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Optimization of Power Consumption in an Airconditioned System

Jonnagiri Sowmya[1], Govada Rambabu[2]

[1]*Senior lecturer at Govt. Polytechnic for Minority, Kurnool, Parttime PhD Scholar, Department of Mechanical Engineering, College of Engineering(A), Andhra University, Visakhapatnam, India, sowmya.jonnagiri@gmaili.com*
[2]*Associate Professor, Department of Mechanical Engineering, College of Engineering(A), Andhra University, Visakhapatnam, India.*

Heating, ventilation, and air-conditioning (HVAC) systems consume considerable amount of power in offices, control rooms including buildings. HVAC operations are under focus as a part of circular economy for reduction of power. hence prediction of power requirements is an important task to be considered, the various factors like occupancy and comfort is also to be considered, multi objective functions are considered. data is taken from a running AHU unit. ANN technique for prediction of boundary limits of objectives is applied. Multi objective optimization using Genetic Algorithm (GA) is applied for controlling the parameters for effective operation control of HVAC unit. There is a strong correlation between power consumption and PPD, productive loss observed.

Keywords: occupancy, thermal comfort, ANN, GA.

1. Introduction

The demand for power is rising due to population growth and industrialization. The International Power Agency (IPA)stated that one of the major consumer is office blocks, residential houses, offices for lighting, electrical machinery and indoor climate conditioning of HVAC purpose, oil, and natural gas are the major non-renewal power sources for power generation, Reda A.M., et al. [1]. Lot of concern is generated globally due to the scarce supply of fossil fuels and generations of greenhouse gas emission. Hence minimization of power consumption in user utilities could lessen greenhouse gas generation. resident comfort, office block maintenance, including air conditioning system design should be considered while minimizing power utilized.

The Main aim of this work is to developing an approach which considers optimization of several criteria's while simultaneous minimization of power consumed using artificial neural technique with multiple criteria

It is a prudent to maintain a better temperature comfort along with improved air quality within the volume considered with minimal power consumption. Hence with minimal power consumption by considering the comfort of inhabitants. Multi-objective HVAC design can be transferred into single objective function by suitable considering the weights of two objectives. The work proposed was a particle swarm optimization algorithm which is based on non-dominated sorting-based G.A. using Kriging technique for achieving optimality of the design of the HVAC system. 40% and 50.0% of power consumption is spent towards in the office and domestic buildings, by Poel, B., et al. [2], Balaras, C., et al. [3].

Occupants of residential buildings generally set their required temperature targets as the thermostat setting features are available to them. Whenever new persons enter the building ,the occupants who were present there feel discomfort as the dynamic occupancy patterns do not commensurate with the original target schedule, Lu, J., et al. [5]. Single zone of thermal area is observed in residential area, Guo, W. and M. Zhou [6], if occupants stagger at one place, which results into unnecessary conditioning of unoccupied space.

From the previous studies it is noticed that a meaningful effort can be made to synthesize characteristics numerically and qualitatively to increase the comfort of the inhabitants in terms of thermal parameters. It is also interesting to show the performance for thermal comfort improvement .

2. Literature Review

The work which was done by earlier researchers in the area of HVAC systems existing articles is presented in Table-1. Chen, et al. [7] and Mulia, et al. [8] have reviewed ventilation systems for conservation of power studies on identification of occupancy and counting of heads but not covered issues like (1) various detecting technologies in consideration of temperature, air flow etc., (2) analyzing performance variations of sensing technology (3) interaction of occupancy models and (4)benchmarking comparisons. Fig. 1 illustrates the saving potential by HVAC operation. GUO, et al. [9] dealt on the technologies available for the thermal comfort of occupants in HVAC systems. Chua, et al.[10] reviewed the strategies available for achieving power efficient air conditioning systems. Yang, et al. [11] reviewed the power consumption implication towards comfort, Antoniadou, et al. [18] also studied the same. D’oca, et al. [19] reviewed human dimensions for power consumption Kwong, et al. [12] developed model for assessment of thermal comfort and for power efficiency. Rupp, etal. [14] reviewed papers on human thermal comfort and concluded it plays a vital role. Mirakhorli, et al. [13] reviewed occupancy behavior model and suggested a predictive control for building indoor climate. Balvedi, et al, [20], Happle, et al. [22] and Zhang, et al. [23] reviewed only occupants behavior. Yan, etal. [15] suggested simulative model. Ortiz, et al. [16] expressed the future challenges towards occupant behavior modelling. Mulia, et al. [17] and Chen, et al.[21] studied building occupancy assessment for assessing the performance of HVAC system. Guyot, et al. [24] developed smart ventilation model for energy optimization

