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Optimization of Environmental Conditioning Equipment Based on Particle Swarm Optimization Algorithm and Genetic Algorithm

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Abstract: The purpose of this paper is to systematically analyze and design the appearance of the 3-in-1 environmental conditioning device by using particle swarm optimization algorithm and genetic algorithm. Firstly, the particle swarm optimization algorithm (PSO) is applied to simulate the indoor temperature change for the placement of air conditioners, the location of the inlet and outlet, and the direction of airflow to design the optimal shapes and sizes to improve the temperature control efficiency. Second, a genetic algorithm optimization model was constructed for the relationship between the shape of the air purifier and the purification effect, aiming to determine the best design that can maximize the purification effect. Next, an optimization analysis of the shape of the humidifier is introduced, and a multi-objective optimization model for the 3-in-1 device is developed using PSO to maximize energy efficiency, comfort, and air quality. The algorithms and models used in this paper not only enhance the comprehensive performance of the device, but also provide a scientific basis for future product development and promote the innovation and application of smart home devices.

Keywords: Versatile Environmental Conditioning; Particle Swarm Optimization (PSO) Algorithms; Genetic Algorithms (GA); Multi-Objective Optimization Algorithms.

1. Introduction

This study aims to design the optimal appearance of the three-in-one device[1] by comprehensively applying multi-objective optimization algorithms[2] such as particle swarm optimization algorithm (PSO)[3] and genetic algorithm (GA)[4]. Firstly, for the influence of air conditioner placement position, airflow direction, inlet and outlet position and number on air conditioner efficiency, particle swarm optimization algorithm (PSO) is used to simulate the temperature distribution in the space through aerodynamic[5] and heat exchange models[6] to obtain the air conditioner optimization model to achieve the best temperature regulation effect. Second, for the relationship between the shape of the air purifier and the purification effect, the genetic algorithm (GA) is used to determine the optimal design that can maximize the purification effect. Finally, PSO, multi-objective optimization algorithm and visual analysis are applied to optimize the appearance of the three-in-one device. Combined with the above studies, this paper establishes a multi-objective optimization model for a 3-in-1 device using PSO to maximize energy efficiency, comfort and air quality, and to improve the overall performance of the 3-in-1 device.

2. Air conditioning Design Analysis

2.1. Factor Analysis

In this section, we study the optimization of various aspects of air conditioner design and the effect of placement of air conditioner on temperature regulation and construct the best optimization model of air conditioner shape to achieve the best temperature regulation. To study the construction of an optimization model for the shape of the air conditioner to improve the temperature regulation effect of the air conditioner. The model needs to be constructed based on the shape, size, inlet and outlet flow rate of the air conditioner, while using an optimization algorithm to obtain the optimal solution.

(1)The placement of the air conditioner affects the circulation of air and temperature distribution in the room. If the air conditioner is placed in the corner of the room, it may lead to poor air circulation in some areas, affecting the cooling or heating effect.

(2) The location and number of air inlets and outlets directly affect the circulation of indoor air. Reasonable design of air inlet and outlet can improve the cooling or heating efficiency of the air conditioner.

(3)Air speed and air volume directly affect the cooling or heating capacity of the air conditioner. Appropriate air speed and air volume can improve the efficiency of air conditioners while reducing energy consumption.

2.2. Objective function

The objective is to optimize the shape of the air conditioner one maximizes the cooling (or heating) capacity; an objective function can be defined as follows:

$$Maximize f(x) = Cooling\ Efficiency = \frac{Heat\ Exchange\ Rate}{Energy\ Consumption} \tag{1}$$

Where the cooling effect is related to the air conditioner's heat exchange rate (related to surface area and air flow rate) and energy consumption (related to air conditioner power, air speed, etc.). Assuming that the heat exchange rate is $Qcool$, The energy consumption is $Penergy$, Then the cooling efficiency can be expressed as:

$$f(x) = Qcool/Penergy \quad (2)$$

Note: Heat exchange rate $Qcool$ is related to the air conditioner's profile surface area A and air flow rate v, assuming:

$$Qcool = hAv(\text{ Tin-Tout }) \quad (3)$$

Note: h is the heat transfer coefficient, A is the surface area of the air conditioner, v is the air flow rate, the Tin and $Tout$ The temperatures of the inlet and outlet air, respectively.

power consumption $Penergy$ Dependent on-air speed and motor efficiency of the air conditioner.

$$Penergy = \eta v^2 \quad (4)$$

Note: η is the constant associated with motor efficiency and v is the wind speed.

2.3. Constraints

(1)Volume Constraints

The volume of the air conditioner must satisfy spatial constraints such as maximum volume:

$$Vm = 0.1m^3 \quad (5)$$

$$x.y.z \leq V_{\max} \quad (6)$$

Where x, y, and z are the length, width, and height of the air conditioner, respectively.

