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Assessment of Anidolic Integrated Ceiling effects in interior daylight quality under real sky conditions

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Abstract

The goal of this research is to demonstrate, according to subjective and objective evaluations, that a passive Anidolic Integrated Ceiling (AIC) is able to provide an adequate illumination level for optimal visual and task performance in deeper office spaces and to prove its effectiveness in enhancing interior daylighting quality. A quantitative study was performed by calculating the D.GI.P from spherical images in an office room, while a qualitative evaluation was achieved by using questionnaire survey. Experimental results confirmed that the AIC significantly improves luminous comfort by providing a uniform luminance distribution throughout space. Responses obtained from 62 subjects show that 64.51% of participants were satisfied with their daylighting. In addition, ANOVA test results showed that there is a significant correlation between quantitative and qualitative evaluations of the interior daylight distribution.

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Keywords: Daylighting; indoor daylight quality; AIC; D.GI.P; questionnaire survey; high luminous sky.

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1. Introduction

Luminous comfort has been considered as a subjective condition of visual well-being induced by the visual environment [1]. Several studies in this field have shown that this aspect involves an interaction between human behavior and the quality of the light environment, and that well-being is related to the satisfaction of people with their luminous environment [2, 3, 4]. However, visual comfort and the quality of indoor daylighting are influenced by several parameters and the degree of satisfaction differs according to three main factors: external factors (environmental and contextual factors), psychological factors and individual factors (physiological and cultural factors) [5]. Lighting design quality in indoor environment in office spaces has been widely studied [6, 7, 8, 9]. Successful daylighting design should guarantee a sufficient quantity of light to ensure a comfortable environment appropriate for its use and the visual performance of users as well as a pleasant indoor atmosphere adequate for visual tasks. However, a deep plan office building cannot be illuminated with a simple window and advanced daylighting systems are necessary to ensure a good interior illuminance level. The Anidolic Integrated Ceiling (AIC) is one of the daylighting strategies in buildings designed to redirect and redistribute the natural light deeper in space; its main objectives are to improve the luminous comfort of users and to enhance the interior daylighting quality by reducing glare discomfort [10,11]. This system has proved its efficiency to increase the illuminance level in office buildings under different climates conditions [6, 12, 13, 14].

Visual comfort has been commonly studied by using different tools in order to evaluate the indoor daylighting quality through a qualitative or quantitative approach or both. Results from different studies focusing on assessment of daylighting in buildings have confirmed that physical models can be used to evaluate the performance of daylighting systems [15, 16]. These can provide photometric measurements and also give a visualization of glare and contrast in the studied space [17, 14]. The objective of the present paper is to study the Anidolic Integrated Ceiling effect on the enhancement of the interior daylighting quality by comparing quantitative measurements with subjective evaluations.

2. Experimental protocol

The measurements were conducted in the city of Biskra, Algeria (latitude: 34.48, longitude: 5.44N) in January under real climate conditions. Research performed by Daich et al [6] has shown that this region is characterized mainly by intermediate sky cover conditions which approximate 40% and that it has a very high exterior horizontal illuminance level especially during summer seasons, reaching 83000lux. This study was carried out using a physical scale model (1:4) and the quantitative and the qualitative assessment of the AIC were performed in this model for two scenarios. The first one, the reference case, was a typical office room with dimensions of 6m (width) x 12m (depth) x 3.5m (height) with the following surface reflectance: wall 50%, floor 40% and ceiling 92%. In the second simulation, we added an AIC located on the shorter wall oriented north with a reflectance of 96%. The anidolic ceiling was designed with regards to the geographical characteristics of the city of Biskra and we have used the mathematical model given by Welford and Winston [18]. The simulations were done in January under clear sky conditions.

3. Questionnaire

3.1. Survey Procedure

During the photometric measurement period, a questionnaire survey was carried out with 62 participants (30 male, 32 female) and conducted in two sessions. In the first one, thirty-one subjects were exposed to the reference model, while in the second one, thirty-one other subjects were asked to evaluate daylighting in the test model. During the experience, participants perceived daylighting in three viewspots of the physical models (see Fig.1) and gave their opinion on the effect of AIC on interior lighting in the space and judged the different light settings by rating. The survey had two objectives. The first one was to collect subjective information about indoor daylight quality, and the second one was to compare the survey responses with D.GI.P results in order to study the correlation between objective and subjective evaluations.

