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Comparing daylighting performance assessment of buildings in scale models and test modules

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Abstract

Physical models are commonly used to assess daylighting performance of buildings using sky simulators for purpose of research as well as practice. Recent studies have pointed out the general tendency of scale model assessments to overestimate the performance, usually expressed through work plane illuminance and daylight factor profiles, when compared to the real buildings. The cause of the discrepancy between buildings and scale models is due to several sources of experimental errors, such as modelling of building details, mocking-up of surface reflectances and glazing transmittance, as well as photometer features. To analyse the main sources of errors, a comparison of a full scale test module designed for experimentation of daylighting systems and its 1:10 scale model, placed within identical outdoor daylighting conditions, was undertaken. Several physical parameters were studied in order to determine their impact on the daylighting performance assessment. These include the accurate mocking-up of surface reflectances, the scale model location, as well as the photometric sensor properties. The experimental study shows that large discrepancies can occur between the performance figures. They lead, on average, to a relative divergence of + 60 % to + 105 % in favor of the scale model for different points located in the side lit room. Some of these

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discrepancies were caused by slight differences in surface reflectances and photometer cosine responses. These discrepancies were reduced to a + 30 % to + 35 % relative divergence, by putting in the effort to carefully mock up the geometrical and photometrical features of the test module. This included a sound calibration of photometric sensors, whose cosine-response appeared at the end to be responsible for the remaining relative divergence observed between the daylighting performance figures.

1. Introduction

Daylighting has a major impact on the physical performance and visual comfort within buildings (Scartezzini et al., 1993) (IEA, 2000). Appropriate architectural design offers access to the stimulating outdoor visual information and contributes in a significant way to sustainable development by substituting and displacing electrical energy use in buildings (Scartezzini et al., 1994). A large variety of novel daylighting systems have been developed over the years, as a way to foster the use of these sustainable building technologies in non-residential buildings (Littlefair, 1990) (Scartezzini and Courret, 2002).

Despite the fact that the capability of computer modelling for daylighting design was significantly enhanced during this last decade (Compagnon, 1993) (Erhorn and Dirksmöller, 2000), scale models still represent a standard method for the assessment of the daylighting performance of buildings (Schiler, 1987): they even generally supersede computer models for common practical daylighting design (Scartezzini et al. 1994). Physical models mock up buildings at different scales. Placed within a sun and/or sky simulator they allow performance assessment in a sound and reproducible way (Michel et al, 1995). (Chauvel et al, 1985), (Tregenza, 1989). Recent studies pointed out the tendency of scale models to overestimate the monitored daylighting performance of real buildings, generally expressed by work plane illuminances for clear sky and daylight factors for cloudy sky.

Some causes of discrepancy were identified by a few authors within previous studies (Schiler, 1987) (Love and Navvab, 1991), as illustrated in Table 1. Inadequate construction of model details, such as window frames and mullions, the difficulty in accurately reproducing internal surface reflectances, as well as penetration of parasitic light into scale models were mentioned as common error sources. Luxmeter calibration, as well as their size, levelling and placement in the models, were also mentioned by these authors, who performed their error analysis considering rather complex buildings (e.g. a museum). A more recent paper confirmed the earlier studies (Cannon Brookes, 1997), pointing out even other physical parameters, such as maintenance and dirt in the building as contributors to these discrepancies : relative divergences of + 30 to 50 % are cited by all these authors as common figures. Table 2 gives a comprehensive list of potential sources of errors within scale models.

Table 1

Table 2

In order to carry out a detailed analysis of the physical parameters responsible for the overestimation of building daylighting performance in small scale models and extend the scope of the previous studies, a comparison of illuminances and daylight factors monitored within a test module designed for daylighting systems studies was undertaken. The test setup comprised a 20 m^2 full scale single office room equipped with side lighting windows and its 1:10 scale model placed within identical outdoor daylighting conditions. A particular emphasis was placed on physical parameters, which were not fully considered in previous studies, such as : a) indoor surface reflectances, b) scale model locations, c) sky view factor and ground reflected component, d) luxmeters size and response. The remaining sources of error in scale model estimation were identified through this comprehensive experimental study, in an attempt to reduce the relative divergence with the full scale model down to zero.

It should lead to the elaboration of an appropriate roadmap for architects and lighting designers for their assessment of building daylighting performance using small scale models.

2. Experimental methodology

The relative divergence between daylighting performance observed in buildings and their corresponding scale models was determined by comparing work plane illuminances and daylight factors monitored in the two cases. A closer view on the physical parameters inducing these discrepancies (cf. Introduction) was used to assess their respective impact on the corresponding performance figures : a scale model showing very high similarities with a simple architectural object (a test module) was used for that purpose within the framework of a step-by-step study procedure (cf. Figure 1).

