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OPTIMIZATION THERMAL COMFORT IN RESIDENTIAL BUILDINGS USING NON-TRADITIONAL OPTIMIZATION

S. Elizabeth Amudhini Stephen
Associate Professor of Mathematics,
Karunya Institute of Technology and Sciences, Coimbatore

ABSTRACT

This study investigates the thermal environment and comfort of residences in the Karunya University, Coimbatore. A total of 102 occupants in naturally ventilated 11 residences buildings (with occupant – operable windows) provided thermal perception data, first field campaign from Mar6, 2017 to Mar15,2017 and second field campaign from Sep1,2017 to Sep 10, 2017 in Karunya University, Coimbatore. In both the sets the same buildings were taken into account for data collection. Indoor climatic data were collected using instruments with accuracies and response times in accordance with the recommendations of ANSI/ASHRAE 55. All the measurements were carried out between 06:00 hours and 20:00 hours. All the houses which were surveyed were non-air-conditioned residences, where natural ventilation is preferred. The result of the filed survey and measurement study can be used to design a low energy consumption system with consideration of occupant thermal comfort in Coimbatore, Tamil Nadu. In the experiment conducted, using ten non-traditional optimization techniques the thermal sensation takes the value -0.5., which is in the acceptable range, where the acceptable range is -0.5 to +0.5 (ANSI/ASHRAE55-2004, 2004). Therefore the thermal comfort of the residential buildings of the Karunya University in Coimbatore is in the acceptable range. Ten non-traditional optimization algorithms were presented. MATLab programs were written to implement each algorithm. The thermal comfort problem for the offices of the Karunya University was solved using all algorithms, and the comparative results were presented and the pattern search method of optimization is the best method.

Key words: Thermal Comfort, Natural ventilation, GA, SA, PS, PSO, GL, FMINCON, EA, LGO, glcCluster, glcSolve.

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1. INTRODUCTION

Thermal comfort can be defined as that condition of mind which expresses satisfaction with the thermal environment. The reference to 'mind' indicates that it is essentially a subjective term; however, there has been extensive research in residential thermal comfort and a number of indices exists which can be used to assess environments for thermal comfort.

Predicted mean vote (PMV) is a parameter for assessing thermal comfort in an occupied zone based on the conditions of metabolic rate, clothing, air speed, besides temperature and humidity. PMV values refer the ASHRAE thermal sensation scale that ranges from -3 to 3 as follows: 3=hot, 2=warm, 1=slightly warm, 0= neutral, -1=slightly cool, -2=cool,-3=cold.

Predicted Percentage Dissatisfied (PPD) is used to estimate the thermal comfort satisfaction of the occupant. It is considered that satisfying 80 of occupant is good; that is, PPD less than 20% is good (ANSI/ASHRAE55-2004, 2004).

2. LITERATURE SURVEY

This approach is based on field surveys of thermal comfort and it demonstrates that people are more tolerant of temperature changes than laboratory studies suggest: they consciously and unconsciously act to affect the heat balance of the body (behavioural thermoregulation). These actions may change metabolic heat production (changing activity or doing something more or less vigorously), the rate of heat loss from the body (clothing, posture) or the thermal environment (windows, doors, blinds, fans, thermostat adjustment) (Humphreys, 1994). Comfort may therefore be achieved in a wider range of temperatures than predicted by ASHRAE when it is something that individuals achieve for themselves. Adaptive variables are extremely important in 'free running' buildings – those without active heating or cooling systems (Nicol, Raja et al. 1999).

People in such buildings need to be able to control their immediate environment by opening and closing windows, dressing in such a way as to maximise comfort indoors and outdoors, and using shading as necessary. Research into the comfort levels of sedentary individuals at home, at work and in a climate chamber, shows that simply being 'at home', in an environment that is familiar and under control, is conducive to comfort and makes people less sensitive to temperature (Oseland 1995). Advocates of the adaptive approach argue that the heat-balance approach can become unduly normative. For example, when people in hot climates say that they do not experience discomfort at temperatures classified as 'severe' according to the heat-balance model, it can be attributed to their 'low expectations' of comfort (Fanger and Toftum, 2002). The possibility that these individuals may, in fact, be comfortable is ignored. Taking this argument further, Stoops (1994) claims that an element of thermal discomfort – thermal experience, beyond the normal comfort boundaries contributes to overall well-being.

