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ANALYSIS OF ERROR SOURCES WITHIN DAYLIGHTING PHYSICAL AND VIRTUAL MODELS OF BUILDINGS

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ABSTRACT

Recent studies have pointed out the general tendency of scale models to overestimate the daylighting performance of buildings, usually expressed through work plane illuminance and daylight factor distribution profiles. An analysis of the corresponding sources of error has allowed to identify the main parameters responsible for the overestimation - such as indoor surfaces reflectance, glazing transmittance and photometers features. It was shown that a careful mock-up of the real building characteristics can reduce the divergence of the scale models daylighting performance down to 30 %, even for locations situated away from the window side. An appropriate tuning of the numerical parameters involved in daylighting computer simulation models lead to comparable accuracies, as shown by different authors.
Daylighting computer simulations of a real building (a 1:1 scale daylighting test module), together with a virtual model of the corresponding 1: 10 scale model placed in a scanning sky simulator, were used to carry out an in-depth analysis of the sources of error of both physical and virtual modeling techniques. Through a computer sensitivity analysis of the most significant parameters influencing the accuracy of the physical model, design rules and error calculation methods for scale models are expected to be drawn.

INTRODUCTION

Daylighting designers and researchers commonly use design tools such as physical and virtual models for the assessment of the daylighting performances of buildings. However, recent studies have shown that both methods could not lead to a perfect analysis of real buildings. As shown in Table 1, these studies have pointed out the sources of errors which cause inaccuracy in physical and virtual models [1], [2], [3], [4]. In order to understand the causes of these errors, scale and virtual models were compared under the same condition, their discrepancies being analyzed. According to a previous study [5], that considered a simple office (1:1 module consisting of a single office room with a single lateral window) and its 1:10 scale model, the reproduction of photometric properties of materials (transmittance and reflectance) as well as, the lux-meter cosine responses are the main factors responsible for overestimation in scale models. However, to what extent the properties of the surface reflectances, window transmittances and geometrical details influence the daylighting performance were not fully solved. In this paper, a virtual models reproduced by the way of an advanced computer simulation technique (Radiance program) and a scale model placed under a scanning sky simulator were considered, in order to identify and quantify each source of error. Moreover, to understand the causes of this inaccuracies, several sets of parameters, described in of Figure 1, were studied by the way of computer simulation.

Scale model	Virtual model
Geometrical features	Geometrical features
Photometrical features	Photometrical features
Photometric sensors	Photometric sensors
Maintenance and Location	Parameter setting and accuracy

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Table 1 : List of potential sources of errors for physical and virtual models.

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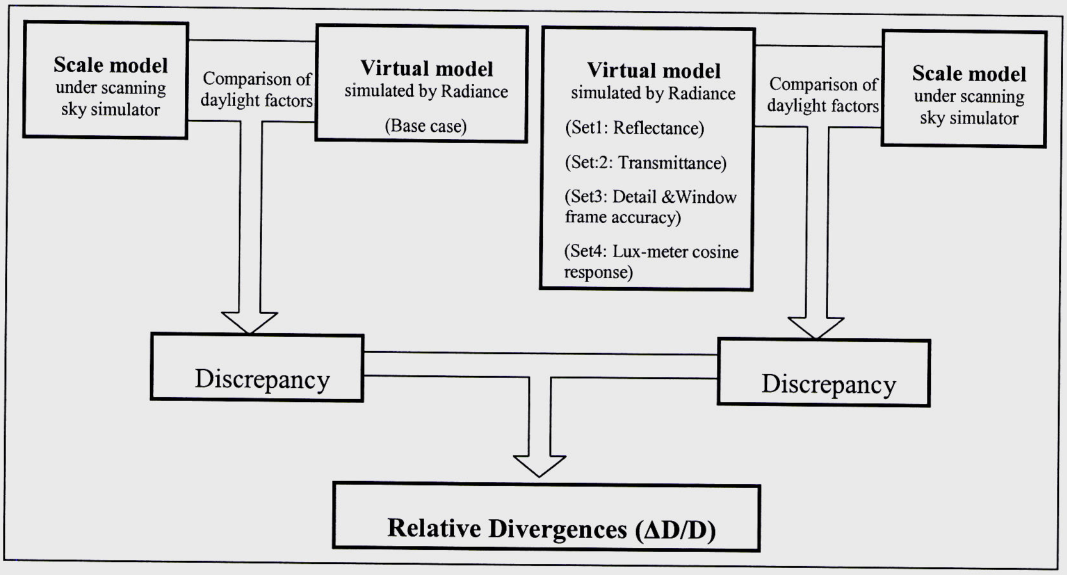


Figure 1: Sensitivity analysis to outline the effect of inaccuracies by the way of computer simulation.

