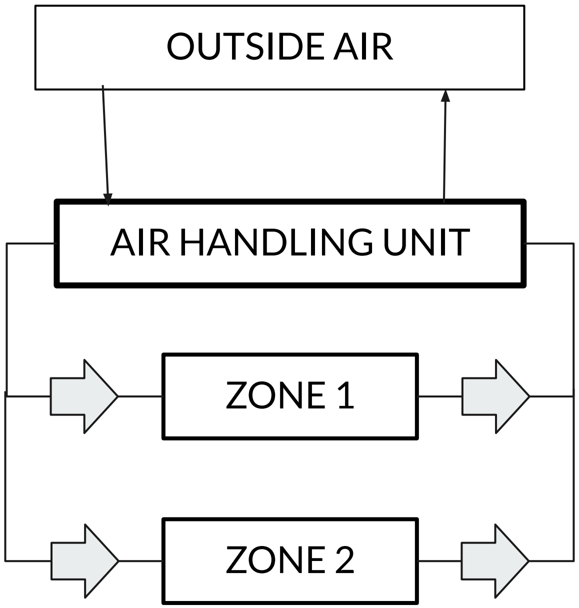


SYSTEM DESIGN

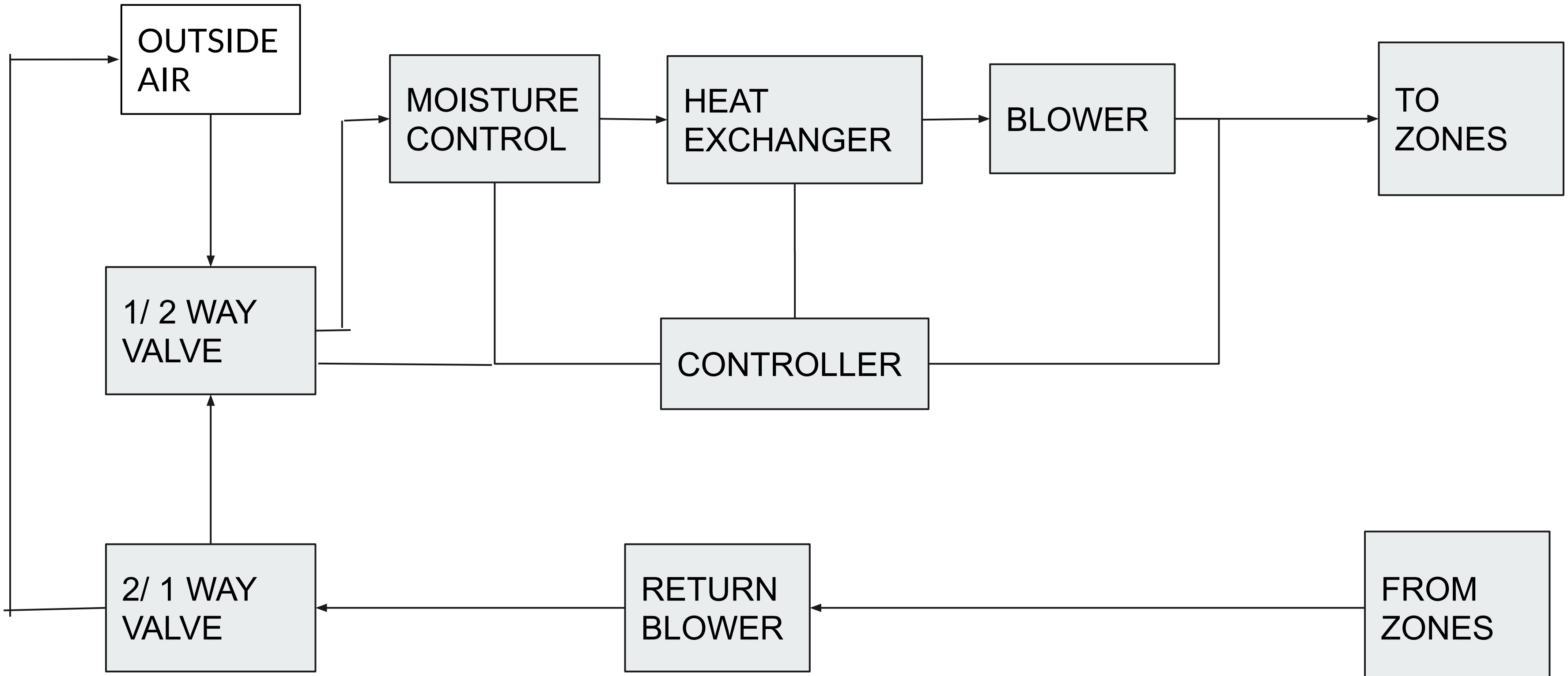
INTRODUCTION

The HVAC system consists of the AHU (Air Handling Unit) and the confined space to which conditioned air is delivered. By the thermal simulation of the space, it can be observed that different parts of the room have different thermal loads. Hence it is appropriate to divide the space into 2 ZONES with each zone demanding a specified flow rate, temperature and other parameters

An AHU is comprised of, among other components, a Moisture controller(MC), Heat Exchanger (HE), Blower (B), reheat coil (RH), return blower (RB), and dampers.

