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OPTIMIZATION OF INDOOR ENVIRONMENTAL QUALITY OF AN OFFICE BUILDING USING TEN NON-TRADITIONAL OPTIMIZATION TECHNIQUES

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ABSTRACT

Due to the difficulty of controlling the indoor thermal environment, it is important to provide thermal comfortable conditions which meet occupants' expectation. In order to realize the long-term thermal comfort in indoor environment, the microclimate in Karunya Institute of Technology campus in Coimbatore, Tamilnadu. India is measured through year. PMV model is applied to calibrate the climate parameters and environment elements. The Indoor environmental quality of an office building is calculated. All the buildings under study are naturally ventilated buildings. The results obtained are optimized using ten different nontraditional optimization models and compared to find which method is suitable in terms of number trails and minimum time taken. ASHRAE standards are verified.

Key words: IEQ, Non-Traditional Optimization, Office Building.

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1. INTRODUCTION

Today, the concept of an acceptable indoor environmental quality (IEQ) as an integral part of the total building performance approach is still not fully appreciated. This state of mind is an intricate response to the indoor environmental factor groups, including physical environment sustained by the building and its service system, and individual physiological conditions such as health, social relations, financial state, etc. Four basic components, namely thermal comfort, indoor air quality, aural and visual comfort were identified for determining an acceptable IEQ. Conventional studies on indoor environment address each of them separately. They are still addressed independently by designers for many office designs. It was realized that successful control of the indoor environment required an understanding of the indoor environmental parameters. An overall IEQ index would be derived to describe the state of mind of a user in balance with the indoor environment.

Subjective evaluation of an indoor environment being perceived by an occupant can be used to assess the acceptance of the IEQ. In particular, occupants' acceptance of the four basic components of IEQ was evaluated and correlated with the overall IEQ acceptance of an office environment. The occupants' attitudes towards the operative temperature, CO2 concentration, equivalent noise level and illumination level and the overall IEQ acceptance recorded by a dichotomous scale were studied. Mathematical expressions were proposed for the overall IEQ acceptance, using a multivariate logistic regression model with the former four parameters recorded. The proposed overall IEQ acceptance can be used as a quantitative assessment criterion for an office environment and similar environment where an occupant's evaluation is expected.

Note: We could not find any standards for India, and so we have used ASHRAE, since they seemed reasonable and applicable in Indian context also. (living-smartly.com)

2. METHODOLOGY

Subjective evaluations made by 220occupants of indoor environmental conditions in natural ventilated Faculty rooms in Karunya University were studied. The sample offices had floor areas ranging from 233.3 m^2 to 937.77 m^2. The offices were spacious with ordinary design and with good quality finishes; flexible layout, average-sized floor plates, adequate lobbies; good lift services zone and parking facilities were available.

The occupant's acceptance of the perceived indoor environment given by four aspects, namely thermal environment, indoor air quality, equivalent noise level and illumination level, was studied with a dichotomous assessment scale. This scale was used for a direct feedback of acceptability with the question 'Is the thermal environment/indoor air quality/noise level/illumination level being perceived in the office environment acceptable to you?' being asked. The ranks '(1) Yes, acceptable' and '(0) No, not acceptable' were self-explanatory. In order to confirm the validity of their responses, each respondent had to use a semantic differential evaluation scale for the subjective assessment of the first two aspects, and a visual analogue assessment scale for the evaluation of the aural and visual comfort. At the end of the survey, an overall acceptance of the IEQ was determined.

A total of 220 occupants were interviewed and their evaluations of the IEQ and the four parameters were obtained. The results are summarized in Table 4.1. The correlation between subjective response to each parameter and the overall IEQ acceptance was evaluated by a statistic χ^2-test. Results showed that all the four parameters contributed to the overall IEQ; and the significance between the acceptance votes on the latter and those on the former, ranking from the most important to the least, was as follows: p = 3.4×10^{-20} for thermal environment, $P = 5.22 \times 10^{-16}$ for air quality, $P = 7.16 \times 10^{-8}$for noise level and $P = 5.83 \times 10^{-6}$ for illumination level.