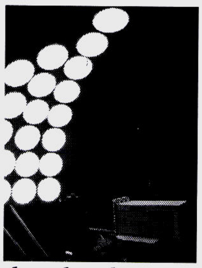
METHOD

The virtual model carefully reproduced the geometrical and photometrical features of the scale model making up by this way a "virtual base case" ; as shown in Table 2. The scale model was placed under a scanning sky simulator simulating the CIE overcast sky (see Figure 2) in order to allow a first validation of the "virtual base case".

Sets of parameters

As mentioned earlier, the surface reflectance, the window transmittance, the geometrical details of the model (such as the lighting fixtures for instance) were considered in the virtual model in order to proceed to a sensitivity analysis. To study the tendency induced by these parameters, four sets were considered in a separate way: (i) surface reflectance, (ii) window transmittance, (iii) geometrical details and (iv) lux-meter cosine response, (see Table 3). Both virtual and scale models were considered under a CIE overcast sky, the daylight factors gradient inside the room being analysed at 7 different points, placed at 0.1 m distance each (i.e.7 lux-meters in scale model).

To identify the causes of the model inaccuracy, the daylight factors discrepancies between the scale and virtual models were assessed and compared. The relative divergences were used in order to quantify the impact of the surface reflectance, window transmittance, model details and lux-meter on the models accuracy .



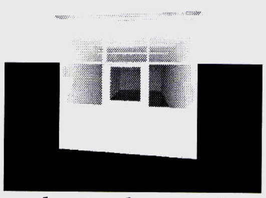


Figure 2 : Scale model placed under a scanning sky simulator and corresponding virtual model elaborated for computer simulation (Radiance program).

Description		1:1 module	1:10 scale model	Virtual model (Base case)
Geometry	Length (m.)	6.5 ± 0.1	0.65 ± 0.005	6.5
	Width (m.)	3.0 ± 0.1	0.30 ± 0.005	3.0
	Height (m.)	2.5 ± 0.1	0.25 ± 0.005	2.5
	Facade area (m2)	7.50 ± 0.2	0.0750 ± 0.01	7.5
	Glazed area (m2)	3.68 ± 0.2	0.0368 ± 0.01	3.68
	Occupants(-)	0	0	0
Fenestration materials	Window	Double glazing	2mm.-single Clear acrylic	-
Indoor surface materials	Floor	Fitted carpet (Green)	Paper (Textured Green)	-
	East wall	Satin (White)	Paper (White)	-
	West wall	Satin (White)	Paper (White)	-
	North wall	Canvas (White)	Paper (White)	-
	Ceiling	Satin (White)	Paper (White)	-
	South wall	Painted metal (White)	Paper (White)	-
Reflectance (%)	Floor	16.14 ± 3	16.47 ± 3	16.47
	East wall	81.53 ± 3	79.47 ± 3	79.47
	West wall	82.37 ± 3	79.37 ± 3	79.37
	North wall	72.10 ± 3	70.83 ± 3	70.83
	Ceiling	79.90 ± 3	76.06 ± 3	76.06
	South wall	82.60 ± 3	79.17 ± 3	79.17
Transmittance (%)	Window	80.54± 3	93.08± 3	93.08
Simulation Parameters*	ab	-	-	9
	aa	-	-	0.3
	ad	-	-	26315
	ar	-	-	8

Table 2 : Geometrical and photometrical properties of the 1:1 module, 1:10 scale model and virtual model. *(*aa: ambient accuracy - this value will approximately equal the error from indirect illuminance interpolation, ab: ambient bounces - this is the maximum number of diffuse bounces computed by the indirect calculation, ad: ambient divisions - the error in the Monte Carlo calculation of indirect illuminance will be inversely proportional to the square root of this number, ar: ambient resolution - this number will determine the maximum density of ambient values used in interpolation.) [6]*

