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Investigation of the Visual Environment of Railway Station Stairs Using Qualitative and Quantitative Evaluation Methods

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Abstract: A qualitative evaluation was performed by comprehensively considering the lighting environment of each staircase of 20 railway stations in Tokyo, the width of the stairs, the type of ceiling, wall lighting fixtures, and the color. As a result of the quantitative evaluation of 20 stairs, it was found that a difference of up to 400 lx occurred in the measurement results of the entrance, exit, and middle landing, even for the same stairs. As a result of qualitative evaluation, it was found that the quantitative evaluation result and the simple proportional relationship were not established. It was found that simply physically brightening a space cannot make a comfortable and safe space, and in some cases, glare is likely to occur. As a result of the analysis of variance and correlation analysis, it was found that the characteristics of the space, especially the material of the wall and the location of the lighting equipment, had a large effect on the impression of the space. As a result of simulation analysis, it was found that the performance varied greatly depending on the installation location of the lighting. In particular, the method of installing the line light source close to the ground was effective. In designing stair lighting for public facilities in the future, it is considered that qualitative factors such as the finishing of walls and ceilings, installation positions, and angles of lighting fixtures, which are environmental components other than lighting, should also be considered.

Keywords: qualitative evaluation; lighting and visual environment; railway station; stair

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Citation: Heo, J.; Kozaki, M.; Koga, T.; Hirate, K.; Kim, H.B. Investigation of the Visual Environment of Railway Station Stairs Using Qualitative and Quantitative Evaluation Methods. *Energies* **2022**, *15*, 7013. https://doi.org/10.3390/en15197013

Academic Editor: Alessandro Cannavale

Received: 8 August 2022
Accepted: 20 September 2022
Published: 24 September 2022

1. Introduction

Among public facilities, railway stations are representative facilities used by many people every day [1]. In the case of Tokyo's Shinjuku Station, about 1.5 million people use it every day, and it creates a very crowded environment in the morning and evening hours. What makes railway stations different from other public facilities is that they are dynamic spaces [2]. People are constantly on the move, and the type of use varies from point to point, such as platforms, concourses, ticket gates, and stairs that make up a railway station. In particular, in the case of stairs, they serve as a passage connecting the railway station's concourse and platform, and users move up and down through these stairs [3]. Therefore, in the case of stairs, structural safety is required, and, at the same time, securing visual safety is also important [4]. A condition that must inevitably be met to ensure the visual safety of space is a sufficient level of brightness [5]. To this end, each public facility strives to provide a comfortable and safe lighting environment for users by designing lighting suitable for their use [6–8]. On a home basis, stairs are the most common drop-off point within a home, which is even more severe for seniors [9–11]. Therefore, people are paying attention to measures such as being barrier-free to ensure the safety of stairs in facilities, including houses [12,13]. In the case of stairs at railway stations, narrow and long passages are common, and there are often not enough places to install lighting [2]. In some cases, lighting is installed on a very low ceiling, and in the case of stairs without a ceiling, lighting is installed on the wall. In this way, the brightness of the floor is sufficiently secured, but glare may occur [14,15]. Glare also occurs when the light source of a luminaire is placed directly within the field of view, which can be dangerous when using stairs, which is a dynamic space.

Accordingly, research for a safe lighting environment for stairs is being actively conducted [16–18]. Past research has shown that it is possible to build a safer stair lighting environment by utilizing high-power LED bulbs [19]. In order for the elderly to safely use the stairs, there has been a study that at least 200 lx of illuminance is required for both ascending and descending [20]. In addition, there are reports that an appropriate level of contrast (50% or more) is required while ensuring sufficient brightness. Some argue that luminance and illuminance should be considered, and this is a valid story considering the direction of the human gaze [21].

Many studies have been conducted for a safe lighting environment for stairs, but most of the existing studies have focused on the performance of lighting itself [22,23]. The lighting environment is not determined only by the physical performance of the lighting equipment but changes according to the shape, reflectance, and area of the structures that make up the space [24]. In particular, when many people use a narrow and long space such as the stairs of a railway station at the same time, it may not be possible to explain it with a simple physical approach. Additionally, the occurrence of glare cannot be overlooked on the stairs of the railway station, where the height of the ceiling and the installation position of the lighting are different [25,26].

In addition, since the 2011 earthquake, Japan has been implementing power-saving operations centered on public facilities nationwide [27–29]. As a result, the railway station is also running a power-saving operation, which has led to a decrease in the illuminance of the platform and the concourse [1]. Although the stairs are one space, they are classified as entrance, exit, and middle landing, and each space is affected by the lighting environment of the platform and concourse. The overall darkened environment of the platform and concourse due to power-saving operation directly affects the stairs. For this reason, qualitative design techniques that improve the lighting environment of stairs with quality rather than quantity are attracting attention [2].

In this study, a large-scale field survey was conducted on the stairs of 20 railway stations in Tokyo. By dividing the stairs into the entrance, exit, and middle landing, physical quantities were measured to understand the actual condition of the lighting environment. In addition, in order to examine the effect of the structure and material of the stairs on the lighting environment, spatial components were further subdivided, and measurements were carried out. Width of stairs, shape of the ceiling, wall lighting fixtures, light reflectance of wall material, step edging, ceiling color, wall color, ceiling height, and lighting position were classified and evaluated. In addition, for a qualitative evaluation of the space, an impression evaluation was conducted for users. Finally, the results were verified through statistical analysis to clarify the relationship between the quantitative and qualitative elements of the space.

2. Materials and Methods

2.1. Target of the Investigation

For this study, 20 railway stations in Tokyo, Japan were studied, and an on-site survey was conducted. Figure 1 shows the view of the stairs of 20 railway stations as the subjects of the investigation. The stairs at the railway station connect the platform and the concourse vertically, and the narrow and long structure is common. In the case of general space, it is efficient to install the lighting on the ceiling. However, in a space that vertically connects space and space, such as a staircase, there are cases where the ceiling is very high, or there is no ceiling. Therefore, the lighting of the stairs is installed in various places, including the ceiling and the wall. Additionally, there are cases in which the main lighting is not installed in the stairs, and the lighting of the platform and concourse is relied on.