Figure 1

2.1 Description of the test module

The principal experimental errors occurring during the assessment of building daylighting performance in scale models were identified and quantified on a simple architectural object – a 20 m^2 single office room equipped with a sidelighting window – in order to reduce the overall number of factors usually encountered in buildings (Cannon-Brookes, 1997). A test module designed for purpose of daylighting systems study (cf. Figure 2) and placed on an appropriate concrete platform to reduce the impact of external obstructions (height angles of surrounding buildings lower than 10 degrees), was used as full scale model. The corresponding office room is 6.55 m deep, 3.05 m wide and 2.65 m high (cf. Figure 4). The sidelighting window is of double glazing (glazed ratio to floor area equal to 0.26), supported by a metallic frame and placed on a 0.94 m high opaque breast wall; the corresponding façade is oriented due south.

The internal room surfaces are achromatic and painted white (walls and ceiling); the floor is covered by a uniform green carpet. Figure 3 shows an indoor view of the room, with close-ups for the surfaces : the corresponding reflectances are given in Table 3. Chromatic properties of the surfaces monitored using XYZ CIE Color Space (i.e, x,y,z chromatic coordinates) (CIE, 1986), are described in Table 4.

Usually occupied by two desks, the room was emptied for the purpose of this study. It is equipped with two rows of recessed luminaries (2 x 36 W fluorescent, Zumtöbel Licht), located respectively at 1.7 and 5 m from the front façade, which were carefully modelled in the 1:10 scale model. Conventional daylighting performance figures, such as work plane illuminances for clear sky and daylight factors for cloudy sky, were monitored under changing outdoor daylighting conditions. The solar blinds were fully retracted during the monitoring periods, and the window was cleaned to eliminate dust.

Figure 2

Figure 3

Figure 4

2.2 Description of the scale model

A 1:10 scale model of the test module (cf. Figures 5 and 6), was constructed using synthetic foam sandwich cardboards characterised by an appropriate mechanical resistance : the different model elements were fixed using screws and glued, with a black tape stretched on the joints to avoid parasitic light. To reduce the bias due to an inadequate mocking up of the test module, the physical parameters of the full scale model, comprising geometrical and photometrical features, were accurately reproduced in the 1:10 scale model and improved by iterations.

Figure 5

Figure 6

Figure 7

Table 3 gives the corresponding features of the full scale test module and the 1:10 scale model. A particular emphasis was placed on the modelling of the reflectance properties of the internal surfaces of the test module (cf. Figures 3 and 6), which were carefully mocked up by testing several sorts of paper with almost perfectly diffusive properties (Lambertian diffusers) to cover the internal surfaces of the scale model. The iterative procedure used for the scale model design led to two different solutions (Scale model 1 and Scale model 2), showing respectively slightly larger reflectances compared to the test module for the first one and lower values for the second one. They were employed to assess the impact of the indoor surface reflectances on the daylighting performance figures. Only a few small constructive details of the test module could not be reproduced in the scale model (window and door knobs, cornices); dust and dirt impact in the full scale object was reduced as much as possible by cleaning.

Table 3

Table 4

The normal-normal transmittance of the transparent elements (double glazing for the test room and acrylic material for the scale model) were measured using a LS 110 Minolta luminance meter (1/3 degree of opening angle); the normal-hemispherical reflectance of the interior surfaces were measured using a xy-1 Minolta chromameter.

2.3 Scale model locations

The overall experimentation was carried out on the EPFL campus, located near Lausanne, Switzerland in Central Europe (latitude 46.5^{o}N, longitude 6.6^{o}E). The test module, placed on a concrete platform, is surrounded by an open plain in the southern and eastern directions and a parking lot in the northern direction, as shown by Figure 2. As a similar object is located on the western side of the daylighting test module, as shown in Fig. 2, the open window façade of the two modules was aligned to avoid any mutual influence during the monitoring of daylighting performance. The window side of this adjacent module is also facing due south.

The 1:10 scale model was placed close to the test module in order to benefit from identical outdoor daylighting conditions (sky view factor and luminance distribution). As a strictly identical position of the scale model and the module is impossible to achieve (this would mean to place the scale model in the module and would affect the monitoring of that object), the scale model was fixed on the western façade of the module to achieve an optimal position (cf. Figure 8).The open side of the scale model was carefully aligned with the plane of the window façade of the considered test module.