This is demonstrated by those who exercise vigorously, use saunas and take holidays in the sun or the snow. It is not far-fetched to claim that variation is an element of comfort and that people will choose to avoid thermal monotony. Adaptive thermal comfort is a function of the possibilities for change as well as the actual temperatures achieved (Nicol and Humphreys, 2002). In the face of evidence from real-life conditions, the argument goes; the controlled PMV method of estimating comfort levels can be seriously misleading and needs revising (Humphreys and Nicol, 2002). Advocates of the adaptive approach hold that it will eventually be possible to produce thermal standards for buildings that do not resort to specifications of the indoor climate, but use characteristics of a building such as materials, orientation, moveable shading, heating system and controls (Nicol & Humphreys, 2002). If buildings are designed and built to incorporate the right mix of these characteristics, the occupants will be able to make themselves comfortable within them.

3. RESEARCH METHODS

3.1. Outdoor Climatic environment.

Under the Koppen climate classification, the Coimbatore city has a tropical wet and dry climate. It has mild winters and moderate summers. Karunya University residential buildings lie in the latitude of 10^0 56’ 18.89” N and longitude of 76^0 45’ 17.44” E with elevation 1510 ft. The surveys in this study were performed in the May 2009 and September 2009.

3.2. Subjects

A Sample size of 102 subjects in 11 different residences in the Karunya University was collected in survey and field measurements. The dwellings interviewed are multi-story apartments. The volunteers participating in the study comprised both men and women. The average age of all respondents was 33.2 years, ranging from 20 to 57 years and all the participants were in good health. The questionnaire covered several areas including Personal factors (name, gender, age, etc.) and personnel environmental control. The questionnaire also included the traditional scales of thermal sensation and thermal preferences, current clothing garment and metabolic activity. The thermal sensation scale was the ASHRAE seven point scale ranging from cold (-3) to hot (3) with neutral (0) in the middle. The three point thermal preference scale asked whether the respondents would like to change their present thermal environment. Possible responses were “want warmer”, “no change”, or “want cooler”. Clothing garment check list were compiled from the extensive lists published in ASHRAE -55, 2004. Metabolic rates were assessed by a check of activities databases published in ASHRAE-55, 2004. The summary of the background characteristics of the subjects are presented.

Table 1 Summary of the sample of residents and personal thermal variables

Sample size		102
Age (year)	Mean	33.2
	Maximum	20
	Minimum	57
Metabolic rate	115(W/m2)	
Clothing insulation	1.10Clo	

3.3. Data collection

Both physical and subjective questionnaires were obtained simultaneously in the visit of the filed survey. This study investigates the thermal environment and comfort of residences in the Karunya University, Coimbatore. A total of 102 occupants in naturally ventilated 11 residences buildings (with occupant – operable windows) provided thermal perception data, first field campaign from Mar 6, 2010 to Mar 15,2010 and second field campaign from Sep 1,2010 to Sep 10, 2010 in Karunya University, Coimbatore. In both the sets, the same buildings were taken into account for data collection. Indoor climatic data were collected using instruments with accuracies and response times in accordance with the recommendations of ANSI/ASHRAE 55. All the measurements were carried out between 06:00 hours and 20:00 hours. All the houses where survey is conducted are non-air-conditioned residences, where natural ventilation is preferred. The result of the filed survey and measurement study can be used to design a low energy consumption system with consideration of occupant thermal comfort in Coimbatore, Tamil Nadu.

A number of instruments were used to measure the thermal environment conditions, while the respondents filled in the subjective thermal comfort questionnaire. The instruments were Standard thermometer for Air temperature, Whirling hygrometer for humidity, Globe thermometer for radiant heat, kata thermometer for air velocity. Metabolic rate can be estimated using standard Table found in ISO 7730. Among the residential respondents, air temperature readings were taken at a minimum of two locations in each space and at two different levels corresponding to the body level and the ankle level, corresponding to approximately 0.1 m and 1.2 m above the floor level, respectively. Instruments used in this study met the ASHRAE 113-2006 standards' requirements for accuracy. The operative temperature is found to be close to the air temperature. The insulation of clothing ensembles was determined using the Olsen's 1985 summation formula: $I_{cl}= \sum I_{clu,i}$ where I_{cl} is the insulation of the entire ensemble and $I_{clu,I}$ represents the effective insulation of the garment i. The garments values published in the ANSI/ASHRAE Stand card 55-2004 was the basis for the estimation of clothing ensemble insulation. The general mean clothing-insulation value of 1.10 Clo was recorded among all the respondents. The great majority of the respondents were seated on partly or fully upholstered chairs at the time of survey.

