Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Influence of scale on the daylighting system evaluation in physical models: Experimental method based on objective and subjective measurements

To cite this article: Safa Daich *et al* 2021 *J. Phys.: Conf. Ser.* **2042** 012121

Influence of scale on the daylighting system evaluation in physical models: Experimental method based on objective and subjective measurements

Safa Daich[1], Mohamed Yacine Saadi[1], Barbara E.A Piga[2], Ahmed Motie Daiche[3]
[1] Departement of Architecture, LACOMOFA Laboratory, Biskra University, Algeria
[2] Departement of Architecture and Urban Studies, Laboratorio di Simulazione Urbana Fausto Curti, Politecnico di Milano, Italy
[3] Departement of Architecture, Bejaia University, Algeria

safa.daich@univ-biskra.dz

Abstract. The daylight evaluation in architectural spaces can be carried out using several tools and methods of investigation and analysis. However, many types of research have proven the usefulness of the scale models to evaluate daylighting system performances in buildings. Several scales of a physical model have been used varying between (1:50) and real scale (1:1), and no comparative study has been done to evaluate the effect of the model size in daylighting assessment. The objective of this investigation is to make a comparison between two different scales of a physical model: the first one is a model with a scale of (1:12) while the second is with the scale of (1: 4), aiming to study the scale effects on daylight perception with models equipped with a daylighting system under very high exterior illuminance levels. The methodology of this study consists in collecting simultaneously the measurement of the exterior and interior illuminance level (lux) and subjective evaluations from a questionnaire survey with the two scale models (1:4 and 1:12) under real sky conditions. A correlation between collected data has been explored. Comparing the measurement results, it is obvious that the quantity of light that penetrates the test models (1:4 and 1:12) was the same. The results are with a range of ±1.6%. Moreover, survey results show that the participants' perceptions regarding satisfaction, light distribution and glare questions differ with the scale of the physical 3D model. The subjects felt more satisfied with the luminous atmosphere with the physical model of (1:4) compared with the model of (1:12).

1. Introduction

Experimental methods are frequently used to assess the daylight availability in new or existing buildings. Physical models are investigative and analytical tools used in various stages in the architectural and lighting design sector. They can be used to (i) study the physical appearance of natural light inside a building, (ii) communicate information and ideas of material, shape, size and colour in a very feasible way, (iii) visualize space, form and structure and its interaction with light, and (iv) assess the performance of architectural design in buildings through objective and subjective measurements [1, 2]. In daylighting studies, they can be useful to predict a lighting atmosphere that meets the lighting requirements of the space. They can be also a very effective way to provide solutions to poorly designed or insufficient lighting in the building. They are often used in the process of designing a daylighting system, while they allow the study of its performance in different situations [3, 4]. In addition, they make it possible to study both the quantitative and the qualitative lighting aspect in the built environment, even under the most delicate conditions (complicated configurations, multiple situations, etc.). However, it has been proved that the quantity and the quality of light present in a scale model is the same as that in a fullsize space if you respect the same experimental conditions and precise rules in the realization of the scale model (reflectance, materials…). The interaction of light with an object is independent of the size of the object and the visual impression that we have will be very close, even identical to that perceived in a real space [5].

The daylighting system used in this investigation is called Anidolic Integrated Ceiling (AIC). This system is a passive device generally used in office rooms to regulate daylight distribution, especially in deep spaces. It consists of three main elements: (i) exterior anidolic element used to capture and collect daylight from the outside, (ii) reflective light pipe used to channel daylight, and (iii) distributors used to diffuse daylight to the interior area. Several studies have proved the AIC's effectiveness to improve visual comfort and reduce the energy consumption for electrical lighting [6]. There have been studies done concerning scale models and daylight, however, few studies have been made to study the effect of the scale of the model when daylighting system performance is investigated and how the daylight is perceived in a scale model.

The objective of this paper is to study the effect of a physical model's scale on the assessment of daylighting system performance in a deep office space under real sky conditions.

