Paper

Pilot Study of Reconsideration of the Lighting Environment in Train Stations under the Restriction of Power Use due to the Aftermath of the Great East Japan Earthquake

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ABSTRACT

Field measurements were conducted to identify how the actual lighting environment has changed in train stations due to the aftermath of the Great East Japan Earthquake. Horizontal illuminance on the floor on the way from the platform to the exit of the station and the number of the lighted luminaires in each area of each station were measured. The measurements were conducted twice, in the summer and in the autumn 2011, to identify the continuity of electricity saving measures and the transition of the lighting environment. From the results of the measurements in the summer, it was identified that nearly 80% of the luminaires was lighted off in maximum. The results of our survey showed the possibility to lower the floor illuminance level for some areas where the passengers felt no inconvenience in walking, such as the ticket gates area and concourse.

KEYWORDS: lighting environment, train stations, field measurement, electricity-saving, The Great East Japan Earthquake

1. Introduction

The incident of the Fukushima Daiichi Nuclear Power Plant due to the Great East Japan Earthquake caused serious shortages of electric power in the metropolitan area of Japan. Planned power outage went into effect for two weeks from 14th till 28th March, 2011 and the Japanese government requested energy saving of 15% or more during the summer season to factories, private households, office buildings and public transportations in the eastern part of the Japanese mainland, including the Tokyo metropolitan area¹⁾. Lighting environment of public streets, downtown areas and other facilities in the metropolitan area have changed dramatically compared to those before the shock of the March 2011 earthquake. In public facilities such as train stations, self-luminous direction board and artificial luminaires illuminated escalator, ticket gates area, restroom, and etc. were lighted off or cut down drastically. As a result, some harmful effects were caused including, lowering visibility levels of direction boards, failure of safety on steps, and difficulties to find the entrance of the train stations, especially in the stations where several lines were connected.

In the summer, electrical power consumption reaches a peak in the daytime for the use of air-conditioners, while daylight contributes for lowering the electrical use for lighting. On the other hand in the winter, electrical power consumption reaches a peak in the evening for the heavy load of starting up heaters in homes, also for the use of electrical power for lighting. The general public in the Kanto region had more fears of the shortage of the electrical power in the winter than in the summer, though the restriction of electricity use was not enforced by the Japanese government.

In this study, luminous environment and visual inconveniences in train stations were investigated to record the actual conditions of the lighting environment after the March 2011 earthquake. The record of the actual conditions of the lighting environment under the restriction of electricity use can contribute identifying the proper design of the lighting environment with the minimum electrical power supply in the future. This paper reports the results of the field measurements of the lighting environment in train stations in metropolitan area in Japan and discusses the future of the lighting environment in train stations.

Table 1 Recommended illuminance ranges in train stations by JIS Z 9110:2011

N: Number of passengers in a day	JIS classification		
	A 150,000≤N	B 10,000≤N<150,000	C N<10,000
Concourse	300–750 lx	200–500 lx	—
Waiting room	300–750 lx	200–500 lx	75–150 lx
Platform, Passage, Stairs	150–300 lx	75–150 lx	50–100 lx
Ticket gate	750–1500 lx	300–750 lx	150–300 lx
Office	300–750 lx	150–300 lx	150–300 lx

2. Recommended illuminance level in train stations

Recommended illuminance ranges of each area in train stations are determined by JIS (Japan Industrial Standards) Z 9110:2011²⁾ as shown in Table 1. The recommended illuminance ranges of the maintained illuminance of each area in train stations are classified into 3 classes according to the number of the passengers per day—150,000 or more (class A), 10,000 or more and less than 150,000 (class B) and less than 10,000 (class C). It can be seen that the larger the number of the passengers is, the higher illuminance is recommended for each area. Additionally, the recommended illuminance range in the ticket gates area is much higher than those in the other areas for each class. Especially in the class A stations, it is recommended for the ticket gates area to maintain 750 to 1500 lx of the floor illuminance. The recommended maintained illuminance, that is the median value of the recommended illuminance range, has not changed from 1979. In those days, it can be assumed that higher visibility on the horizontal level was required for the station staffs to observe small letters written on the tickets very quickly. However in recent years, the passengers mainly pass through the automated ticket gates and the speed for observing the tickets is less significant for the station staffs. Additionally for the occasions of the passengers to enter the station, the size of the slot is large enough to feel for putting the tickets in. The recommended illuminance levels by JIS Z9110:2011 for some areas might be excessive for the present situations.

