Occupant seating optimization to reduce lighting energy consumption and improve comfort

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Abstract. Occupant presence and behavior are non-negligible factors affecting building energy consumption. It should be emphasized: guaranteed building core functions is a prerequisite for energy saving. This paper proposes a method that can minimize building energy consumption and improve occupant comfort. Through monitoring the entry and exit of a 24-person office, occupant presence is obtained. And the difference in comfort of occupants is investigated and analyzed. The occupant is moved to a seat that is more thermally comfortable. Then occupants with a high degree of overlap in-room time are gathered in the same lighting area to reduce lighting energy consumption. Through the multi-objective optimization model, the lighting energy consumption is reduced by 16.2%, and the overall indoor comfort is slightly improved.

1 Introduction

Global CO2 emissions have dropped sharply during the COVID-19 pandemic. But as the economy recovers, global CO2 emissions from energy combustion and industrial processes rebounded in 2021 to reach their highest ever annual level. To achieve the carbon neutrality, there is still a long way to go to reduce emissions. Building energy consumption has always been an important expenditure of social energy consumption. End-use energy for global building construction and building operations accounts for 35% of global energy consumption and contributes about 28% of global energy-related carbon monoxide emissions. With the improvement of the economy and infrastructure, the stock of construction areas in China continues to develop rapidly. As of 2018, China's construction area reached $6.01 \times 10^{10}$ $m^2$. This number will rise in the future as more projects are completed. The Rocky Mountain Institute (RMI) predicts that by 2050, the urbanization rate in China will reach 75%, and the total construction area (residential and commercial) will reach $8.5 \times 10^{10}$ $m^2$. Therefore, promoting building energy efficiency is an important way to move towards a zero-carbon China.

Some building structures (such as walls and windows) and internal equipment have been upgraded and optimized to achieve the effect of energy saving and emission reduction. Motalebi optimizes the integrated BIM-LCA framework for building energy retrofit projects that analyze projects from a sustainable perspective. By applying energy retrofit measures, 58% annual energy saving is achieved. By optimizing passive energy efficiency measures such as building orientation, window type, and window-to-wall ratio, N. Abdou achieved energy savings of more than 21% in buildings.

In addition to passive energy-saving measures for retrofitting houses, active energy-saving measures can also play a great role. Muhammad found active energy efficiency measures such as air-conditioning (AC), lighting control, thermostat setting, etc. The building energy performance index (EPI) can be reduced by about 63.5%. The energy consumption behavior of occupants is an important factor affecting building energy consumption. Human behavior has the potential to reduce building energy consumption by 10%-25%. Therefore, many studies have carried out analysis and optimization of human regulation behavior, so that the building can achieve the effect of energy saving. The more energy-using behaviors studied are: start-stop of air conditioner and its set temperature, opening and closing of windows, lighting, and regulation of sunshade devices. Humans spend most of their lives indoors. Human health, physical, and psychological activities are affected by the indoor environment. Therefore, while reducing building energy consumption, it is also necessary to ensure the comfort of indoor occupants. In Qing's research on optimizing green building retrofits, about 4% of energy can be saved by the optimal combination of building parameters. At the same time, the environmental comfort is improved. Afshin uses PCA-ANN to integrate NSGA-III to optimize dormitory building design. Among the overall best building alternatives, energy efficiency and daylight performance throughout the year and thermal comfort performance during free-running are improved by 41.27%, 42.24%, and 15.57%, respectively, over their reference model.

The above studies are all upgrading the hardware facilities or management systems of buildings to achieve the purpose of energy saving and emission reduction and improving comfort. Due to differences in human needs,
a single environment created by equipment such as air conditioners cannot meet the comfort needs of all occupants in a building[22]. None of the previous studies have considered matching personnel with the indoor microenvironment to achieve similar effects on the basis of reducing renovation costs.

2 Methodology

A method to match occupant comfort needs with the indoor microenvironment is proposed, which can reduce energy consumption and improve comfort at the same time. The method consists of two parts: (1) Based on actual measurements and experiments, the occupant comfort sensitivity and office environmental conditions are obtained. (2) Using the genetic algorithm model, the comfort level of occupants in different microenvironments and the energy consumption of indoor lighting are calculated, and the corresponding occupant seating arrangement is optimized.

2.1 Data collection

To test the proposed method, an office of a university in Beijing was used for actual data collection for 21 days. Located on the 11th floor of the building, the office has only one inner door and the exterior windows face south. There are 6 rows of desks in the office with 4 occupants in each row. The office is centrally heated by radiators in winter and cooled by two wall-mounted air conditioners in summer. Since the experimental period is the heating season, the air conditioner in the office has not been turned on, so the energy consumption mentioned later is the lighting energy consumption. There are 6 lighting fixtures of the same specification in the office, and the same fixture is responsible for the 4 adjacent desks. As shown in Figure 2, the area that the same luminaire is responsible for is called a lighting area. The office can be divided into 6 lighting zones.