2. Methodology

The methodology of this study consists of two parts. In the first part, measurements in situ of the physical lighting data (exterior and interior illuminance level, lux) were carried out with the scale models under real sky conditions. On the other hand, a questionnaire survey was used to collect subjects' assessments of the daylighting environment in two physical models that only differ by their scale. The objective and the subjective data were then analyzed using IBM SPSS Statistics 25, aiming to find the most decisive parameter that leads to a good choice of the scale of the built physical model when the performance of the daylighting system is investigated. The method application aims to:

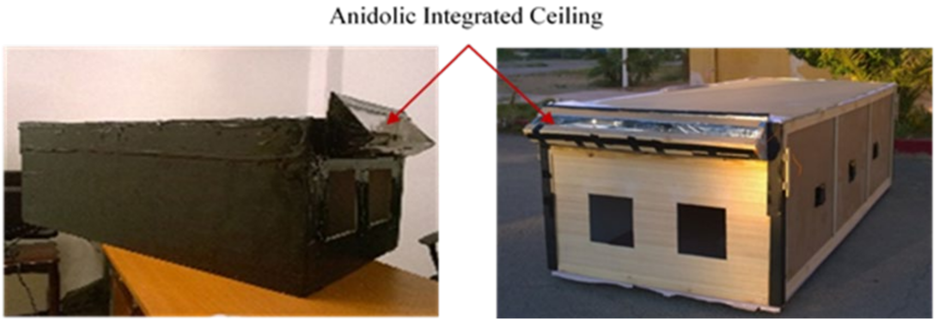
1) Evaluate whether the scale of a model affects the perceived daylight in the test room;
2) Study the performance of the daylighting system concerning the physical model scale;
3) Identify the subjective variables that affect the participant perception.

In this section, the following subsection describes the experimental physical models, survey procedure and data collection.

2.1. Physical 3D models characteristics

Scale models vary in size according to the study objective, from 1:500 for urban environments to 1:1 for interior daylight studies. Scale models can be used in all stages of the design process. The models built for the measurements differ in scale and material. They represent commonly used model scales for the detailed facade (1:1-1:10), room (1:20) and building design (1:50) [7, 8]. The scale model can be made of cardboard, plastic or plywood [9, 10]. In this investigation, two scales of a 3D model have been built: the first one is in scale 1:4 while the second is in scale 1:12 (see Figure 1). The purpose is to study which scale is the most ideal when it comes to analysing the performance of the Anidolic Daylighting System in a scale model. Space represents a typical space of an office room with a width of 6 m, a depth of 12 m and a height of 3.5 m. Two external openings of 1.2m x1.2m are located in the smallest façade. The two models were identical to each other, which meant that the same level of detail and number of objects were in each scale model and that they have the same geometric and photometric characteristics (see Table 1). In the realization of the scale models, some rules have been respected to have the same 3D view inside the two models: a minimum ceiling height of 15cm and a minimum room depth of 30cm was chosen.

The physical 3D models were then experienced under real sky conditions of the city of Biskra (South East of the capital Algiers: Latitude: 34° 52′ North, Longitude ° 45′ East). The microclimate of this city is characterized by hot and arid sunny days, intermediate sky conditions (40%) and high exterior illuminance levels exceeding 80000 lux [4].



(a) Model (1 :12) (b) Model (1 :4)

Figure 1: Physical models used in the experience

Table 1: Geometric and photometric characteristics of the physical 3D models

Models characteristics	Elements	Dimensions (m)
Interior photometric proprieties (Refletance %)	Walls : -Model (1 :12)	52%
	-Model (1 :4)	51%
	Floor : -Model (1 :12)	39%
	-Model (1 :4)	41%
	Ceiling :	90%
	Anidolic Integrated Ceiling :	95%

2.2. Questionnaire procedure

During the measurement period, a survey was carried out to collect subjective information about the subject's preference regarding the scale of the 3D model. The subjective assessments were conducted with 62 master students in architecture, aged 20~23 years old in two sessions in the same period: in the first one, thirty-one subjects were exposed to the scale model of (1:4), while in the second one, thirty-one other subjects were asked to evaluate daylighting in the model with a scale of 1:12. Each subject perceived only one scale model and gave his/her evaluation by answering a set of questions. The subjective evaluations were collected by asking the participant to perceive daylighting from the viewspot located in the shorter wall of the scale models in order to obtain a general appreciation of the interior luminous atmosphere. The view position was situated at the same human eye level (150 cm), in a comfortable situation when they were asked to place their head inside the model and give their opinion. The experiment began with an explanation of the procedure (10 min). After experiencing the setting of the experiment (5 min), the participants were asked to observe daylighting in the physical models and to answer a question regarding (i) scale size, (ii) satisfaction, (iii) light distribution and (iv) glare. The questions presented in Table 2 were based on many studies [3, 5]. The data collected (objective and subjective data) were then compared and analysed using IBM SPSS Statistics 25.