Figure 8

Another scale model location was considered to investigate the impact of slightly different sky view factors and ground reflected component of daylight. The scale model was placed for that purpose inside the adjacent module (cf. Figure 9), its open façade perfectly aligned with the façade of the real object. Shadowing effects of the blind fixtures were avoided by attaching the scale model outside the window at a distance of 10-20 centimeters.

Figure 9

The monitoring of daylighting performance was carried out during the winter season (no presence of snow) for different kinds of sky luminance distributions (clear and cloudy skies).

2.4 *Sky view factor and ground reflected component*

As the 1:10 scale model and test module were placed in slightly different locations (cf. Figures 8 and 9), they experienced different sky view factors, which could lead to discrepancies between the assessed daylighting performance. As a consequence, a detailed analysis of the corresponding sky view factors in the scale model and the test module was carried out using a digital Nikon camera and fish eye views.

The camera was placed vertically in the scale model and in the module at 6 different locations corresponding to the positions of the photometric sensors used to monitor daylighting performance (cf. Figures 10). The digital pictures corresponding to similar positions were compared one by one to identify possible significant differences of sky views.

Figure 10

Figure 11 illustrates the views taken in the scale model for the two considered scale model locations (cf. Figure 8 and 9) and in the module for two different luxmeter positions close to the southern facade (0.22 and 0.42 m from window plane). For experimental reasons (size of the camera), all model sides were taken off for the pictures, except the southern facade.

Figure 11

All pictures show identical solid angles either for the sky or for the ground, visible up to the horizon line (cf. Figure 11). This observation, valid for all 6 luxmeter positions, indicates that all the corresponding photometric sensors placed in the model and the module experience the same daylight contribution from sky and ground. As a consequence, differences in sky view factors are not expected to be a cause of discrepancy in the daylighting performance.

Figure 12

In order to assess the sky view factors from the windows of the test module, the camera was placed inside the module in front of each glazed panel of the southern façade at a distance of one meter from the window, at 3 different heights (cf. Figure 12).

Figure 13

, As illustrated by the pictures shown in Figure 13, all cases have identical sky and ground views, which confirms the earlier conclusion. Each glazed panel benefits from a comparable daylight flux from the sky vault and from the ground in all test cases.

Figure 14

A more careful analysis was carried out in order to assess the influence of the two different scale model locations regarding the contribution of the ground reflected component of daylight. Figure 14 shows the corresponding placement of the digital camera in the model and in the module in front of the window.

Figure 15

Figure 15 shows the corresponding pictures : the sky view as well as the position of the horizon line are identical for all three cases, indicating that their respective contribution to work plane illuminances and daylight factors can be considered as equal. This is not fully true for the external reflected component due to the concrete platform (showing a rather light grey color), which appears different on these pictures (especially for the model location in the adjacent test module). Experimental results discussed later suggest that the ground reflected component is not a major contributor to the discrepancies observed.

2.5 Description of the photometric sensors

Two different types of luxmeters were used to monitor the work plane illuminances and daylight factors in the scale model and the test module :

- a LMT Pocketlux-2 illuminance-meter (1 cm. diameter sensing area) for the scale model;
- BEHA 93408 digital illuminance-meters (4 cm. diameter sensing area) for the test module.

Costs reasons prevented the use of the same LMT luxmeters in the scale model and the test moduleas these photometers cost an order of magnitude more than BEHA illuminance meters. Low cost BEHA illuminance-meters were employed for this reason in the full scale object (after proper calibration): the size of these sensors impeded however their use in the scale model.

A Hagner ELV-641 illuminance-meter was used on the roof of the test module to monitor outdoor daylighting conditions. The work plane illuminances in the module were monitored every 15 minutes by means of a Campbell 23x data logger. Almost simultaneously, a luxmeter measured work plane illuminances at the seven corresponding points in the scale model; data was collected this way manually every 15 minutes in a synchronous way. Sliding the luxmeter in the scale model allowed data recording. (cf. Figure 16).

Levelling of the photometer sensors in the test module was carefully checked using a spirit level; such a check was also carried out in the scale model. In this case, however the sliding of the luxmeter, leads to a lower levelling and position accuracy during the monitoring procedure.

The way the monitoring of illuminance had to be carried out in the scale model could lead to a slight difference in daylight factor reading due to the dynamic change of sky illuminances distribution during the monitoring process.

Figure 16

The two different luxmeters used in the study were calibrated by monitoring the global horizontal illuminance on the concrete platform in front of the test module under cloudy skies (cf. Figure 17). The distance between luxmeters was reduced as much as possible by placing the instruments close to each other. A regression method was used to determine the multiplication coefficient adjusting the data monitored by the two types of sensors (cf. Figure 18).