Fig. 1. Physical model with viewspots positions

In this investigation, two questions out of twenty were selected according to the study objectives. One question related to satisfaction with daylighting and the second about the pleasantness perceived by the subjects. The questions used in the survey were based on many studies [19, 20] and are listed below:

Table 1. Questions used in the survey.

Factors	Questions	Survey Scale						
		-3	-2	-1	0	+1	+2	+1
Evaluative	1- Overall, how satisfied are you with your level of visual comfort in the office?	very dissatisfied			Neutral			very satisfied
Pleasantness	2- The light in this office is pleasant?	unpleasant			Neutral			pleasant

4. Results and analysis

4.1. Measurement results

The visual comfort is closely related to glare [21] and a recent research has shown that the daylight glare probability can be assessed by using scale models [17]. For this, three viewspots given in Fig. 1 were made on the west façade of the model at the eye level in order to take photographic images (HDR Image) of the whole space. The HDR images were calibrated in Evalglare and Aftab Alpha in order to calculate the D.GI.P and predict the appearance of discomfort glare in these spaces. The D.GI.P analyses were done according to the scale given by Jakubiec and Reinhart [22]. At the same time, measurements in terms of illuminance level were monitored in three points on the work plane of 0.85m. The results are presented in Fig.2 and Fig.3.

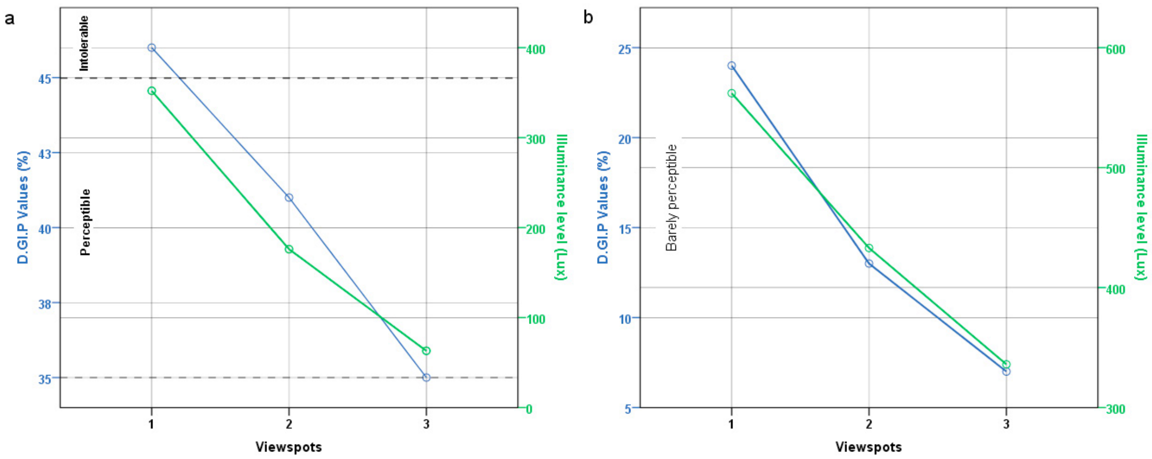

Fig. 2. (a) reference model; (b) test model.

The graphs illustrated in Fig. 2 present results of the illuminance level measured and the D.GI.P values calculated from the HDR images in the three points in the two scenarios. The illuminance values monitored in the models have shown that the Anidolic Integrated Ceiling improves the daylight level; the illuminance values in these points are comparatively situated between 300lux and 600lux. Therefore, the daylight distribution seems to be more homogeneous by reducing the difference of the illuminance level between the window area and the rear part of the room. Moreover, the results have shown that the probability of glare is considerably reduced when the AIC is installed. The D.GI.P values recorded in the different viewspots are less than 30%, the glare is considered as imperceptible for the whole space. In addition, the D.GI.P values calculated in the reference model vary according to the view position. The graphs showed that the discomfort glare is intolerable (46%) in the first viewspot and considered as perceptible in the center and in the depth of the space (41% and 35%).

4.2. Survey results

The graphs given in Fig. 3 and Fig. 4 present the level of satisfaction and pleasantness of the participants toward the interior daylight environment in the scenarios and in the different visual fields. It is clear from the results that the participants felt more satisfied and pleasant with the luminous environment of the test model. Therefore, the graphs can indicate that the level of satisfaction reported by the subjects was the same with the pleasantness level in the two models and the degree of the positive responses to the two questions decreases with the room depth.