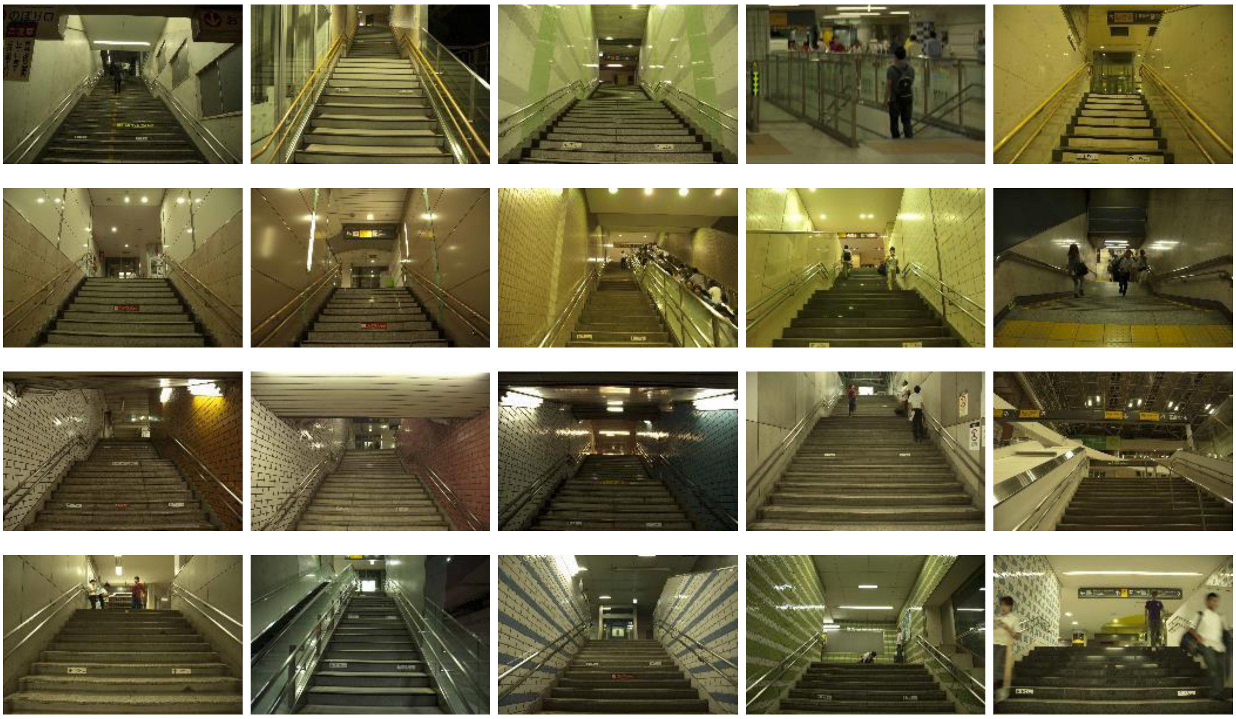

Figure 1. Front view of the stairs.

The stairs are small in area, but their shape is unique. Therefore, various criteria are applied in evaluating the space, and in particular, the effect of lighting changes according to the spatial components. In this study, to clarify the factors affecting the psychology of users other than the lighting environment, the forms of stairs were classified, as shown in Table 1. Factors evaluating the impression of space were classified in detail, including 'width' and 'ceiling', etc., which affect the visual sense of openness.

The details of the classification criteria are as follows. 'Width' of the stairs; 'Ceiling' means the shape of the ceiling; 'Wall lighting fixtures' means lighting fixtures installed on the wall; 'Light reflectance of wall material' means the reflectance of the wall; 'Step edging' is related to safety in transit; 'Ceiling color' and 'Wall color' are related to the atmosphere and reflectivity of the space; 'Ceiling height' is related to the sense of openness of space; and 'Lighting position' is related to the induction of glare. The investigation was conducted by classifying the above 9 items. In the case of ceiling-related items, the places where it was difficult to install lighting fixtures because the ceiling height was very high were considered as having no ceiling.

Table 2 shows the information of 20 places by classification of the shape of the stairs. Regarding 'width', A ~ C other than D were evenly distributed, and it was found that most of the railway station stairs had a width of 10 m or less. 'Ceiling' was the most common type of 'Staircase type 1′ with a step difference. It is thought to have taken the form of a flat surface in consideration of installing facilities such as lighting. There were six locations where wall lighting fixtures were installed. Because the stairs were narrow, ceiling lights were often installed if possible. As for the wall material, H and M were 14 places, and materials with high reflectivity were applied to the majority in consideration of the efficiency of lighting. 'Step edging' was installed in 11 places. As for the ceiling color, 'bright' and 'neutral' were the most at 7 places each, and 'Wall color' had the most 'neutral' at 9 places. As for the ceiling height, 'medium' and 'low' were 7 places each, and 'high' was 5 places, and it was difficult to install ceiling lights in some places. In the lighting position, there were 14 places B and C where the lighting was directly visible. This means that there is always a risk of glare when using the stairs and that countermeasures against safety accidents must also be prepared. As described above, the environment of the stairs has a complex configuration, and even a small difference can have a huge effect on the lighting environment.

Table 1. Form classification criteria table of the stair.

Form	Classification	Classification Criteria
Width	A	More than 10 m, no escalator
	B	5–9 m, with escalator
	C	5–9 m, no escalator
	D	More than 10 m, with escalator
Ceiling	Staircase type 1	Parallel ceiling shape with two stages
	Staircase type 2	Parallel ceiling shape with two or more stages
	Slanting	The ceiling has a slanted shape
	None	No ceiling or very high ceiling
Wall lighting fixtures	Installed	With wall lighting
	None	No wall lighting
Light reflectance of wall material	H	Very high reflectance
	M	Normally
	L	Almost no reflectance
Step edging	Installed	There is a line at the end of the treads on the stairs.
	None	There is no line at the end of the treads on the stairs.
Ceiling color	Bright	The color of the ceiling surface is bright
	Neutral	The color of the ceiling surface is a neutral color
	Iron plate	The ceiling surface is made of iron plate
	None	No ceiling or very high ceiling
Wall color	Bright	The color of the wall is bright
	Neutral	The color of the wall is a neutral color
	Mixing	The wall color is a mixture of bright and neutral colors
Ceiling height	High	Ceiling height is 6 m or more
	Medium	Ceiling height is 4 m–6 m
	Low	Ceiling height less than 4 m
	None	No ceiling or very high ceiling
The relative position of lighting *	A	Lighting equipment is out of sight
	B	The light source is not exposed but is in the field of view
	C	The light source is exposed and in the field of view

* Lighting equipment in the field of view when looking up.

Table 2. Stair morphology classification table.

	Form Classification								
	Width	Ceiling	Wall Lighting Fixtures	Light Reflectance of Wall Material	STEP EDGING	Ceiling Color	Wall Color	Ceiling Height	The Relative-Position of Lighting
1	A	Staircase type 1	None	L	None	Neutral	Neutral	Medium	C
2	C	Staircase type 1	None	L	Installed	Bright	Neutral	High	A
3	A	Staircase type 2	None	H	Installed	Iron plate	Bright	Low	C
4	B	Staircase type 1	None	M	Installed	Neutral	Bright	Low	C
5	B	Staircase type 1	None	H	Installed	Bright	Bright	High	A
6	C	Staircase type 1	None	M	Installed	Bright	Neutral	High	A
7	C	Slanting	Installed	M	Installed	Iron plate	Neutral	Medium	B
8	B	Staircase type 2	None	M	Installed	Bright	Neutral	Low	C
9	B	Slanting	None	M	Installed	Iron plate	Bright	Low	C
10	C	Staircase type 1	None	M	Installed	Neutral	Neutral	High	C
11	A	Staircase type 1	Installed	H	None	Neutral	Mixing	Low	C
12	C	Staircase type 1	None	H	None	Bright	Mixing	Medium	C
13	C	Slanting	Installed	H	None	Iron plate	Mixing	Medium	C
14	A	Staircase type 1	None	L	None	Neutral	Neutral	Medium	C
15	A	None	None	L	None	None	Bright	None	A
16	A	Staircase type 1	Installed	L	None	Neutral	Neutral	High	C
17	B	Staircase type 1	None	L	Installed	Neutral	Neutral	Medium	A
18	B	Slanting	Installed	H	None	Iron plate	Mixing	Low	C
19	A	Staircase type 1	Installed	H	None	Bright	Mixing	Medium	B
20	D	Staircase type 2	None	H	Installed	Bright	Mixing	Low	A

2.2. Physical Quantity Measurement Method

The measurement items of physical quantities are shown in Table 3. For the floor illuminance, which is an index according to the JIS standard, which is the standard for lighting design of railway stations, horizontal illuminance at 1500 mm height assuming human eye level and vertical illuminance were selected as physical quantity measurement indicators. In particular, in the case of stairs, more detailed measurements were made because they are dynamic, long, and narrow structures, unlike platforms or concourses. Measurements were made at each point by dividing the stair space into the entrance, exit, and middle landing. In the case of vertical illuminance, it was measured based on the direction of movement of pedestrians. In the middle landing, in principle, it was measured by dividing it into upward and downward directions. In addition, an illuminance meter (IM-2D, TOPCON) was used for all illuminance measurements at each point, and measurements were made under conditions where there was no influence of the body of the investigator or the shadow of the stair user. The illuminometer is capable of precise measurement in the range of 0.1 to 19,990 lx, which corresponds to Class A specified in the Japanese Industrial Standards (JIS). In order to increase the accuracy of illuminance measurement, the measurement was made in a situation where there are no pedestrians in consideration of the decrease in illuminance due to shadows.