Table 2: Questions used in the experience

Questions/Scale used	1	**2**	**3**	4	**5**	**6**	7
Question 1: Is the scale of the model apt to represent a real room?	Not representative			Neutral			Very representative
Question 2: Rate your level of satisfaction with daylighting?	Not satisfied			Neutral			Very satisfied
Question 3: How is the light distributed in the space?	Not homogenous			Neutral			Very homogenous
Question 4: Rate your level of sensitivity to glare?	Very sensible			Neutral			Not sensible

2.3. Data collection

The experiment took place on January 04, 2017, under clear sky conditions of the city of Biskra (Algeria). The measurements were done with models at 10:00 a.m. The interior illumination values were taken on a horizontal work plane located 0.80 m from the ground. The illuminance was measured at fifteen points on two axes situated in the middle of the windows. The interval between two measurement points was 0.8 m in the longitudinal direction and 1.5 m in the transverse direction. All illuminance measurements were taken using the VOLTRAFT type. MS 4 IN 1 #DT 8822 Environment Meter and a Chauvin Arnoux CA-811 type digital luxmeter. Figure 2 (a and b) shows the measurement points and the axis location in the test room (scale 1:4 and 1:12).

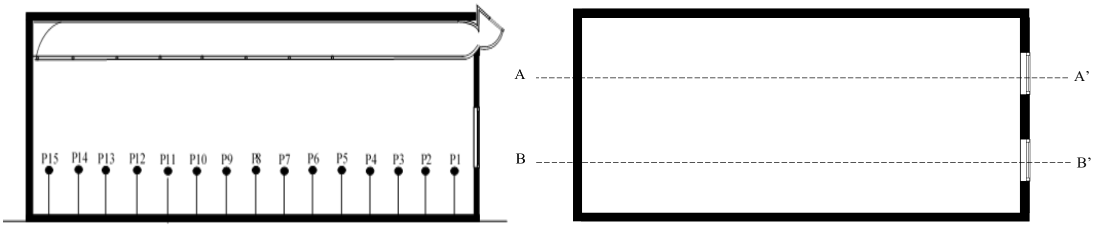


Figure 2: Measurement points and axes location in the test room

3. Results and discussion

3.1. Measurement results

In order to analyse the measurements results obtained from the test models, a Coefficient of Variation (CV) has been calculated, aiming to compare the propagation of daylighting inside two physical models of different sizes. This coefficient represents a measure of relative variability. It is the ratio of the standard deviation to the mean (VF-VI) where VF is the final value and VI is the initial value. In our case and for the scale assessment, the initial and the final values represent the illuminance level measured at a given point in both scale models (1: 4 and 1:12). The results are presented in Figure 3 and Table 3.

Table 3: Measurement results of illuminance level in both physical 3D models

Measuring points	Distance from opening (m)	Interior illuminance level in Lux (Scale model 1:2)		Interior illuminance level in Lux (Scale model 1:4)	
		Axe AA	Axe BB	Axe AA	Axe BB
1	0,8	1302	1334	1418	1397
2	1,6	928	949	1461	1437
3	2,4	1171	1196	1158	1139
4	3,2	1099	1120	1077	1065
5	4	810	829	848	835
6	4,8	772	789	811	801
7	5,6	565	579	757	743
8	6,4	677	690	717	707
9	7,2	413	420	370	364
10	8	460	470	413	406
11	8,8	438	445	389	382
12	9,6	392	397	294	289
13	10,2	424	432	412	405
14	11	567	578	538	531
15	11,8	412	421	454	446