Sets of comparative data	Adjustment in Radiance	Sets of comparative data	Adjustment in Radiance
Set 1: Reflectance (ρ)	$\rho_{scale\ model} = \rho_{base\ case}$	**Set 2**: Transmittance (τ)	$\tau_{scale\ model} = \tau_{base\ case}$
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.9		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.9
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.8		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.8
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.7		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.7
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.6		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.6
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.5		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.5
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.4		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.4
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.3		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.3
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.2		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.2
	$\rho_{scale\ model} = \rho_{base\ case}$ x 0.1		$\tau_{scale\ model} = \tau_{base\ case}$ x 0.1
	$\rho_{scale\ model} = \rho_{base\ case}$ x 1.1		τ = 100%
	$\rho_{scale\ model} = \rho_{base\ case}$ x 1.2	**Set 3**: Details	Without lamp and details
	$\rho_{scale\ model} = \rho_{base\ case}$ x 1.3		0.1 m shifted in direction x
	$\rho_{scale\ model} = \rho_{base\ case}$ x 1.4		0.1 m shifted in direction y
	$\rho_{scale\ model} = \rho_{base\ case}$ x 1.5		0.1 m shifted in direction z
		Set 4 : Lux-meter Cosine response	1° shifted towards window
			2° shifted towards window
			3° shifted towards window

Table 3 : Sets of comparative data used to outline the effect of inaccurate geometrical and photometrical features of models on the daylighting performance.

RESULTS

Underneath CIE overcast sky conditions, the virtual base case and the scale model, lead to a maximal relative divergence of 9.22 % at 2.2 m from window (Figure 3) and a minimal discrepancy of 0.99% at 1.2 m from window; the average relative divergence is equal to 4.85%, confirming the excellent simulation capability of the Radiance program.

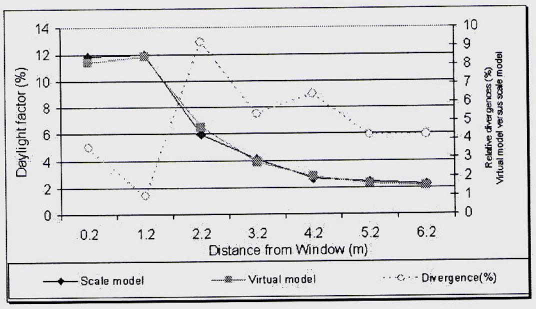
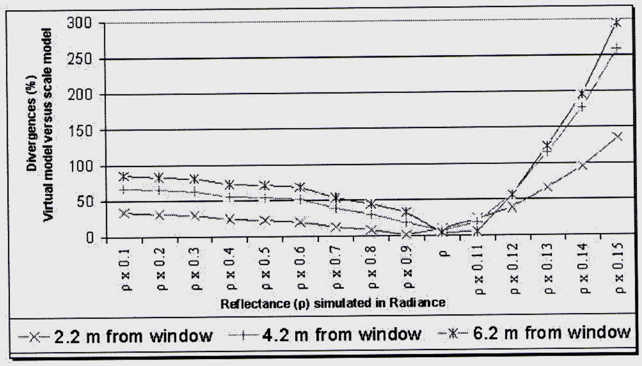
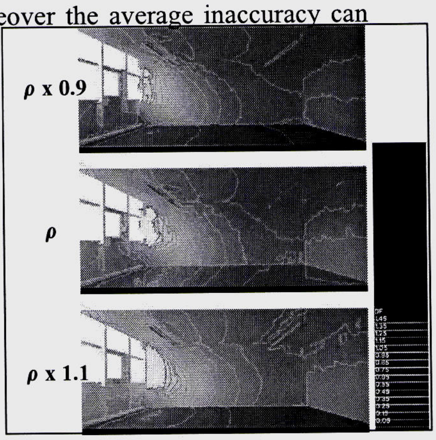


Figure 3 : Comparison of daylight factors observed in the scale model and calculated by a virtual model (Radiance program) for the base case.