Table 3. Physical quantity measurement items.

Measurement Item	Measurement Contents
Floor illuminance	Measured upward from the floor
Horizontal illuminance	Measured upward from a height of 1500 mm
Vertical illuminance	Measured in the direction of movement of pedestrians from a height of 1500 mm

2.3. Impression Evaluation Method

In all investigations in this study, physical quantities were measured, and impression evaluations by users were also performed at the same time. The impression evaluation items are shown in Table 4, and a total of 7 items were classified into perception amount and recognition amount. Regarding the perceptual amount, three items of 'Brightness', 'Darkness', and 'Glare' of space were evaluated on a unipolar 7-step scale. Regarding the cognitive amount, four items of 'Calmness', 'Anxiety', 'Appropriateness', and 'Change the lighting' were evaluated on the positive 7-level scale.

Table 4. Impression evaluation items.

Evaluation Items		Evaluation Scale	
Perceptual amount	Brightness Darkness Glare	Unipolar scale	The higher the number, the stronger the tendency ※ Example (brightness) 1: Not bright at all 4: Neither 7: Very bright
Cognitive amount	Calmness Anxiety Appropriateness		
	Change the lighting	Bipolar scale	1: Want the lighting to be bright 4: Neither 7: Want the lighting to be dark

2.4. Statistical Analysis and Simulation Analysis

In this study, statistical analysis was performed to understand the relationship between quantitative and qualitative evaluation and the degree of influence. Analysis of variance (ANOVA) and correlation analysis was performed as statistical analysis. The effect of the lighting installation method and space structure on qualitative evaluation was reviewed through ANOVA. Through correlation analysis, the impact of the physical measurement results of space on the impression evaluation result, which is a qualitative evaluation, was clarified.

In addition, simulation analysis was conducted to examine the effect of the change in lighting method on the light environment of the space. Dialux evo was used as the simulation software, and the change and distribution of physical quantities according to the installation location of lighting were reviewed.

3. Results of Physical Quantity Measurements

3.1. Entrance of Stairs

The floor illuminance measurement result of the entrance is shown in Figure 2. Furthermore, due to the characteristics of the on-site measurement, data may not have been taken in some cases because the situation on the site at the time of the actual measurement may have had an influence on the investigation. For this study, floor illuminance data of stair 4 were not taken. As a result of the measurement, the distribution was mainly around 200 lx, the maximum value was 459 lx, and the minimum value was 81 lx.

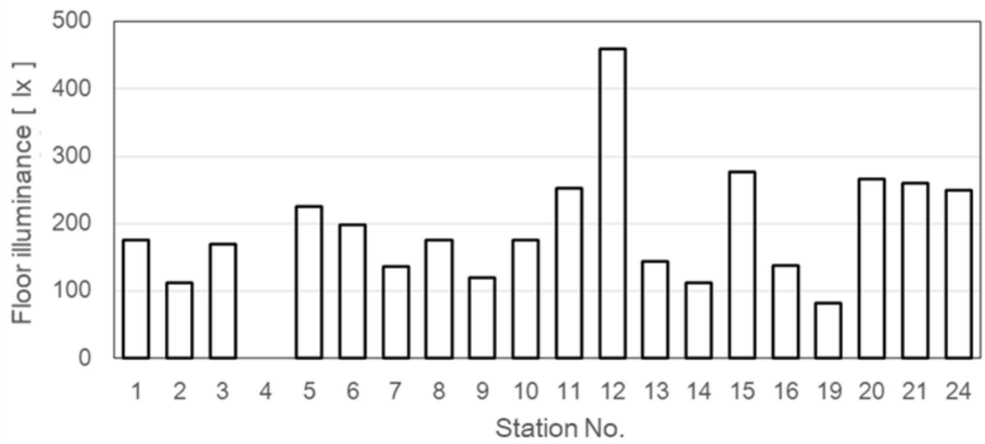

Figure 2. Floor illuminance measurement result at the entrance of stairs.

There was a difference in brightness depending on whether the connection point with the stairs was a concourse or a platform (Figure 3). In addition, in the case of stairs, the lighting environment of the standing place and viewing target (the upper space viewed from the bottom) are important. Therefore, it is considered that an approach from a more complex point of view is necessary for the lighting design of stairs. Since the stairs are narrow and long compared to other spaces, they have high lighting efficiency. However, due to the nature of the narrow space, it is also a space where glare is easy to occur, such as lighting fixtures being directly visible in the field of view. For this reason, it is necessary to pay attention to the selection of the installation location of the lighting when designing the lighting of the stairs.

Figure 3. Entrance of No. 12 and 19 ((**left**): No. 12, (**right**): No. 19).

Figure 4 shows the vertical illuminance in the stair "entrance", that is, the measurement result of illuminance in the direction of the gaze measured from the eye level of a person. The value of vertical illuminance varied depending on whether a lighting fixture was installed in the viewing direction or the reflectance and material of the wall.

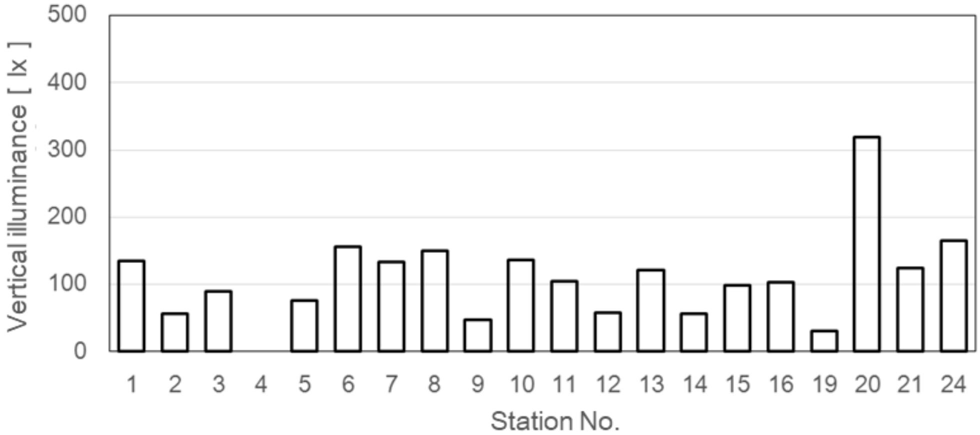

Figure 4. Vertical illuminance measurement result at the entrance of stairs.

Stairs with no walls such as No. 19 had low vertical illuminance. As in No. 20, if there were walls on both sides and a lighting fixture was installed on the top, vertical illuminance was high (Figure 5).

Figure 5. Comparison of maximum and minimum points of vertical illuminance ((**left**): No. 20, (**right**): No. 19).

3.2. Exit of Stairs

Figure 6 shows the results of floor illuminance measured at the top of the stairs, "exit". The illuminance distribution at each point ranged from a maximum of 401 lx to a minimum of 56 lx, and the overall distribution was around 200 lx like the result of "entrance". However, there was a difference in the results of "entrance" and "exit" even for the measurement results of the same stairs. This difference means that pedestrians are momentarily exposed to sudden changes in the lighting environment, given that the time to move through the stairs is short.

