



Analysis of the Requirements of the Elevator Emergency Lighting Device based on Ergonomics

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Abstract. The requirements of elevator emergency lighting device are not clear in view of the domestic and international standards. This paper analyses the requirements of standards, parameter, wiring and other aspects, based on the principle of human ergonomics. Finally, this paper explains the requirements of the elevator emergency lighting device on the minimum time, capacity, maintenance illuminance and other requirements, combined with the actual situation and reference to the relevant scholars.

Keywords: Elevator, Emergency lighting devices, Ergonomics

1 Introduction

Elevator is the mechanical and electrical equipment driven by power, lifting or transporting people and goods in parallel by using the box running along the rigid guide rail or the steps running along the fixed line^[1]. With the continuous development of society, as an important machine in the process of urban development, the number of elevators is increasing, and the growth rate is obvious. By the end of 2023, China had 10.63 million elevators, accounting for 50% of the total number of special equipment^[2]. Although the design, manufacture and installation of the elevator with the function of transporting personnel consider multiple safety protection for personnel, it still can not guarantee the absolute safe operation of the equipment, so it can not guarantee the absolute safety of personnel. In 2022, there were 22 elevator accidents in China, 17 people died, and the death toll of 10000 sets of equipment was 0.017, far lower than the control target of no more than 0.46 issued by the State Council work safety commission. Today, reports of people trapped in the car due to elevator failure or power failure are still available in the media. Not only in China, but also in western industrial developed countries, the incidents of "elevator trapped people" often occur. Only through en 81-1, en 115-1 and other standards to install emergency alarm device, emergency lighting, the car must have vent and other measures to reduce the risk of people trapped in the car. According

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to the methods of risk assessment and reduction, and referring to the practices of other countries in the world, China has stipulated that emergency lighting devices must be installed in relevant technical standards^[3-4]. As an important measure to reduce the risk of "elevator trapped people", some requirements of the standard on emergency lighting are not clear, and there is no publicity and implementation data, official interpretation documents and so on^[5].

Ergonomics takes the system composed of human machine environment as the research object, and ultimately achieves the best matching of the entire system^[6]. Since Sweden first established the International Ergonomics Association (IEA) in 1961, ergonomics has been widely applied and developed in industrial production. As an important research branch of ergonomics, visual ergonomics mainly studies the normal physiological values of human visual channels to achieve the best work efficiency, safety, and comfort in science^[7]. Therefore, applying the theoretical principles and research results of ergonomics to the design and manufacturing of elevator emergency lighting devices can effectively enhance the role and effectiveness of elevator emergency lighting devices for trapped passengers, thereby reducing the safety risks caused by elevator trapping.

At present, many scholars have conducted research on the design of elevator emergency lighting devices, including design parameters and manufacturing processes^[8-9], but there is a lack of research from an ergonomic perspective. Therefore, starting from the principles of ergonomics, this article comprehensively studies the key core technical indicators of elevator emergency lighting devices.

2 Configuration Scope

As an important technical specification to guide and standardize the elevator design, manufacturing, installation, transformation, repair, daily maintenance and responsibilities of users and inspection units, TSG T7001-2023, which is the regulation for lift supervisory inspection and periodical inspection in China, clearly stipulates that traction and forced drive elevators, firefighter elevators, explosion-proof elevators and hydraulic elevators should be equipped with emergency lighting meeting the following requirements - when the normal lighting power supply is interrupted, the emergency lighting power supply can be automatically connected^[10]. In terms of technical content, GB 7588-2003, which is equivalent to en 81-1:1998 of European Committee for Standardization (CEN), stipulates in article 8.17.4 that there shall be an emergency lighting power supply with automatic recharging, which can supply at least 1 W bulb for 1 hour in case of interruption of normal lighting power supply. In case of failure of normal lighting power supply, emergency lighting power supply shall be automatically connected^[11].

Therefore, all elevators that can transport passengers in the car are required to be equipped with emergency lighting devices, while escalators, moving walks and utility elevators are not required because they are not transported by the car or do not transport passengers^[12].

3 Analysis of Parameter Requirements

As an important measure to reduce the safety risk of trapped people in emergency, emergency lighting device must at least have the following two functions: button lighting and passenger stability^[13-14]. Therefore, the trapped people can identify the emergency alarm device, precautions, safety instructions and other contents in the car with only emergency lighting, and achieve the role of stability.

According to the construction industry standard, emergency lighting refers to lighting activated due to failure of normal lighting power supply, including evacuation lighting, safety lighting and standby lighting^[15]. According to the function of button lighting, emergency lighting is similar to evacuation lighting, that is, lighting used to ensure effective identification and use; according to the function of passenger stability, emergency lighting belongs to safety lighting, that is, emergency lighting used to ensure the safety of people in potential danger. Therefore, the emergency lighting device should take into account the requirements of evacuation lighting and safety lighting, and from the high requirements.