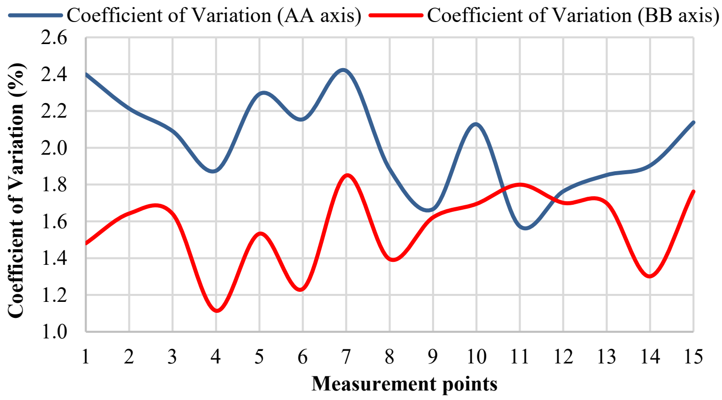
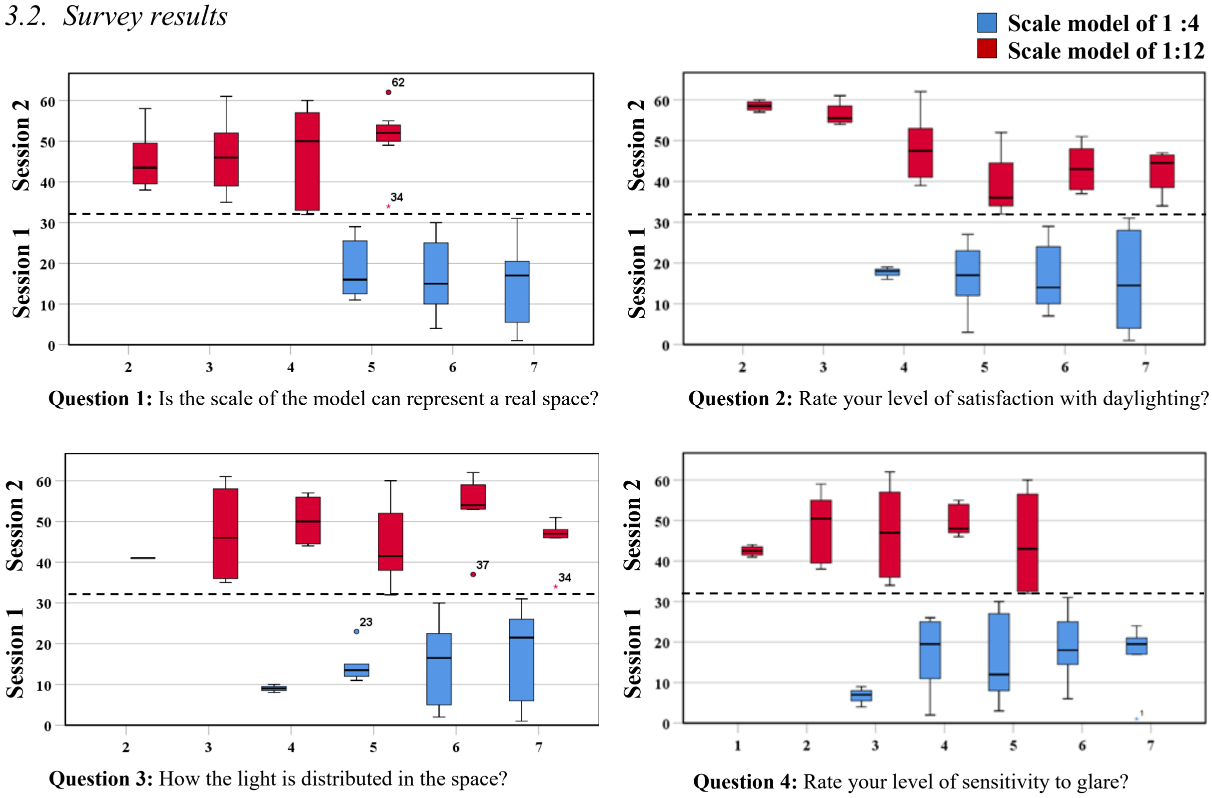


Figure 3: Coefficient of Validation result

The results presented in Table 2 indicate that the illuminance values obtained in the two models in both axes are very close. The maximum gap of 32 lux was recorded in the AA axis and 24 lux in the BB axis. Moreover, Figure 3 shows that, in the fifteen measurement points, a good correlation between the results were observed. In the AA axis, the CV is situated between ± 1.6% and ± 2.4% with an average of ± 2% and in BB axis, the CV was between ± 1.1% and ± 1.6% with a mean of ± 1.6%. This study confirms that the scale of the model did not have a significant effect on the quantity of light received inside the model. It is almost identical regardless of the scale of the physical model.