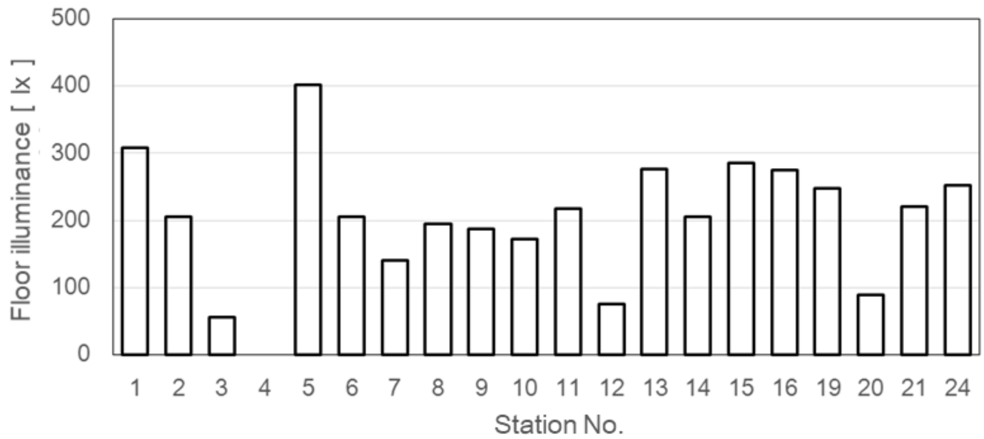

Figure 6. Floor illuminance measurement result at the exit of stairs.

In the case of vertical illuminance(Figure 7), it was affected by the structural and reflective properties of walls and ceilings. When there was a billboard in front of the exit, the billboard functioned as a surface light, thereby increasing vertical illuminance. As such, in the case of investigation from a staircase in a narrow space, it is necessary to consider various environmental factors other than the main lighting from a qualitative point of view.

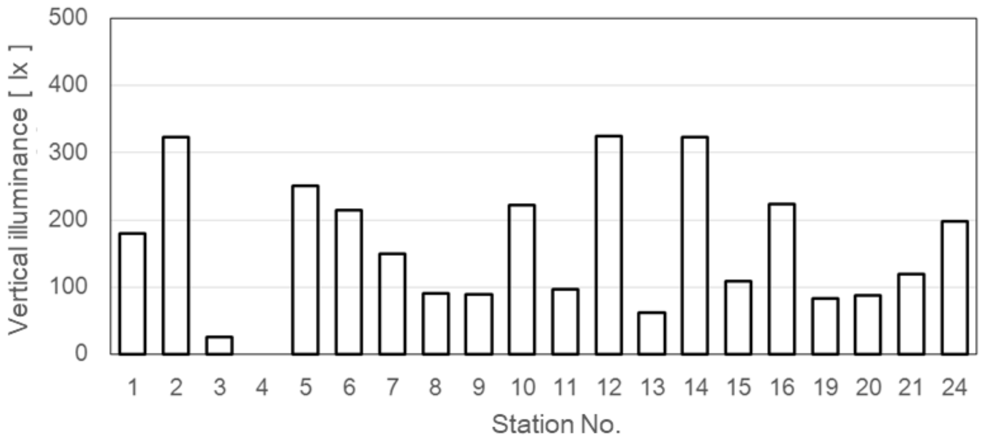

Figure 7. Vertical illuminance measurement result at the exit of stairs.

3.3. Middle Landing

From the point of view of the residence time in space, the time to use the stairs is shorter than at other spaces. Therefore, it is true that the lighting design of the stairs is overlooked compared to the lighting design of other places, and there are many cases where the goal is to secure the brightness. However, in the case of stairs with dynamic characteristics, there is a high possibility that safety problems occur despite the short stay time. In particular, in a short process of passing the stairs, the lighting environment often changes significantly. In this study, the lighting environment of the "middle landing" located in the middle of the stairs was also considered meaningful, and measurements were also carried out in the middle landing. As a result of measuring the floor illuminance of "middle landing"(Figure 8), it showed various distributions depending on the point such as "entrance" and "exit". The presence or absence of a ceiling above the middle landing, that is, the presence or absence of lighting fixtures directly illuminating the floor, is judged to be necessary.

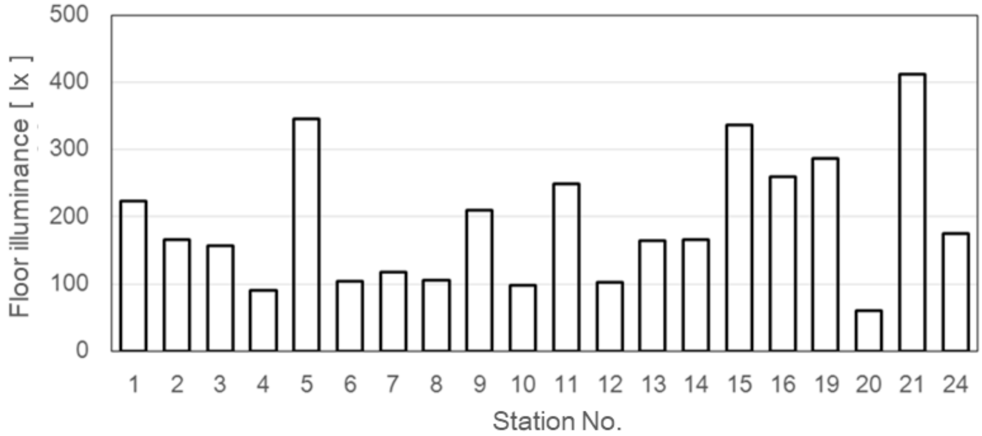

Figure 8. Floor illuminance measurement result at the middle landing.

3.4. Comparison of the Entrance and Exit of Stairs

As described above, the lighting environment changes depending on whether the stairs are "entrance" or "exit". The reason is that the general function of the stairs is to connect the station platform and the concourse. As long as the lighting environment of the starting point and the destination depends on the lighting environment of the platform and the concourse, respectively, this difference will inevitably occur.

The results of comparing the entrance and exit results are shown in Figures 9 and 10. As a result of the comparative examination of floor illuminance, the difference between "entrance" and "exit" was found to be up to 400 lx. It is thought that such a sudden change has an adverse effect on the comfort or safety of using the stairs. Deviation or unevenness in the lighting environment on the stairs where a floating population is always existing may cause accidents such as falling.

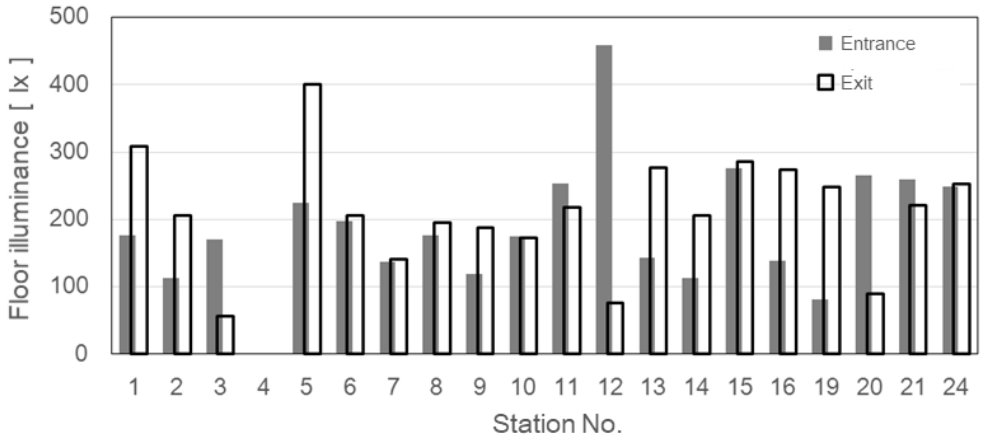

Figure 9. Comparison of floor illuminance measurement results at the entrance and exit of stairs.