The metabolic rates were determined from the activities filled by the subjects and as observed at the time of the survey. Uniform value of 115 W/m^2 was assumed for respondents of the residential buildings. This assumption is based on the ISO 7730 Table of metabolic rates for provisions for relaxed seating which was assumed to be the case with all subjects in their houses.

3.4. Subjective questionnaire

The subjective questionnaire consists of the following areas. All the surveys are "right now" surveys. It takes 15 minutes in average for a participant to answer those questions.

3.5. Indoor climate

TABLE.2 (a) Summary of indoor climatic conditions in the first session for Resident thermal comfort

MEAN	25.23667	0.486833	21.64	0.5365	27.9
MAX	34	1.1	23	1	30
MIN	16	0.1	19.5	0.01	26
AVERAGE	5.827869	0.282102	0.932501647	0.310051	0.76

Table 2 (b) Summary of indoor climatic conditions in the Second session for Resident thermal comfort

MEANN	24.95333	0.514833	21.60167	0.559833	27.955
MAX	34	1.1	23	1	30
MIN	16	0.1	19.5	0.01	26
AVERAGE	5.585437	0.279136	0.81334	0.31706	0.887087

The following values are taken from the data collected from questionnaire and measurements for further optimization, using different non-traditional algorithms. The minimum and maximum values of each of these parameters were taken as the lower and the upper limits of the parameters. These values were taken from both the sets put together which were taken in March and September so as to take a generalized thermal comfort of the university buildings. These values are used in the optimization techniques to optimize the final value and also to find the optimum value of the PMV

Table.3. Range of values

	F_{cl}	T_a	T_{mrt}	V_{air}	P_a	T_{cl}	M(met)	I_{cl}(clo)
Min	0	16	19	0.1	0.01	26	115	1.1
Max	1.5	34	23	1.1	1	30	115	1.1

In an attempt to reduce the processing time and improve the quality of solution, particularly to avoid being trapped in local minima, the non- traditional optimization is used. In this problem to find the optimum thermal comfort, ten non- traditional optimization techniques are used. Each one has its own characteristics. Twenty trial runs were performed for the problem in each of the ten methods. The performance of the different algorithms was compared. The characteristics led to different solutions and run times. The results are finally examined based on different criteria.

Each algorithm with its own option set and stopping criteria was used. All the non-traditional optimization was run using MATLab2011 to get the global optimum value for each of the parameter and also the final value of the thermal comfort.

Hence the Problem is

To minimize PMV for office with the regression coefficients is:

$$PMV = (0.028 + 0.3033e^{-0.036M}).\{(M - W) - 3.05[5.733 - 0.000699(M - W) - Pa] - 0.42[(M - W) - 58.15] - 0.0173M(5.867 - Pa) - 0.0014M(34 - T_a) - 3.96.10^{-8}fcl[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] - fcl.h_c(T_{cl} - T_a)\}$$

$$T_{cl}35.7 - 0.28(M - W) - 0.155I_{cl}[3.9610^{-3}\ fcl[(T_{cl} + 2273)^4 - (T_{mrt} + 273)^4] - fcl.h_c(T_{cl}T_a)]$$

$$h_c = \begin{Bmatrix} 2.38(T_{cl} - T_a)^{0.25}\ for\ 2.38(T_{cl} - T_a)^{0.25} \geq 12.1\sqrt{V_{air}} \\ 12.1\sqrt{V_{air}}\ for\ 2.38(T_{cl} - T_a)^{0.25} \leq\ 12.1\sqrt{V_{air}} \end{Bmatrix}$$

Subject to the following constraints (bounds)

$0 \leq F_{cl} \leq 1.5$;

$16 \leq T_a \leq 34$;

$19.5 \leq T_{mrt} \leq 23$;

$0.1 \leq V_{air} \leq 1.1$;

$0.01 \leq P_a \leq 1$;

$26 \leq T_{cl} \leq 30$;

$M = 75$;

$I_{cl} = 1.5$

4. ALGORITHMS

4.1. Genetic algorithm

4.1.1. Stopping criteria

The options set for the resident problem is same as that of the office problem using genetic algorithm. The stopping criteria reached is same as in the office problem. It is therefore the "Minimum difference between two successive values of objective function value is less than 10^{-6}" condition brings the stop of the iteration. Hence we say that the solution is naturally converged to the global optimum point.