(2)Air Flow Constraints

The maximum inlet and outlet air flow rates for air conditioning are $Q_m = 600\ \mathrm{m}^2/\mathrm{h}$ and $Q = 600\ \mathrm{m}^3/\mathrm{h}$.

(3) Wind Speed Constraints

The maximum value of wind speed is $vm = 8.0\ \mathrm{m/s}$,The wind speed must not exceed this value to ensure system stability.

(4) Cooling Capacity Constraints

The cooling capacity must meet the demand, assuming a minimum cooling capacity of $Q_{\text{cool.min}}$:

$$Q_{\text{cool} >=} = Q_{\text{cool.min}} \quad (7)$$

2.4. Particle Swarm Optimization Algorithm (PSO)

PSO is a heuristic optimization algorithm that combines the social learning behavior of particles and the cooperative interaction of groups to achieve the problem solution. The basic steps are as follows:

(1)Particle Swarm Initialization

Each member of the particle swarm has two attributes.

Position: the values of the length, width and height of the current air-conditioned design solution.

Velocity: the speed at which the solution is moving in the search space.

(2)Velocity and Position

The algorithm abstracts each individual particle in the population as a single prime with velocity Vi and position Xi. Along with the optimization process, each particle is led by the global optimal position $gbest$ and the individual historical optimal position $pbest$.

$$V_i = V_i + c_1 r_1^*(\, pbest_i - X_i) + c_2 r_2^*(\, gbest\ - X_i) \quad (8)$$

$$X_i = X_i + V_i \quad (9)$$

Note: c1 and c2 represent the learning factor for each particle to move to the proximity of $pbest$ and $gbest$, respectively, and $r1$ and $r2$ are random numbers between $[0,1]$. $pbest$ and $gbest$ guide the particles so that the particles can explore in a wider space, and at the same time endow the particles with a certain degree of intelligence, so that the particles are able to make use of their historical optimal position and global optimal position to continuously guide their search, allowing the population to continue to optimize. Constantly guiding its own search, allowing the population to be continuously optimized.

$$V_i = \omega V_i + c_1 r_1^*(\, pbest_i - X_i) + c_2 r_2^*(\, gbest\ - X_i) \quad (10)$$

3. The Effect of Air Purifier Shape on Purification Effectiveness

In a relatively enclosed space, the release of air pollutants is characterized by persistence and uncertainty, thus the use of air purifiers to purify indoor air is one of the internationally recognized methods to improve indoor air quality. So, the study must analyze the working principle of air purifier, consider the influence of its shape and appearance on the purification effect, and design the optimal shape and size of air purifier to maximize the purification effect.

3.1. Objective Function

To maximize the effect of the air purifier, this section study and analyze the shape of the purifier, the optimal size and so on. By regulating the air flow and purification efficiency model, it can get the following objective function:

$$f(x) = -(\eta \cdot Q(x)/A(x)) \quad (11)$$

Note, x denotes the parameters of the purifier, to achieve the maximum purification efficiency of $-f(x)$.

3.2. Constraints

(1)the form factor of the air purifier is limited by the space of the environment in which it is used.

(2)The production of air purifier needs to consider the cost of raw materials, processing costs and assembly costs.

(3)The shell material of the air purifier needs to have a certain degree of strength and durability to ensure that it will not be easily damaged during use.

(4)The shape design needs to match the internal purification technology and air flow technology.

3.3. Modeling

Through mathematical model building and Genetic Algorithm (GA), research made an analysis of the efficiency of the purifier based on the different shapes of the air purifier and designed the optimal shape and size of the air purifier.

3.3.1. Three-dimensional modeling

It is assumed that there is some kind of functional relationship between the purification effect and the length, width, and height:

$$E = f(l, w, h) \quad (12)$$

Note: l denotes length, w denotes width, and h denotes height.

This section draws the effect of different shapes of 3D graphics through the relevant data as shown in Figure 1.

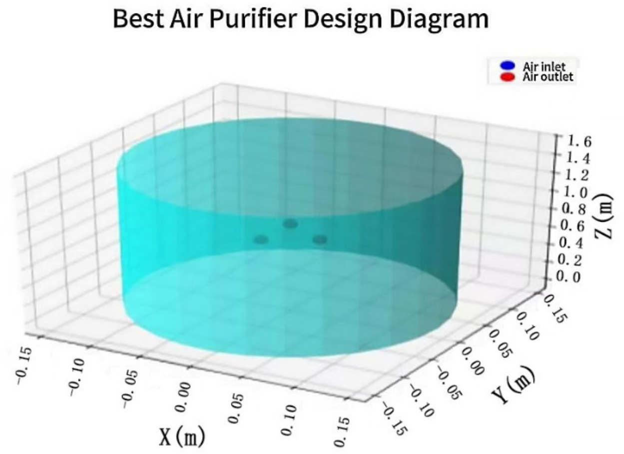

Figure 1. Three-dimensional graphic effect

3.3.2. Genetic Algorithm (GA)

The function can be defined as:

$$f(x) = Purification\ efficiency\ (x) \quad (13)$$

Note: x indicates each preset parameter of the air cleaner, such as length, width, material, etc.