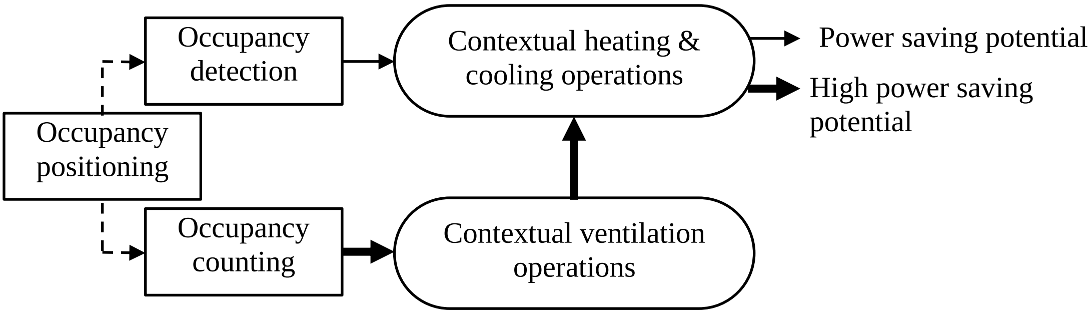

Figure 1. HVAC operations

Table 1. Articles reviewed

Authors	Year	Content	Area
Reda, A.M., et al.[1]	2016	Design of solar HVAC system	Buildings
Poel, B., et al. [2]	2006	Model for energy calculation and savings	Building
Balaras, C. et al. [3]	2007	Performance model for evaluating of energy spent	Buildings
Ren Lina, et al. [4]	2009	Forecasting of power consumed using ANN	Power systems
Lu, J., et al. [5]	2010	Based occupancy and sleep patterns ,models developed to save energy	Buildings
Guo, W. and M. Zhou [6]	2009	Different technologies for HVAC power savings - review	Buildings
Chen, Z., et al. [7]	2018	Application of different sensors for detection of occupancy-a review	Buildings
Mulia, M.T., et al., [8]	2017	Occupancy estimation using neural networks	Indoor of buildings
Guo and Zhou [9]	2009	HVAC activities using fuzzy systems utilizing neural networks	Office, business buildings including and domestic accommodation
Chua, et al. [10]	2013	New cooling systems including functioning methods	Office, business buildings including and domestic accommodation
Yana, et al. [11]	2014	Inhabitant environmental comfort	Office, business buildings including and domestic accommodation
Kwong, et al. [12]	2014	Power conservation	Non domestic and domestic systems
Mirakhorli and Dona [13]	2015	Predictive c model controller HVAC operations.	Research utility
Rupp, et al. [14]	2015	Review paper on comfort standards	Office, school
Yan, et al. [15]	2015	Power simulation including monitoring,	Office, business buildings including and residential accommodation
Ortiz, et al. [16]	2017	Ergonomics and human thermal comfort	Office, business buildings including and domestic accommodation
Mulia, et al. [17]	2017	Residents identification	Non domestic and domestic utilities
Antoniadou and Papadopoulos [18]	2017	Numerical and qualitative non numerical techniques for characterization assessment of inhabitants' relaxation	Non domestic utility
D'Oca, et al.19]	2018	Power consumption of each stakeholder in the utility	Office, business buildings including and domestic accommodation
Balvedi, et al. [20]	2018	Simulating power consumption performance.	Office, business buildings including and residential accommodation
Chen, et al. [21]	2018	Residents identification	Office, business buildings including and domestic accommodation
Happle, et al. [22]	2018	Modeling of behavior of the Residents	Office, business buildings including and domestic accommodation
Zhang, et al. [23]	2018	Power-conservation possibilities	Office, business buildings including and domestic l accommodation

Authors	Year	Content	Area
Guyot, et al. [24]	2018	System which is modeling on ventilation dependent on demand	Office, business buildings including and domestic accommodation
Page, J., et al. [25]	2008	Markov model application for simulating presence of occupants	Building
Duarte, C., et al. [26]	2013	Energy calculation by simulation and application of sensors	Building
Kosonen, R. and F. Tan [27]	2004	Computation of productivity loss	Buildings
Qureshi, O.A., et al.[29]	2023	Energy quantitative assessment by quantitative method of HVAC	Buildings
Timotius, et al.[30]	2022	Energy reduction in chilled water plant of HVAC system	Building

HVAC performance depends on testbed factors, the performance is computed based on identification of sensing data, modeling, prediction of the data collected by survey or measurement. The performance depends on type of building, office, factory, etc., the modality depends on type of occupancy driven and comfort.

- HVAC performance depends on human presence for Adjusting target point and target back temperatures based on occupancy of spaces and their number. For adjusting ventilation load and position for providing personalized comfort areas across different spaces.