4.2. Simulated annealing

4.2.1. Convergence criteria met

The stopping criteria and options set are same as that of the options for the simulated Annealing for office problem. This case also reaches the final value with the criteria "Minimum difference between two successive values of objective function value is less than 10^{-6}" stops the iteration. Hence we can say that the solution is global optimum.

4.3. Pattern search

4.3.1. Stopping Criteria Reached

The solution is reached by the stopping condition, "difference in function value less than 10^{-6}" and also comparatively the iterations are of less in number, this indicates quick convergence. The final value of the solution is naturally obtained.

4.4. Particle swarm optimization

4.4.1. Stopping Criteria Reached

The options and the stopping criteria which are set are same as that for PSO in the IEQ Office Buildings problem. This case also the final solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-6}" but the specialty is the elapsed time which is less than other solvers. The global optimum solution is obtained without any other stopping conditions.

4.5. GODLIKE

4.5.1. Stopping Criteria Reached

The options and the stopping criteria which are set are same as that for GODLIKE in the IEQ Office Buildings problem. This case also the final solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-6}".The solver exchanges the population among the solvers hence the iteration indicates number of times the population is exchanged. The global optimum solution is obtained without any other stopping conditions.

4.6. Fmincon

4.6.1. Stopping Criteria Reached

The options and the stopping criteria which are set are same as that for Fmincon in the IEQ Office Buildings problem. This case also the final solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-6}". The global optimum solution is obtained without any other stopping conditions. The exception is that the elapsed time is high comparatively; this is due to the traditional technique modified version of using Lagrange's multipliers.

4.7. Direct evolution

4.7.1. Stopping Criteria

The options and the stopping criteria which are set are same as that for DE in the IEQ Office Buildings problem. This case also the final solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-6}". It is seen from the results that the final vectors (parameter values) is not consistent, this is because DE uses different type of cross over method. The global optimum solution is obtained without any other stopping conditions.

4.8. LGO

4.8.1. Stopping Criteria

The options and the stopping criteria which are set are same as that for LGO in the IEQ Office Buildings problem. The global solution reaches by the stopping condition," the change in the final value of the system did not improve". The elapsed time is close to that of other Direct algorithm solvers but it does not use Lipchitz constant

4.9. GlcCluster

4.9.1. Stopping Criteria

The default options are taken from the solver from the previous run of the IEQ Office Buildings problem. The global solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-7}".Though glcCluster uses Clustering algorithm in addition it has very less elapsed time.

4.10. glcSolve

4.10.1. Stopping Criteria

The options and the stopping criteria are taken from the previous run of IEQ Office Building problem. The final solution reaches by the stopping condition," the change in the final value of the system is less than 10^{-6}". glcSolve uses one of the complex algorithm and even after giving long range values for parameters (which is not recommended) it takes little time to complete optimization.

Table 4 Comparative results of optimization methods for resident thermal comfort

PMV PPD RESIDENCE										
Methods	Fcl	Ta	Tmrt	Vair	Pa	Tcl	PMV	PPD	TIME	ITER
Genetic algorithm	0.74862	18.53478	20.67412	0.54805	0.371608	28	-0.5	5	0.27043725	51
Simulated annealing	0.90409	19.98347	21.62081	0.598485	0.51407	28.2	-0.5	5	3.6431679	3000
Pattern search	1.25	25	21.5	0.875	0.0853	28	-0.5	5	0.12296225	20
PSO	1.079095	22.154	21.402	0.48551	0.48974	28.2	-0.5	5	0.13170705	51
G-L	0.934402	21.79226	21.25764	0.62792	0.604205	27.9	-0.5	5	2.35035365	4
fmincon	1.16108	23.83097	20.48477	0.608998	0.171662	28	-0.5	5	7.64714423	10726
DE optimization SOLUTION	1.125365	22.34901	21.48069	0.488745	0.511418	28.1	0.35975	5	0.5724512	120000
LGO	0.5144	16.4846	21.4127	0.5952	1	29.4	-0.5	5	0.9535372	3822
glcClus	1.2505	24.9993	20.083	0.6009	0.0649	28	-0.5	5	39.336999	6499
glcSolve	1.25	25	20.0817	0.6	0.051	28	-0.5	5	10.7008494	15777

