Research on applications of LEDS in evaluation index For Interior lighting design

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Abstract. With their technology getting mature, LED are energy efficient and have almost replaced the traditional light source. Therefore, in practice, there is a need to apply LED in an evaluation index for the interior lighting design. In this study, the fuzzy Delphi method (FDM), Analytic Hierarchy Process (AHP) method, and Multi-attribute Decision Making method were used to analyze applications of LED in an evaluation index for the interior lighting design. The results indicated that the design value dimension has the most significant influence, followed by the equipment functionality dimension and the application economy dimension. The results also pointed out that, in terms of lamp configuration and selection, the top three important indicators are lamp configuration and selection, compilation of programmed lighting scenes, and intelligent lighting control. Meanwhile, in-depth interviews concluded that the applications of LED in Taiwan design industries were insufficient, leading to results not as good as expected. Therefore, this study suggested: 1) Establish school education training and on-the-job training mechanisms, and increase lighting design courses to enrich professional knowledge of the design talents. 2) The government is advised to promote a special certification and license test or skill test for lighting designers in conjunction with the implementation of the practice signing system to improve the market mechanisms. 3) Taking the outstanding effectiveness of promoting energy-saving labels as an example, the government should encourage the development and application of intelligent lighting devices, and award qualified manufacturers with subsidies and certifications such as intelligent energy labels.

Introduction

In the last ten-odd years, LED have caused an acceleration of reform of lighting fields. With the characteristics of energy saving and environmental protection, high stability light source (color temperature, color rendering), relatively low price, and increasingly mature technology, LED have almost comprehensively replaced the traditional light source, and have been comprehensively applied in the lighting design [1]. The evaluation index for applying LED to the interior lighting design focused more on the investigations of relevant environmental protection and energy saving issues, light source technical aspect, and lighting physical characteristics in the past, with user-centered demand ignored, where the “equipment functionality”, “design value” and application economy” were considered [2, 3]. Aimed at the above three aspects, this study deeply investigated the factors needed to be considered in the applications of LED in the interior lighting design. 1) Equipment functionality: Illuminance calculation, Color rendering index, lamp lighting efficiency. 2) Design value: luminaire arrangement and selection, healthy lighting, controlled color temperature. 3) Application economy: Equipment acquisition cost, Energy consumption burden, planned lighting maintenance.

As can be seen from the above, due to numerous factors, it is difficult to a certain degree to establish an ideal evaluation index, and there should be an appropriate evaluation model to be applied. On these grounds, the topics of this research included: a sum-up of interior lighting design, related literature of using lighting device technology, and applications of the FDM [4]; collecting expert opinions, and extracting the key factor influencing the applications of LED in interior lighting design, with prior studies used as a reference [5, 6]; evaluating and selecting factors. Next, the AHP method was employed to analyze the relative weights and application order of each aspect and each

evaluation factor [7]; and proposing an evaluation index for the applications of LED in interior lighting design and related suggestions.

Research Method

Index Factor Description

A semi-structured questionnaire was designed after summarizing related literature, followed by an expert in-depth interview, which aimed to gain insight into the themes of respondents, suggesting that depth is more important than width [8]. Individual observation of some respondents showed the strength of one hundred people experience accordingly [9], to implement the quantitative Analysis of decision-making behaviors, we would summarize related literature, and investigated the considerations of applying LED to the interior lighting design. Experts or scholars with over 10 years of work experience in building and interior related areas were used as the survey object in this study, where the industry experts referred to architects, interior designers, lighting designers, or high-ranking chief officials holding a PhD or MS degree, the government sector experts referred to those holding a PhD or MS degree, and the academic scholars referred to professors and lecturers. With their assistance in the questionnaire, we obtained complete and effective data, which was classified into “Equipment functionality”- related data (factors 1-7), “Design value” - related data (factors 8-14), and “Application economy”- related data (factors 15-21), with a total of 21 factors being collected and organized, and compiled into the questionnaire (please refer to Table 1).

Table1. A summary table of evaluation criteria for items and factors

Project aspect	Related Factor	References
Equipment functionality	1. lighting calculation (X1)	[4, 6]
	2. intelligent illumination control system (X2)	[4, 11]
	3. luminous efficacy (X3)	[4]
	4. distribution curves of luminous intensity (X4)	[4, 12]
	5. glare (X5)	[4, 13]
	6. color rendering index (X6)	[4]
	7. wavelength of light source (X7)	[4, 13]
Design value	8. basic lighting demand (X8)	[4]
	9. luminaire arrangement and selection (X9)	[4]
	10. programmed light change (X10)	[4]
	11. healthy lighting (X11)	[4]
	12. lighting economics (X12)	[4, 6]
	13. controlled color temperature (X13)	[4]
	14. dynamic lighting (X14)	[4, 6]
Application economy	15. planned lighting maintenance (X15)	[4]
	16. lighting power density (X16)	[4]
	17. equipment acquisition cost (X17)	[4]
	18. energy consumption burden (X18)	[3, 4]
	19. maintenance convenience (X19)	[3, 4]
	20. maintained illuminance (X20)	[4]
	21. lighting energy-saving (X21)	[4]