The difference in vertical illuminance was more significant than that of floor illuminance (Figure 10). From this, it can be seen that the lighting environment of the concourse seen from the platform and the lighting environment of the platform seen from the concourse were significantly different. The brightness of the gaze direction when using the stairs is an essential factor in determining the impression of a space. It can also cause glare, so reducing that deviation is a significant challenge in stair-lighting design.

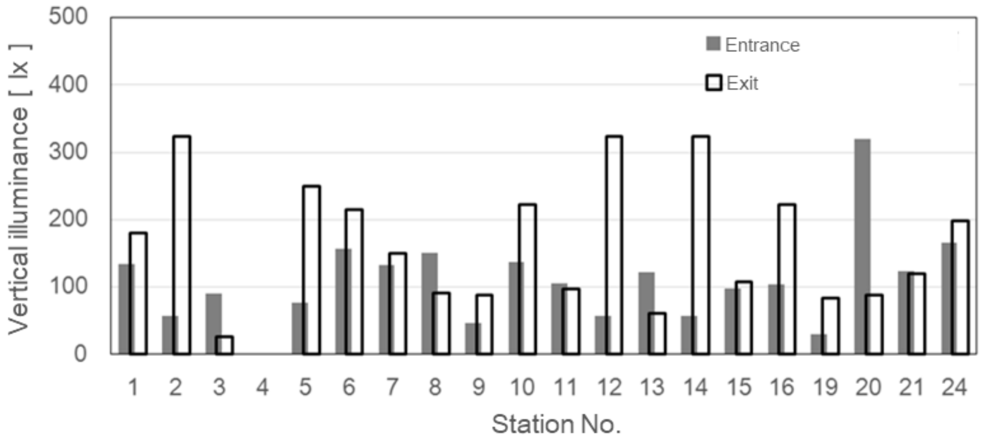

Figure 10. Comparison of vertical illuminance measurement results at the entrance and exit of stairs.

4. Results of the Impression Evaluation

The measurement of the physical quantity of the stairs was carried out by dividing it into three points: "entrance", "middle landing", and "exit". However, in the case of impression evaluation, since there is no division of points as a comprehensive evaluation of stairs, it is expressed as 1 data per location.

The result of examining the correlation between each point of the stairs (entrance, middle landing, exit) and the result of the brightness impression evaluation are shown in Figure 11. The results of the middle landing showed a high correlation compared to other points. It is considered that the influence of floor illuminance has increased because the middle landing, which corresponds to flat ground, has a large floor area among stairs. Therefore, the physical quantity shown in the graphs after 4.1 was taken as "floor illuminance" of "middle landing". By loading the physical quantity measurement result and the impression evaluation result simultaneously, it is for a more in-depth examination.

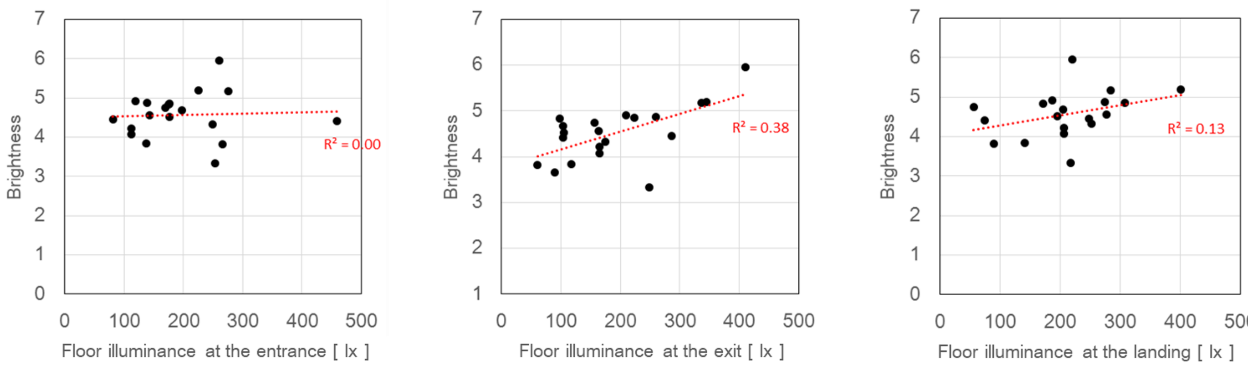

Figure 11. Correlation between illuminance and brightness evaluation results.

4.1. Brightness

The evaluation result of "Brightness" is shown in Figure 12. Some spaces showed a proportional relationship with the physical quantity and floor illuminance, but many spaces did not. In particular, in the case of No. 11, the floor illuminance was high as the lighting fixtures on the wall acted as the main lighting, but the impression evaluation value was the lowest. This means that the physical brightness of space is not absolute in determining the atmosphere and impression of a space.

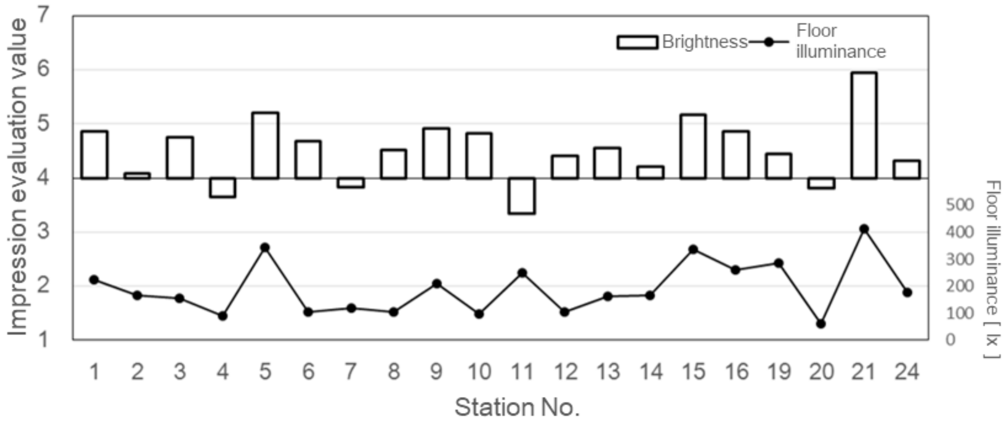

Figure 12. Results of impression evaluation of brightness and floor illuminance.

4.2. Appropriate Lighting

Figure 13 shows the impression evaluation result of "appropriate lighting". In the case of No. 11, where the evaluation of "brightness" was low, "appropriate lighting" was also found to be low. In the case of No. 6, 7, and 8 in a relatively dark environment with low floor illuminance, the result of the impression evaluation was found to be highly evaluated.