As mentioned above, the sources of errors inducing inaccuracies in the scale model were considered by the way of four parameters sets. In the first set, the study was performed for different surface reflectance (ρ) corresponding 10% up to 150% of the scale model surface reflectance (base case). As shown in Figure 4, after varying the corresponding surface reflectance, the average discrepancy reaches 17.2% (from 4.85% for the base case) for a 10% reflectance reduction and 10.22% for 10% increase. Moreover the average inaccuracy can reach up to 177.7% for a 50% reflectance increment.



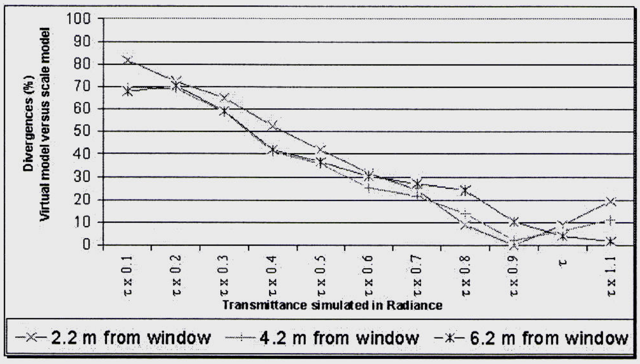


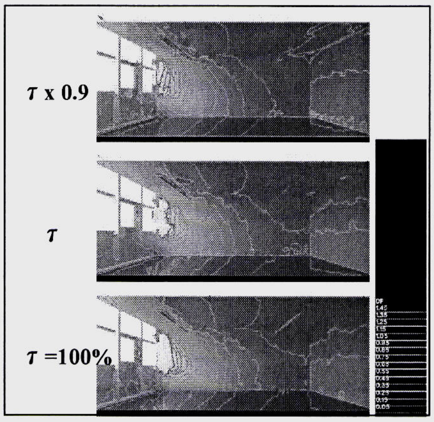
Divergences	ρ x 0.1	ρ x 0.2	ρ x 0.3	ρ x 0.4	ρ x 0.5	ρ x 0.6	ρ x 0.7	ρ x 0.8	ρ x 0.9	ρ	ρx 0.11	ρx 0.12	ρx 0.13	ρx 0.14	ρx 0.15
2.2 m	33.79	31.44	29.42	24.58	22.44	19.43	12.97	8.62	1.53	9.22	23.21	37.52	64.85	94.64	135.0
4.2 m	67.06	64.75	62.81	54.95	53.78	50.31	37.81	29.53	17.94	6.43	18.58	56.67	114.7	177.7	258.5
6.2 m	85.24	82.89	80.33	72.66	71.12	67.64	53.11	44.01	32.21	4.23	4.89	55.33	123.1	196.0	293.7
average	55.14	53.02	50.96	45.18	43.75	40.58	31.57	25.44	17.16	4.86	10.22	36.51	77.05	120.5	177.7

Figure 4 : Comparison of relative divergences for set of different surface reflectances.

The surface reflectance inaccuracy induces significant discrepancies between the scale and the virtual model, particularly in the deeper area of the room: it is one of the main factors to be considered to model daylighting performance in an appropriate manner.

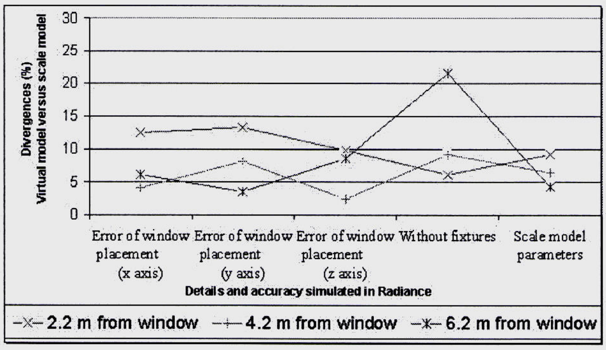
In the other set of study, the window transmittance was considered under the same conditions. Comparisons of results obtained for different window transmittances are shown on Figure 5. Range of window transmittances from 10%-90% of those of the virtual model base case were considered, as well as a perfect transmittance of 100%. As shown in Figure 5, the average relative discrepancy reaches 8.97% (4.85% for the base case) for a 10% reduction.