3.1 Minimum Time Requirements

As for the time requirement of emergency lighting, firstly refer to the relevant standards of the construction industry: JGJ 16-2008 requires that the minimum continuous power supply time of evacuation lighting shall not be less than 30 minutes; GB 50045-95(2005 Edition) requires that the continuous power supply time of emergency lighting shall not be less than 20 minutes, and that of high-rise buildings shall not be less than 30 minutes; GB 17945-2010 requires that the emergency working time shall not be less than 90 minutes. The above standards have different emphases, so the requirements are not the same.

Then review the elevator standard GB 7588-2003, which requires emergency lighting devices to provide at least 1 W bulb for 1 hour, but it is not clear whether 1 W and 1 hour are the minimum requirements that must be met at the same time. For this reason, we can make the following assumption: if only the requirement is to provide at least 1 W bulb power for 1 hour, that is, to provide at least 1 Wh of energy, the requirement only specifies the power storage capacity, which has little connection with the role of emergency lighting devices; even if at least 1 A circuit power for 1 hour", that is, the requirement with at least 1 Ah power storage capacity is more relevant to the actual situation. Therefore, the 1 W and 1 hour required by the standard are the minimum requirements, which must be met at the same time, that is, the bulb of emergency lighting device should be at least 1 W, and can use electricity for at least 1 hour.

According to the results of ergonomics research, people will feel anxious after staying in a closed narrow environment for 30 minutes, but they will breathe faster and feel irritable after more than 1 hour^[16]. Therefore, when people are trapped in the elevator, the best rescue time is within 30 minutes, and if they are not rescued after more than 1 hour, it should be avoided as far as possible. At the same time, considering the actual time taken by elevator maintenance personnel to rush to the scene to implement rescue, Article 15 of TSG T5001-2009 stipulates that the arrival time of municipalities directly

under the central government or cities divided into districts shall not exceed 30 minutes, and that of other regions shall not exceed 1 hour generally.

According to the above analysis, the standard requires that the minimum duration of emergency lighting device is 1 hour, which not only considers the risk of personnel trapped, but also combines with the actual rescue status, which is a more reasonable requirement^[17].

3.2 Minimum Capacity Requirements

According to the definition of emergency lighting, the elevator emergency lighting device belongs to self-contained emergency lighting, that is a continuous or non continuous emergency lighting device^[18]. At present, due to the stable and reliable power supply, no switching time and less investment of the battery device, the battery device is often used in the emergency power supply, usually sealed nickel cadmium battery or valve regulated lead-acid battery, which is mainly placed in the middle position of the car roof, shaft or control cabinet^[16], such as figure 1. The cadmium nickel battery should be able to work under the limit conditions of maximum continuous overcharge rate of $0.08C_5(a)$ and maximum discharge rate of $0.6C_5$ for one hour, while the lead-acid battery should be able to work under the limit conditions of maximum charging current of $0.4C_{20}$ and maximum discharge rate of $0.4C_{20}$ for 1 hour. According to the conclusion in the previous section, emergency lighting devices should be powered for at least 1 hour, referring to the actual situation of the same 1 W emergency lighting lamps, the author thinks that the capacity of emergency lighting battery should not be less than 300 mAh, and if high-power bulb or long reuse time is required, the capacity of battery can be as high as 2 Ah or even higher^[19-20].



(a) car roof



(b) control cabinet

Fig. 1. Installation position of battery for elevator emergency lighting device

In addition, GB 50052-2009 stipulates that under normal operation, the voltage deviation at the terminals of the electrical equipment for emergency lighting should be $+5\% \sim -10\%$ of the rated voltage, which is different from $\pm 7\%$ of the input voltage fluctuation deviation of the whole elevator power supply.

3.3 Minimum Maintenance Illumination Requirements

At present, in the elevator industry caused widespread controversy, mainly in the emergency lighting illumination requirements. As an important device to directly protect the safety of passengers, the elevator emergency lighting device belongs to important inspection items in the safety technical specifications, that is, if one item does not meet the requirements, it can be determined that the elevator is unqualified. However, in recent years, there are some elevators that can not play a practical role due to low illumination and too hidden placement position, although the emergency lighting device is installed in the market. There is no quantitative requirement, which brings great confusion to elevator regulatory departments, inspection institutions, maintenance units and other relevant units.

According to the two functions of emergency lighting in CEN, if there is no other explanation except for the alarm button in the car, the method of placing the light bulb in a translucent alarm button can directly tell the personnel the position of the alarm button, and at the same time play the role of stabilizing passengers, so it meets the requirements. This view is also consistent with the response given by CEN.