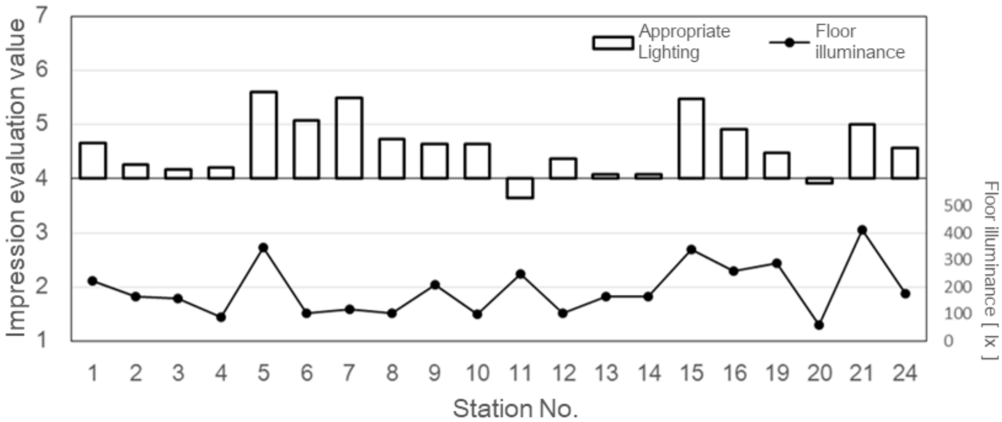

Figure 13. Results of impression evaluation of appropriate lighting and floor illuminance.

In the case of No. 6 and No. 8 (Figure 14), downlights that do not expose lighting fixtures were applied, and the walls were illuminated brightly. Therefore, the floor illuminance of the physical space was not high, but visually, it tended to be evaluated as bright and pleasant. This again suggests that qualitative techniques are essential as well as quantitative techniques in lighting design.

Figure 14. Front views of the No. 6 (**left**) and No. 8 (**right**).

4.3. Glare

In the case of “glare”(Figure 15), no particular space was dazzlingly evaluated throughout the entire point. However, like No. 10 or No. 15, although the floor illuminance value is lower, there are cases where it is evaluated more dazzlingly. This is related to the structural characteristics of the stairs and the installation method of lighting. In narrow and long spaces such as stairs, qualitative studies such as lighting methods and locations should be accompanied by quantitative studies.

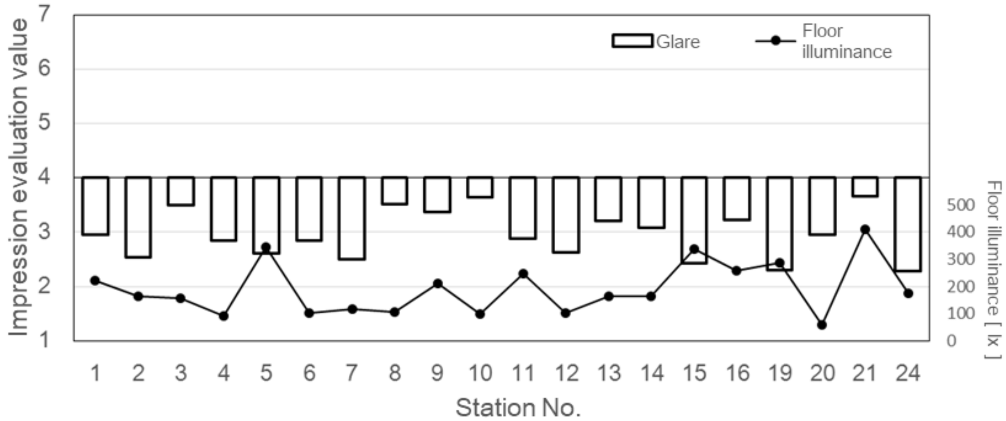

Figure 15. Results of impression evaluation of glare and floor illuminance.

The foreground of No. 10 and No. 15 is shown in Figure 16. Although the floor illuminance was low, there was a problem with the lighting installation method in the case of No. 10, which was evaluated as a dazzling space compared to other points. Lighting fixtures composed of a point and line light sources are directly exposed to the ceiling surface, so you can see that light enters the eye directly when using the stairs. On the other hand, in the case of No. 15, there was no light source directly entering the field of view, so a soft lighting environment was realized overall. It can be seen that the factors affecting “brightness”, “appropriate lighting”, and “glare” in the stairs were not only the physical quantities of the space. In particular, glare prevention is critical in lighting design on an equal footing with ensuring the required brightness. For this, it is necessary to make clear the importance of a qualitative lighting plan.

Figure 16. Font views of the No. 10 (**left**) and No. 15 (**right**) platforms.

4.4. Anxiety

The impression evaluation result of “anxiety“ is shown in Figure 17, and No. 11 and No. 20 were evaluated as relatively unstable spaces. In the case of No. 11, as described in the “Brightness” result, the wall lighting fixture was a problem. Since the lighting device was located close to the floor, although the floor illuminance itself was high, comfort may decrease, and anxiety may increase. Additionally, the case of No. 20 shows a similar trend with the same lighting method.

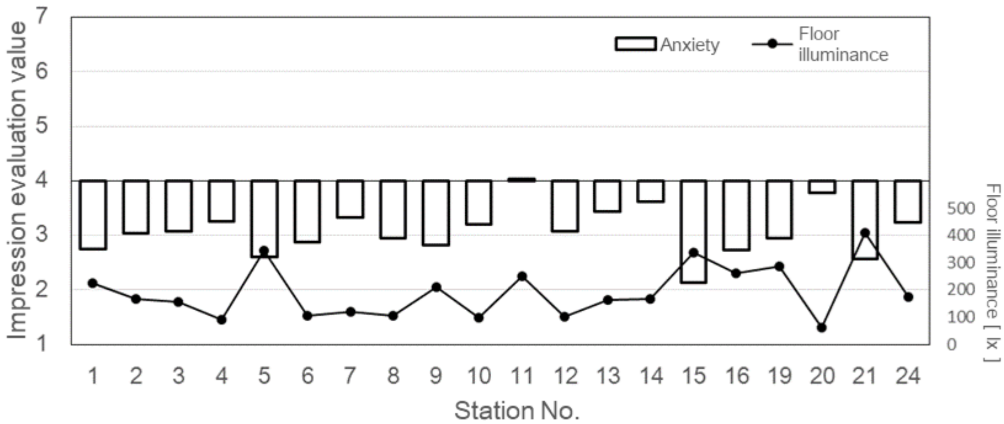

Figure 17. Results of the impression evaluation of anxiety and floor illuminance.

Figure 18 shows the view of the stairs' lighting method in No. 11 and No. 20. All of them had a ceiling, but because the ceiling height was low, the location of the lighting fixtures was set to the wall. The physical brightness of the space increased due to the close distance between the lighting fixtures and the floor, but it was evaluated as an inadequate lighting environment.

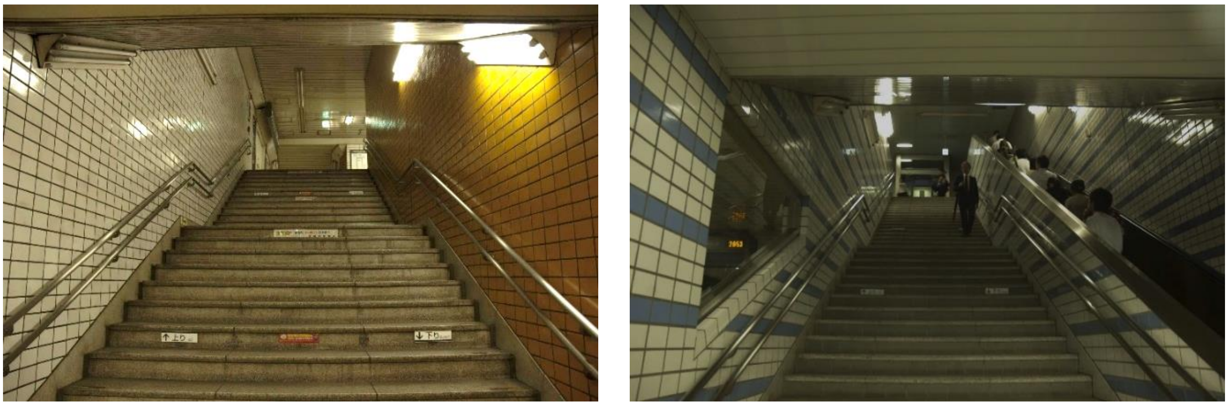

Figure 18. Front views of the No. 11 (**left**) and No. 20 (**right**) platforms.