Door and window sensors are installed on office windows and doors. Infrared pedestrian flow sensors are installed at the entrance. Temperature and humidity sensors, illuminance sensors, and noise sensors are installed in 3 locations in the office. The installation locations are shown in Figure 2, and some on-site installation diagrams are shown in Figure 3. In addition, the relevant environmental parameters are recorded manually in each area by means of portable measuring instruments.

Fig. 1. An overview of the research methodology.

An overview of the research methodology is shown in Figure 1. First, data on occupant behavior, occupant comfort, and different environmental seats in the room are collected. Second, the collected data is preprocessed, cleaned and integrated, and the occupant comfort-sensitive database and indoor environment database are built. Third, using the genetic algorithm, the positional arrangement of personnel is optimized on the existing data set. While the energy consumption is reduced, the thermal comfort, light comfort and sound comfort of personnel are improved.
sensitivity. Crew timetables are primarily recorded by manpower. Most of the instruments that record the flow of occupants on the market can only record the number of occupants entering and leaving the room, and it is impossible to identify who is going in and out. Therefore, the data of the infrared pedestrian flow sensor is only used for calibration verification. The indoor comfort of the occupants is mainly obtained through questionnaires. For thermal comfort, acoustic comfort and light comfort a 5-level link table is used. To prevent occupants from appearing to be middle-of-the-road, a negative scale was used for each rating (0=comfortable, -1=slightly uncomfortable, -2=uncomfortable, -3=extremely uncomfortable, -4=unbearable).

2.2 Data preprocessing

Data processing mainly includes three parts: data cleaning, data transformation and integration. During the experiment, some staff had a short time in the room due to business trips and other reasons. The number of completed questionnaires was not enough to support the subsequent analysis, so these occupants were excluded from the subsequent analysis. The occupant presence data was collected at a 10-minute interval, which was large and unintuitive. So it is aggregated as hourly in and out behavior. And for the convenience of subsequent optimization research, all data sources are assembled into the same format. Data sets are normalized to avoid single variable overflow.

2.3 Comfort sensitivity and microenvironment Scores

The comfort sensitivity of personnel is obtained through the statistics of questionnaire data and corresponding adjustment behaviors. The experiment mainly considers thermal and acoustic comfort sensitivity. First of all, because the illumination range of the office is 330~520lux, most of the occupants respond well, and everyone's light comfort sensitivity is taken as 1. Second, at the same temperature, those who reported that the questionnaires felt cooler had higher thermal comfort sensitivity. Similarly, occupants who actively conduct behavioral adjustments (such as closing windows and adding clothes) have higher thermal comfort sensitivity. Third, similar to thermal comfort sensitivity, acoustic comfort sensitivity is also composed of two parts. In the same acoustic environment, the occupants who feel the louder feedback are more sensitive to the sound. When there is noise outdoors, occupants who actively close windows and doors are more sensitive to sound. The two parts are weighted and summed, and each individual's comfort sensitivity is derived. The environmental thermal coefficient and sound coefficient are obtained by instrument measurement and weighting of occupant ratings. A 5-level link scale (larger means less comfortable) was used for occupant ratings. The larger the finally obtained environmental coefficient, the less ideal the environment is. The environmental coefficients of each seat are shown in Figures 4 and 5, where the seat numbers correspond to those in Figure 2. It is not the indoor light source that affects light comfort indoors. It is the sunlight that is projected into the office from the glass between the unreasonably installed curtains. From 9 am to 11 am, the two rows near the window will experience severe light discomfort due to direct sunlight or reflections from computer screens. Therefore, the light coefficient of this office environment is a function of time.

![Fig. 4. sound coefficient of office seating](image)

![Fig. 5. Thermal coefficient of office seating](image)

The crew room schedule for this office from 8:00 am to 23:00 pm is collected as shown in Figure 6. Because it is an office used by students in the school, there is no restriction on punching in and out of getting off work. And because of the arrangement of courses and experiments, students are less concentrated in indoor time. If occupants with similar indoor time are arranged together, it means that light requirements are concentrated, which saves lighting energy consumption.

![Fig. 6. occupant schedule from 8:00 to 23:00](image)
2.4 Multi-objective optimization based on genetic algorithm

The 24 seats are numbered, based on the initial seat correspondence relationship, and the initial positional arrangement relationship of occupants is regarded as a matrix, denoted as [a1, a2, a3,...a24]. The sum of indoor discomfort C is the sum of the discomfort of each person in the room.

\[ C = \sum_{i=1}^{24} p_i u_i \]  \hspace{1cm} (1)

Among them, i is the person in the room, P is the probability of the person appearing, and U is the discomfort of the person at the place where they leave, mainly considering the three aspects of sound, light and heat.

\[ U = S_t K_s + S_t K_r + \sum_{j=i}^{24} S_j K_s \]  \hspace{1cm} (2)

Among them, Ss is the sound sensitivity of occupants, Ks is the acoustic coefficient of the seat, Sr is the thermal sensitivity of the occupants, Kt is the thermal coefficient of the seat, St is the light sensitivity of the occupants, and Klt is the light coefficient of the seat.