3.2. Survey results



Question 1:	1.Not representative	4. Neutral	7. Very representative
Question 2:	1. Not satisfied	4.Neutral	7.Very satisfied
Question 3:	1. Not homogenous	4.Neutral	7. Very homogenous
Question 4:	1.Very sensible	4.Neutral	7. Not sensible

Figure 4: Survey results

It is clear from the results given in Figure 4 that the majority of the participants prefer the large model (1:4) for daylighting perception and consider it more representative of the reality compared to the small model with a scale of 1:12. The large model (1:4) was preferred by most of the subjects (more than 98% of the respondents were positive) while the small model (1:12) was considered too small to evaluate the luminous environment (77.41% of the assessments were negative). In addition, Box-Plot graphics indicate that the level of satisfaction regarding visual comfort, light distribution and glare differs according to the scale of the physical 3D model. The subjects felt very satisfied with the interior luminous atmosphere of the large model, most of the answers were positive compared to the small physical model where participants have used positive and negative scales in their assessment.

4. Conclusion

The objective of this paper was to study the effect of the scale of a physical 3D model on the evaluation of the interior luminous environment equipped with a daylighting system. For this, several objective and subjective data have been collected through two different sizes of scale models (1:4 and 1:12) under real luminous sky conditions of the city of Biskra (Algeria). The measurement results show that the scale of the model does not have a significant impact on the amount of light that penetrates the space. Both models receive nearly the same quantity of daylight. On the other hand, subjective evaluations obtained from the survey indicate that the large model (1:4) was the most preferred by the subjects compared with the small model (1:12). This investigation can be useful and help architects, engineering and students, on the choice of the scale of the physical model when investigating daylighting system performances in buildings under similar conditions. Further work is required on the comparison of software simulation results with measurements and survey results.

References

[1] Gibson I, Kvan T and Wai Ming L 2002 Rapid prototyping for architectural models *Rapid Prototyping Journal* 8 (2).
[2] Kesten D, Fiedler S, Thumm F, Löffler A, and Eicker U 2010 Evaluation of daylight performance in scale models and a full-scale mock-up office *International Journal of Low-Carbon Technologies* 5(3):158-165.
[3] Daich S, Zemmouri N, Morello E, Piga EAB, Saadi M Y, and Daiche AM 2017 Assessment of Anidolic Integrated Ceiling effects in interior daylight quality under real sky conditions *Energy Procedia* 122:811-816.
[4] Thanachareonkit A, Scartezzini JL, and Andersen M 2005 Comparing daylighting performance assessment of buildings in scale models and test modules *Solar Energy* 79(2):168-182.
[5] Yngvesson L, and Adolfsson E 2018 The impact of scale when using models of daylight analysis *Dissertation, Jönköping Technical University*.
[6] Binarti F, and Satwiko P 2018 Assessing the energy saving potential of anidolic system in the tropics *Energy Efficiency*11(4):955-974.
[7] Bodart M, Deneyer A, De Herde A and Wouters P 2011 A Guide for Building Daylight Scale Models *Architectural Science Review* 50 (1):31-36.
[8] Reinhart C 2014 Daylight Handbook 1 Fundamentals Designing with the Sun USA.
[9] DAICH S 2011 Simulation et optimisation du système light shelf sous des conditions climatiques spécifiques, Cas de la ville de Biskra *Doctoral dissertation Université Mohamed Khider Biskra*.
[10] Zazzini P, Romano A, Di Lorenzo A, Portaluri V and Di Crescenzo A 2020) Experimental analysis of the performance of light shelves in different geometrical configurations through the scale model approach *Journal of Daylighting* 7(1): 37-56.