TSG T5001-2009 clearly stipulates that the user should place the safety precautions and warning signs of elevator use in the prominent position that passengers are easy to pay attention to, indicate the name of the user management unit, emergency rescue telephone number, the name of maintenance unit and their emergency repair and complaint telephone number in the prominent position of the elevator. These instructions include the disposal methods after the occurrence of "elevator trapped persons". In 2011, Ningbo Municipal Bureau of quality and Technical Supervision issued a document requiring that, the use of emergency lighting should be able to clearly identify when the car is powered off. This means that illumination requirements are not dispensable.

GB/T 13379-2008 requires that the illumination value of safety lighting should not be less than 5% of the general illumination value of the place, and the minimum illumination value of evacuation lighting should not be less than 0.5 Lx. At the same time, the elevator car should be equipped with electrical lighting device, the illumination on the control device should not be less than 50 Lx, and the illumination on the car floor should not be less than 50 Lx. According to the above requirements and taking the high value, it can be calculated that the elevator car should have at least 2.5 Lx after the elevator emergency lighting device works.

Although there is no illumination requirement in the standard, it defines 1 W bulb, that is, incandescent lamp. The luminous efficiency of general incandescent lamps is about 7-20 Lm / W, and that of most domestic incandescent lamps is 15 Lm / W^[21]. According to the formula $1 \text{ Lx} = 1 \text{ Lm} / \text{m}^2$, the basic illumination requirement of emergency lighting can be estimated. However, it is noted that CEN replied in its No.549 explanation that emergency lighting should have at least 1 Lx illumination on the emergency alarm device (alarm button and instructions).

Although some quantitative requirements of emergency lighting illuminance are obtained or calculated according to many standards, it is necessary to elaborate the concept of illuminance first. Illuminance refers to luminous intensity per unit area. Some

scholars have studied the minimum maintenance illuminance of lighting devices in different scenarios based on ergonomic principles, namely: the maintenance illumination of reading lighting should not be less than 300 Lx^[22], and the visual acuity should be close to normal in a short time when it is 100 Lx; and the night indicator lighting should not be less than 5 Lx^[23]. Some scholars point out that the minimum illumination that can be distinguished under the premise of satisfying human visual effect is about 1Lx(0.65-1.02 Lx)^[24].

By comprehensively comparing the requirements of various standards and combining with the principle of ergonomics, the author thinks that when only the emergency lighting device provides the light source, the car personnel should be able to easily identify the emergency alarm button and the relevant instructions, that is, there should be at least 2.5 Lx illumination at the emergency alarm button and at least 1Lx illumination at the emergency alarm instructions.

3.4 Other Requirements

As a self-contained emergency lamp, emergency lighting should meet the requirements of GB 7000.2, especially the following points^[25]:

- a) Bulbs should be used instead of fluorescent lamps with built-in glow starters;
- b) The battery shall be charged by normal power supply;
- c) The battery shall work normally for at least 4 years;
- d) There shall be no switch between the battery and the emergency lighting source(except for the conversion device);
- e) Protection measures should be taken to avoid polarity reversal and excessive discharge of individual batteries;
- f) It not be affected by short circuit, touching ground or interruption in normal power supply line.

4 Analysis of Wiring Requirements

GB 7588-2003 stipulates that emergency lighting power supply shall be automatically connected in case of failure of normal lighting power supply. Figure 2 is a wiring diagram of power box which is widely used. Only when the emergency lighting power box detects that the normal lighting line(input)is cut off, the output end will start to work, providing corresponding voltage power supply for emergency lighting, emergency alarm and intercom system respectively.

At the same time, the standard requires that the main switch of elevator should not cut off the power supply circuit of car lighting and alarm device, such as figure 3. If the former method is adopted, the possibility of power failure caused by factors other than elevator should be avoided. At present, elevators in use in our country generally adopt the latter method, that is, the power supply for lighting, socket and alarm device is provided by the lead at the power supply end of main switch^[26-27].