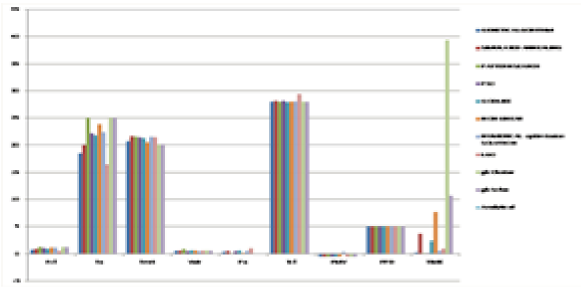

Figure 1 Comparative results of optimization methods for resident thermal comfort

From the above graph, we can observe that the PMV and PPD values are the same for the all the ten optimization techniques as -0.5 and 5 except for DE which is 0.359 for PMV. The elapsed time is maximum for glcCluster and minimum for Pattern search and particle swarm optimization. All the other parameters, more or less, have the same values for all the ten optimization techniques. Now individual parameters are taken into account separately to find out which optimization method yields the best result.

5. PARAMETERS

5.1. Ratio of body's surface area when fully clothed to body's surface area when nude-F_{cl}:

The heat produced must be dissipated to the environment, or a change in body temperature will occur. The deep body temperature is about 37°C, whilst the skin temperature can vary between 31°C and 34°C under comfort conditions. Variations occur in time, but also between parts of the body, depending on clothing cover and blood circulation. There is a continuous transport of heat from deep tissues to the skin surface, from where it is dissipated by radiation, convection or (possibly) conduction and evaporation.

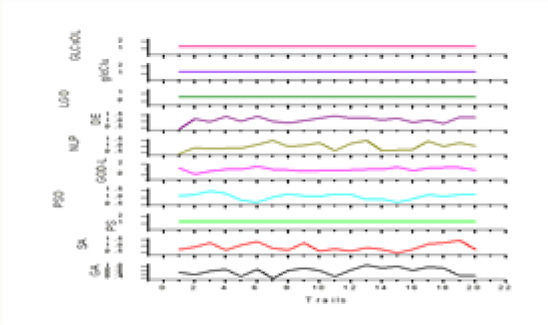

Figure 2 Graph for F_{cl} results in all 10 methods

5.2. Air Temperature -T_a

The temperature of the air surrounding the occupant, the operative temperature is the uniform temperature of an imaginary enclosure in which the occupant would exchange the same heat by radiation and convection as in the actual environment. When air temperature is low, convective heat loss increases with air motion associated with increased activity, thereby decreasing the heat load on the body evaporative system and resulting in a wider range of activity before discomfort is felt.

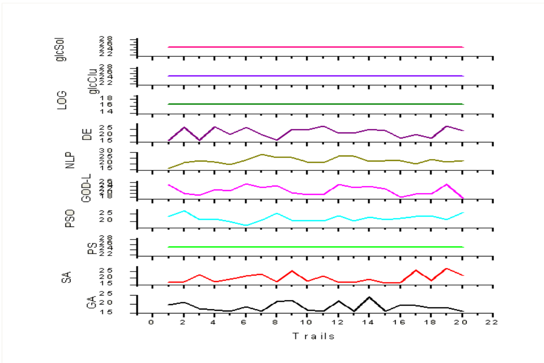

Figure 3 Graph for T_a results in all 10 methods

5.3. Mean radiant temperature-T_{mrt}

It is the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non uniform space. The MRT affects the rate of radiant heat loss from the body. Since the surrounding surface temperatures may vary widely, the MRT is a weighted average of all radiating surface temperatures within a line of sight. In winter, levels of wall, roof, and floor insulation together with window treatments such as double glazing, blinds, and drapes contribute to Mean Radiant Temperature.

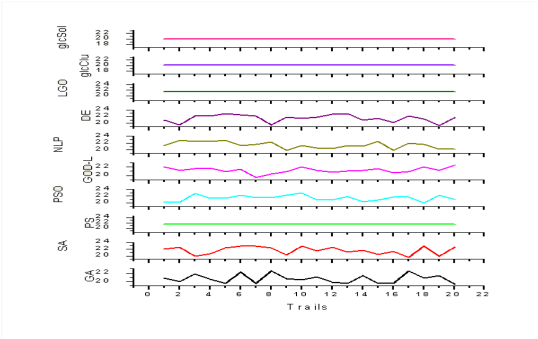

Figure 4 Graph for T_{mrt} results in all 10 methods

5.4. Relative air velocity-V_{air}

Air motion significantly affects body heat transfer by convection and evaporation. AirMovement results from free convection from the occupants' bodily movements. The faster the motion, the greater the rate of heat flow by both convection and evaporation. When ambient temperatures are within acceptable limits, there is no minimum air movement that must be provided for thermal comfort. The natural convection of air over the surface of the body allows for the continuous dissipation of body heat. When ambient temperatures rise, however, natural air flow velocity is no longer sufficient and must be artificially increased, such as by the use of fans.