(1)Chromosome Coding:

A set of parameters can be used to represent the shape of an air purifier. For example, for a simple cylindrical air purifier, parameters such as its height, diameter, inlet size and outlet size can be represented by chromosome coding. It is assumed that a chromosome consists of 4 genes corresponding to these 4 parameters.

(2)Initialize the Population

A certain number (e.g. $N = 100$) of chromosomes are randomly generated to form the initial population. Each chromosome represents an air purifier form factor. The parameter values in these chromosomes are randomly generated within a reasonable range.

(3)Defining the Fitness Function

The fitness function is used to evaluate the goodness of each chromosome (i.e., air purifier form design). The fitness function should be related to the purification effect of the air purifier. The purification effect can be evaluated by experimental data or theoretical models. We designed the optimal shape and size by selection, crossover, and mutation operations in genetic algorithm, plotted the 3D convergence curve, and got the optimization model diagram of air purifier, as shown in Figure 2.

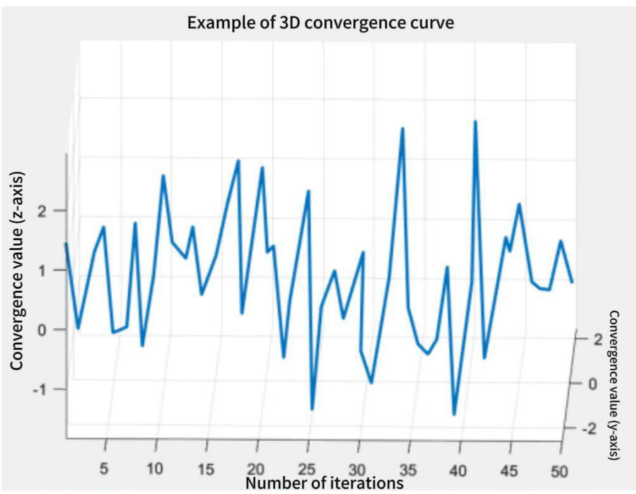

Figure 2. 3D convergence curve

(4)Selection Operation

Select some chromosomes from the current population as parents to produce the next generation.

(5)Crossover Operation

Crossover operation is performed on the selected parent chromosomes to produce new offspring chromosomes. Partial mapping crossover first selects two crossover points and copies part of the sequence of the parent to the corresponding position of the offspring, keeping the order of the operation reasonable.

For two parent chromosomes $Parent1 = [h1, d1, is1, os1]$ and $Parent2 = [h2, d2, is2, os2]$, a single-point crossover is used to crossover at the second gene (i.e., diameter d), which may produce children $Child1 = [h1, d2, is1, os1]$ and $Child2 = [h2, d1, is2, os2]$.

(6)Mutation Operations

Mutation operations are performed on the chromosomes of the offspring produced after crossover to introduce new genetic variants. A mutation operation usually involves randomly changing certain genes in a chromosome with a certain probability (e.g., mutation probability $Pm = 0.01$).

(7)Iterative Population Renewal

Repeat steps 4 - 6 until a certain number of iterations is reached (e.g. 1000) or the value of the best fitness in the population is no longer significantly improved over multiple generations.

(8)Determine the Optimal Solution

At the end of the iterations, the air cleaner shape represented by the chromosome with the highest fitness in the population is the best shape found by the genetic algorithm. Its corresponding parameter values are the optimal shape and size parameters.

4. Three-IN-One Optimization Analytics

This section introduces the effect of the shape of an air humidifier on the effectiveness of humidification, research build a multi-objective optimization model to map out the shape and size parameters of the best appearance using particle swarm optimization algorithm.

4.1. Factor Analysis

(1)Interaction Between Equipment

Air conditioners, air purifiers and air humidifiers operate in the same indoor environment and their air flow and function can affect each other.

(2)Integration of Environmental Parameters

Parameters such as temperature, humidity and pollutant concentration of the indoor environment are interrelated.

(3) Location and Number of Air Inlets and Outlets

Determine the efficiency of air circulation.

4.2. Constraints

(1)Physical Space Constraints

Lac, Lap, and Lah denote length; Wac, Wap, and Wah denote width; Wac, Wap, and Wah denote height, respectively.