3. Method

Field measurements of the lighting environment in train stations in the metropolitan area were conducted to identify the actual conditions of the lighting environment under the restriction of electricity use in 2011. A total of 107 stations (class A: 23, class B: 64, class C: 20) of 19 different lines were chosen as the target of the measurement. This paper reports the results of 382 areas in 70 train stations of 12 different lines shown in Table 2 where we could obtain the measurement data

with adequate accuracy. Table 2 shows the outline of each measured station^{3)–5)}. The listed stations shown in gray cells mean the subway lines.

Field measurements were conducted twice, in the summer (during July 7 and September 9, 2011 when the restriction of electricity use went into effect) and in the autumn (during the end of October and the end of November, 2011 when the restriction of electricity use was not urged). The measurements were started from 20:00 until the last train to avoid the effects of daylight and commuter rush. The measurement routes were determined to follow the common route of the passengers. Horizontal illuminance on the floor on the way from the platform to the exit of the station was measured using mobile measurement cart shown in Figure 1 at intervals of one second. The measurer walked along the measurement route at the speed of 0.5 m/s with dragging the mobile measurement cart. Illuminance logger (HIOKI 3640) was carried with the mobile measurement cart and the sensor was positioned at the height of 1 cm from the floor as shown in Figure 2.

The shadows of the passengers, the measurer and the measurement cart itself reduced the horizontal illuminance to some extent. The effect of the shadow of the measurement cart, that of the measurer and that of the person near the sensor on the measured illuminance was tested. Figure 3 shows the relationship between the illuminance on the floor without any obstructions and that measured by the mobile measurement cart with surrounding people near the sensor. Three levels of the floor illuminance, 130 lx, 300 lx and 500 lx, and 3 patterns of the surrounding people, with a measurer beside the mobile measurement cart, with a measurer and two people within a 1.5 m radius from the sensor, and with a measurer and four people within a 1.5 m radius from the sensor, were tested in the experimental room with the size of 3.0 m in wide, 3.0 m in length and 2.55 m in height. The experimental room was illuminated uniformly by eight neutral white tubular type LED luminaires of 40 W. The levels of the illuminance were controlled by dimming. It was quite natural that the measured floor illuminance became lower as the number of the surrounding people became higher. In the case when only a measurer and the measurement cart were beside the illuminance sensor, that was when the effects of the surroundings were the smallest, the measured illuminance was lowered by 14%. In the section 4.5, the floor illuminance under the assumption that all of the installed luminaires were lighted on was calculated by getting 14% return on the measured illuminance and the values corresponded to the floor illuminance level before the March 2011 earthquake or less.

In addition, the numbers of the installed luminaires including the ceiling luminaires and the signboards, as well as the lighted luminaires at the moment of the