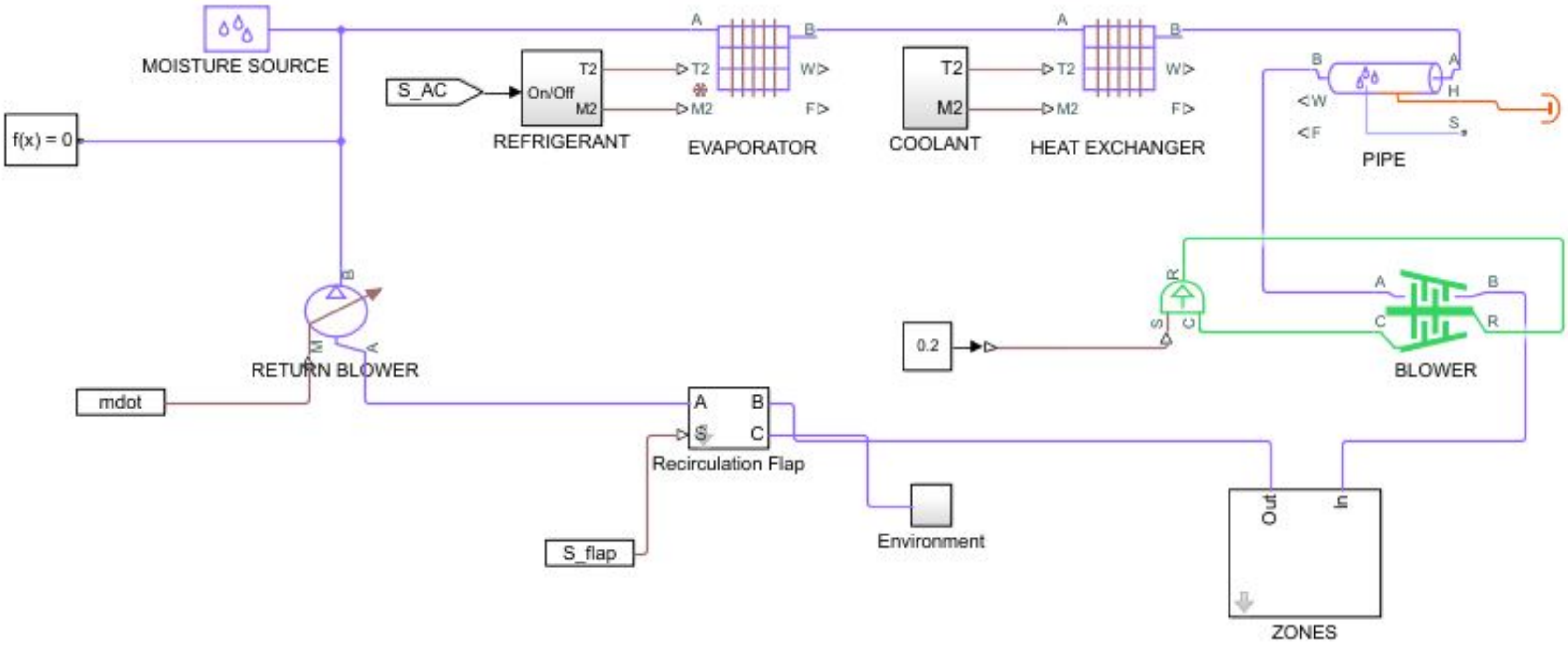


CIRCUIT DIAGRAM

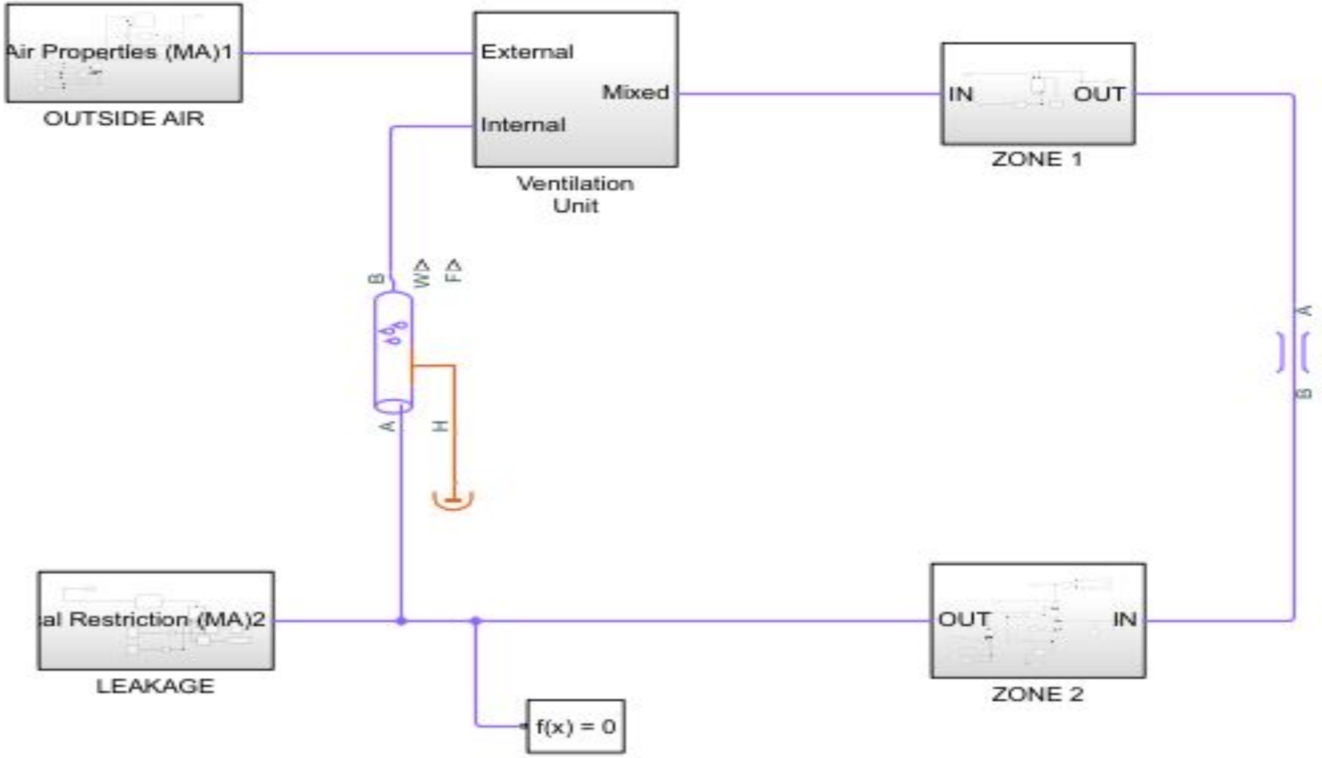