$Lac + Lap + Lah <= L$ (Sum of equipment lengths does not exceed room length).

$Wac + Wap + Wah <= W$ (The sum of the widths of the equipment does not exceed the width of the room).

$Hac + Hap + Hah <= H$ (The sum of the equipment heights does not exceed the room height).

(2)Energy Consumption Constraints

Let the energy consumption of the air conditioner be EAC, the energy consumption of the air purifier be EAP, the energy consumption of the air humidifier be EAH, and the maximum total energy consumption that the room can withstand be Emax.

The constraints are:

$$EAC + EAP + EAH <= Emax \quad (14)$$

(3) Cost Constraints

Let the cost of the air conditioner be $CostAC$, the cost of the air purifier be $CostAP$, the cost of the air humidifier be $CostAH$, and the budgeted cost be $Costmax$.

The constraints are:

$$CostAC + CostAP + CostAH <= Costmax \quad (15)$$

4.3. Multi-Objective Optimization Analysis

Multi-objective optimization algorithms can deal with multiple optimization objectives at the same time, providing designers with richer selection samples as well as the distribution of optimal solutions, which is conducive to the analysis of key factors. In multi-objective optimization, the objective function is a mathematical expression used to measure the good or bad results of the optimization. For this section, the objective function aims to synthesize the four aspects of energy consumption (E), comfort (C), purification effect (P) and humidification effect (H). An objective function is established based on these four values.

4.3.1. Objective Function

The expression of the objective function is:

$$\begin{gathered} \text{Minimize } E = E0 - k1c - k2P - k3H \\ C >= \text{Cmin} \\ P >= \text{Pmin} \\ H >= H\text{min} \\ P \in [\text{ Pmin}, P\text{max}] \\ C \in [\text{ Cmin}, C\text{ max }] \\ H \in [\text{ Hmin,Hmax }] \end{gathered} \quad (16)$$

4.3.2. Particle Swarm Optimization Algorithm

(1) Initialize the particle swarm: determine the number of particles and initialize the position and velocity of each particle.

(2) Define the fitness function: set the fitness value of each particle as Z.

(3) Update the velocity and position of the particles.

The velocity updates the position:

$$V_i(t+1) = w\text{Vi}(t) + c1r1(Pi(t) - Xi(t)) + c2r2(G(t) - Xi(t)) \quad (17)$$

Position update formula:

$$Xi(t+1) = Xi(t) + Vi(t+1) \quad (18)$$

Where w is the inertia weight, $c1$ and $c2$ are acceleration constants, $r1$ and $r2$ are random numbers between 0 and 1, Pi is the individual optimal position of particle i, and G is the global optimal position.

(4) Iteration: Repeat the above steps until the maximum number of iterations is reached or the value of the fitness function converges.

The following heat map of particle distribution is shown Figure 3.

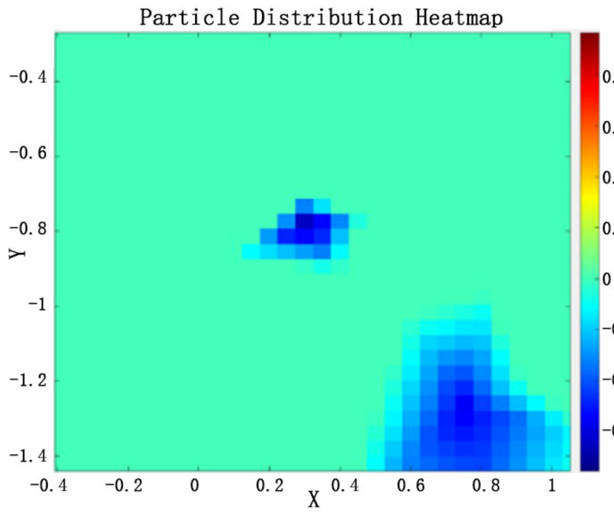

Figure 3. Heat map of particle distribution

5. Conclusion

In this study, the appearance of multifunctional environmental conditioning equipment is systematically analyzed and optimally designed through the application of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). In terms of performance enhancement of air conditioners, humidifiers and air purifiers, the study clarifies the key impacts of device shape, size and placement on their functional efficiency. First, for the optimal design of air conditioners, the application of particle swarm optimization (PSO) algorithm has successfully simulated the indoor temperature changes under different conditions, providing a scientific basis for the selection of the optimal shape and size. Secondly, genetic algorithm in the shape optimization of air purifier ensures the maximization of purification effect, which highlights the importance of shape design. Taken together, the multi-objective optimization model constructed in this study not only maximizes energy efficiency and air quality, but also provides an innovative solution for the aesthetics and practicality of the device.

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