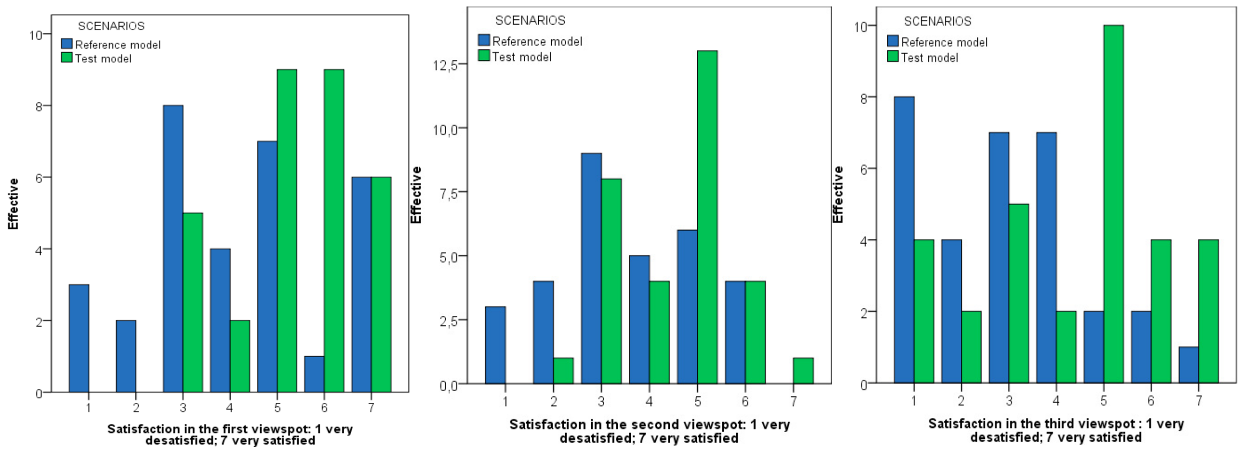

Fig.3. Subjects satisfaction in the two scenarios

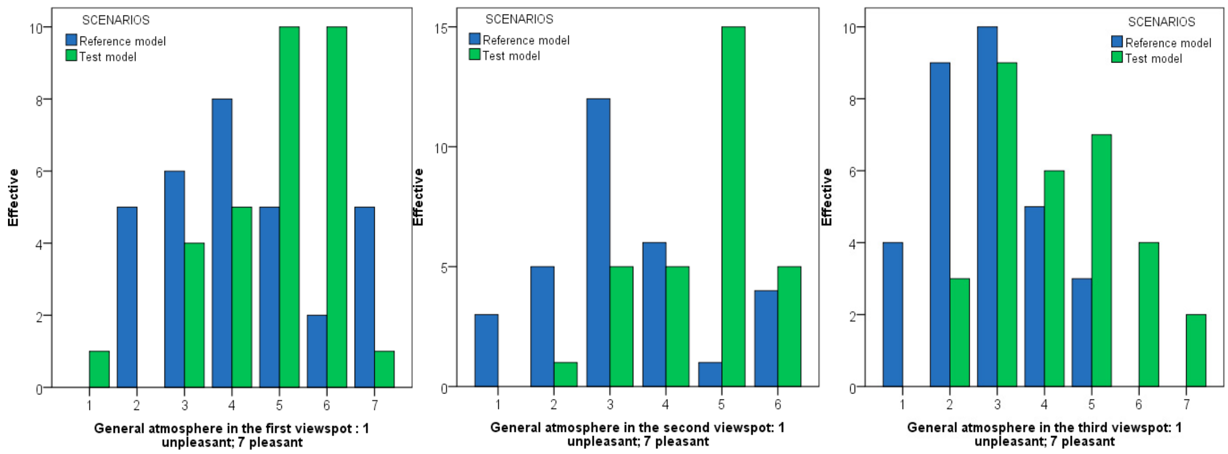

Fig.4. Subjects general atmosphere evaluations in the two scenarios

The comparison of collected data illustrated in Fig.3 showed that in the test model, 77% of the subjects were more satisfied with the quality of daylighting in the first position and 58% in the second and the third position while in the reference model, the participants were more dissatisfied with the luminous comfort: 41% in the first viewspot, 51% in the second and 61% in the third viewspot. In addition, the responses of the pleasantness factor given in Fig.4 showed that the participants preferred the ambiance generated by the AIC. Some 67% were pleasant in the near part of the window, 64% in the middle and 41.9% in the rear part of the room and as a consequence, the subjects were dissatisfied with the atmosphere of the reference model, 35% of participants were dissatisfied with the general atmosphere of the space in the zone near the windows, 61% in the center and 74% in the depth.