Table 2 Outline of the measured stations

Line	No.	JIS Class	Number of passengers in a day	Line	No.	JIS Class	Number of passengers in a day
$a^{(3)}$	$a\ 1$	A	184,995	$g^{(3)}$	$g\ 1$	A	287,293
	$a\ 2$	B	88,068		$g\ 2$	B	149,749
	$a\ 3$	B	15,679		$g\ 3$	B	83,346
	$a\ 4$	B	45,095		$g\ 4$	B	77,189
$b^{(3)}$	$b\ 1$	A	525,357		$g\ 5$	B	110,358
	$b\ 2$	A	183,846		$g\ 6$	B	52,608
	$b\ 3$	B	134,521		$g\ 7$	B	11,307
	$b\ 4$	B	87,043		$g\ 8$	B	38,813
	$b\ 5$	B	75,468	$h^{(4)}$	$h\ 1$	A	344,536
	$b\ 6$	B	24,149		$h\ 2$	A	209,020
$c^{(3)}$	$c\ 1$	B	11,292		$h\ 3$	A	338,004
	$c\ 2$	B	58,200		$h\ 4$	B	99,189
	$c\ 3$	B	14,102		$h\ 5$	B	101,702
	$c\ 4$	C	24		$h\ 6$	A	183,605
$d^{(3)}$	$d\ 1$	A	260,227		$h\ 7$	B	98,617
	$d\ 2$	B	144,983		$h\ 8$	B	134,339
	$d\ 3$	B	121,279		$h\ 9$	B	84,737
	$d\ 4$	B	134,879		$h\ 10$	B	65,799
$e^{(3)}$	$e\ 1$	A	658,213		$h\ 11$	B	42,335
	$e\ 2$	B	108,556		$h\ 12$	B	24,179
	$e\ 3$	B	115,333	$i^{(3)}$	$i\ 1$	B	71,975
	$e\ 4$	B	74,149		$i\ 2$	B	10,096
	$e\ 5$	B	70,727		$i\ 3$	C	797
	$e\ 6$	B	60,848	$j^{(3)}$	$j\ 1$	A	329,124
	$e\ 7$	B	19,113		$j\ 2$	B	96,544
$f^{(3)}$	$f\ 1$	A	158,918		$j\ 3$	B	44,452
	$f\ 2$	B	105,636		$j\ 4$	B	22,534
	$f\ 3$	B	99,907		$j\ 5$	C	6,269
	$f\ 4$	B	98,294	$k^{(3)}$	$k\ 1$	C	5,375
	$f\ 5$	B	52,907		$k\ 2$	B	52,465
	$f\ 6$	B	24,268		$k\ 3$	B	25,111
	$f\ 7$	B	21,351		$k\ 4$	C	9,618
	$f\ 8$	B	11,355		$k\ 5$	C	7,444
subway				$l^{(5)}$	$l\ 1$	A	487,133
					$l\ 2$	A	433,589
					$l\ 3$	A	422,329
					$l\ 4$	B	36,578

measurement were counted. In addition, the wattage of each luminaire was recorded when the measurers could identify the type of the lamp. The type of the lamp was distinguished by its shape, i.e. the length for tubular fluorescent lamps, and the luminous flux of each luminaire was determined from the data shown in catalogues published by manufacturers. The luminaires of

the same shape, i.e. wattage, were assumed to have the same luminous flux.

4. Results

4.1 Lighted luminaires rate

To estimate the percentage of the lighted luminaires, lighted luminaires rates were calculated in two ways as

Figure 1 Mobile measurement cart

Figure 2 How to use the mobile measurement cart

Figure 3 Effects of the surroundings on the measured illuminance

Figure 4 Comparison of the lighted luminaires rates for ceiling luminaires

shown below.

$$LR I = \frac{\text{The number of the lighted luminaires}}{\text{The number of installed luminaires}} \quad (1)$$

$$LR II = \frac{\left(\text{Sum of the wattage of the lighted luminaires} \right)}{\text{Sum of the wattage of installed luminaires}} \quad (2)$$

LR I, LR II: Lighted luminaires Rate

With the measurement data of illuminance on the floor and the lighted luminaires rates, illuminance levels on the floor before the March 2011 earthquake, that is the illuminance levels without any restriction of the electricity use, can be calculated.

The lighted luminaires rates in the summer were calculated for 222 areas in 58 train stations of 12 lines and those in the autumn were calculated for 463 areas in 61 train stations of 12 lines, where the measurers could identify the type of the lamp. Figure 4 shows the comparison of the lighted luminaires rates calculated for ceiling luminaires in the two ways. It can be seen that the lighted luminaires rate *LR I* was mostly higher than *LR II* both in the summer and in the autumn. It could be assumed that the luminaires of higher wattage were lighted off. Hereafter, *LR I* was determined as the lighted luminaires rates to estimate the illuminance levels before the March 11 earthquake, because the number of lighted luminaires could be identified in every measured area.