The individual comfort in terms of temperature and group requirement. The various factors of interest for accessing are whether, any human movements are involved, ambient variation., communication network and electrical appliances etc., the other factors which influence are cloth insulation, human physical activities and physiological processes. The criticality of human beings dynamics enhances with bigger tests, machine-learning methods were applied earlier with a view of conserving power (e.g., Page et al. [25] and Duarte et al. [26]). Strategy for Continuous air conditioning based on setting room parameters by monitoring occupants arrival or otherwise by proactively with predictive approach. Fig. 2 gives a glimpse on a layout of HVAC operation methodology

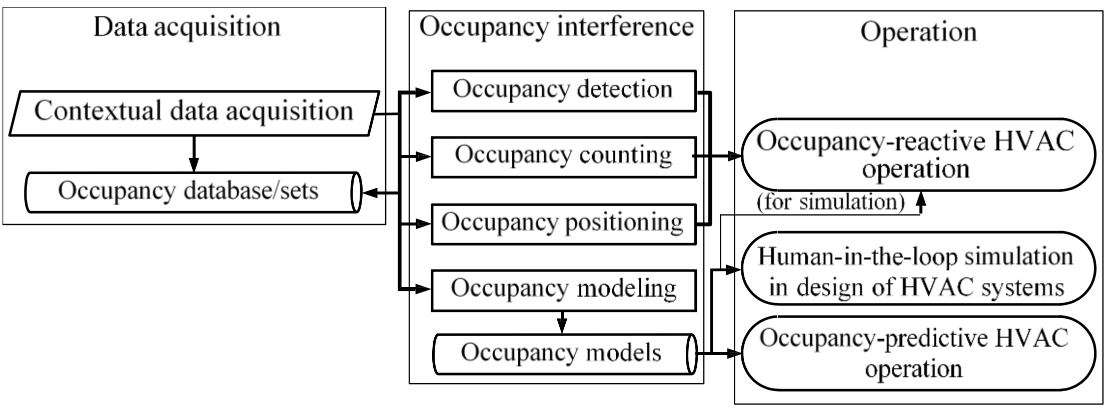

Figure 2. A layout of HVAC operation methodology

The power minimization of have the issues to be taken into consideration (1) bank on inhabitants activities, (2) value from inhabitants expressions which is thermal in nature (3) extent of fluctuations in surrounding parameters influenced due to the existence of occupant,

(4) inhabitants electronic devices like remotes and cell phones, and (5) depends on inhabitant-environment interfaces activities, capacity, and coefficient of performance (COP), as well as the monitored indoor temperature, relative humidity, and CO_2 levels for assessment of energy by authors A.O. Qureshi, et al.[29], they have not considered other factors. Timotius et al. [30] has applied dynamic optimization technique in energy reduction of chilled water pump in HVAC system by considering a sole object for conserving energy with ANN and GA technique.

A gap is found in considering the combined optimization of objectives such as power minimization, PPD and productivity loss, Combination of occupancy percentage and parameters of operation controls and environment parameters are also combinedly considered in this work.

3. THE OBJECTIVES CONSIDERED FOR THIS WORK

For this research work the trade-offs between targets of different nature are computed and are as follows (a) power consumption, (b) comfort which is thermal in nature, and (c) productivity loss .

Power consumption

The power consumed is computed directly An ANNual simulation accounted for entire requirements of cooling are simulated for ANNual and aggregated to total power consumed, stated in megawatt-hours (MWh).

Thermal comfort

The thermal comfort is measured by 2 metricest. It consists of the following two components:

a) The Mean vote which is predicted (PMV), and

b) The proportion of people who are dissatisfied is being Predicted (PPD), using with Fanger's model [28].

Productivity loss

The equation to measure the above stated parameter is by using the equation developed by Kosonen and Tan [27]:

$$\text{Productivity loss}(\%) = 13.366 * \log(xx) - 14.895 \quad (1)$$

where xx is the average ANNual PPD index.

The consumption of normalized root- mean-square deviation (NRMSD) is defined by the following equation:

$$NRMSD = \frac{\sqrt{\frac{\sum_{t=1}^{T}(n_t - n_t)^2}{T}}}{n_{\max} - n_{\min}} \quad (2)$$

n_t is the expected number of inhabitants at a time t, nt is the actual number of inhabitants at a time t, nmax and nmin are representing the maximum and minimum number of people in the system considered.

Power-saving potential

Table 2 explains different rationale for power conservation. the objectives are considered taking this into account.

Table 2. Rationale behind each feature

Feature	Rationales
Patterns of occupancy	• Power savings is correlated with habitation
Ambience	• outdoor temperature and target point temperatures influences power-conserving
Building shape	• Poor insulation decreases· potential for power conservings • Higher number of thermal zones influence potentials for power conservings
Operation	• Power conservings from a brief period of non-occupancies are marginalized by recovery conditioning loads

Table 2.1. Relevant data to be considered for HVAC system

Factors	Metric
Contextual data	
Building	• Number of thermal areas • Dimensions Age and factors like insulation, windows, etc.
Temporary information	• Time of operation
Occupant data	
Occupancy	• Fractional occupancy
Com ton	• Inhabitants' thermal choice
Operation data	
Evaluation technique	• Simulation
Policy considered for Operation	• Identification and counting of occupancy, occupancy-reactive or proactive, relaxing and recovery time
Performance analysis	
Power consumption	• Absolute Power-consumption value of the baseline and occupancy-driven operation dynamic levels • Power-conserving values say .25% of conserving)

Methodology adopted

1. Applying ANN techniques to find out the correlation among objectives and for predicting the objective values for a given input values.