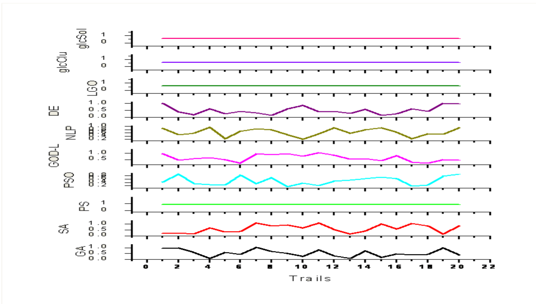

Figure 5 Graph for V_{air} results in all 10 methods

5.5. Partial water vapour pressure-P_a

The upper and lower humidity limits on the comfort envelope are based on considerations of respiratory health, mould growth, and other moisture-related phenomena in addition to comfort. Humidification in winter must be limited at times to prevent condensation on cold building surfaces such as windows. The environmental parameters of temperature, radiation, humidity, and air movement necessary for thermal comfort depend upon the occupant's clothing and activity level.

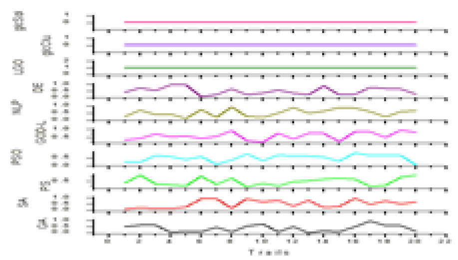

Figure 6 Graph for P_a results in all 10 methods

5.6. Surface temperature of clothing-T_{cl}

Clothing, through its insulation properties, is an important modifier of body heat loss and comfort. The insulation properties of clothing are, a result of the small air pockets separated from each other to pre air from migrating through the material. When preferred amount of clothing worn by building occupants decreased, then correspondingly, the preferred temperatures increased. These seasonal clothing variations of building occupants allow indoor temperature ranges to be higher in the summer than in the winter and yet remain comfortable. In winter, additional clothing lowers the ambient temperature necessary for comfort and for thermal neutrality.

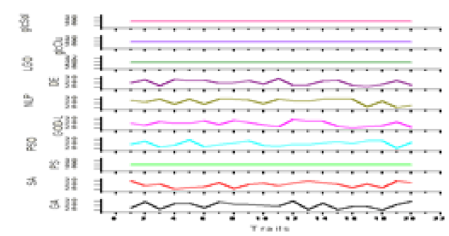

Figure 7 Graph for T_{cl} results in all 10 methods

5.7. Predicted mean vote (PMV)

PMV is an index that predicts the mean value of the votes of a large group of persons on the seven point thermal sensation scale. There is not even a single set of conditions that will satisfy all occupants. Each person has a distinct perception of too hot, too cold, and comfortable. The objective in designing a common thermal environment is to satisfy a majority of occupants and to minimize the number of people who will inevitably be dissatisfied.

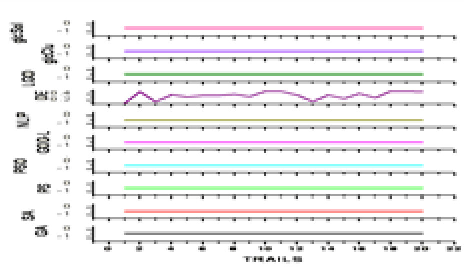

Figure 8 Graph for PMV results in all 10 methods

5.8. Predicted percentage of Dissatisfied. (PPD)

An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV. As PMV changes away from zero in either the positive or negative direction, PPD increases. Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort uses limits on PMV as an explicit definition of the comfort zone.