4.2 Measured illuminance on the floor

Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 show some examples of the measured illuminance on the floor. Average illuminance in each area and lighted luminaires rates of signboards and those of ceiling luminaires are also shown in the tables illustrated beside

Figure 5-1 Measured illuminance on the floor and the lighted luminaires rates in each area of *b3* station (class B) Figure 5-2 Measured illuminance on the floor and the lighted luminaires rates in each area of *h8* station (class B) Figure 5-3 Measured illuminance on the floor and the lighted luminaires rates in each area of *f6* station (class B)

each figure. There could not be seen neither significant differences nor similar tendencies of the floor illuminance and lighted luminaires rates among JIS classification, here showed some examples of the JIS class B stations, where we could obtain plenty of the measurement data. The stations that showed significant difference between the floor illuminance and the lighted luminaires rates in the summer and those in the autumn

were selected to be illustrated. The number of the passengers of the station *b3* and *h8* are almost the same and could be classified in the larger number group of the measured JIS B class stations. On the other hand, the number of the passengers of the station *f6* and *c3* could be classified in the smaller number group among the JIS B class stations. Only *c3* station had connecting area. Each measurer did his/her best to walk along the

Figure 5-4 Measured illuminance on the floor and the lighted luminaires rates in each area of c3 station (class B)

Figure 6 Lighted luminaires rate in the summer and in the autumn of each area

measurement route at the same speed both in the summer and in the autumn. However, sometimes it was impossible because crowd density differed from day to day. For some cases, a time needed for the measurement in each area differed between in the summer and in the autumn. The results are shown by dividing the measurement data according to the area.

In *b3* station (see Figure 5-1), lighted luminaires rate in the passage became lower in the autumn than that in the summer. Lighted luminaires rate in the other areas remained almost the same since in the summer. In *h8* station (see Figure 5-2), illuminance in each area except for the concourse in the autumn was quite the same with that in the summer. In *f6* station of the JIS class B (see Figure 5-3), the illuminance on the floor in each area, except for platform, in the autumn was higher than that in the summer. As can be seen in the table beside, all ceiling luminaires were lighted in the ticket gates area, in the passage and in the stair in the autumn, while only about half of the ceiling luminaires

were lighted on in the summer. In *c3* station of the JIS class B (see Figure 5-4), illuminance on the floor in each area was higher in the autumn than that in the summer except for the platform. As shown in the table beside, all of the ceiling luminaires were lighted on in the stairs and in the ticket gates area and all of the signboard was lighted on in the connecting area in the autumn. Comparing the measurement illuminance data and calculated lighted luminaires rate *LR I*, it was certified that the floor illuminance varied in proportion to the lighted luminaires rate in each area of the station.

4.3 Lighted luminaires rates in each area

Figure 6 shows the cumulative frequency of the lighted luminaires rates in the summer and that in the autumn of each area (platform, stairs, ticket gates area, connecting area, passage and concourse). The values in the parenthesis in each figure represent the numbers of the measured stations for each JIS class. In this paper, the results of the class A and the class B stations are

shown. The class C stations were not included in this analysis due to the number of the measured stations was insufficient. It was identified that the lighted luminaires rates in platforms and that in stairs were approximately equal in the summer and in the autumn for both class A and class B stations. Additionally for the platform, the lighted luminaires rates were higher than those in the other areas. The lighted luminaires rate $LR I$ lower than 0.9 in platforms of JIS class A stations accounts for only 20% of the all measured stations. All luminaires were lighted in 80% of the measured class A stations and in 50% of the measured class B stations both in the summer and in the autumn. On the other hand, in ticket gates area, passage and concourse, it could be seen that the percentage of the station with lower lighted luminaires rates decreased from the