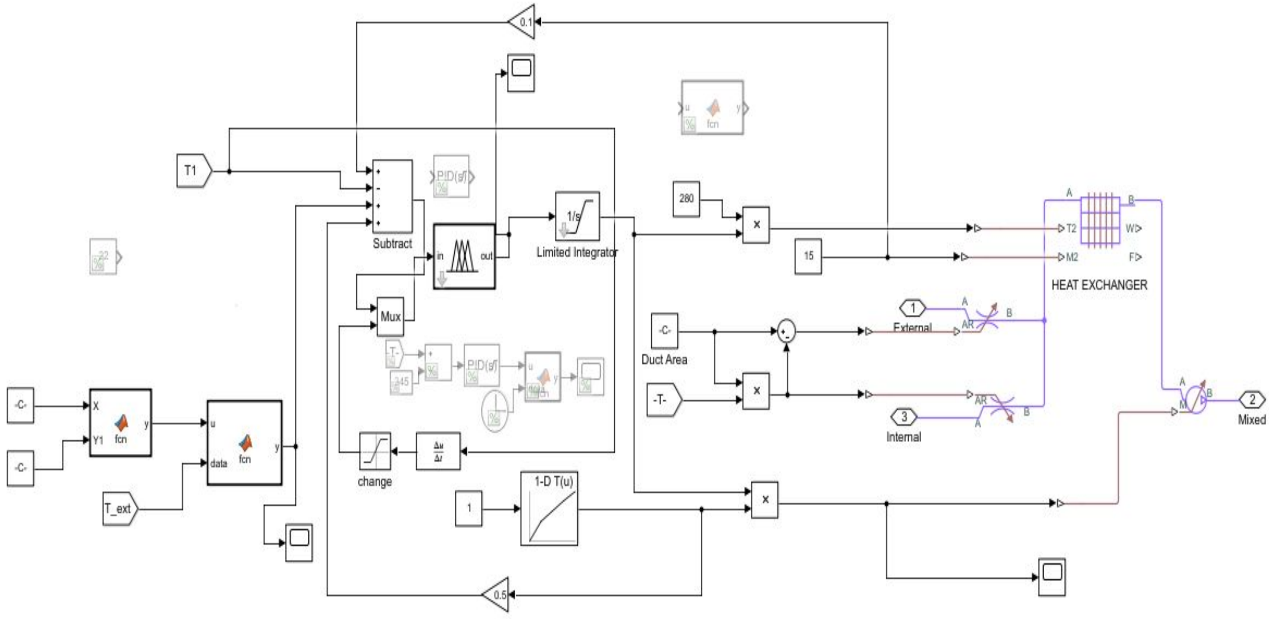
INSPIRED BY MODEL IN [7], [14]