Figure 17

Figure 18

The illuminance data of the two luxmeters was then fitted to those provided by the Hagner luxmeter of the meteorological station by going through the same exercise and placing the instruments on the roof of the module close to each other.

The cosine responses of the two luxmeter types used in the test module and the scale model (respectively BEHA and LMT illuminance meters) were also carefully examined. Both instruments were placed for that purpose on a tilting platform under a sunlight simulator (Scartezzini et al, 1994) and illuminated by a collimated light source (2.5 kW HMI discharge lamp) showing spectral features close to daylight (240000 Lumen, 5600 K). The platform average illuminance is equal to 2700 Lux with a 3.4 % relative divergence measured on the 1.2 m x 1.2 m mechanical support. Figure 19 shows the cosine response of the two luxmeters, as well as the theoretically ideal response (cosine function), measured for 10° incident angle steps. The mean relative divergence of the BEHA luxmeter (test module) below the ideal cosine-response reaches - 5.4 %; the corresponding figure of the LMT luxmeter (scale model) above the ideal figure is equal to + 15.0 %, indicating surprisingly a poorer cosine-response for this higher cost instrument. A previous experimental study of the cosine-response of these two types of photometers already pointed out such a particular result (Michel, 1999). The overall relative divergence between the two instruments, which are particularly sensitive in case of light grazing incidence (e.g. reflected internal component for horizontal illuminance), is estimated at +20.4 % in favour of the LMT luxmeter used in the scale model. Such a significant difference is a relevant source of error for daylighting performance assessments (cf. 3 Experimental results).

Figure 19

Work plane illuminances and daylight factors were experimentally determined, according to this procedure, for different types of sky covers (respectively for clear and cloudy skies). The relative divergence between the data monitored in the test module and the scale model, was used to quantify the impact of the different physical parameters on the performance assessment.

3. Experimental results

3.1 Impact of surface reflectances

The impact of the scale model surface reflectances was determined by comparing daylight factors monitored from 10.00 to 17.00 under cloudy sky (winter conditions). The model characterised by surface reflectances slightly higher than the real figures (2.5 % points higher surface reflectances on average), was used for that purpose: Table 3 gives a full description of the latter (Scale model 1). The relative divergences between the daylight factors observed in the test module and the scale model at distances of 2.2, 4.2 and 6.2 m from the window are shown in Figure 20.

Figure 20

The relative divergence between daylight factors is larger than 50 % and reaches a maximal value of + 80 % in favor of the scale model at a 2.2 m distance from the window, confirming the tendency of models to overestimate daylighting performance. This divergence increases even further for positions located deeper in the room and reaches up to + 115 % at 4.2 m and + 150 % at 6.2 m from window: this indicates that the internal reflected component of daylight contributes in a significant way to experimental error.

The same monitoring was carried out using the scale model showing surface reflectances slightly lower than the real figures (- 2.2 % point lower surface reflectances on average), described in Table 3 (Scale model 2). Figure 21 shows the relative divergence between daylight factors observed in this case at the same window distances.

Figure 21

Significantly lower divergence values were observed for the second model compared to the former one, confirming that the mocking up of surface reflectances has a very strong impact on scale model accuracy. Daylighting performance figures remain nevertheless higher for the model in comparison to the test module, reaching a maximum of + 55 % maximal for the three different window distances.

Table 5 illustrates the minimal, maximal and average relative divergences observed for the two different scale models. The impact of surface reflectances on the model accuracy can be pointed out, as a consequence, showing that a – 8 to - 49 % point diminution of average relative divergence can be achieved through a -6 % point average reduction of surface reflectances. However, despite the accurate geometrical and photometrical modelling represented by the second model (Scale model 2), a significant overestimation of daylighting performance is still observed.

Table 5

3.2 Impact of scale model location

The impact of the scale model location was considered in the following part of the study. The model was for that purpose physically moved between two locations next to the test module (cf. Figures 8 and 9). The second scale model, which showed a lower divergence in regard to the real object (cf. Table 3, Scale model 2), was used for that purpose. Daylight factors were monitored in the same way during the daytime period of 14.00 to16.00 under clear sky conditions.

Figure 22 shows the divergence observed between model and module work plane illuminances for the three different distances from the window : the scale model was first placed in the adjacent test module (cf. Figure 9), which corresponds to the largest relative distance to the real object.

Figure 22

The relative divergence is on average equal to + 35 % for the three distances from the window side. The divergence remains almost constant for the three cases, leading to minimal and maximal relative divergences close to the average value (resp. + 32 and + 37 %).

