Academic Journal of Management and Social Sciences
ISSN: 2958-4396 | Vol. 9, No. 3, 2024

A Multi-Area Illumination Adjustment Method based on Metro Passenger Flow

Junwei Fan *, Meijun Zhao [a], and Jianbo He [b]

Guangzhou Metro Design & Research Institute Co., Ltd., Guangzhou, Guangdong, China
*** Corresponding author:** Junwei Fan (Email: Fanjw_vip@163.com), [a] zhaomeijun@dtsjy.com, [b] chejianbo@dtsjy.com

Abstract: Lighting energy consumption in subway stations is an important part of energy consumption, and improving lighting energy efficiency in stations can effectively reduce overall energy consumption. The article proposes a multi-area, intelligent lighting control model based on passenger flow density to realize the dynamic adjustment of lighting intensity in each area, effectively enhance the energy efficiency of the subway lighting system and save subway operating costs. At the same time, this control model also helps to reduce energy consumption and carbon emissions, and promote the sustainable development of urban transportation.

Keywords: Multi-Area; Intelligent Lighting; Illumination Adjustment; Passenger Flow.

1. Introduction

Amidst the increasingly severe global climate change, countries worldwide are taking proactive measures to reduce carbon emissions and promote green, sustainable development. As an environmentally friendly mode of public transportation, subways significantly reduce urban traffic congestion and play a crucial role in lowering greenhouse gas emissions. Data from Guangzhou Metro operations indicates that lighting within subway stations accounts for 15% to 20% of total energy consumption. Therefore, enhancing lighting efficiency in subway stations can effectively reduce energy use and subsequently lower carbon emissions. Moreover, appropriate lighting levels contribute to passenger comfort while also improving travel safety [1].

Traditional lighting control generally relies on fixed schedules or predefined brightness standards, adjusting lighting based on preset times such as morning, noon, and evening. However, this approach falls short in adapting to continuously fluctuating passenger flow and is thus limited in energy-saving effectiveness. Additionally, different areas of a subway station—such as waiting areas, entrances, escalators, and corridors—require varied lighting levels. Implementing a rational, multi-zone lighting control strategy that dynamically adjusts illumination according to passenger flow in each area is essential. By tailoring illumination levels to real-time passenger density across zones, passenger safety and comfort can be maintained, and energy efficiency is significantly enhanced. Although existing studies have explored sensor-based lighting control, most current models in practical applications focus on single-zone control strategies, lacking research on coordinated control across multiple zones. Therefore, designing a comprehensive, efficient intelligent lighting control model that accounts for passenger density, lighting requirements, and safety constraints across multiple zones remains a valuable area for further research.

This study proposes an intelligent lighting control model for multi-zone subway environments based on passenger density, aiming to achieve precise illumination adjustments across various areas. By incorporating factors such as passenger density and illumination requirements for each zone, we propose a dynamic lighting control strategy to meet the diverse lighting needs of different areas and times. This approach enhances the energy efficiency of subway lighting systems, ensures passenger safety and comfort, and actively contributes to low-carbon urban development. Ultimately, it helps reduce energy consumption and carbon emissions, advancing sustainable development in urban transportation.

2. Current State of Subway Station Lighting

2.1. Classification of Subway Station Lighting

Subway station lighting can be categorized based on its functional purposes into general lighting, emergency lighting, guidance lighting, advertising lighting, and safety lighting. Emergency lighting is classified as a primary load, while general lighting, guidance lighting, and safety lighting are typically secondary loads, and advertising lighting is a tertiary load [2].

Additionally, based on usage areas, subway station lighting can be divided into three main types: tunnel lighting, equipment area lighting, and public area lighting. Tunnel lighting is designed for train operation and stopping areas, providing a safe operational environment for subway trains. Equipment area lighting includes station equipment rooms, management rooms, and equipment corridors, primarily accessible only to subway personnel. Public area lighting covers areas frequently accessed by passengers, such as station concourses, platforms, and entrances/exits. As the public area is the most heavily trafficked, its lighting significantly impacts overall energy consumption, accounting for more than 90% of total lighting energy use.