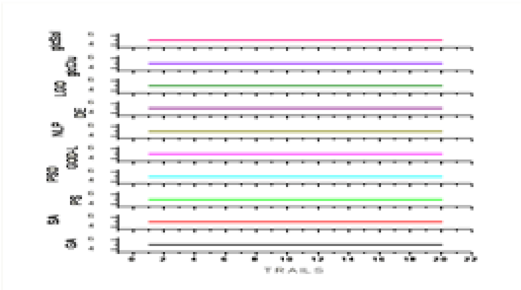

Figure 9 Graph for PPD results in all 10 methods

5.9 Elapsed Time

CPU time is the time for which the CPU was busy executing the task. It does not take into account the time spent in waiting for I/O (disk IO or network IO). Since I/O operations, such as reading files from disk, are performed by the OS, these operations may involve noticeable amount of time in waiting for I/O subsystems to complete their operations. This waiting time will be included in the elapsed time, but not CPU time. Hence CPU time is usually less than the elapsed time.

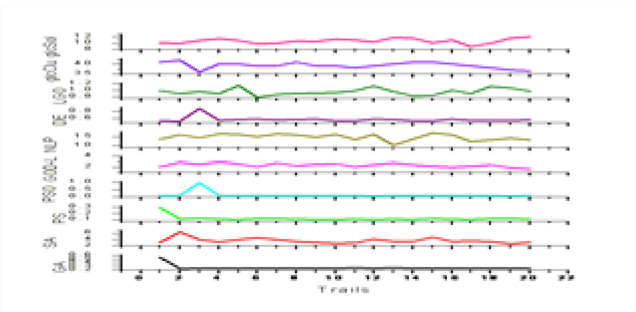

Figure 10 Graph for Elapsed time results in all 10 methods

5.10. Iterations

Iteration is a computational procedure in which a cycle of operations is repeated, often to approximate the desired result more closely. Iteration means the act of repeating a process usually with the aim of approaching a desired goal or target or result. Iteration in computing is the repetition of a process within a computer program. It may also refer to the process of iterating a function i.e. applying a function repeatedly, using the output from one iteration as the input to the next. Another use of iteration in mathematics is in iterative methods which are used to produce approximate numerical solutions to certain mathematical problems. Newton's method is an example of an iterative method.

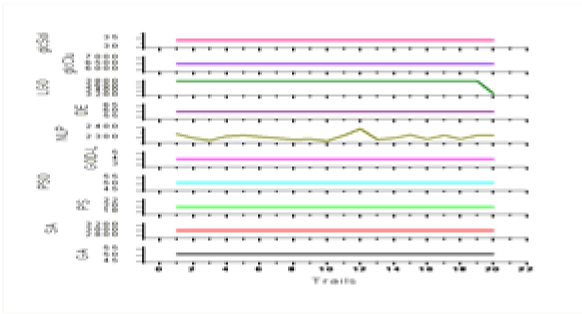

Figure 11 Graph for Iterations results in all 10 methods.

Table 5 Comparative results of the parameters in all 10 methods.

Variables	GA	SA	PS	PSO	G-L	Fmincon	DE	LGO	glcCluster	glcSolve
Fcl	X	X	✓	X	X	X	X	✓	✓	✓
Ta	X	X	✓	X	X	✓	X	✓	✓	✓
Tmrt	X	X	✓	X	X	✓	X	✓	✓	✓
Vair	X	X	✓	X	X	✓	X	✓	✓	✓
Pa	✓	√	✓	✓	✓	✓	✓	✓	✓	✓
Tcl	X	X	✓	✓	X	X	X	X	X	X
PMV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PPD	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time			0.12	0.13						
Iter	X	X	✓	✓	X	X	X	X	X	X

6. RESULT AND DISCUSSION

With the two extreme values of parameters from survey, the optimization is carried out with different solvers. As they are of stochastic type their results may vary from trial to trial so and the problem is made to run for 20 trials (Elbeltagi, Tarek Hegazy, & & Grierson, 2005) and an average of all trials is taken as the final value of the parameter, by the solver. The solvers are compared with three different criteria

CONSISTENCY

The consistency Table gives the parameters that remain constant for all the trials. All the solvers give the same value of PMV& PPD for all the runs except DE, which in turn indicate that the comfort requirements are in the acceptable range

Fcl - P.S (1.2), glcSolve (1.25), glcCluster (1.25), LGO (0.51)

Ta - P.S (25), glcSolve (25), glcCluster (25), LGO (16.48)

Tmrt - P.S (21.5), glcSolve (20.08), glcCluster (20.08), LGO (21.41)

Vair - P.S (0.8), glcSolve (0.6), glcCluster (0.6009), LGO (0.59)

Pa - P.S (0.485), glcSolve (0.05), glcCluster (0.064), LGO (1)

Tcl- P.S (28), glcSolve (28), glcCluster (28.001), LGO (29.44)

So we see that the solvers **Pattern Search, glcSolve, glcCluster& LGO** remain constant throughout their runs.