Table 1 Occupant's votes on acceptance of a perceiving indoor environmental quality

Overall acceptance	Votes	Thermal environment φ_1		Air quality φ_2		Noise level φ_3		Illumination level φ_4	
		U	A	U	A	U	A	U	A
U	98	47	51	52	46	30	68	26	72
A	122	3	119	12	110	7	115	9	113
TOTAL	220	50	170	64	156	37	183	35	185

U - Unacceptable; A -Acceptable.

The overall IEQ acceptance θ for an office environment perceived by an occupant expressed by a multivariate logistic regression model is proposed

$$\theta = 1 - \frac{1}{1 + \exp\left(k_0 + \sum_{i=1}^{4} k_i \phi_i(\zeta_i)\right)},$$

Where the regression constants determined from the 220 occupant evaluations are k_0 = -14.98; k_1 = 6.04; k_2 = 4.92; k_3 = -4.70; k_4 = 3.74; Values of k_1, k_2, k_3, k_4 confirm the relative importance of the four contributors to θ, the larger the value, the greater the importance and it is seen that the occupants were very sensitive to the operative temperature as compared with the other three parameters. Various combinations of contributors i=1, 2, 3, 4 and the corresponding overall IEQ acceptance were considered. A total of 2^4 possibilities were found. Taking the binary notation for the acceptance i.e., 0 for 'unacceptable' and 1 for 'acceptable' the predicted acceptance of IEQ (θ) is calculated.

φ_1=1 - (PPD/100). Where, PPD = 100 – 95 x $e^{-(0.03353\,(PMV^4) + 0.2179\,(PMV^2))}$; $-2 \le PMV \le 2$

$\varphi_2 = 1 - \frac{1}{2}\left(\frac{1}{1+exp(3.007-0.0018\,\xi_2)} - \frac{1}{1+exp(3.192-0.00211\xi_2)}\right)$; $330 \le \xi_2 \le 1500$,

$\varphi_3 = 1 - \frac{1}{1+exp(9.85-0.443\xi_3)}$; $67 \le \xi_3 \le 78$,

$\varphi_4 = 1 - \frac{1}{1+exp(-1.021+0.00614\,\xi_4)}$ $187 \le \xi_4 \le 1522$.

Table 2 Overall IEQ acceptance

Case No.	Survey Sample	Contributors				Predicted acceptance of IEQ θ
		Φ1	**Φ2**	**Φ3**	**Φ4**	
1	0	0	0	0	0	3.1208×10^{-7}
2	5	0	0	0	1	1.313×10^{-5}
3	1	0	0	1	0	2.84×10^{-9}
4	14	0	0	1	1	1.1949×10^{-7}
5	3	0	1	0	0	4.275×10^{-5}
6	3	0	1	0	1	1.7967×10^{-3}
7	5	0	1	1	0	3.88×10^{-7}
8	20	0	1	1	1	1.637×10^{-5}
9	1	1	0	0	0	5.486×10^{-3}
10	8	1	0	0	1	1.31×10^{-4}
11	9	1	0	1	0	1.1918×10^{-6}
12	27	1	0	1	1	5.017×10^{-5}
13	3	1	1	0	0	0.017636
14	16	1	1	0	1	0.43045
15	13	1	1	1	0	1.6326×10^{-4}
16	92	1	1	1	1	6.827×10^{-3}

3. ALGORITHMS

3.1. Genetic algorithm
3.2. Simulated annealing
3.3. Pattern search
3.4. Particle swarm optimization
3.5. GODLIKE
3.6. Fmincon.
3.7. Direct evolution
3.8. LGO
3.9glc Cluster
3.10. glcSolve