4.5. Change the Lighting

Figure 19 shows the impression evaluation results of "Change the Lighting". The change the lighting item corresponds to an item that actively evaluates whether the subject wants to improve lighting. First, in the case of No. 5, 16, and 21, which were evaluated as wanting to change the lighting of the space to be darker, the floor illuminance was high, and the impression evaluation result of "Brightness" was also high.

On the other hand, points 4, 11, and 20 were evaluated for wanting to brighten the lighting. In the case of No. 4 and No. 20, it can be judged that it was because the floor illuminance was distributed low. However, in the case of No. 11, where various problems were found as described above, there was a negative trend across all evaluation items.

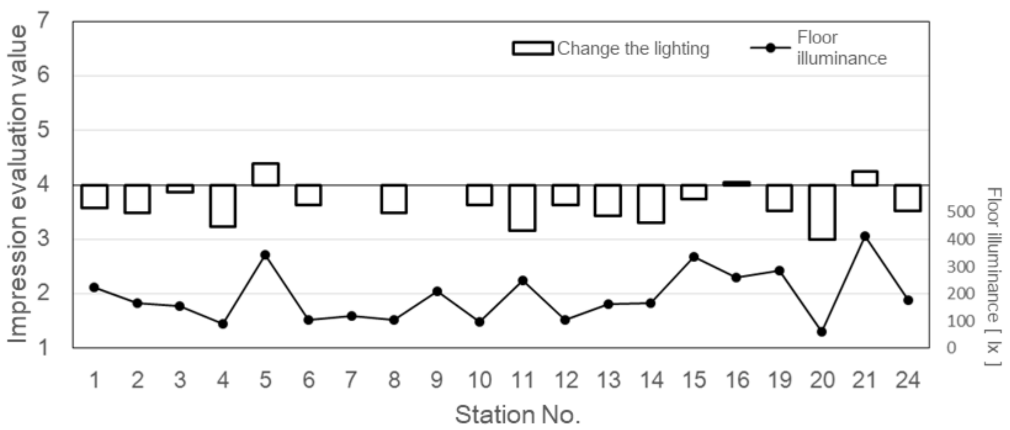

Figure 19. Results of the impression evaluation of 'want to change the lighting' and floor illuminance.

5. Results

5.1. Overview of the Statistical Analysis

In this study, physical quantity measurement and impression evaluation were performed using an actual railway station as a field. However, in the case of impression evaluation evaluated by humans, subjectivity is reflected data, and individual differences may occur. Therefore, in this study, the relationship between the physical quantity of the field, which is an objective evaluation, and the psychological quantity, which is a subjective evaluation, was examined using a statistical method. Accordingly, causal relationships related to various phenomena in the field can be revealed, and objectivity can be given to the results of impression evaluation.

The statistical analysis mainly performed in this study was "Analysis of variance" and "Correlation Analysis". Through a significant difference test from the analysis of variance, factors showing a significant difference in evaluating the environment of each space were determined. In addition, the purpose of correlation analysis was to reveal the relationship between various physical quantities and impression evaluation items, and at the same time, to examine the degree of influence of various environmental factors on impressions. All statistical analyses in this study were analyzed with JMP 11 software.

5.2. Analysis of Variance

Table 5 shows the results of analysis of variance of the impression evaluation results according to the classification of the physical environmental factors of the stairs. It was found that there was a significant difference with the impression evaluation items of two or more items from factors other than "ceiling". In particular, significant differences were detected in 'Width', 'Wall lighting fixtures', 'Light reflectance of wall material', 'Wall color', 'Ceiling height', and 'Lighting position'. This means that there are various environmental factors to consider besides lighting. It is thought that the shape of the space or the condition of the wall located close to the field of view has a great influence on the atmosphere and impression of the space. Looking at the impression evaluation items as a standard, there were many significant differences with respect to 'brightness' and 'darkness' of perception. It can be seen that the intuitive impression was quite different depending on the shape of the space. In addition, although a significant difference was not seen by the shape of "Ceiling", the fact that a significant difference was detected by "Ceiling height" also suggests that the installation location of the lighting should be sufficiently considered. In long and narrow spaces such as stairs, it is judged that the distance between the user's eyes and the lighting equipment is a major factor. If the installation location of general lighting fixtures is the ceiling surface, and since the installation height is low, there may be a discrepancy between the brightness and comfort of the space that is actually felt. Such a trend can also be confirmed from the "Width" and "Wall lighting fixtures" results.

Table 5. ANOVA results according to stair type classification (** significant difference).

Form	Brightness	Calmness	Appropriateness	Darkness	Glare	Anxiety	Change the Lighting
Width	**			**			**
Ceiling							
Wall lighting fixtures		**		**			**
Light reflectance of wall material	**	**		**			
Step edging				**			**
Ceiling color	**	**					
Wall color	**			**	**	**	**
Ceiling height				**			**
Lighting position				**			**

5.3. Correlation Analysis

Table 6 shows the correlation analysis results of the railway station stairs. The floor illuminance and horizontal illuminance, excluding vertical illuminance, which showed very low correlation, were reviewed. As a result of the analysis, the correlation between the physical quantity of "middle landing" and the impression evaluation result was found to be the highest. To be precise, entrance and exit were mainly affected by the lighting environment of the railway station platform and concourse, and the closest point to the lighting environment of the stairs was the middle landing. In order to calculate more accurate results, it was judged that it is necessary to classify the impression evaluation into the entrance, exit, and middle landing.

Table 6. Correlation between physical quantities and impression evaluation items (* $p < 0.05$).

	Brightness	Calmness	Appropriateness	Darkness	Glare	Anxiety	Change the Lighting
Floor illuminance at the entrance	0.05	−0.07	0.01	0.00	−0.15	−0.04	−0.04
Floor illuminance at the landing	0.62 *	0.27	0.41	−0.46 *	−0.06	−0.56 *	0.57 *
Floor illuminance at the exit	0.36	0.20	0.43	−0.19	−0.25	−0.42	0.31
Horizontal illuminance at the entrance	−0.35	−0.15	−0.25	0.37	−0.06	0.41	−0.41
Horizontal illuminance at the landing	0.61 *	0.10	0.25	−0.38	0.02	−0.47 *	0.49 *
Horizontal illuminance at the exit	−0.16	−0.25	−0.12	0.33	−0.26	0.02	−0.31

6. Simulation Analysis

As shown above, the physical performance of the lighting equipment was not the only factor that is important for the establishment of the lighting environment of the stairs. It was influenced both by the shape of the space (for example, the width and ceiling height) and by the color of the space (ceiling and wall colors). Qualitative lighting schemes such as wall lighting fixtures and lighting positions also play a significant role. Here, we focus on qualitative lighting planning for positioning lighting. The width, ceiling, ceiling color, wall color, etc., are determined at the initial stage of construction and are not easily changed through renovation. This requires considerable time and money, and its use may be restricted during construction. However, changing the location of lighting fixtures has plenty of room for renovation and can provide psychological comfort without physical environment improvement. In this chapter, we examine how lighting location affects the lighting environment and the illuminance distribution of the stairs through visualization and numerical values.