4.3. Correlation between subjects' responses and DGP results

In order to study the relationship and the correlation between the D.GI.P calculated values, satisfaction and pleasantness from the subjects' responses, a statistic 'Anova one way' test was used. The test reveals no correlation between the glare calculated and pleasantness responses in the three viewspots; the p-values are greater than .05. In addition, the test showed that there is a very strong correlation between the D.GI.P variable and the responses of the subjects regarding satisfaction with daylighting only in the third position; the p-value is .031. From Fig.5 and Fig.6, it can be seen that the daylight quality in the test model was perceived as more satisfying than in the reference room. It is also apparent from the graphs that this index has a big effect on subjects' satisfaction. The degree of satisfaction gradually increased when the D.GI.P level decreased by more than 30%. However, the comparison of the results given in Fig.6 shows that in the test model the subjects gave positive evaluations and were more satisfied when the D.GI.P was between 5% and 15%. It can clearly be seen in Fig.5 that the D.GI.P values monitored in the reference model are situated between 28% and 61% and the results indicate that the majority of participants perceived that the daylighting quality of the room is insufficient when the D.GI.P level was between 35% and 55%.

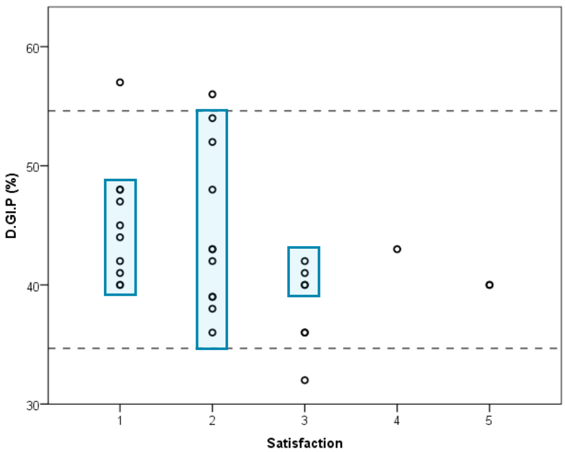

Fig. 5. D.GI.P and daylight satisfaction in the reference model.

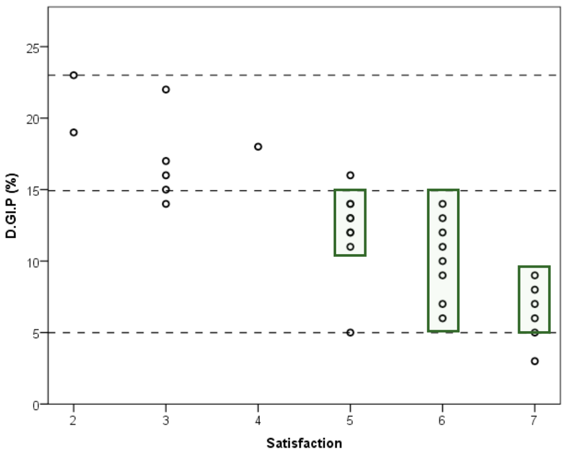

Fig. 6. D.GI.P and daylight satisfaction in the test model.

5. Conclusion

The results presented lead to the conclusion that the use of anidolic integrated ceilings in deep office buildings under high luminous sky conditions provides a comfortable and pleasant luminous environment by providing a more homogeneous daylight distribution and by reducing discomfort glare. Quantitative results in terms of illuminance level showed that the AIC regulates the daylight distribution in the model and met the requirements of more than 300lux for the whole space while the passive area in the reference room is very restricted. The D.GI.P values calculated from the spherical images showed that the AIC reduces significantly the probability of glare; it is considered as barely perceptible for all positions but in the reference model the D.GI.P values varied between intolerable and perceptible. The study has confirmed that a survey is a valid way to study the effects of an AIC on interior daylighting quality, human behavior and satisfaction in a physical scale model and also to provide more information for improved understanding between measurements and subjects' responses. We conclude from the questionnaire results that the participants were more satisfied (average of 64.33%) and more pleased (average of 53%) with the daylight quality. It is clear that the general ambiance in the test room and the degree of positive response strongly depend on the visual field of the observer which decreases with depth. It also appears that the D.GI.P values showed a very strong correlation with the response of the subjects regarding satisfaction with daylighting (p-value is .031). Participants satisfaction increased with reducing glare discomfort level and the satisfaction with daylight can be maximized for the level of D.GI.P (5% to 15%).

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