Table 3 Comparative results of optimization

Method	Thermal sensation	Carbon dioxide	Sound level	Horizontal illumination	IEQ	TIME	iterations
GA	1.785	1613.71	63.695	1381.06	1	1.02834	51
SA	0.2	1272.77	60.715	962.05	1	2.49694	2010.05
PS	2	1800	70.5	1600	1	0.1482	60
PSO	-0.2	1581.18	58.0872	1188.64	1	0.094	56.8
GL	-0.2	1792.31	62.17	1509.08	1	1.19686	4
Fmincon	2	1800	72	1600	1	10.73477	5624
DE	0.38385	1189.74	56.9655	1023.34	1	0.00337	40
LGO	2	1759.81	68.7652	1561.97	1	0.82818	2699
glcCluster	1.98756	1150	49.5	433.334	1	0.6171	1513
glcSolve	-1.9259	1727.78	70.5	1522.22	1	1.01347	1503

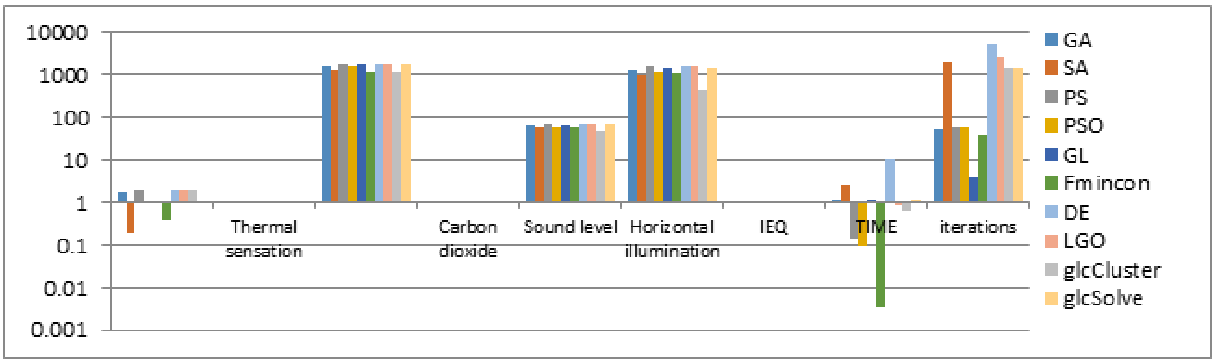

Figure 1 Comparative graph for office Indoor Environmental Quality

4. DISCUSSION OF THE COMPARATIVE RESULTS

All the ten methods yield the IEQ value as 1 which is the acceptable optimum value. The time taken by Fmincon is maximum. Number of iterations was maximum for DE and minimum for GL. Carbon dioxide, sound and illumination level are more or less the same for all 10 methods. The thermal sensation alone was different for different methods

5. PARAMETERS

5.1. THERMAL SENSATION

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Thermal environment encompasses characteristics which affect a person's heat loss. In terms of bodily sensations, thermal comfort is a sensation of hot, warm, slightly warmer, neutral, slightly cooler, cool and cold. From the physiological point of view, thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating between the heat exchange between the human body and the environment.

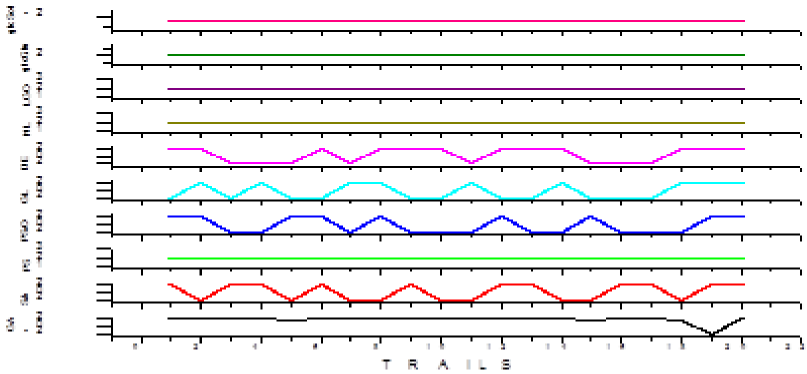

Figure 2 Graph of Thermal sensation results in all 10 methods

From the graph we can see that Pattern search, Fmincon, LGO, glcCluster and glcSolve are consistent in all 20 trials.