2. Finding the maximum and minimum objective function values for a given parameters.

3. Applying multi-objective technique using GA and finding better parameters for controlling the HVAC.

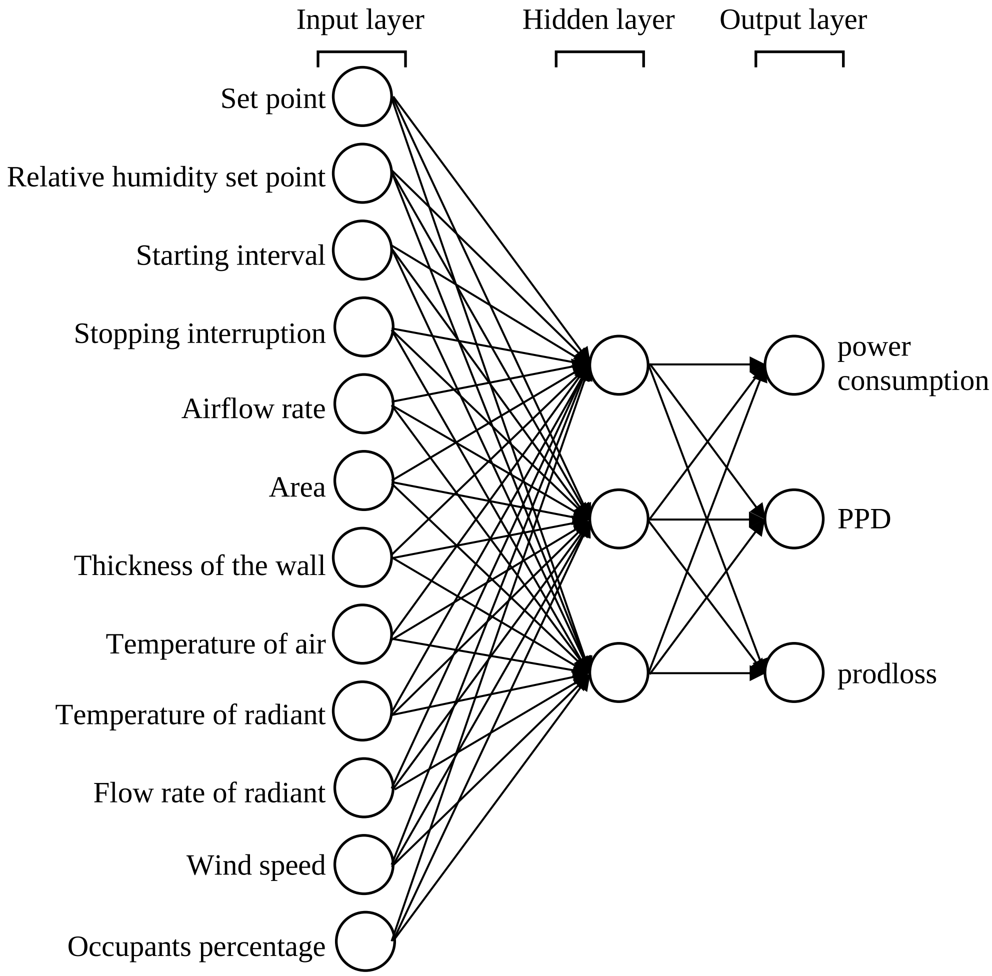

Figure 3. ANN-Multilayer perception network

Fig. 3 ANN model with parameters.

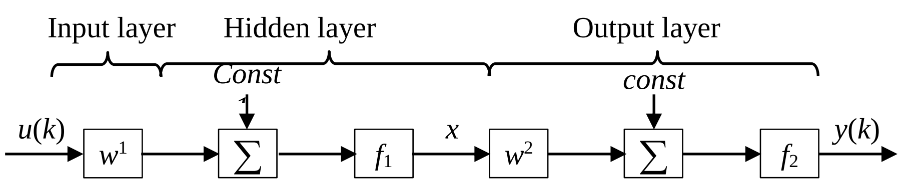

Figure 4. ANN model input-output flow

ANN modeling

For determining the performance of HVAC system, the key parameter considered are temperature set point, humidity, starting time set, interruption interval, air flow rate, area of openings wall thickness, air temperature, radiant temperature, flowrate, wind speed etc., it is designed for 12 inputs and 3 outputs. Figs.3 and 4 illustrates the ANN model adopted.

The correlation between the input u(k) and output y(k) in the MLP network,

$$y(k) = f_2(w^{2*}x(k) + const2 \tag{3}$$

$$x(k) = f_1(w^{1*}u(k) + const1 \tag{4}$$

Here the value of the x(k) represents the vector related to the output from the hidden layer. Then $f_1(.)$ represents the transfer function which is between hidden layer to the output layer, and the value of w^2represents the weight which is between hidden layer to the output layer and similarly Then $f_2(.)$ represents the transfer function which is between input layer to the hidden layer, and the value of w^2represents the weight which is between input layer to the hidden layer. The values of $const1_1$ and $const2b_2$demonstrate bias numbers, Ren Lina, et al. [4].

$$f(z) = \frac{(1-e^{-2s})}{(1+e^{-2s})} \tag{5}$$

of $z = f(\Sigma w_i, x_i)$.