6.1. Simulation Modeling

The width of the stairs was set to 1500 mm, assuming that this was in a typical small and medium-sized station. The number of steps was 12, considering the average number of steps from the ground to the middle landing; both sidewalls and a ceiling were used. Most of the lighting of the station to be measured was fluorescent; however, by 2030, Japan will implement a next-generation lighting policy to make all public facilities use LEDs instead. Considering the future utility of the results of this study, the lighting fixtures were set as LEDs for the simulation review. The types of lighting fixtures used in the simulation were downlight and line lighting. The installation locations were set to the ceiling and wall, and each character was reviewed through a simulation.

The lighting fixtures used in the simulation are presented in Table 7 and Figure 20. There are two types of downlights (DOMO 220 G2 2000), which assume a general environment where lighting is installed on the ceiling, and a line light (erx9454 s), which carries a particular environment where lighting is installed on a wall.

Table 7. Specifications of lighting fixtures.

	Lamp Type	Nominal Power	Flux	Efficacy	CCT
Downlight	LED	23.9 W	1597 lm	67 lm/W	3000 K
Line lighting	LED	19.6 W	2866 lm	146.2 lm/W	4000 K

Figure 20. The lighting fixtures used in the simulation ((**Left**): Downlight, (**Right**): Line lighting).

6.2. Simulation Results

The visualization results of the simulation are shown in Figure 21 and Table 8. When ceiling lights were installed, the average illuminance of the room was 395 lx, which was lower than the 700 lx found when wall lights were installed. This is because, in the case of wall lighting, the lighting was installed close to the ground. However, when a wall light was installed, the minimum illuminance was 3.71 lx, and the maximum was 1332 lx, which is a huge difference. Because the distance between the ground and the light is small, the brightness decreases significantly when the distance from the light increases. In contrast, the minimum illuminance for ceiling lights was 24.6 lx, and the maximum was 562 lx. Line lighting on the wall illuminates the stairway more brightly and evenly. However, when applying this in practice, additional lighting should be installed on the landing.

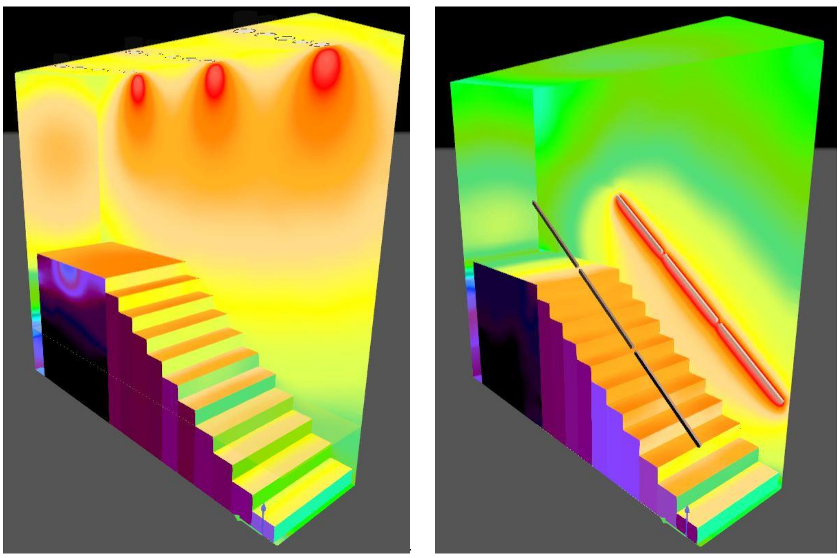

Figure 21. Simulation results ((**Left**): Downlight, (**Right**): Line lighting).

Table 8. Simulation results.

	Illuminance_Avg.	Illuminance_Min.	Illuminance_Max.
Downlight	395 lx	24.6 lx	562 lx
Line lighting	700 lx	3.71 lx	1332 lx

According to the Japanese Industrial Standards for railway station illuminance, the average illuminance of stairs is specified to be 200 lx or more. Considering the shape of the stairs, which makes it difficult to secure the proper lighting installation location, the use of a handrail can provide a qualitatively safer visual environment while satisfying quantitative standards.

7. Conclusions and Discussion

This study conducted the measurement of the physical quantity of stairs, evaluation of impressions from subjects, and statistical analysis of 20 railway stations in Tokyo. The main results of the qualitative analysis are as follows.

As a result of measuring the physical quantity of the stairs, it was found that there was a difference in the illuminance of "entrance" and "exit" even for stairs at the same point. It has been clarified that the lighting environment of space is felt differently depending on the evaluation location and gaze direction, even with the same stairway.

As a result of the impression evaluation of the stairs, it was found that environmental factors that affect the impression evaluation act in a complex way compared to other spaces. In particular, it is a dynamic space of vertical movement, and it is characterized by being influenced by the lighting environment of the platform and the lighting environment of the concourse at the same time. In addition, since it is narrow and elongated, the sidewall is located close to the user, and the lighting equipment is also close to the line of sight in many cases. Although this is effective in improving physical brightness, it causes glare, and in some cases may cause anxiety and safety problems.

As a result of analysis of variance with the impression evaluation results by the shape of stairs, significant differences were detected from most factors other than "ceiling". The lighting design of stairs cannot create a comfortable environment by simply pursuing physical improvement based on lighting alone. It has been clarified that, due to the nature of the narrow space, the reflectivity and material of the wall and ceiling surfaces have a significant impact, and adequately hiding the light source of the lighting fixture is also a significant task.

Among the three spots constituting the stairs, the physical quantity of the middle landing, which is the only flat land, had the highest correlation with the result of the impression evaluation. This is considered because there is no room to judge the space in the evaluation during vertical movement comprehensively. For a more accurate analysis, it is necessary to classify the impression evaluation of the stairs in the future by spots.

As a result of the simulation analysis, it was found that the light environment of the space varies depending on the installation location even if the same lighting equipment is used. The light environment of space is not determined only by the specifications of lighting equipment but is affected by structures such as walls, ceilings, and floors. In particular, the influence of the installation position and installation height is significant. It is possible to implement a bright environment without glare by lowering the installation position and hiding the light source from view. When installing a light on the ceiling is impossible, it is considered adequate to apply a linear light source instead of a point light source on the wall.

In the case of all public facilities in Tokyo, the energy-saving operation is being actively carried out. However, when a temporary method such as turning off some lights is applied, there is a risk of causing a safety problem by causing an uneven and dark lighting environment. Therefore, it is necessary to introduce next-generation lighting equipment, and LED lighting, in particular, can be a good alternative. Due to the nature of the staircase space connecting the platform and the concourse, it is not easy to simply define the lighting environment. In particular, considering that the difference in illuminance is up to 400 lx within the same space and it is a dynamic space, safety problems are likely to occur. In addition, in the case of stairs, glare is likely to occur due to the installation location of the lighting, the lighting method, and the structure of walls and ceilings. This can be solved by hiding the source of the light from view and using the wall surface as a surface light source. Through this study, it was clarified that qualitative factors and physical factors affect the impression and atmosphere of a space. In the future, it is thought that it will be necessary to comprehensively consider the platform and concourse, which are spaces connected to the stairs.

Author Contributions: Conceptualization, J.H.; methodology, T.K.; software, M.K.; validation, M.K., T.K. and K.H.; formal analysis, J.H.; investigation, M.K.; resources, K.H.; data curation, H.B.K.; writing—original draft preparation, J.H.; writing—review and editing, H.B.K.; visualization, H.B.K.; supervision, J.H.; project administration, K.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to appreciate 'Tokyu Corporation' for allowing us to investigate the station building.

Conflicts of Interest: The authors declare no conflict of interest.

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