2.2. Dimming Zones and Illumination Standards in Subway Stations

2.2.1. Division of Public Areas in Subway Stations

Lighting in subway station public areas is primarily intended to provide passengers with a safe and comfortable environment. Since passenger distribution within the station is uneven and varies significantly across different areas and times, public areas should be divided into distinct dimming zones based on passenger distribution, in accordance with relevant lighting codes and standards. These zones include the passenger movement area, transition zones, passenger resting areas, automated ticketing and validation areas, manual ticketing halls, advertising lighting zones, and entrance/exit areas, as shown in Figures 1 and 2.

Figure 1. Illumination Zoning Diagram for Concourse Level

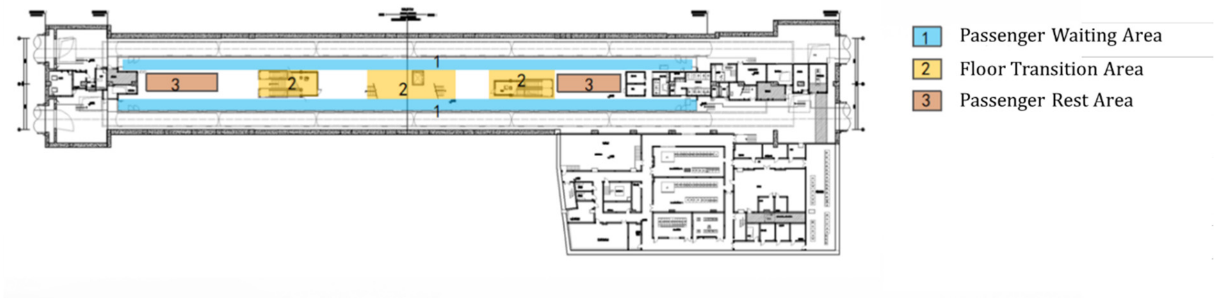

Figure 2. Illumination Zoning Diagram for Platform Level

2.2.2. Illumination Standards for Dimming Zones

Table 1. Illumination standards for different areas in subway stations

Category	Reference Surface	Illumination Standard (lx)
Entrance/Passageway/Flow Area	Floor	150
Staircases/Escalators	Floor	150
Underground/Ground Concourse	Concourse Surface	200/100
Underground/Ground Platform	Platform Surface	150/100
Ticketing Counters/Validation Gates	Counter Surface	300

The current national standards specify illumination levels for different public areas within subway stations. According to the latest GB/T 50034-2024 Building Lighting Design Standard, illumination levels are categorized as 0.5 lx, 1 lx, 2 lx, 3 lx, 5 lx, 10 lx, 15 lx, 20 lx, 30 lx, 50 lx, 75 lx, 100 lx, 150 lx, 200 lx, 300 lx, 500 lx, 750 lx, 1000 lx, 1500 lx, 2000 lx, 3000 lx, and 5000 lx [3]. It is evident that illumination requirements vary significantly across different areas, with standard values for subway public areas generally ranging between 100 and 300 lx, as shown in Table 1.

According to Article 5.3 of GB/T 16275-2008 Urban Rail Transit Lighting [4], the illumination level in public areas such as station platforms, concourses, and corridors may be adjusted up or down by one lighting grade, depending on building classification, usage conditions, and regional factors. Therefore, the illumination adjustment range is 150–300 lx for concourses and 100–200 lx for platforms.