SIMULINK MODEL - The Beginning

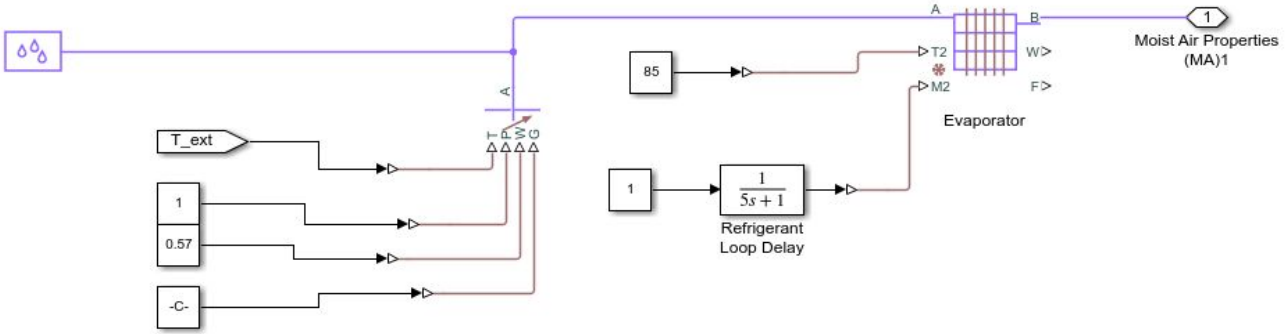


SIMULINK MODEL - Final version

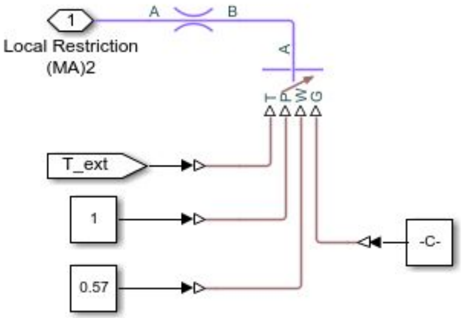




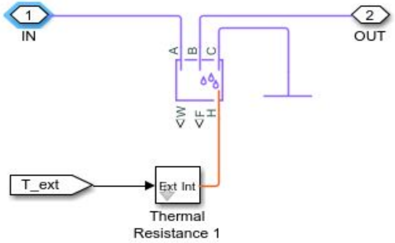
VENTILATION SYSTEM



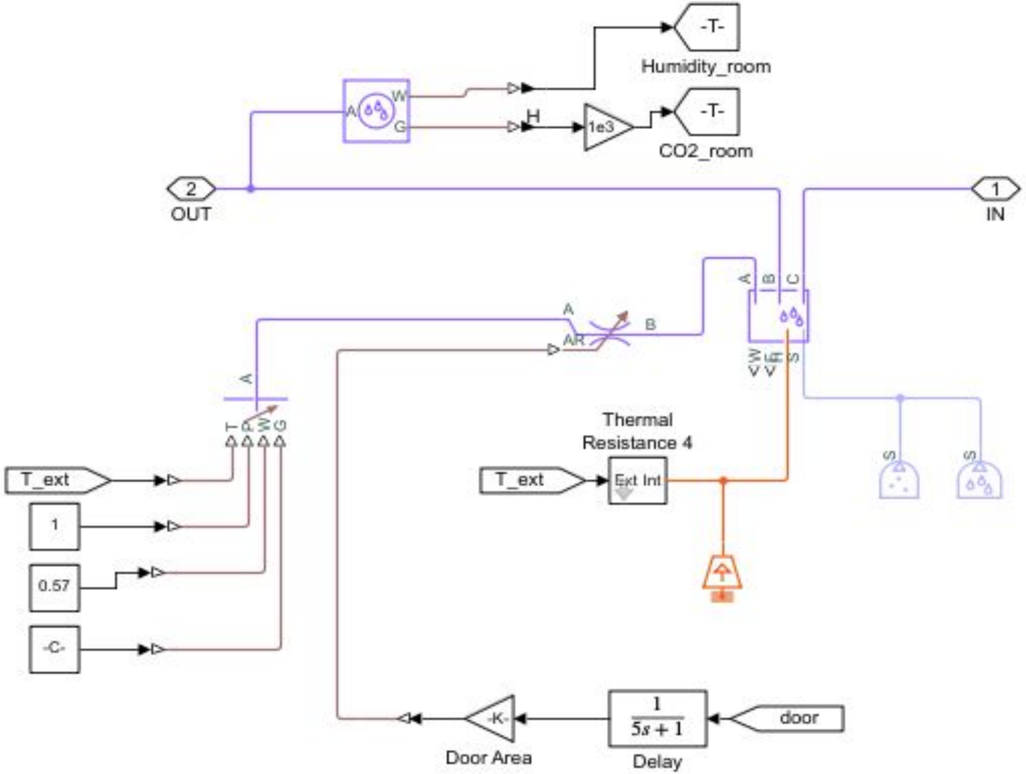
OUTSIDE AIR INLET



LEAKAGE



ZONE 2

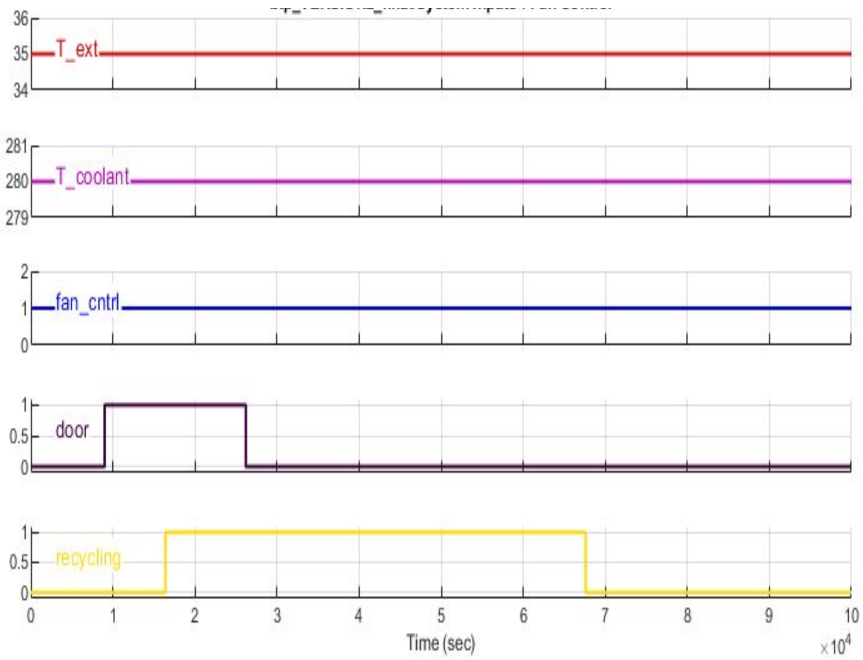


ZONE 1

SYSTEM INPUTS

Inputs to the system to control the temperature & CO_2 level are given in the form of -

1) External temperature
2) Coolant temperature
3) Coolant mass flow rate
4) Blower speed
5) Mass ratio of recirculated : fresh air
6) Door opening/ closing



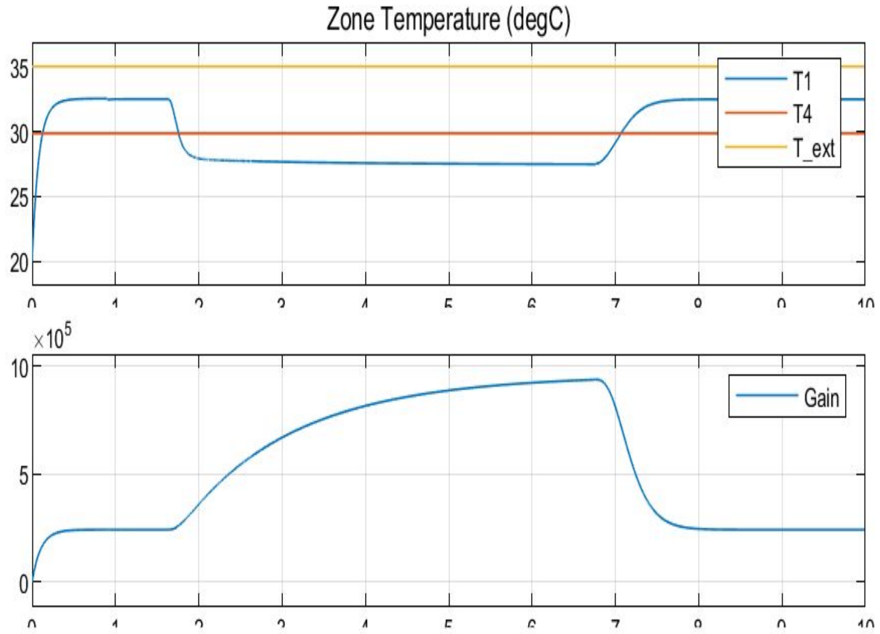
RESULTS

System's performance has been evaluated by using 2 parameters -

1) ROOM TEMPERATURE (ZONE 1)