5.2. CARBON DI-OXIDE

Carbon dioxide (CO2) is the chief greenhouse gas that results from human activities and causes global warming and climate change. Though carbon dioxide is not toxic in itself, the amount found in the indoor environment is used as an indicator for human comfort. Elevated levels of carbon dioxide indicate that an insufficient amount of fresh, outdoor air is being delivered to the occupied areas of the building. This also indicates that other pollutants in the building may exist at elevated levels since there is not enough fresh air to dilute them. Since carbon dioxide is an unavoidable, predictable, and easily measured product of human occupancy, it is used as a marker for other pollutants emanating from humans or other sources in the building. However, carbon dioxide is mostly a threat to health, when the concentration is high enough to displace the oxygen, which can lead to suffocation in a confined space.

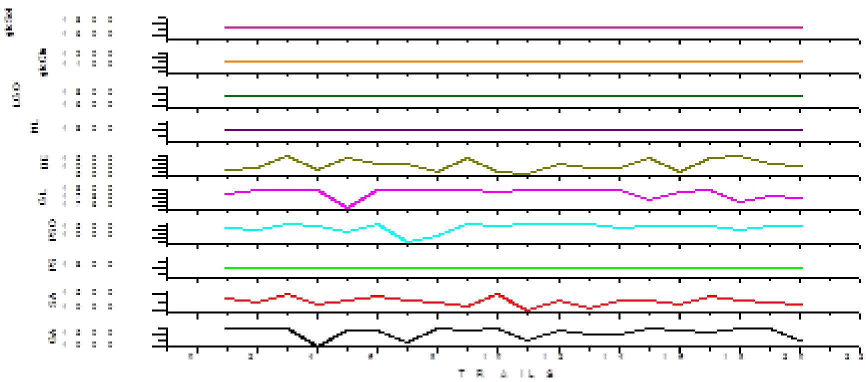

Figure 3 Graph for Carbon Dioxide concentration results in all 10 methods

From the graph we can see that Pattern search, Fmincon, LGO, glcCluster and glcSolve are consistent in all 20 trials.

5.3. SOUND PRESSURE LEVEL

Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound and infrasound. The perception of sound in any organism is limited to a certain range of frequencies. Hearing loss due to prolonged exposure to noise is well documented. Excessive noise also has an adverse effect on personal health and wellbeing, ability to perform quiet tasks, and productivity in general. Because land is becoming scarcer, buildings are being constructed closer together and closer to noise sources such as highways, railways, and airports. As a result, sound or acoustic control is becoming increasingly important. The reduction of airborne sound through a wall is called sound transmission loss (STL).

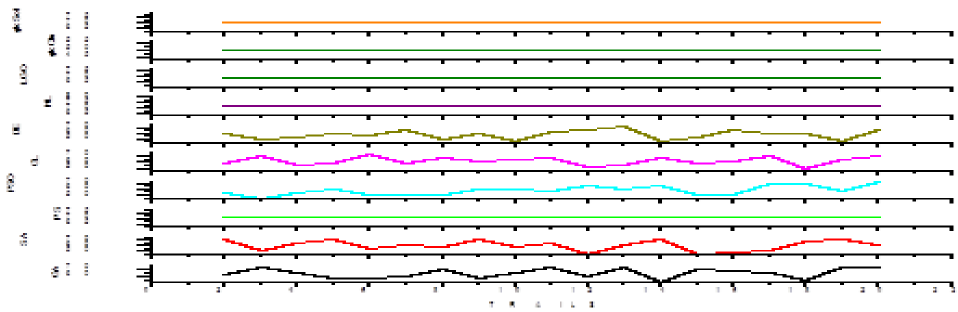

Figure 4 Graph for Sound Pressure level results in all 10 methods

From the graph we can see that Pattern search, Fmincon, LGO, glcCluster and glcSolve are consistent in all 20 trials.