Figure 23

The same monitoring procedure was repeated after placing the scale model in the location corresponding to the closest relative distance to the real object, illustrated by Figure 8. Figure 23 shows the corresponding work plane illuminances and relative divergences. Table 6 gives an overview of these figures, showing the minimal, maximal and average relative divergences monitored for the two cases.

A very small reduction of the average relative divergence was observed for the same three luxmeters positions compared to the previous case (-1 to -2 % point reduction for the closest model location). This indicates, as a consequence, that the remaining + 33 % overestimation of the daylighting performance in the scale model cannot be assigned to the model location.

Table 6

3.3 Impact of sky view factor and ground reflected component

The hypothesis that the remaining overestimation of the scale model assessed daylighting performance is due to the different sky view factors experienced by the scale model and the module, was carefully examined by means of 360° pictures taken at appropriate locations (six luxmeter positions, three window apertures), as illustrated by Figures 11 and 13.

Both groups of pictures show identical solid angles for the visible part of the sky vault, as well horizon lines placed in the same position on the pictures, indicating that no significant difference exist between the scale model and the test module experienced sky view factors. This is true for all model locations, whatever the distance from the real object.

The ground reflected daylight component was considered as another possible source of experimental error (cf. Figure 15). The quasi-constant relative divergences observed in the last case study when moving the scale model from one location to the other on the concrete platform (cf. Figures 22 and 23) indicates that no significant influence can be assigned to the ground reflected components, beside a - 2 % point impact on the average relative divergence (cf. Table 6). As a consequence, this physical parameter was considered not to be responsible for the remaining performance overestimation.

3.4 Impact of photometric sensors

The assignment of the remaining + 35 % relative divergence to the different features of the photometric sensors used was considered. The impact of the different sensing area (one and 4 centimeters diameter), leading to a different integration scale for the illuminance gradient, was examined by comparing the response of BEHA luxmeters equipped with one centimeter diameter cache with the original instrument (after a new calibration procedure). No significant difference was observed that would have been in contradiction with the larger relative divergence observed for positions located deeper in the room characterised by lower illuminance gradients than those located closer to the window (cf. Table 5).

Most of the remaining overestimation of daylighting performance was assigned to the difference luxmeters' cosine-responses illustrated by Figure 19. A + 20.4 % average relative divergence characterises the two different photometric sensors regarding their cosine-responses : this difference is accentuated for grazing angles, which are typical for the internal reflected component of daylight due to the wall reflections in case of monitoring of work plane illuminances and daylight factors (horizontal sensor placement). The properties of the scale model surfaces, checked by adequate luminance measurements and looking closer to the Lambert diffuser than the module's surfaces, indicate even a strengthening of this effect.

4. Conclusion

This study is an attempt to identify the main sources of experimental errors occurring in the assessment of building daylighting performance by means of scale models, which show a general trend of overestimation. It is aiming to complement the error analysis carried out by a few authors on rather complex buildings and/or sky simulators.

A test module designed for full scale daylighting systems studies (a 20 m2 single office room equipped with a sidelighting window) and placed on an appropriate platform, was used for that purpose. Work plane illuminances and daylight factors were monitored under outdoor sky conditions and compared to the corresponding figures observed in a 1:10 scale model of this simple architectural object placed under strictly identical outdoor lighting conditions.

The accuracy of the mocking-up by the scale model of the geometrical dimensions of the test module, as well as those of its internal surface reflectances, were identified as key factors regarding the discrepancies between the scale model and the test module. Average relative divergences reaching up to + 60 to + 105 % were monitored, even in case of very careful geometrical design of the scale model.

Large relative divergences were found moreover when comparing the impact of slight differences in model surface reflectances: a - 6% point difference on average surface reflectances reduced the relative divergence down to + 50 % on daylight factors monitored in the deeper part of the room. Scale model location as well as the ground reflected component, appeared to be non significant in this case, as the divergence remained constant for two locations close enough to the test module, but characterised by slight differences in the distance to the real object.

The different cosine-response of the photometers used in the scale model and the test module is apparently responsible for most of the + 30 to + 35 % relative divergence, which is still observed after elimination of all other possible error sources. Small differences in the photometric sensors' placement and levelling can explain the remaining discrepancy, which could not be reduced below this typical figure. Table 7 gives an overview of the main factors contributing to experimental errors within scale models, which were identified in this study.