summer to the autumn for class A stations. That is to say, the numbers of the lighted luminaires in the ticket gates area, in the passage and in the concourses became higher in the autumn than those in the summer. Additionally for the ticket gates area of JIS class B stations, $LR I$ shifted toward the higher level in the autumn than in the summer. From the results of ANOVA, the lighted luminaires rate in platform and that in concourse was significantly different between seasons for class A stations as shown in Table 3-1. Significant difference in the lighted luminaires rate between seasons for class B stations was found for connecting area and concourse. No significant differences in the lighted luminaires rates between JIS classes was found for each area for both seasons as shown in Table 3-2.

Table 3-1 Significant difference in $LR I$ between seasons

	Summer	Autumn
Platform	0.78	0.15
Stairs	0.66	0.70
Connecting area	0.083	0.17
Ticket gates area	0.66	0.56
Concourse	0.084	0.56
Passage	0.060	0.27

*: $p < 0.05$ **: $p < 0.01$

Table 3-2 Significant difference in $LR I$ between JIS classes

	JIS class A	JIS class B
Platform	0.028*	0.64
Stairs	0.069	0.052
Connecting area	0.18	0.0033**
Ticket gates area	0.69	0.33
Concourse	0.037*	0.039*
Passage	0.15	0.14

*: $p < 0.05$ **: $p < 0.01$

4.4 Non-uniformity of floor illuminance along the measurement route in each area

Figure 7 shows the cumulative frequency of the uniformity ratio (minimum/average) of the floor illuminance along the measurement route in platform, connecting area and concourse of the class A and class B stations. In platform of JIS class A stations, lighted luminaires rate in the summer and that in the autumn were significantly different. In the autumn, uniformity of the floor illuminance became higher than in the summer. The same tendency was also found in concourse of the class A stations. In connecting area and in concourse of JIS class B stations, remarkable difference in uniformity of the floor illuminance was not found between in the summer and in the autumn although lighted luminaires rate became significantly higher in the autumn than in the summer.

4.5 Prediction of floor illuminance level before the March 11 earthquake

Illuminance level under the assumption that the all installed luminaires were lighted on, that is equal to the illuminance level before the March 2011 earthquake,

Figure 7 Non-uniformity of floor illuminance in each area

Figure 8 Predicted floor illuminance in each area

was calculated by Eq. (3) with the measured average illuminance in each area and the lighted luminaires rates $LR I$ obtained from the results of the measurements in the summer. The results are shown in Figure 8.

$$E_p = E_m / LR I / 0.86$$

E_p : Predicted floor illuminance [lx]

E_m : Measured floor illuminance [lx] (3)

As Figure 3 showed, the floor illuminance was reduced by 14% at least with the shadows of the measurement cart and the measurer. So the predicted floor illuminance got 14% return on the measured illuminance. In actual situations before the March 11 earthquake, the floor illuminance must be higher than the predicted floor illuminance. It was supposed that the floor illuminance in platform, stairs, connecting area and passage exceeded the recommend illuminance range by JIS for most of the measured stations of both classes A and B. On the other hand, in the ticket gates area, it was supposed that the floor illuminance of the all measured stations of the JIS class A was lower than the recommended illuminance range by JIS. The floor illuminance in concourse was predicted to be within the recommended illuminance range for most of the measured stations.

4.6 Evaluation of the lighting environment in b3 station by the passengers

Questionnaire survey on the lighting environment

was conducted in b3 station (JIS class B) during November to December in 2011. The contents of the questionnaire were brightness sensation of each area (7 step scale, Very bright-Bright-Slightly bright-Neither bright nor dark-Slightly-dark-Dark-Very dark), easiness for detecting of direction boards (7 step scale, Very easy to detect-Easy to detect-Slightly easy to detect-Slightly hard to detect-Hard to detect-Very hard to detect-No direction board), inconvenience in the detection of direction boards (3 step scale, Not inconvenient-Slightly inconvenient-Inconvenient), visibility of the steps (6 step scale, Very high-High-Slightly high-Slightly low-Low-Very low) and safe in walking (7 step scale, No problem-Slightly inconvenient-Inconvenient-Slightly anxiety-Anxiety-Slightly dangerous-Dangerous). The answers were obtained from 143 respondents aged from 20 to 70. The respondents were the students and the employees of the university whose nearest station was b3 and they used the station almost every day. The evaluation point of each area was not restricted and they answered each question based on their usual experience or impression in each area.