2.2.3. Current Illumination Status in Subways

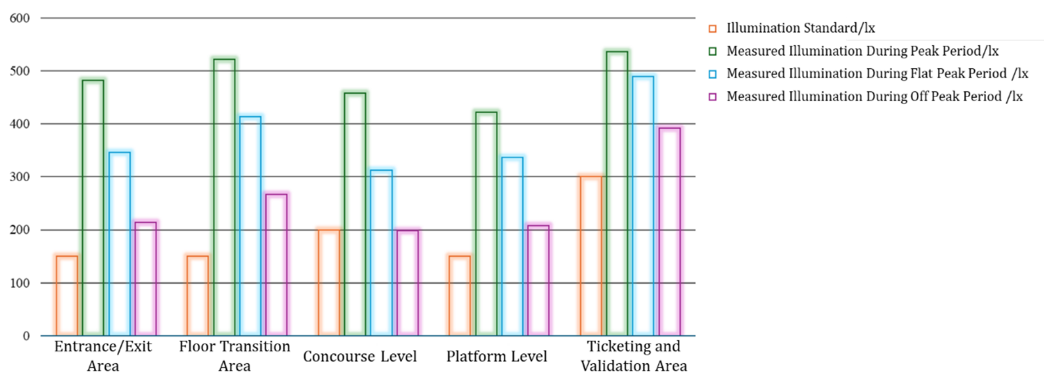

Figure 3. Measured illuminance values in various areas of the metro station

Although national standards clearly specify the illumination levels for public areas in subways, stations that control lighting based on time intervals often experience excessive illumination levels. For example, an illumination test conducted in the public areas of a station on the Guangzhou Metro revealed that illumination frequently exceeded the standard values by a large margin, as shown in Figure 3. This indicates that there is significant room for optimization in the current subway station lighting systems to improve illumination control. Properly adjusting the lighting levels can reduce unnecessary energy consumption while ensuring a comfortable experience for passengers, achieving a balance between lighting effectiveness and energy efficiency.

2.3. Illumination Limits for Different Dimming Zones

Studies in lighting-related literature suggest that higher illumination levels help improve people's comfort and satisfaction. Therefore, from the perspective of passengers, higher illumination in subway station public areas may seem desirable. However, higher illumination also leads to increased energy consumption and operational costs. As a result, implementing graded illumination standards for different public areas of the station is a more cost-effective approach.

Considering the uneven distribution of passengers within a subway station, higher illumination can be applied to areas with heavy traffic and frequent activity to meet the visual needs of the majority of passengers. In areas with fewer passengers or less activity, illumination can be appropriately reduced to minimize unnecessary energy consumption.

According to the GB/T 50034-2024 Building Lighting Design Standard and other relevant codes, the illumination standard refers to the required illumination level during normal operation. The GB/T 16275-2008 Urban Rail Transit Lighting standard allows for increasing or decreasing the illumination level in subway concourses, halls, and corridors by one lighting grade based on actual conditions. Therefore, the illumination limits for various public areas in the subway are summarized in Table 2.

Table 2. Illumination limits for various areas in subway stations

Category	Illumination Standard (lx)	Minimum Illumination (lx)	Maximum Illumination (lx)
Passenger Flow Area	200	150	300
Floor Transition Area	150	150	200
Passenger Rest Area	150	100	200
Automated Ticketing and Validation Area	300	300	500
Passenger Waiting Area	150	150	200
Advertising Lighting Area	100	50	150
Entrance/Exit Area	200	150	300

3. Zonal Illumination Adjustment Model based on Passenger Flow Control

The significant fluctuations in subway passenger flow, particularly the large differences between peak and off-peak hours, require that the lighting system dynamically adjust according to real-time passenger volume. Additionally, varying passenger density, functional requirements, and safety considerations across different areas of the station create differing illumination needs. For example, areas such as platforms, corridors, and entrances/exits each have unique patterns of passenger density variation, necessitating distinct lighting control strategies for each zone.