5.4. HORIZONTAL ILLUMINATION

Lighting or illumination is the deliberate application of light to achieve some aesthetic or practical effect. In some design instances, materials used on walls and furniture play a key role in the lighting effect. Surfaces or floors that are too reflective create unwanted glare. Specification of illumination requirements is the basic concept of deciding how much illumination is required for a given task. Clearly, much less light is required to illuminate a hallway or bathroom compared to that needed for a word processing work station. Generally speaking, the energy expended is proportional to the design illumination level. Beyond the energy factors being considered, it is important not to over-design illumination, lest adverse health effects such as headache frequency, stress, and increased blood pressure be induced by the higher lighting levels. In addition, glare or excess light can decrease worker efficiency.

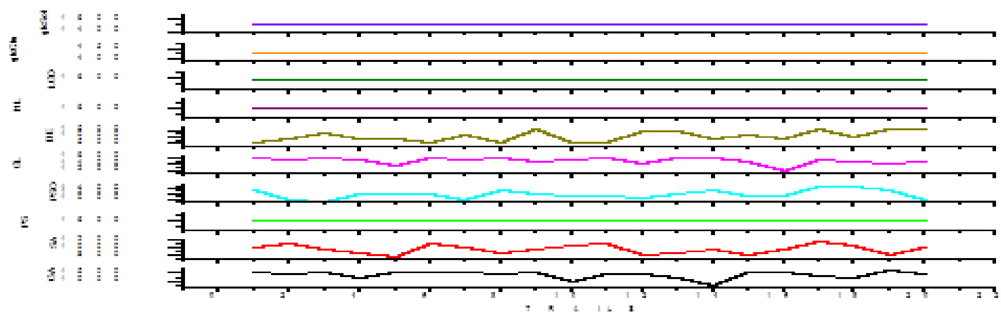

Figure 5 Graph for horizontal illumination results in all 10 methods

From the graph we can see that Pattern search, Fmincon, LGO, glcCluster and glcSolve are consistent in all 20 trials.

5.5. IEQ

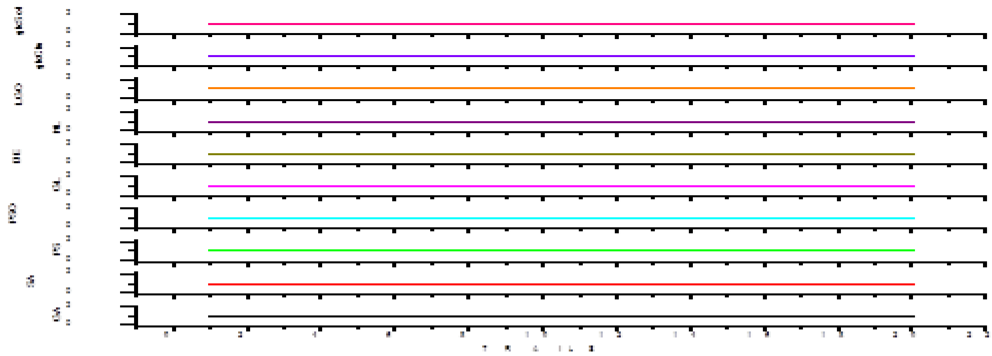

Figure 6 Graph for IEQ results in all 10 methods

From the graph we can see that all ten methods are consistent in all 20 trials with value 1 which is the optimum acceptable value.

5.6. 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.