Fuzzy Delphi Method (FDM)

The FDM was used to screen the factors to simplify the questionnaire, where the non-discriminatory factors were deleted. The test results (Table 2) indicated that the threshold for expert consensus (G^i) is 6.45. 6 factors, including X3, X7, X8, X11, X15 and X18 were deleted because they did not meet the threshold requirement.

Table2. Analysis of the fuzzy Delphi method statistics

Factors	Conservative value			Optimistic value			G^i
	C_L^i	C_U^i	C_M^i	O_L^i	O_L^i	O_M^i	
X1	4	7	5.24	6	10	8.20	6.56
X2	4	8	5.44	7	10	8.32	7.34
<u>X3</u>	<u>3</u>	<u>7</u>	<u>4.88</u>	<u>6</u>	<u>9</u>	<u>7.08</u>	<u>6.34</u>
X4	3	7	5.32	6	10	8.28	6.58
X5	3	7	5.20	6	10	7.88	6.51
X6	4	7	5.36	6	10	7.96	6.54
<u>X7</u>	<u>4</u>	<u>6</u>	<u>4.60</u>	<u>5</u>	<u>9</u>	<u>7.64</u>	<u>5.65</u>
<u>X8</u>	<u>3</u>	<u>6</u>	<u>4.60</u>	<u>6</u>	<u>10</u>	<u>7.76</u>	<u>6.00</u>
X9	4	8	5.72	7	10	8.56	7.41
X10	4	8	5.36	7	10	8.32	7.33
<u>X11</u>	<u>3</u>	<u>7</u>	<u>4.88</u>	<u>6</u>	<u>9</u>	<u>7.28</u>	<u>6.38</u>
X12	3	7	5.20	6	10	8.24	6.55
X13	4	7	5.44	6	10	8.08	6.57
X14	4	7	5.32	7	9	8.08	7.00
<u>X15</u>	<u>3</u>	<u>7</u>	<u>5.12</u>	<u>6</u>	<u>9</u>	<u>7.44</u>	<u>6.43</u>
X16	3	7	5.00	6	10	8.28	6.53
X17	4	7	5.16	7	10	8.28	7.00
<u>X18</u>	<u>4</u>	<u>7</u>	<u>4.84</u>	<u>5</u>	<u>10</u>	<u>7.72</u>	<u>6.12</u>
X19	3	7	5.32	6	10	8.28	6.58
X20	3	7	5.20	6	10	8.52	6.58
X21	4	8	5.36	7	10	8.32	7.33

Note: Table2. Data underlined refers to the factor item with the consensus value lower than 6.45.

Analysis of Empirical Data

AHP framework and Expert Questionnaire Description

The AHP expert questionnaire survey was conducted in the second stage based on the 15 sub-criterion factors selected by the FDM in the first stage. The AHP research process was divided into two stages. The consistency check of the expert evaluation results was performed in the first stage to confirm that the expert evaluation results are effective. The opinions of each expert were integrated in the second stage to find the relationship between the relative weight and overall weight of each hierarchy factor, which would be used for establishing the evaluation index for the interior lighting design subsequently.

The related factors of applying LED to the interior lighting design would be proposed. They would be used to determine the priority order and weight distribution of each factor, in the hope of reducing the hypothetical values to produce more objective and appropriate results that meet the practical requirement.

Analysis and Verification of AHP Questionnaire Data

A total of 30 questionnaires were distributed in this study, with 27 returned (a questionnaire return rate of 90%). The analysis provided by Table 3 (weight order of the AHP overall evaluation index) suggested the main criteria that experts and scholars placed the highest value were design value 40.23%, equipment functionality 37.32% and application economy 22.45%. Experts and scholars unanimously thought that design value had the most significant influence. If an item with insufficient “equipment functionality” and “application economy”, then design value would be the key to influencing the design results.

Next, the top three sub-criteria were lamp configuration and selection (X9), compilation of programmed lighting scene (X10) and intelligent lighting control system (X2), where lamp configuration and selection (X9) had the largest weight value, indicating that correct space should be planned in conjunction with the consideration of the aspect of economy to achieve a good lighting design, which, however, was usually ignored.