To address this, this study proposes a zonal intelligent lighting control strategy based on passenger density. This model dynamically adjusts illumination levels in different public areas of subway stations according to real-time changes in passenger flow. The aim is to enhance energy efficiency while ensuring passenger safety and comfort.

$$E_{f_i} = \begin{cases} \min\left(E_{\max_i}, E_{\text{base}_i} \times \left(1 + k_{1_i} \times \left(\rho_{\text{f}_i} - \rho_{\text{high}_i}\right)\right)\right) & ,if\ \rho_{\text{f}_i} \geq \rho_{\text{high}_i} \\ E_{\text{base}_i} & ,if\ \rho_{\text{low}_i} < \rho_{\text{f}_i} < \rho_{\text{high}_i} \\ \min\left(E_{\max_i}, \max(\phi_{\min_i}, \phi_{\text{base}_i} \times \left(1 - k_{2_i} \times \left(\rho_{\text{low}_i} - \rho_{\text{f}_i}\right)\right)\right) & ,if\ \rho_{\text{f}_i} \leq \rho_{\text{low}_i} \\ E_{\text{base}_i} \times m_i & ,if\ \text{night} \end{cases} \tag{1}$$

$$\rho_{\text{f}_i} = \left\lfloor \frac{N_i}{S_i} \right\rfloor \tag{2}$$

$$\phi_i = \frac{E_{f_i} \times S_i}{k_{u_i} \times k_{w_i}} \tag{3}$$

$$P_{i,j} = \frac{\phi_i}{M_i \times \eta_j} \tag{4}$$

$$W_i = \sum_{n=1}^{N} \sum_{t=1}^{T} P_{i,j} \times T \tag{5}$$

Where E_{f_i} represent the actual illumination level in area *i*, lx ;

E_{base_i} represent the reference illumination level in area *i*, lx ;

E_{high_i} and E_{low_i} represent the maximum and minimum illumination levels in area i, respectively, lx ;

k_1 and k_2 represent the high and low illumination adjustment coefficients in area i, respectively, typically ranging from 0.2 to 0.5;

ρ_{f_i} represent the actual passenger flow density in area i, person/m^2;

ρ_{high_i} and ρ_{low_i} represent the maximum and minimum passenger flow densities in area i, respectively, person/m^2;

m_i represent the minimum illumination coefficient in area i during nighttime periods, person/m^2;

N_i and M_i represent the total number of passengers and the total number of light fixtures in area i, respectively;

S_i represent the area of the region i, m^2;

ϕ_i represent the luminous flux in area i, lm;

$\overline{k_{u_i}}$ and $\overline{k_{w_i}}$ represent the average utilization factor and the average maintenance factor of the lighting fixtures in area i, respectively;

$P_{i,j}$ represent the actual power consumption of fixture j in area i, respectively, W;

η_j represent the luminous efficacy of fixture j in area i;

W_i represent the total power consumption of lighting fixtures in area i;

Based on the design requirements for urban rail transit outlined in relevant standards, such as the Code for Design of Metro (GB 50157-2013), Code for Urban Rail Transit Engineering Projects (GB 55033-2022), and Load Code for the Design of Building Structures (GB 50009-2012), the reference values for crowd density in different areas of subway stations are as follows:

Table 3. The reference values for crowd density in subway stations

Category	ρ_{high_i} (person/m^2)	ρ_{low_i} (person/m^2)
Passenger Flow Area	6	2
Floor Transition Area	6	2
Passenger Rest Area	5	1
Automated Ticketing and Validation Area	7	2
Passenger Waiting Area	6	2
Advertising Lighting Area	5	3
Entrance/Exit Area	5	1

4. Example Analysis

4.1. Changes of Illuminance Under Different Control Methods

Taking a station of Guangzhou Metro as an example, the public area of the station is divided as shown in Fig. 1 and Fig. 2, and according to the actual data of the operation center in January 2024, the illuminance values of each area of the public area of the station under different passenger flow scenarios are shown in Fig. 4.