The prediction accuracy is evaluated using the equation below:

$$RMSE = \sqrt{\frac{1}{p}\sum_j \left|t_j - o_j\right|^2} \tag{6}$$

where the data points are represented by p, the target is denoted by t_j, output value is denoted by o_j respectively.

The finding indicates that data points 250 and 150 are exhibiting same accuracy.

Multi Objective Optimization

The process of optimization applied in this work is presented in Fig 6. The combination of data targets that represent 300 different points are created. Simulation is carried for each parameter for 15 min. in ANN.

The data and the flow chart of model is described in Table-3 and Fig. 5.

Table 3. Data range

Decision variables	Range	Unit
Target	22-28	°C
Target	40-65	%
Initial interruption	0-32	min
Endpoint	0-62	min
Inlet air flow rate	140-225	cm^3/sec
Wind speed	4-11	m/se
Area	7-15	m^2
Thickness of wall	0.05-0.26	M

Air temperature	14-20	°C
Radiant temperature	14.8-18.5	°C
Radiant systems rate of flow	0.2-0.5	cm^3/sec

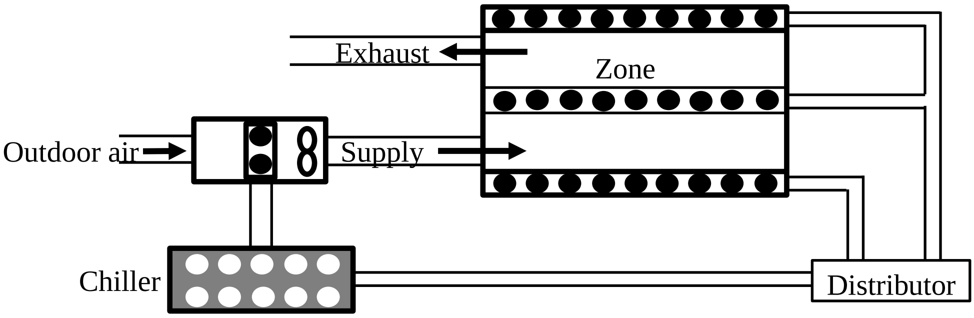

Figure 5. Diagram of cooling system

A multi-objective problem as follows:

Find $\quad y = (y_s) \quad \forall s=1,2,3....N_{par} \quad (7)$

Minimize or maximize $-/(x) \quad \forall z = 1.2,3....N_{obj} \quad (8)$

$$k_j(y) = 0 \quad \forall bj = 1.2,3....m \quad (9)$$

$$l_k(y) = 0 \quad \forall c = 1.23,....n \quad (10)$$

Here the decision variable vectors are indicated by s, is number of decision variables are represented by N_{par}, objective function is presented by $f_i(x)$, number of objective functions are indicated by N_{obj} And finally the .constraints which indicate equality and inequality are represented by $g_j(x)$ and $h_k(x)$, whereas the constraints itself are indicated by m and n.

Multi objective formulation

Here the average ANNual PPD index of the building is indicated by x

$$MinZ_1(X) = PowerConsumption(X) \quad (11)$$

$$MinZ_2(X) = PPD(X) \quad (12)$$

$$MinZ_3(X) = prodloss(X) \quad (13)$$

Subject to, $\quad min \leq x_i \leq max \quad$ for i = 1,2,…,12 $\quad (14)$

The model adopted for controlling the HVAC is illustrated in Fig. 6, multi objective problem is solved using genetic algorithm as per Fig. 7.

Objective considered:

To minimize multiple objectives, we would like then to minimize the following function where w1, w2, and w3 are the weights for the different objectives and sum of w1, w2, w3 is 1

$$F = (w1 * (Z_1(X) - Z_1min)/(Z_1max - Z_1min)) + (w2 * (Z_2(X) - Z_2min)$$
$$/(Z_2max - Z_2min)) + (w3 * (Z_3(X) - Z_3min)/(Z_3max - Z_3min)) \quad (15)$$

where Z_1min minimum energy value achieved from the parameters; $Z_{1\,max}$ maximum energy value achieved from the parameters. Z_2min minimum PPD achieved from the parameters; Z_{2max} maximum PPD value achieved from the parameters Z_3min minimum prodloss achieved from the parameters; $Z_{3\,max}$ maximum prodloss achieved from the parameters.

Fitness function:

Minimizing is then equivalent to maximizing the following fitness function in our GA:

$$Fitness = maximize 1/F \tag{16}$$

Chromosome:

The chromosome is demonstrated in Table 4.