Table 7

Further studies are required, however, to investigate the sources of experimental error due to the simulation of daylight within sky simulators, which were not taken into account in this study. It should be extended moreover to computer modelling of daylighting systems for which a comparable analysis could be carried out for the same simple architectural object. Great care should be taken,in the construction of scale models used to predict daylighting performances of buildings, if a reasonable daylight factors and work plane illuminances accuracy is expected. Photometers should be carefully chosen and calibrated to reduce the significant impact of their cosine-response. All these measures will contribute to reducing the overestimation tendency of scale models in daylighting performance assessment.

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Authors	**Schiler et al., 1987.**	**Love and Navvab, 1991.**	**Cannon-Brookes, 1997.**
Physical Factors	• Model details • Surface reflectances • Light leakages	• Sensor calibration • Surface reflectances • Model replication • Fenestration details • Luxmeters size (sensing aperture) • Sensor levelling • Sensor placement	• Dimentional accuracy • Photometric properties • Surface reflectances • Window transmit-tance • Maintenance and dirt
Relative Divergence vs. Real Building	-	+ 30 to + 50 %	+ 10 to + 25 %

Table 1

Geometrical features	Photometrical features
<u>Window Frame</u> a) Depth b) Slope c) Handle* d) Dimension e) Material f) Hinges* <u>Door</u>* a) Doorknob* b) Frame* (material and dimension) c) Door-panel* d) Hinges* <u>Wall</u> a) Dimension b) Material c) Texture <u>Floor</u> a) Texture b) Small pieces of scientific equipment * c) Moving track for luxmeter° <u>Ceiling</u> a) Dimension b) Materials c) Texture (furrow)* <u>Furniture</u> a) Cupboard and computer* b) Tripod and mount*	<u>Surface reflectances</u> a) Window Frames b) Door c) Wall d) Floor e) Ceiling f) Furniture <u>Window transmittance</u> a) Grazing incident angles b) Dust and dirt° **Photometric sensors** <u>Calibration</u> <u>Cosine response</u> <u>Placement and levelling</u> <u>Sensing aperture and shape</u> **Maintenance** <u>Dirt on the Surfaces and windows</u> <u>Dust in the air</u>*

* None in scale model
° None in test module

Table 2

Description		Test module	Scale model 1	Scale model 2
Geometry	Length (m.)	6.5 ± 0.1	0.65 ± 0.005	0.65 ± 0.005
	Width (m.)	3.0 ± 0.1	0.30 ± 0.005	0.30 ± 0.005
	Height (m.)	2.5 ± 0.1	0.25 ± 0.005	0.25 ± 0.005
	Facade area (m2)	9.30 ± 0.2	0.0930 ± 0.01	0.0930 ± 0.01
	Glazed area (m2)	4.02 ± 0.2	0.0402 ± 0.01	0.0402 ± 0.01
	Occupants	0	0	0
Fenestration materials	Window	Double glazing	2mm.-single Clear acrylic	2mm.-single Clear acrylic
Indoor surface materials	Floor	Fitted carpet (Green)	Paper (Textured Green)	Paper (Textured Green)
	East wall	Satin (White)	Paper (White)	Paper (White)
	West wall	Satin (White)	Paper (White)	Paper (White)
	North wall	Canvas (White)	Paper (White)	Paper (White)
	Ceiling	Satin (White)	Paper (White)	Paper (White)
	South wall	Painted metal (White)	Paper (White)	Paper (White)
Reflectance (%)	Floor	16.14 ± 3	16.90 ± 3	16.47 ± 3
	East wall	81.53 ± 3	83.20 ± 3	79.47 ± 3
	West wall	82.37 ± 3	83.03 ± 3	79.37 ± 3
	North wall	72.10 ± 3	78.70 ± 3	70.83 ± 3
	Ceiling	79.90 ± 3	83.70 ± 3	76.06 ± 3
	South wall	82.60 ± 3	85.10 ± 3	79.17 ± 3
Transmittance (%)	Window	76.2 ± 6	78.6 ± 6	78.6 ± 6

Table 3

Description		Test module			Scale model 1			Scale model 2		
		x	**y**	**z**	**x**	**y**	**z**	**x**	**y**	**z**
Chromatic coordinate	Floor	0.34	0.36	0.3	0.33	0.38	0.29	0.32	0.41	0.27
	East wall	0.31	0.33	0.36	0.32	0.33	0.35	0.31	0.33	0.36
	West wall	0.31	0.33	0.36	0.32	0.33	0.35	0.31	0.33	0.36
	North wall	0.32	0.34	0.34	0.31	0.32	0.37	0.32	0.33	0.35
	Ceiling	0.32	0.34	0.34	0.32	0.34	0.34	0.31	0.32	0.37
	South wall	0.32	0.34	0.34	0.32	0.34	0.34	0.31	0.33	0.36