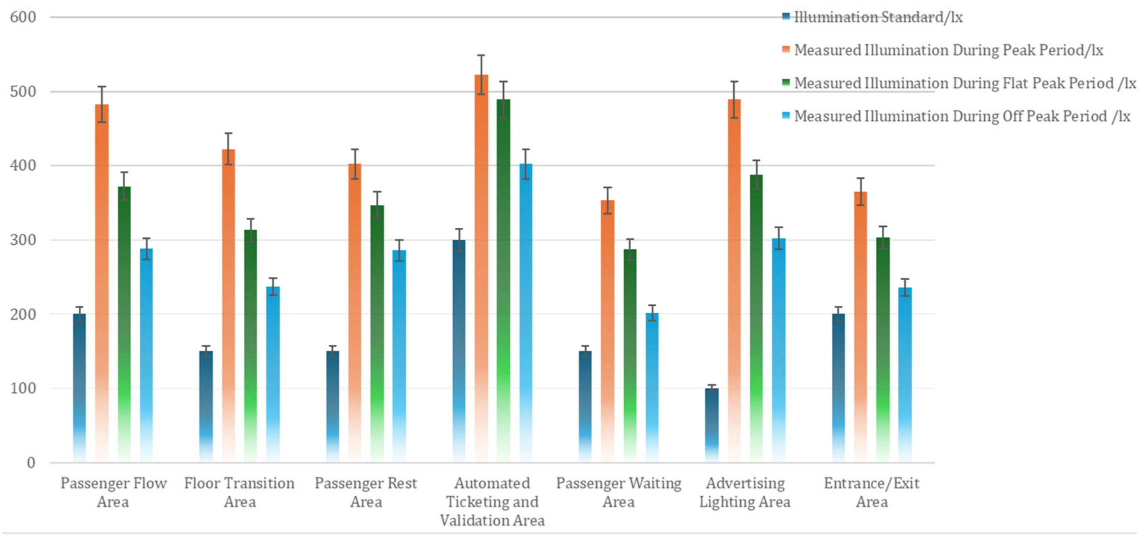

Figure 4. Illuminance values for each area under conventional control methods

As can be seen in the figure, the actual illuminance value of most areas is much higher than the standard value of illuminance stipulated in the specification, and the change of illuminance of some areas is not obvious in different time of passenger flow, which is not conducive to the saving of energy consumption. After applying the multi-area illuminance control method based on passenger flow regulation proposed in this paper, the illuminance value of each area in different time periods is shown in Figure 5.

As can be seen from Figure 5, after applying the multi-region passenger flow illumination control method proposed in this paper, the illumination limit of each public area of the station is well controlled, and there are more obvious changes in the illumination during different passenger flow hours, which can save the utilization of resources.

4.2. Energy Consumption Comparison and Cost Analysis

According to the station meter data statistics, before and after the application of the illumination control proposed in this paper, the lighting energy consumption in each area of the station is shown in Figure 6, it can be seen that, compared with the traditional illumination control method, after the application of the subarea illumination control strategy based on passenger flow control, the energy consumption of each area has been reduced to a different degree, and the total energy and cost saving rate reaches 30%.