Minimum Run Time

For minimum run time of the problem, we got **PSO** (0.131 seconds), **Pattern Search** (0.122 seconds).

Minimum Evaluation

This criterion will determine the effectiveness of the algorithm. From the result table, we see that the **Pattern Search and GODLIKE** algorithms have minimum evaluation of 20 and 4 respectively

Simplicity of Algorithm

Of all the algorithms, we have taken the **Pattern Search** algorithm is the most simplest followed by **GA, PSO,** DE, Simulated Annealing, GODLIKE, Non-Linear, Direct algorithm.

Results according to Standards

This is the most important criterion that determines whether the solver is practical or not. We got the standard values for a naturally ventilated building from ASHRAE as:

- Humidity: 30% to 60%.This gives that the Pa should lie within the range of: 0.0765 to 0.501
- Operative Temperature: 17.75 to 28.5
- Air velocity:0.2 to 0.8 ms^{-1}(1 ms^{-1} only at extreme conditions)

With the above standards the solvers which adhere to the standard are:

- Air-Velocity: Fmincon, GA, SA, PSO, GL, DE, glcSolve.
- Partial vapour pressure: GA, PS, PSO, LGO, glcCluster, glcSolve
- Operative temperature: GA, SA,PS, PSO, Fmincon, DE, GL, LGO, glcCluster, glcSolve

The following Table gives a summary of all the criteria for the solvers:

Table 6 Summary of all the criteria for the solvers

Criteria	GA	SA	PS	PSO	Fmincon	DE	GL	LGO	glcClus	glcSolve
Result according to ASHRAE	3/3 =100%	2/3 =67%	2/3 =67%	3/3 =100%	2/3 =67%	3/3=100 %	2/3 =67%	2/3 =67%	2/3 =67%	3/3 =100%
Consistency	-	-	✓	-	-	-	-	✓	✓	✓
Min-Time	-	-	✓	✓	-	-	-	-	-	-
Min-Evalu	-	-	✓	-	-	-	✓	-	-	-
Simple Algo	-	-	✓	-	-	-	-	-	-	-

Thus, it is seen that the Pattern Search solver satisfies all the criteria and scores 67% for its practicality in giving results according to ASHRAE. So the appropriate algorithm, for optimization of thermal comfort is suggested as **direct search algorithm** & the solver is **PATTERN SEARCH**

7. CONCLUSION

This study investigates the thermal environment and comfort of residences in the Karunya University, Coimbatore. A total of 102 occupants in naturally ventilated 11 residences buildings (with occupant – operable windows) provided thermal perception data, first field campaign from Mar6, 2010 to Mar15,2010 and second field campaign from Sep1,2010 to Sep 10, 2010 in Karunya University, Coimbatore. In both the sets the same buildings were taken into account for data collection. Indoor climatic data were collected using instruments with accuracies and response times in accordance with the recommendations of ANSI/ASHRAE 55. All the measurements were carried out between 06:00 hours and 20:00 hours. All the houses which were surveyed were non-air-conditioned residences, where natural ventilation is preferred. The result of the filed survey and measurement study can be used to design a low energy consumption system with consideration of occupant thermal comfort in Coimbatore, Tamil Nadu.

In the experiment conducted, using ten non-traditional optimization techniques the thermal sensation takes the value -0.5., which is in the acceptable range , where the acceptable range is -0.5 to +0.5 (ANSI/ASHRAE55-2004, 2004). Therefore the thermal comfort of the residential buildings of the Karunya University in Coimbatore is in the acceptable range.

Here, ten non-traditional optimization algorithms were presented. These include: GA, SA, PS, PSO, GL, FMINCON, EA, LGO, glcCluster, glcSolve. A brief description of each method is presented along with a Pseudo code to facilitate their implementation. MATLab programs were written to implement each algorithm. The thermal comfort problem for the offices of the Karunya University was solved using all algorithms, and the comparative results were presented and the pattern search method of optimization is the best method.

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