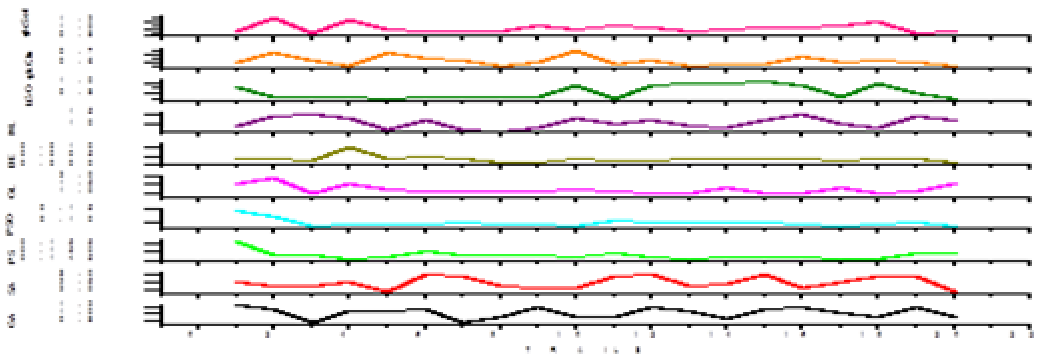

Figure 7 Graph for Elapsed time results in all 10 methods

From the graph, we can see that none of the methods was consistent in all 20 trials but Pattern search method alone got a more or less same value – average of 0.148 seconds. Which is second best in terms of time. Therefore it is the best method.

5.7. ITERATIONS

In a computational procedure, 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.

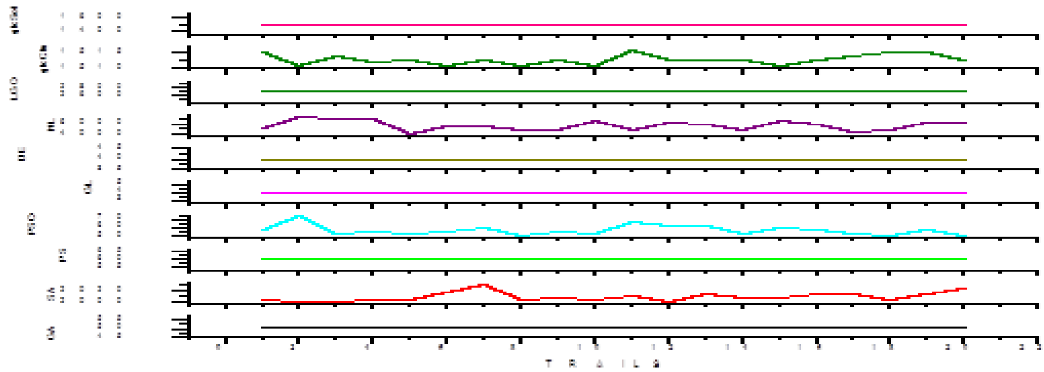

Figure 8 Graph for Iterations results in all 10 methods

From the graph we can see that GA, Pattern search, GL, DE, LGO and glcSolve are consistent in all 20 trials.

Table 4 Comparative table for parameters in all 10 methods

Variables	GA	SA	PS	PSO	GL	fmincon	DE	LGO	Glc Cluster	Glc Solve
PMV	X	X	✓ 2	X	X	✓ 2	X	✓ 2	✓ 1.9	✓ 1.9
CO2	X	X	✓ 1800	X	X	✓ 1800	X	✓ 1759	✓ 1150	✓ 1727.7
Sound	X	X	✓ 70.5	X	X	✓ 72	X	✓ 68.76	✓ 49.5	✓ 70
Illumina tion	X	X	✓ 1600	X	X	✓ 1600	X	✓ 1561.9	✓ 433.3	✓ 1522.2
IEQ	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1
TIME			0.148	0.093		0.003				
ITERS	✓	X	✓ 60	X	✓ 4	✓ 40	X	✓	X	✓

- Represents the parameters which are consistent for all the 20 trials and the corresponding parameter values are given in the respective cell.