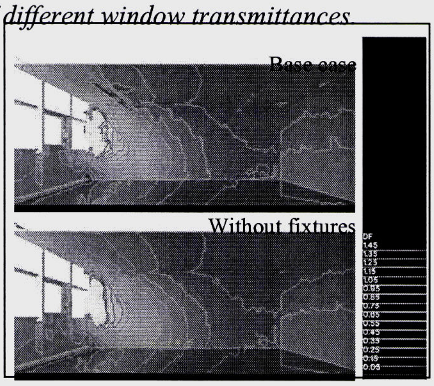




Divergences	τ x 0.1	τ x 0.2	τ x 0.3	τ x 0.4	τ x 0.5	τ x 0.6	τ x 0.7	τ x 0.8	τ x 0.9	τ	τ =100
2.2 m	81.79	72.38	65.10	52.56	42.03	31.65	24.43	9.10	0.01	9.22	19.47
4.2 m	69.58	69.20	58.64	41.24	35.60	25.27	21.96	14.08	2.39	6.43	11.17
6.2 m	67.89	70.25	59.19	42.04	36.63	30.48	27.26	24.22	10.37	4.23	1.76
average	76.96	73.21	64.46	50.64	43.38	34.39	28.91	19.61	8.97	4.86	7.32

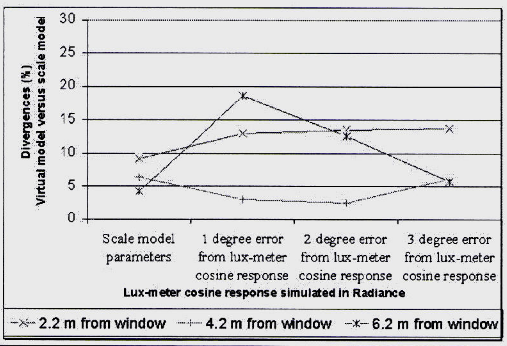
Figure 5 : Comparison of relative divergences for set of different window transmittances.





Divergences	Error of window placement (x axis)	Error of window placement (y axis)	Error of window placement (z axis)	Without 2 lamps	Scale model parameters
2.2 m	12.47	13.19	9.79	6.07	9.22
4.2 m	4.16	8.19	2.43	9.16	6.43
6.2 m	6.13	3.48	8.56	21.61	4.23
average	5.25	4.83	5.89	11.36	4.86

Figure 6 : Comparison of relative divergences for a set of accuracy of model details.



Divergences	Scale model parameters	1 degree error from lux-meter cosine response	2 degree error from lux-meter cosine response	3 degree error from lux-meter cosine response
2.2 m	9.22	12.97	13.55	13.76
4.2 m	6.43	3.03	2.42	6.15
6.2 m	4.23	18.59	12.57	5.82
average	4.86	9.00	7.39	6.21

Figure 7 : Comparison of relative divergences for different lux-meter cosine response.

The impact of the geometrical details (window frame accuracy for instance) were considered in a following data set, the lighting fixtures in the room and the window frame being moved in the virtual model for that purpose.

Figure 6 shows the divergences observed between the base case and the different virtual models described in Table 3. The average divergences remains comparable for the window details and are slightly different for fixture details (4.83%-11.36%).

From the last data set, the impact of lux-meter cosine response was examined by tilting the lux-meter towards window by 1-3 degrees, slight error of lux-meters placements leading to inaccuracies. Figure 7 shows the daylight factors observed near the window (2.2 m from window) and the discrepancy reaching 18.59% for a one degree of lux-meter tilting.

From all the results mentioned above, the surface reflectance and window transmittance features appear to have the greater impact on the daylighting performance in both virtual and scale models, model details construction and materials selection being obviously very significant. The lux-meter placement lead by no way to negligible discrepancy as well.

CONCLUSION

This study is an attempt to identify the tendency of the causes of the errors and inaccuracies occurring in the assessment of building daylighting performances by means of virtual and scale models. Thanks to the convenience of sensitivity analysis carried out with the Radiance program, the range of relative divergence for different sets of parameters sets were assessed. The study identified the discrepancies due to surface reflectance, window transmittance, details and lux-meter cosine response. The larger range of discrepancies in both models occurred when the surface reflectance and window transmittance were modified, especially in case of surface reflectance overestimation. The geometrical details and lux-meter cosine responses was also found to be significant parameters, although their impact remains quite constant in magnitude.

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