2) ROOM CO2 LEVEL

Humidity & thermal comfort determined by PMV index are 2 important parameters that have been excluded



SYSTEM OPTIMIZATION

OPTIMIZING SET TEMPERATURE POINT

- Linear regression (machine learning) has been used to optimize set temperature point.
- The data set for the machine learning model has been taken from - ASHRAE Global Thermal Comfort Database - http://www.comfortdatabase.com/
- Out of wide range of options 5 parameters have been chosen to be the feature vector to predict the optimum temperature of the room, They are - Age, Gender, Height, weight & Outside temperature
- The model used is linear regression. It gives the optimum temperature as the output which becomes the input to the overall system

Age	Sex	Subject´s height (cm)	Subject´s weight (kg)	Outdoor air temperature (°C)	Air temperature with max comfort (°C)
58	1	173	70	34.8	27
24	0	165	65	34.3	27
35	1	165	75	33.8	27.6
44	1	168	79	33.8	26
44	1	168	63	33.3	26.5
18	0	152	45	17	23
17	0	155	58	17	24
19	0	163	52	18.2	18.9
18	0	170	65	17	21

OPTIMIZING SYSTEM PERFORMANCE

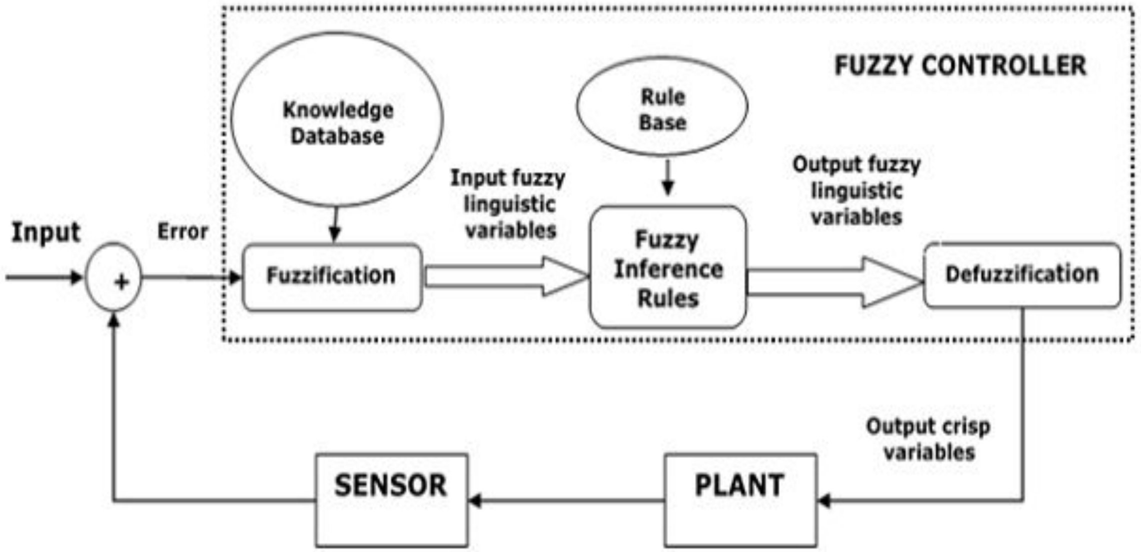
- PID & fuzzy logic control have been used to optimize the performance of the system by making it closed loop
- Error is calculated from desired parameter values and actual values and the inputs to the system are modified such that error is minimized

A PID controller is reliable and efficient. Its parameters require precise adjustment to obtain optimal performance, and they are heavily dependent on system parameters. The output of a PID is given by:

$$u(t) = k_{\mathrm{p}} e(t) + k_{\mathrm{i}} \int_{0}^{t} e(t) + k_{\mathrm{d}} \frac{\mathrm{d}e(t)}{\mathrm{d}t}$$

A fuzzy control system is a control system based on fuzzy logic—a system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1 based on IF-THEN type rules

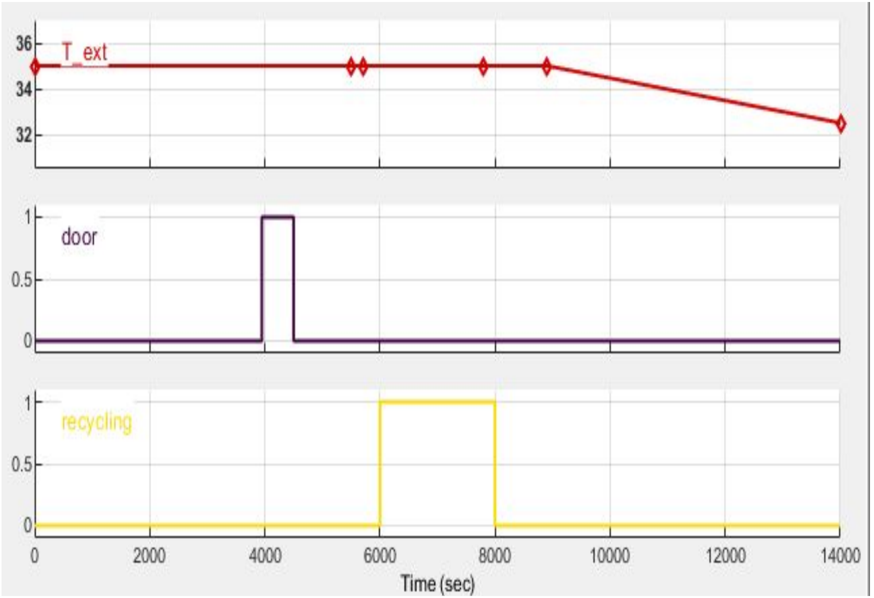
ARCHITECTURE OF A FUZZY CONTROLLER



SYSTEM INPUTS

Since the system works in closed loop the input parameters are -

1) External temperature
2) Consumer details - (age, sex, dimensions)
3) Coolant temperature
4) Mass ratio recirc : fresh air
5) Door open/ closed