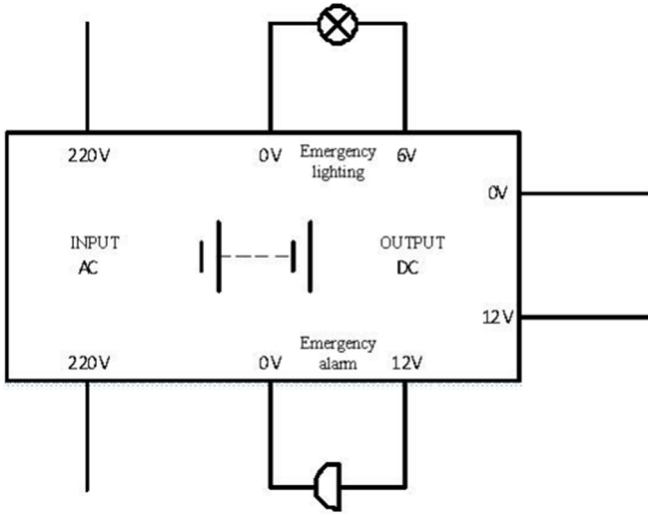


Fig. 2. Wiring diagram of emergency lighting power box

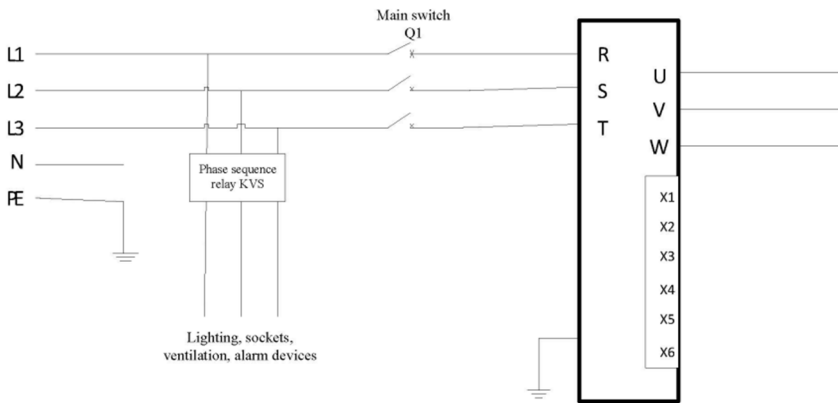


Fig. 3. Elevator main circuit diagram

Therefore, when testing whether the emergency lighting device is effective or not, the air switch controlling lighting in the distribution box should be directly disconnected. When the emergency lighting device detects that the car lighting circuit is powered off, it will automatically turn on the emergency power supply to work. At this time, it is meaningless to just turn off the main switch, because the main switch cannot cut off the power supply of lighting, socket, ventilation and alarm devices.

5 Instance Validation

In order to verify the effectiveness and scientificity of the above parameter indicators, this study selected 21 healthy and emotionally stable participants to simulate a normal elevator passenger being trapped in the elevator due to a power outage from an external power source. The trapped elevator personnel sought help according to the requirements of the emergency alarm instructions when maintaining only 1 Lx of illumination, touched the emergency alarm button with only 2.5 Lx of illumination to send a distress call to the outside world, and waited for rescue in the elevator car for 30 minutes until 1 hour. The emotional status of each trapped person was recorded one by one, see tables 1 and 2 for details. Mild discomfort includes conditions such as stuffiness, moderate discomfort includes conditions such as panic and restlessness, and severe discomfort includes conditions such as panic and shortness of breath. The selected 21 participants were divided into three groups based on adult males, adult females, and underage students, with 7 participants in each group. According to the difficulty level of identifying trapped individuals under emergency alarm instructions with only 1 Lx of maintained illumination, they are divided into three groups: easy to identify (able to identify immediately), careful to identify (requiring word for word recognition), and difficult to identify (unable to identify the instructions). According to the difficulty level of the trapped person in finding and operating the emergency alarm button with only 2.5 Lx of maintained illumination, it is divided into three groups: easy to identify (able to find and operate immediately), careful to identify (requiring careful searching and slow operation), and difficult to identify (difficult to find or operate).

Table 1. Emotional state of elevator trapped people

grouping emotional state	trapped for 30 minutes			trapped for 1 hour		
	mild discomfort	moderate discomfort	severe discomfort	mild discomfort	moderate discomfort	severe discomfort
adult male	7	0	0	6	1	0
adult female	5	2	0	3	3	1
underage students	5	1	1	1	4	2

Table 2. Identification of elevator trapped people

grouping emotional state	emergency alarm instructions for maintaining illumination at 1 Lx			emergency alarm button for maintaining illumination at 2.5 Lx		
	easy to recognize	medium difficulty to recognize	hard to recognize	easy to recognize	medium difficulty to recognize	hard to recognize
adult male	4	2	1	5	2	0
adult female	3	2	2	5	1	1
underage students	2	3	2	4	1	2

6 Conclusions

This paper conducts an analysis on the requirements of parameter, wiring and other aspects, based on the principle of human ergonomics. What's more, this paper makes a comprehensive comparison of the minimum time, minimum capacity, minimum maintenance illuminance, and other requirements of emergency lighting devices systematically, combined with the research theory and conclusions of ergonomics. Finally, this paper identifies several key parameter indicators for elevator emergency lighting device, namely: a minimum duration of 1 hour, a maintenance illuminance of 2.5 Lx at the emergency alarm button, and a maintenance illuminance of 1 Lx at the emergency alarm usage instruction. Based on the research results in the previous section, the requirements of battery capacity are no less than 300mAh. All the conclusions can provide references for the standardization of elevator practitioners, which can be used for subsequent standard revisions or related work.

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