Table 4

Sky condition Cloudy sky	Relative Divergence (%) Scale model 1			Relative Divergence (%) Scale model 2			Percent-point Reduction (%) From model 1 to model 2		
	2.2m.from window	4.2m.from window	6.2m.from window	2.2m.from window	4.2m.from window	6.2m. from window	2.2m.from window	4.2m.from window	6.2m. from window
Average	60	84	103	52	54	54	8	30	49
Maximal	80	114	153	55	56	57	25	58	96
Minimal	52	13	50	45	51	50	7	-37	0

Table 5

Sky condition Clear sky	Relative Divergence (%) In the adjacent module			Discrepancies(%) Fixed to the module side			Percent-point Reduction (%)From location 1 to location 2		
	2.2m.from window	4.2m.from window	6.2m.from window	2.2m.from window	4.2m.from window	6.2m. from window	2.2m.from window	4.2m.from window	6.2m. from window
Average	34	35	35	32	33	34	2	2	1
Maximal	35	36	37	33	36	37	2	0	0
Minimal	32	34	33	31	32	32	1	2	1

Table 6

Physical Factors	Relative Divergence vs. Real Building
Surface reflectances	+50 %
Photometric properties	+30 to +35 %
Scale model location	None

Table 7

Table 1 : Principal factors contributing to experimental errors within scale models identified in recent studies

Table 2 : List of potential sources of errors for scale models

Table 3 : Geometrical and photometrical properties of the full scale test module and the 1 : 10 scale model constructed by iteration (Scale model 1 : higher surface reflectances; Scale model 2 : lower surface reflectances)

Table 4 : CIE Chromatic coordinates of the surface of the full scale test module and the 1 : 10 scale model constructed by iteration (Scale model 1 : higher surface reflectances; Scale model 2 : lower surface reflectances). Chromatic coordinates equal to (0.33, 0.33, 0.33) correspond to grey surfaces.

Table 5 : Comparison of the relative divergence between two different scale models and the test module (impact of internal surface reflectances)

Table 6 : Comparison of the relative divergence between the scale model and the test module for two different scale model locations (impact of sky view factor and ground reflected component)

Table 7 : Main physical factors contributing to experimental errors within scale models identified in this recent study

Figure 1: Study procedure used to outline the impact of physical parameters of the scale model

Figure 2: External view of the test module (full scale object)

Figure 3: Internal view of the test module (walls, ceiling and floor)

Figure 4: Schematic drawing of the test module. (a) Plan view, (b) and (c) Section views

Figure 5: External view of the scale model (1: 10 scale object)

Figure 6: Internal view of the scale model (walls, ceiling and floor)

Figure 7: Schematic drawing of the scale model. (a) Plan view, (b) and (c) Section views

Figure 8: Scale model location close to the test module (fixed to the western side)

Figure 9: Scale model location close to the test module (in the adjacent module)

Figure 10

: Digital camera positions in the test module (a) and in the scale model (b) to assess the sky view factors of the 6 different luxmeter positions

Figure 11: Fish-eye views in the test module (center) and the scale model (two model locations, left and right) corresponding to two different luxmeters positions : 0.22 m from window façade (a) and 0.42 m from window façade (b).

Figure 12: Digital camera position in the test module to assess the sky view factors of the three different windows of the southern facade

Figure 13: Fish-eye view in the test module (center) and the scale model (two model locations, left and right) corresponding to the three different windows of the southern facade

Figure 14: Digital camera position in the test module (a) and the scale model (b) to assess the sky view factor of the central window facade

Figure 15: (a) Fish-eye views in the test module (center) and in the scale model (two model locations, left and right) corresponding to the central window façade (b) Parallax angles of the two scale models (two locations)

Figure 16: Luxmeter positions in the test module (a) and the scale model (b) during the monitoring

Figure 17: Luxmeter positions during calibration on the outdoor concrete platform (a single LMT photometer is visible on the right of the picture)

Figure 18: Comparison of global horizontal illuminances monitored under cloudy skies with BEHA and LMT luxmeters (before and after correction by regression analysis)

Figure 19: Comparison of cosine responses of LMT (a) and BEHA (b) luxmeters measured under a sunlight simulator.

Figure 20: Comparison of daylight factors monitored in the scale model with higher surface reflectances (Scale model 1) and the test module, under cloudy sky (29 January 2003). (a) 2.2 m. from window side, (b) 4.2 m. from window side, (c) 6.2 m. from window side.