The indoor lighting energy consumption B is

\[ B = \sum_{j=1}^{24} \left( 1 - \prod_{i=1}^{24} (1 - P_i) \right) w \]  \hspace{1cm} (3)

Among them, j represents the lighting area corresponding to each lamp tube, L corresponds to the personnel in the lighting area, and w is the energy consumption of a single lighting lamp, which is 15W.

The optimization of occupant comfort and energy consumption means that the arrangement and combination of occupants’ seats in the fixed office are reasonably reorganized. Occupant discomfort and interior energy consumption are reduced.

\[ \min \{ A(a_1, a_2, a_3,...a_{24}) \} \]
\[ \min \{ B(a_1, a_2, a_3,...a_{24}) \} \]  \hspace{1cm} (4)

An implicit constraint of this function is that there is at most one person at each location.

Based on the genetic algorithm, the above problem is solved optimally. It is found that energy consumption and discomfort cannot achieve the optimal solution at the same time. Therefore, the objective function dispersion ranking method is used to determine the function weight[23]. When there are g objective functions (m, n=1,2,3,...g), let the optimal solution of a single objective function be \( f_m(x) \), denoted as \( x_m \).

\[ f_m^n = f_m(x^n) \]  \hspace{1cm} (5)

Average dispersion for each objective function:

\[ \bar{\sigma}_m = \frac{1}{g-1} \sum_{m=1}^{g} (f_m^n - f_m^m) \]  \hspace{1cm} (6)

Weight factor:

\[ \lambda_i = \frac{\mu_i}{\sum_{n=1}^{g} \mu_n} \]  \hspace{1cm} (7)

3 Results and discussion

In order to balance the effective solution range, a larger objective function is usually multiplied by a smaller weight coefficient. The weights \( \lambda_1 = 0.16 \) and \( \lambda_2 = 0.84 \) are calculated by the objective function dispersion sorting method. The value of discomfort level B is larger in the above two objective functions. According to the combination principle, the aggregated objective function is:

\[ \min f = 0.16A + 0.18B \]  \hspace{1cm} (8)

In Figure 7, the difference between the occupant’s discomfort in the optimal solution scenario and the initial scenario is shown. The higher the difference, the better the comfort improvement effect. Occupants with improved comfort are represented by red in the graph, and occupants with reduced comfort are represented by blue in the graph. Although the overall occupant comfort of the room has been improved from the overall evaluation, the improvement effect is not obvious. In Figure 8, the effect of reducing the turn-on probability of lamps in each zone in the optimal scenario is shown compared to the base scenario. The higher the difference, the better the energy saving effect. In Figure 8, the blue part indicates that the light-on probability of the light zone increases, and the red part indicates that the light-on probability decreases. It can be seen intuitively from the figure that the overall turn-on probability of the lamps in this room decreases, achieving the effect of energy saving. The final optimization results show that 6.2% of the indoor lighting energy can be reduced, and overall occupant comfort has also improved.

Fig. 7. Optimisation of occupant comfort

Fig. 8. occupant schedule from 8:00 to 23:00
But this approach has certain limitations. When the indoor occupant changes, or is optimized for a new environment. Occupant comfort sensitivity needs to be re-measured. In addition, in some office buildings, the seating position of occupants may affect collaboration efficiency. In future research, work efficiency will be taken into consideration to form more pareto optimal solutions of the objective function. At the same time, the measurement conditions in summer are supplemented, and the energy consumption of air conditioners is supplemented.

4 Conclusion

This paper proposes an optimization method for occupant seats, which can improve occupant comfort and reduce lighting energy consumption without increasing any retrofit costs. The thermal, light and acoustic comfort sensitivity of each occupant was assessed through preliminary experimental measurements and statistics. The microenvironment of each seat in the office was assessed. Combined with the subjective scores of the occupants, the corresponding heat, light and sound environmental coefficients of each seat are obtained. Match occupant comfort needs with the seat microenvironment to improve occupant comfort without any optimization modifications. At the same time, the probability that the occupant is indoors hour by hour is recorded. Occupants with similar room time are grouped together to avoid unnecessary lighting energy consumption. Using a genetic algorithm, multi-objective optimization is carried out, which can reduce energy consumption and improve occupant comfort. The actual calculation example shows that in an open plan office with 24 office desks, the optimization method can reduce the energy of indoor lighting by 16.2%, and slightly improve occupant comfort.

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