X - Represents the parameters which are not consistent for all the 20 trials

In case of iterations and elapsed time only the two or three minimum values alone are given.

6. RESULTS 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 and so 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 trails. All the solvers give the same value of IEQ for all the runs, which in turn indicates that the quality requirements are acceptable.

Thermal - P.S (2), NL (2), LGO (2),glcSolve (-1.9), glcCluster (-1.9)

CO_2 - P.S (1800), NL (1800), LGO (1759),glcSolve(1727.7), glcCluster (1150)

Sound - P.S (70.5), NL (72), LGO (68.76),glcSolve (70), glcCluster (49.5)

Illumination -P.S (1600), NL (1600), LGO (1561.91),glcSolve (1522.2), glcCluster (433.3)

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

Minimum Run Time

For a minimum run time of the problem we got **PS** (0.093 seconds), **Pattern Search** (0.148 seconds), **DE** (0.003 seconds).

Minimum Evaluation

This criterion will determine the effectiveness of the algorithm. From the result table, we see that the **Pattern Search, GODLIKE** and **DE** algorithms have minimum evaluation of **60, 4** and **40** respectively

Simplicity of Algorithm

Of all the algorithms we have taken the **Pattern Search** algorithm is the simplest followed by **GA, PSO,** DE, Simulated Annealing, GODLIKE, Non-Linear, and 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 from ASHRAE, IES, Guidance for employers on the Control of Noise at Work Regulations 2005 as:

- Thermal comfort: -3 to 3
- Carbon dioxide: less than 1000ppm
- Sound level: 40 dBA to 70dBA
- Illumination level: 1000 lux to 2000 lux
- With the above standards the solvers which adhere to the standard are:

- Thermal comfort: GA, SA, PS, PSO, FMINCON, DE, GL, LGO, glcCluster, glcSolve
- Carbon dioxide: GA, SA, PS, PSO, FMINCON, GL, LGO, glcCluster, glcSolve
- Sound level: GA, SA, PS, PSO, FMINCON, DE, GL, LGO,glcCluster, glcSolve
- Illumination level: DE, glcCluster, glcSolve
- The following table gives a summary of all the criteria for the solvers:

Table 5 Summary of all the criteria for the solvers

Criteria	GA	SA	PS	PSO	Fmincon	DE	GL	LGO	glcCluster	glcSolve
Result according to ASHRAE	¾ =75%	¾ =75%	¾ =75%	¾ =75%	¾ =75%	¾ =75%	¾ =75%	¾ =75%	4/4 =100%	4/4 =100%
Consistency	-	-	✓	-	-	-	-	✓	✓	✓
Min-Run Time	-	-	✓	✓	-	-	-	-	-	-
Min-Evaluation	-	-	✓	-	-	-	✓	-	-	-
Simple Algorithm	-	-	✓	-	-	-	-	-	-	-

Thus it is seen that the Pattern Search solver satisfies all the criteria and scores 75% for its practicality in giving result according to ASHRAE, IES and Guidance for employers on the Control of Noise at Work Regulations 2005, So the appropriate algorithm, for optimization of thermal comfort is suggested as **Direct search algorithm** & the solver is **PATTERN SEARCH**

7. CONCLUSION

Office environment is generally designed to the design guides and practises for the occupant's comfort. In this work, the overall IEQ of offices of Karunya University in Coimbatore was evaluated by 220 occupants in four aspects, namely thermal comfort, indoor air quality, equivalent noise level and illumination level. All the offices considered are naturally ventilated buildings. The results showed that the operative temperature, carbon dioxide concentration, equivalent noise level and illumination level had important effects on the overall IEQ acceptance. Empirical expressions have been proposed to approximate the occupant's acceptance of the IEQ in office. The nontraditional algorithms are used to find the optimum value of the IEQ.

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 programswere written to implement each algorithm. The IEQ problem for the offices of the Karunya University was solved using all algorithms, and the comparative results were presented.

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