OBJECTIVE FUNCTION

- The main aim is to improve the performance in terms of Room temperature, Room CO_2 level at the same time, optimize the energy consumption
- Room temperature is controlled by coolant flow rate, blower speed. (Coolant temperature can be included if precise control of temperature is possible). So the error control should be applied on these 2 elements. The ideal objective function would be the difference between desired & actual temperature
- Coolant flow rate & blower speed optimization results in decreased energy consumption

Hence the objective function would be

O = 1*(T- Ti) + 0.1* Coolant mass flow rate + 0.5 * Blower speed

To mass ratio of recycled air : fresh air (To optimise CO_2) : [FUTURE SCOPE]

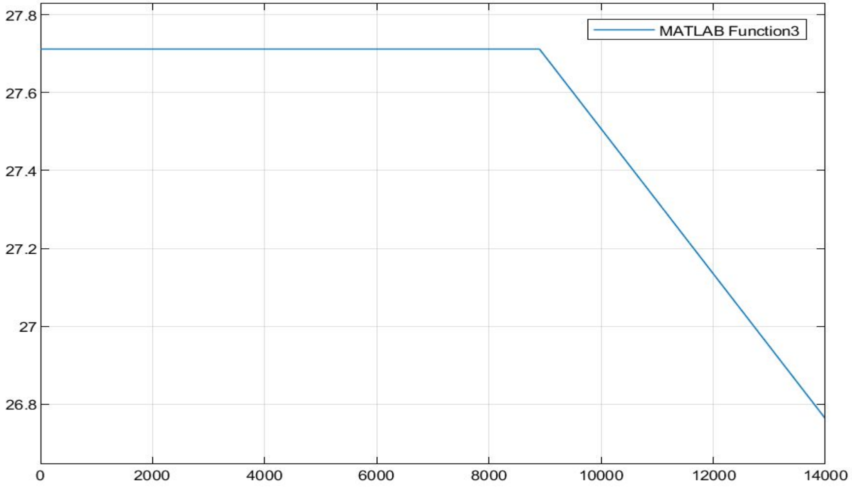
O = 1*(Desired C02 - Actual CO_2)

PERFORMANCE EVALUATION (PID VS FUZZY)

The ML Model has been trained on around 1500 samples.

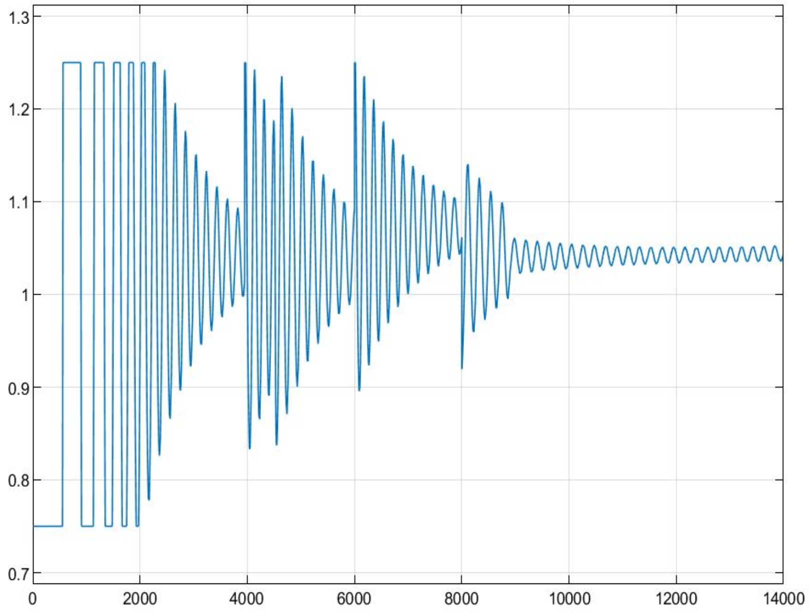
Input has been given as 21, Male, 181 metres tall and 72 kg weight.

It predicted the optimum temperature to be 27.7 degrees @35 deg outside temperature & 26.8 degrees @32.2 deg