Table-4: Chromosome

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12

The population size, the number of generations, single point cross over considered, the crossover possibility, mutation probability and the total number of evaluations are set to be 40, 60, 0.85, 0.2 and 1500 respectively. The chromosome considered for parameters illustrated above.

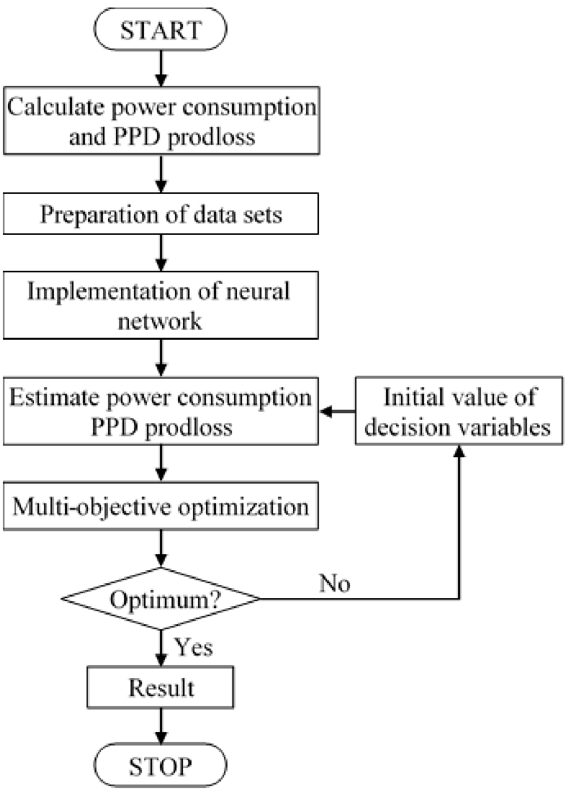

Figure 6. Model for controlling the HVAC

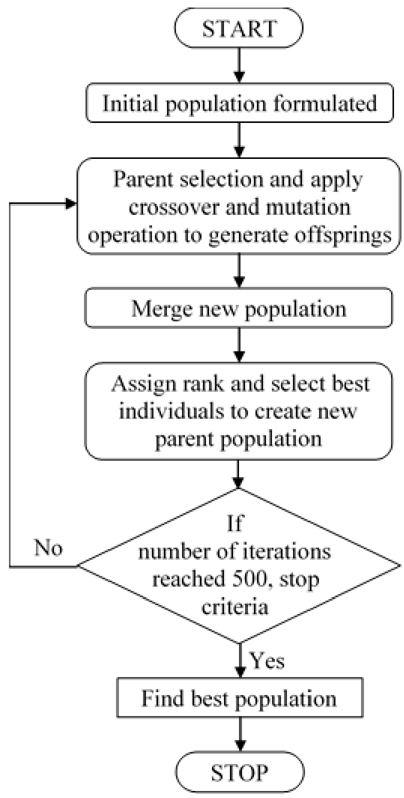

Figure 7. Flowchart of genetic algorithm

Table 5. Results

Parameters	Case a	Case b	Case c
Target point	23.11	23.11	23.11
Target point	42.9	41.58	42.17
Starting interruption	0.95	0.7	0.91
End point	1.07	1.08	0.97
Supply air flow rate	185	155.5	183.8
Wind speed	7.17	6.95	7.05
Area	0.25	0.25	0.25
Wall thickness	15.2	16.4	14.3
Air temperature	15.68	15.21	15.55
Radiant temperature	0.3	0.4	0.35
Flow rate (radiant system)	8.17	14	11.14
Occupants percentage	80	65	75
PPD			
Power consumption	7.48	4.5	6.12
prodloss	9	15	10

4. RESULTS AND DISCUSSION

Interaction among objectives

From the results it is evident when power consumption increases ,the productivity loss and PPD decreases. Hence a tradeoff is required at the time of operation control. Using ANN Figs. 8,9,10,11,12,13shows the ANN results and shows strong correlation between PPD and power consumption. Table-5shows the results for different cases with when different parameters exist.

The impact of temperature of supply air temperature and its flow rate

The simulation pattern representing the impact of flow rate of supply air and temperature of supply air on ANNual power which is consumed and also it affected in the utilization of PPD. The fluctuations in flow rate of supply air and the fluctuations in temperature of supply air can affect heat removal and ANNual power consumption. The thermal comfort and productivity are positively correlated with a non-linear pattern

In Fig.15temperature of air which is supplied is changed from 14 °C to 24 °C while keeping the remaining parameters are kept at fixed. The increase in the temperature of supply air reduces the power consumption from chiller to main the building temperature. The working load of the system which is maintaining the chiller is based on the difference of temperature between ambient and supply air. Hence, the variation in PPD depends on the temperature of supply air. Similarly, the flow rate of the supply air also effects the changes in PPD and in power consumption. Fig. represents that variation of the supply air flow rate is from

158Cm^3/sec to 200 Cm^3/sec, The power used by the fan for circulation of the air in the system is not exceeding the entire power consumed by the HVAC system.