Finally, the interview revealed that designers should determine the direction and location of the light source in conjunction with the spatial situation, with lamp selection being the most important factor. The first two factors could still be within the control of the designers, but most designers lacked the professional knowledge concerning lamp selection, that is, a design could not be implemented unless designers had a more understanding of the difference among lamps. In summary of the above index factor data and the project execution process, (X2) provided a favorable execution basis for (X9) and (X10), where (X9) was the indispensable element for a mature design case.

Table3. Weight order of the AHP overall evaluation index

Criteria	Level (1) Wi	Sub-Criteria	Level (2) Wi	Overall Wi	Overall Sequence
Equipment functionality	37.32	X1	13.49	4.50	13
		X2	26.61	8.87	3
		X4	22.71	7.57	6
		X5	15.61	5.20	10
		X6	21.58	7.19	7
Design value	40.23	X9	28.72	9.57	1
		X10	28.29	9.43	2
		X11	16.28	5.43	9
		X12	13.71	4.57	12
		X13	13.00	4.33	14
Application economy	22.45	X16	12.74	4.25	15
		X17	26.44	8.81	4
		X19	26.31	8.77	5
		X20	20.50	6.83	8
		X21	14.00	4.67	11
Wi = Wi * 100%					

Response and Discussion of Establishment of Key Index

Table 3 (weight order of the AHP overall evaluation index) indicated that the top three important evaluation indicators were luminaire arrangement and selection (X9), Programmed light change (X10) and Intelligent illumination control system (X2), based on which relevant responses and suggestions were proposed as follows:

luminaire arrangement and selection (X9)

Referred to a good interior lighting design, which aimed to present the space function and purpose, and to create a lighting environment with an atmospheric situation. The configuration and selection of LED lamps, an important part of the lighting design, were described below:

- ┆ The direction and location of the light source should be determined in conjunction with the spatial situation.

- ┆ The key to lamp type selection is to select appropriate lamp equipment for use.

- ┆ A more understanding of lamp types enabled a more flexible application of lamps, which was the key to influencing the design results.

Programmed light change (X10)

Represented the process where designers implemented the concept of the lighting design in the applications of the intelligent lighting control system, as described below.

- ┆ The process included brightness adjustment, color temperature conversion, timing control, situational scenes, etc., which could be complied based on years, weeks, festivals or seasons into the intelligent lighting control system through computer programming.

- ┆ The implemented concept ensured a timely adjustment of the space atmosphere, and enabled users to operate in a comfortable lighting environment, where the overall effectiveness was maximized to achieve more humane functions as well as to increase the diversified features.

- ┆ Compilation of programmed lighting scene required designers to understand the scene compilation to a certain degree and to be capable of communicating and cooperating with engineering personnel.

Intelligent illumination control system (X2)

With a rapid development of computers and internet technology, the LED technology has been increasingly mature, thereby causing people to have more demand for lighting control, and producing the intelligent lighting control system. The functions are to:

- ┆ Provide a time illuminance based on the requirements of activities.

- ┆ Achieve the multiple lighting functions by creating multiple scenes in a limited space.

- ┆ To lower the maintenance and management costs and to achieve the functions of centralized management and monitoring through remote monitoring, where all status information such as lamp damage could be obtained.

In summary, through the interview with the experts and scholars, we learned that most designers lacked or ignored such professional knowledge, which influenced the design results. Meanwhile, due to high costs, it was a pity that the installation of intelligent lighting control systems was not very popular.

Conclusion and recommendations

Currently LED have almost comprehensively replaced the traditional light source, and have been applied in the lighting design. The FDM, AHP and MADM methods were used to propose the evaluation index of applying LED in the interior lighting design to meet the requirements of practical applications, where 15 evaluation indicators were proposed, which could serve as a reference for the industries. Lamp configuration and selection, compilation of programmed lighting scene and intelligent lighting control were the most important evaluation indicators of applying LED to the interior lighting design. However, the evaluation indicators were still insufficient in terms of concrete applications, leading to results not as good as expected. Hence suggestions to be referenced by the government and related design units were made, as described below, in the hope of perfecting the interior lighting design.

┆ Establish school education (including building or the interior design related departments) training and on-the-job training mechanisms, and increase professional lighting design courses such as lamp configuration and selection and compilation of programmed lighting scenes to enrich professional knowledge of the design talents.

┆ The government is advised to promote a special certification and license test or skill test for lighting designers in conjunction with the implementation of the practice signing system to improve the market mechanisms.

┆ By referencing the administrative measures of energy saving labels promoted with great effectiveness by the Bureau of Energy of MOEA to encourage energy saving, the government should publicly encourage the research and development of the intelligent lighting control system, and award the manufacturers with subsidies and product certifications such as intelligent energy labels.

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