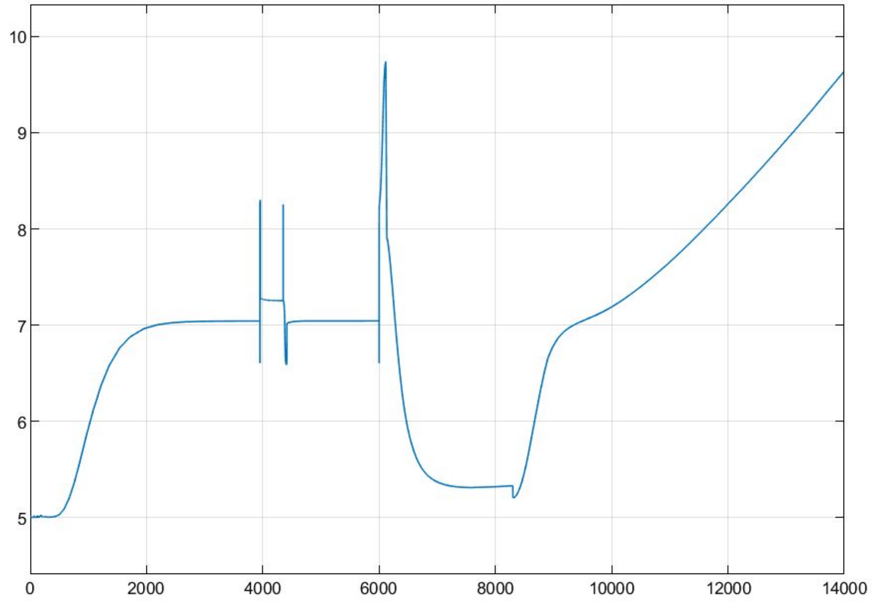


ERROR CONTROL

PID

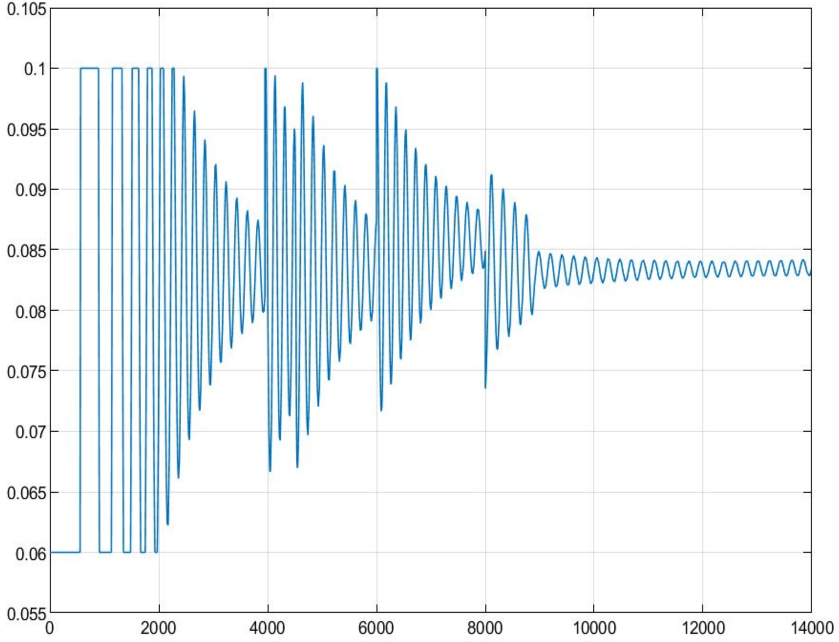


FUZZY LOGIC

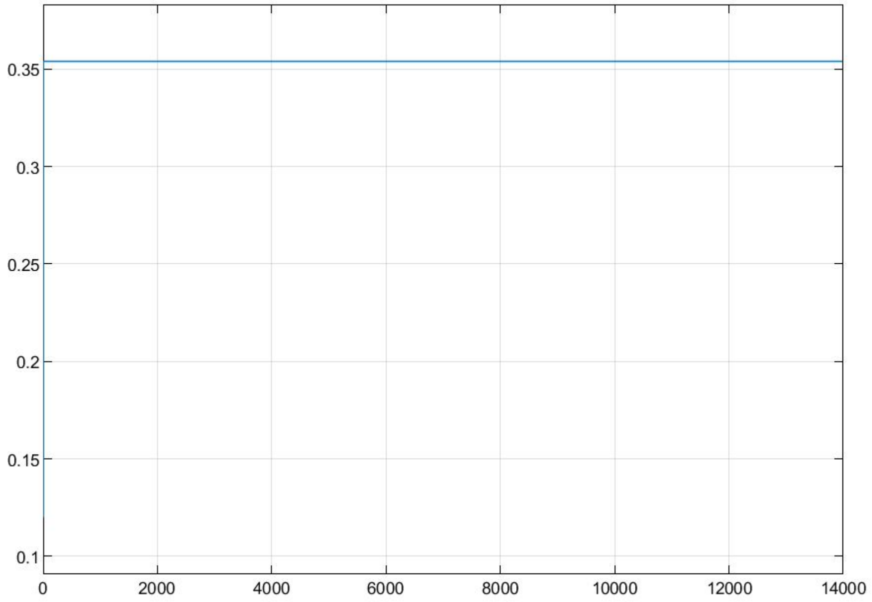


BLOWER SPEED & COOLANT FLOW RATE

PID

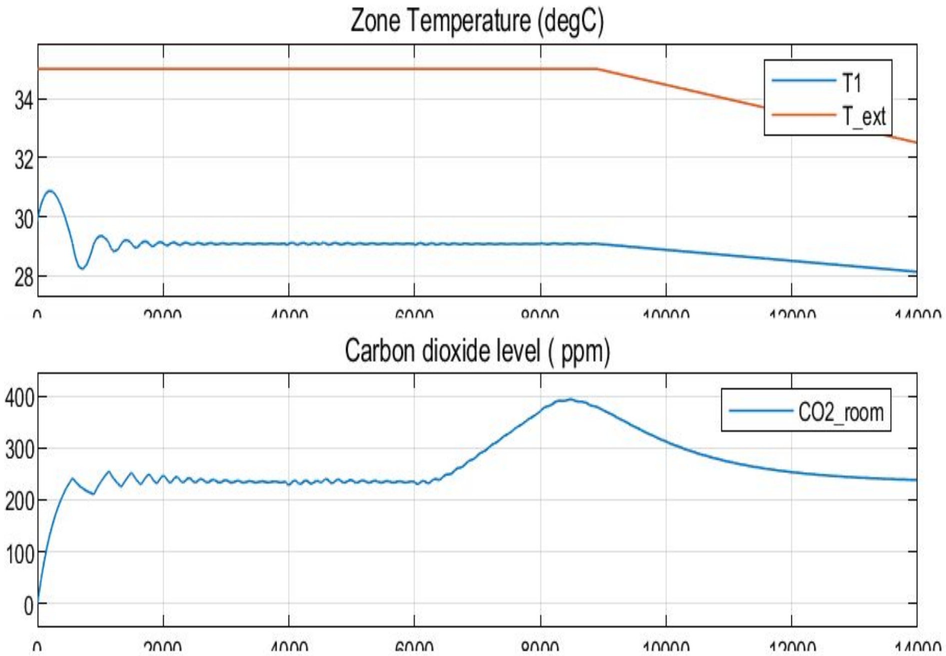


FUZZY LOGIC



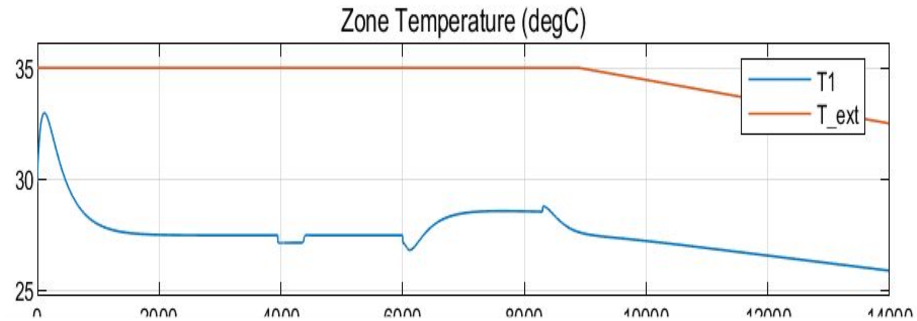
PARAMETERS (PID)