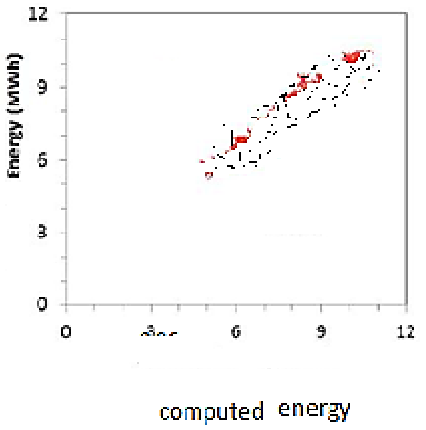

Figure 8. Training data power calculated and predicted (RMSE 0.28,$R^2$0.943)

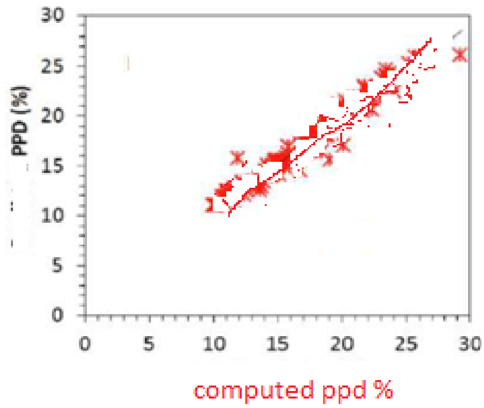

Figure 9. Training PPD calculated and predicted (RMSE 0.9,$R^2$0.94)

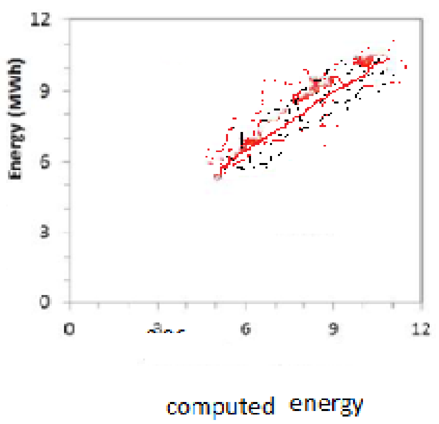

Fig. 10: Validation power calculated and predicted (RMSE 1,$R^2$0.93)

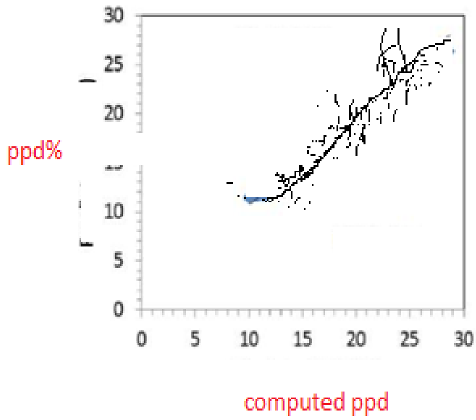

Fig. 11: Validation PPD calculated and Predicted (RMSE 4,$R^2$0.92)

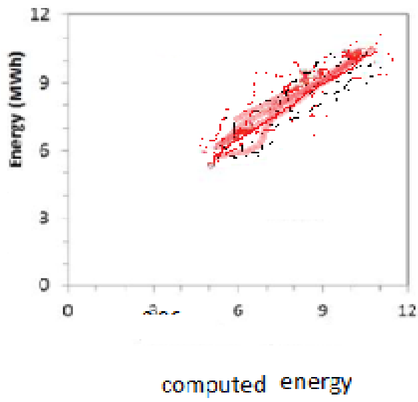

Fig. 12: Total data power calculated and predicted (RMSE 0.3,$R^2$0.94)

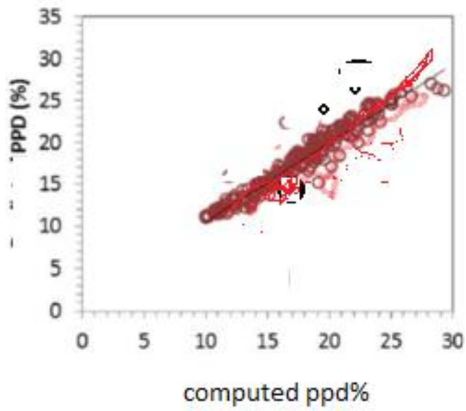

Fig. 13: Total data PPD calculated and Predicted (RMSE 1,$R^2$0.93)