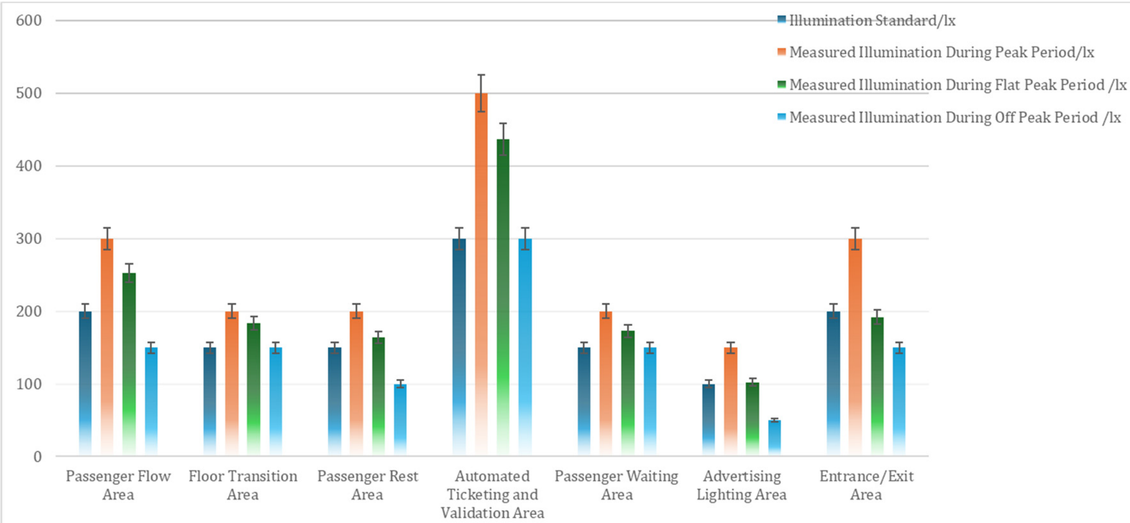

Figure 5. Illuminance values for each area under the passenger flow regulation method

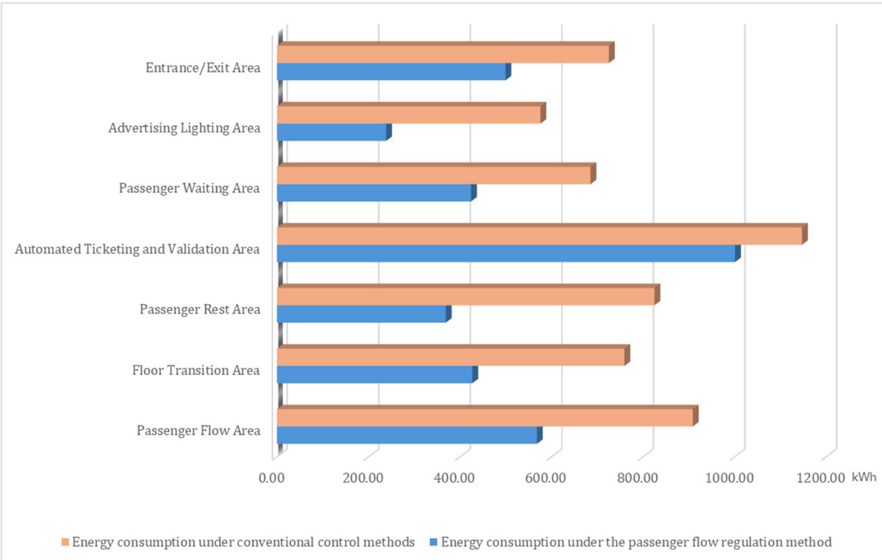

Figure 6. Comparison of energy consumption in two control modes

5. Conclusion

For the public area of the subway station, the traditional lighting control method cannot effectively respond to the changing passenger demand, this paper proposes a multi-area, intelligent lighting control model based on passenger density, can be combined with the density of the passenger flow in each area, illuminance limitation requirements, and other factors, dynamically adjust the subway station illumination of the different public areas, to protect the safety of the passengers, comfort, and the specification of the illuminance limitations, while effectively enhance the energy efficiency of the subway lighting system and save subway operating costs.

References

[1] Y. Tang, Y. Liu, YC Du, Y Jiang: Study on Dynamic Dimming Control for Public Area Lighting in Subway Stations (Modern Urban Rail Transit), Vol. 09 (2023) p.100-106. (In Chinese).

[2] G.Y. Mu, X.L. Li, L.M. Yin: Analysis of energy consumption and energy saving countermeasures of subway station lighting system (Urban Rail Transportation Research), Vol. 13 (2010), No.8, p.100-106. (In Chinese).

[3] GB/T 50034-2024, Building Lighting Design Standard.

[4] GB/T 16275-2008, Urban Rail Transit Lighting.