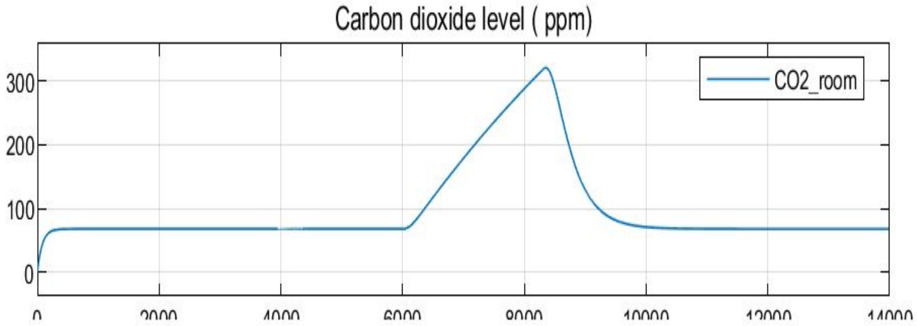
- Steady state temperature = 29.1 degC, 28 degC (For 27.7, 26.8)
- Steady state error = 1.4 deg C, 1.2 deg C
- Time taken to reach steady state = 1730 Sec = 28 mins approx
- Fluctuations due to door/ recycling = 0.05 deg C
- Steady state CO_2 = 235 ppm
- Peak CO_2 = 395 ppm

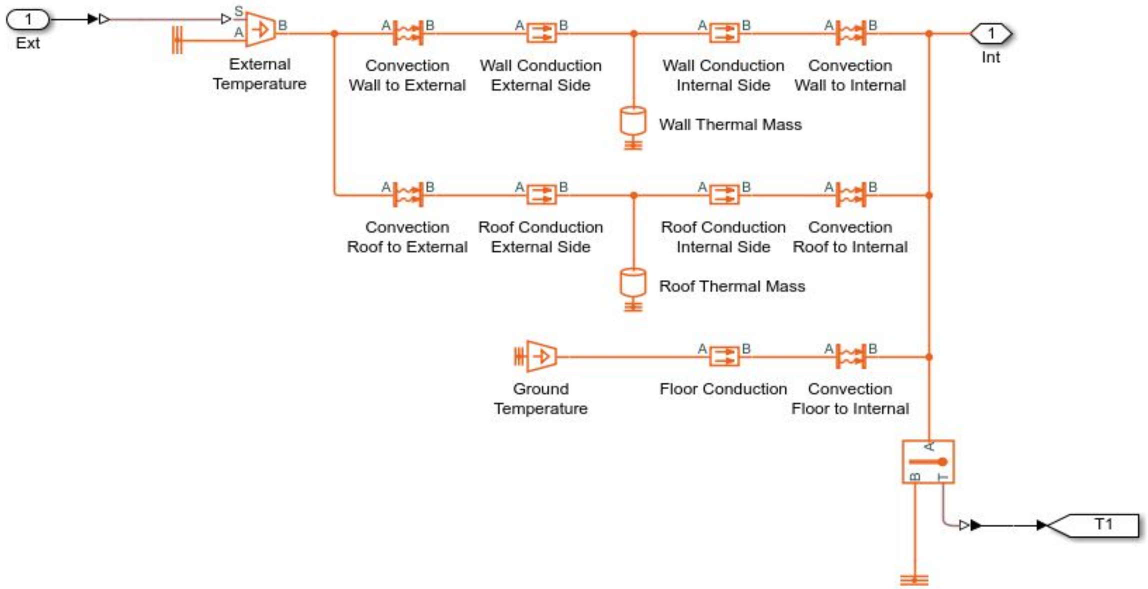


PARAMETERS (FUZZY)

- Steady state temperature = 27.6 degC, 26.3 degC (For 27.7, 26.8)
- Steady state error = 0.1 deg C, 0.5 deg C
- Time taken to reach steady state = 1510 Sec = 24 mins approx
- Fluctuations due to door/ recycling = 1.8 deg C
- Steady state CO_2 = 90 ppm
- Peak CO_2 = 302 ppm







1
Ext
S
A
B
External Temperature
Convection Wall to External
Wall Conduction External Side
Wall Conduction Internal Side
Convection Wall to Internal
1
Int
Wall Thermal Mass
Convection Roof to External
Roof Conduction External Side
Roof Conduction Internal Side
Convection Roof to Internal
Roof Thermal Mass
Ground Temperature
Floor Conduction
Convection Floor to Internal
T1

CONCLUSIONS

- While the thermal simulation gave appropriate results, Control results were not satisfactory due to the enormous number of parameters and more detailing that it requires.
- Arriving at optimal values of PID required hundreds of iterations which doesn’t make it ideal to work with
- While fuzzy logic control did not behave as expected it did not raise any errors of insolvability. It adapted according to situations. It is sensitive to changes
- Use of fuzzy logic is encouraged as it causes less damage to mechanical parts due to less fatigue

FUTURE SCOPE

- Temperature prediction could be made much better by using Deep learning & reinforcement learning techniques which would adapt to extreme situations very quickly
- Temperature prediction could be made dependent on real time features such as mass ratio of recirculated air, door opening, no of people in the room And also external features such as radiant, operative & global temperature, cloth insulation, comfort index like PMV
- Better implementation of fuzzy logic controller. Fuzzy logic could be used for more dynamic systems or be implemented with better rules and logics written especially for this system

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