Figure 9 shows the floor illuminance in median along the measurement route in each area in the autumn, the percentage of the respondents who evaluated each area 'Very bright', 'Bright', 'Slightly bright' and 'Neither bright nor dark'. Moreover the percentage of the respondents who didn't feel danger in walking, that is who answered 'Neither dangerous nor safe', 'Slightly

Figure 9 Floor illuminance and evaluation by the passengers in b3 station

safe', 'Safe' and 'Very safe'. As shown in Figure 5-1, floor illuminance varied significantly in each area. 75 percentile value and 25 percentile value of the measured floor illuminance along the measurement route are also shown in the figure to express the degree of non-uniformity of the floor illuminance in each area.

In the ticket gates area and the concourse, floor illuminance was significantly lower than the recommended illuminance range by JIS. However, more than 80% of the respondents evaluated that they did not feel danger in walking, though the floor illuminance was quite lower than the recommended illuminance range by JIS. The floor illuminance in platform, that in stairs and that in the connecting area satisfied the recommended illuminance range by JIS. On stairs, the percentage of the respondents who did not feel danger in walking was quite lower than that in the other areas. It can be said that just meeting the recommended floor illuminance is not enough for safety in walking on stairs.

5. Discussion

In 2011, electricity saving was strictly requested for its state of emergency¹⁾. In 2012 and 2013, the Japanese Ministry of Economy, Trade and Industry has requested power conservation in a manner ensuring that expected power-saving efforts are made without undue stress and with minimum effects on people's lives and economic activities⁶⁾⁻⁸⁾. It can be suspected that the electricity saving measures for lighting were taken continuously if any critical problems were not occurred due to the lowered illuminance level.

From the results of our survey, it was identified that the lighted luminaires rates in platform were higher than those in the other areas. It could be predicted that in the areas where should be kept enough safety for the passengers, the number of the lighted luminaires was remained kept at higher level.

From the results of the questionnaire, it was identified that the passengers did not feel danger in walking in the ticket gates area and in the concourse even the

floor illuminance was considerably lower than the recommended illuminance level by JIS. Some other researches have also pointed out that the passengers' brightness sensation did not link with the floor illuminance for some areas⁹⁾¹⁰⁾. For the space where the vertical illuminance is much important rather than horizontal illuminance to retain the passengers' brightness, such as ticket gates area and concourse, etc., illuminating interior surface of higher reflectance can be one of the solutions without increasing the electricity use¹¹⁾. However, the target of the respondents of the questionnaire survey in this study was only who had normal vision. Lighting is not only for brightening the space but also for guiding the directions for the visually impaired¹²⁾¹³⁾. More investigations are necessary to judge the optimum illuminance level for train stations to consider all of the visual characteristics.

6. Conclusions

Field measurements were carried out to identify the actual situations of the lighting environment in train stations under the restriction of electrical power use in 2011 due to the aftermath of the Great East Japan Earthquake. From the results of the measurement of the floor illuminance using the mobile measurement cart and the observed number of the lighted luminaires, the floor illuminance level before the March 2011 earthquake was predicted. Additionally from the results of the questionnaire for the passengers, it was identified that they did not feel danger in walking in the ticket gates area and in the concourse even the floor illuminance was substantially lower than the recommended illuminance level by JIS. Reconsidering the optimum illuminance level in each area of train stations in line with the actual way of use with considerations of the all visual characteristics of the passengers should be commenced.

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