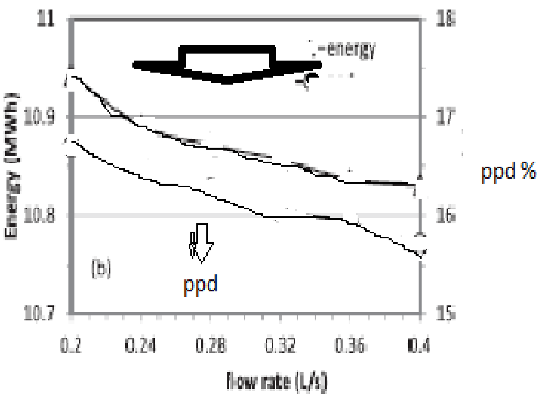

Fig. 14: Radiant temperature power and PPD versus set point

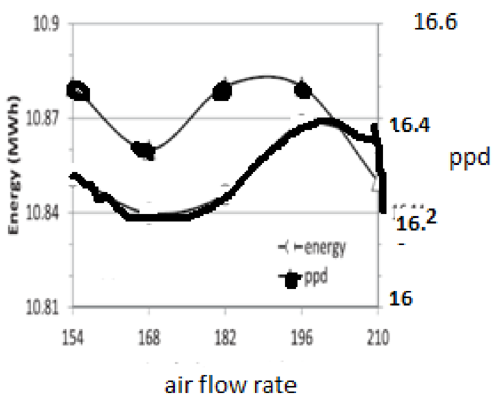

Fig. 15: Air flow rate versus power and PPD

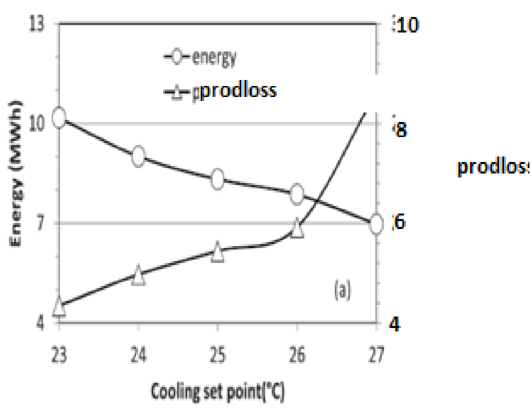

Fig. 16: Cooling setpoint versus prodloss

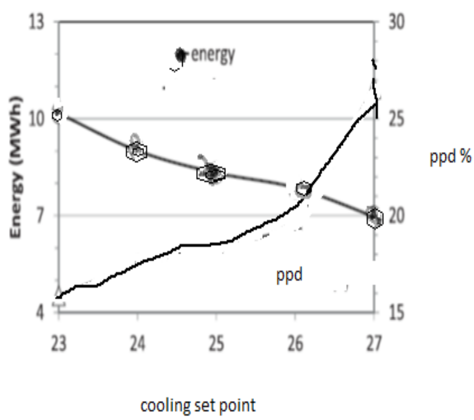

Fig. 17: Cooling set point versus PPD power consumption

The impact of air temperature and flow rate of supply air

The Fig. 14 indicates the simulation outcomes of the radiant temperature and the flow rate of supply air on the ANNual power consumed and on the spent PPD. Here the radiant temperature and flow rate parameters of supply air are varied while keeping remaining factors at a fixed value to indicate the impact of these two factors on power consumed and on the consumed PPD. The radiant temperature of supply air is varied from 17°C to 21 °C and the flow rate of supply air is varied from 0.25Cm^3/sec to 0.39^3/sec.. The increase in the radiant temperature of supply air resulted in utilization of more power usage and similarly it also resulted in increase in the consumed value of PPD. Variation of the supply air flow rate is from 158 cm^3/sec to 200 cm^3/sec, the power consumed by the fan for air circulation in the system is not exceeding the total power consumption of the HVAC system.

Effect of cooling and Rh target point

Figs.16 and 17 demonstrates the effect of cooling on power consumption and prod loss PPD. By varying the above factor resulted a changes in power consumption and PPD. The cooling parameter is gradually changed from 24 °C to29 °C and while keeping the other variables are to be constant at their best values. Further The value of Humidity is gradually changed from 42% to 89%. The increase in the temperature of cooling air and in increase in the value of humidity resulted in reduced power consumption is also observed. The lesser the difference between ambient condition and the cooling temperature and humidity resulted in reduction of power consumption in the system.

Table-6: Comparison between present and proposed system

Description	Energy consumption	PPD	Productivity loss
Proposed system (a)	7.48	8.17	9
Existing system(b)	8	9	10
Percentage = 100 * (b-a)/8	6.5(improvement in saving)	9.22 (decrease in dissatisfaction)	10 (decrease in productivity loss

5. CONCLUSION

Simulated to evaluate ANNual power consumed by the cooling system and the performance of the thermal comfort using PPD value. Table 6 shows comparison between present and proposed system. There is a saving of approximately 6.5 percent of energy along with decrease in dissatisfaction levels

The formulated Artificial Neural Network design indicates an accurate prediction in the phase of the training and the value of the RMSE of 0.34for power usage and its value is 1 for production loss and PPD. respectively. As per the optimization with multi-objective nature has resulted a phenomenal growth in the performance of HVAC and it provides a better r thermal comfort, at the same it resulted in lower power usage when compared to non-optimized condition.

FUTURE SCOPE OF STUDY

As a future scope cost of retro fitting along with more extreme weather conditions while using advanced software's like python.

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