Figure 21: Comparison of daylight factors monitored in the scale model with lower surface reflectances (Scale model 2) and the test module, under cloudy sky (29 January 2003). (a) 2.2 m. from window side, (b) 4.2 m. from window side, (c) 6.2 m. from window side.

Figure 22: Comparison of work plane illuminances monitored in the scale model (Scale model 2) and the test module for the most distant model location (model placed in the adjacent test module). (a) 2.2 m. from window side, (b) 4.2 m. from window side, (c) 6.2 m. from window side.

Figure 23: Comparison of work plane illuminances monitored in the scale model (Scale model 2) and the test module for the closest model location (model against the module side). (a) 2.2 m. from window side, (b) 4.2 m. from window side, (c) 6.2 m. from window side.

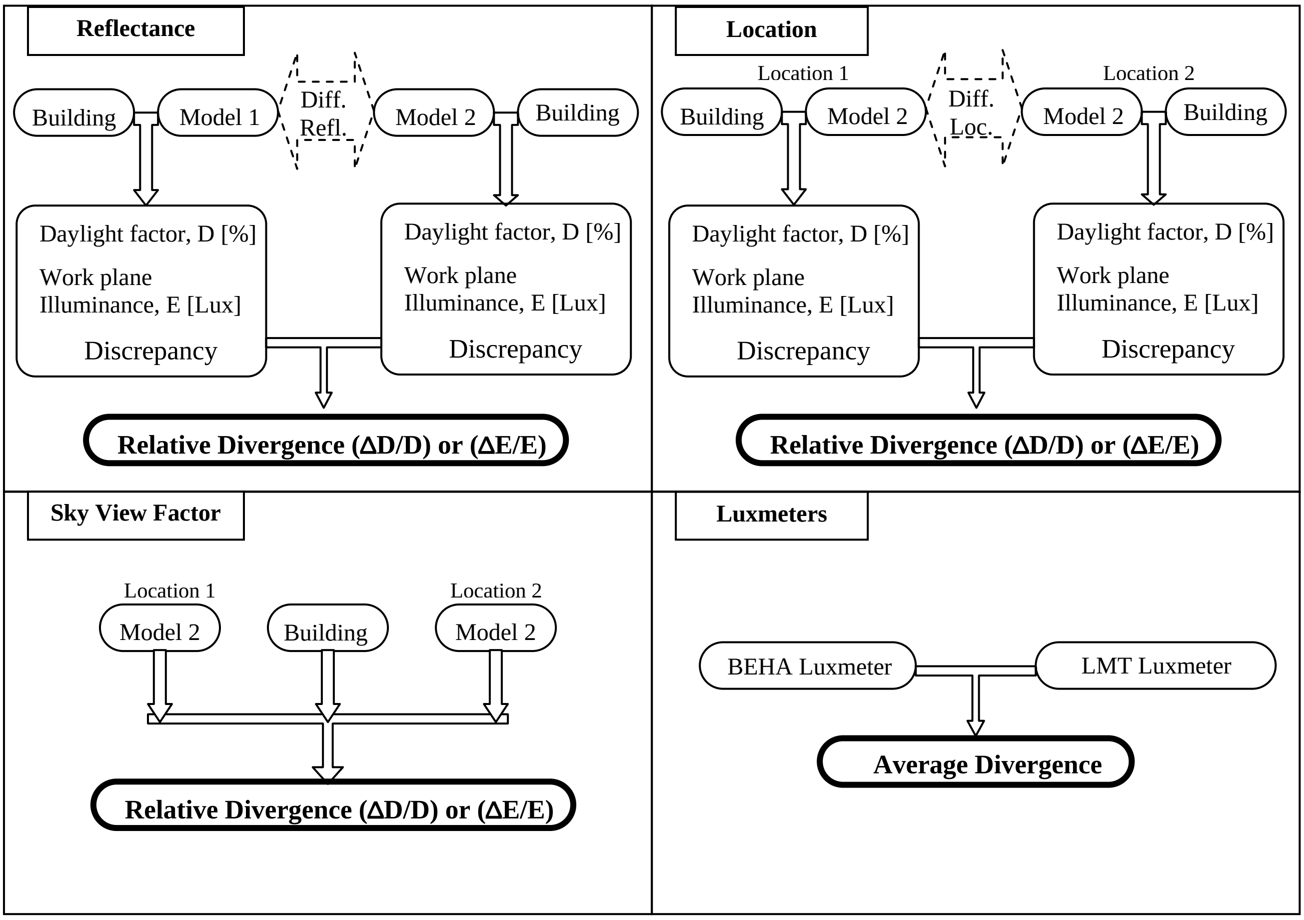
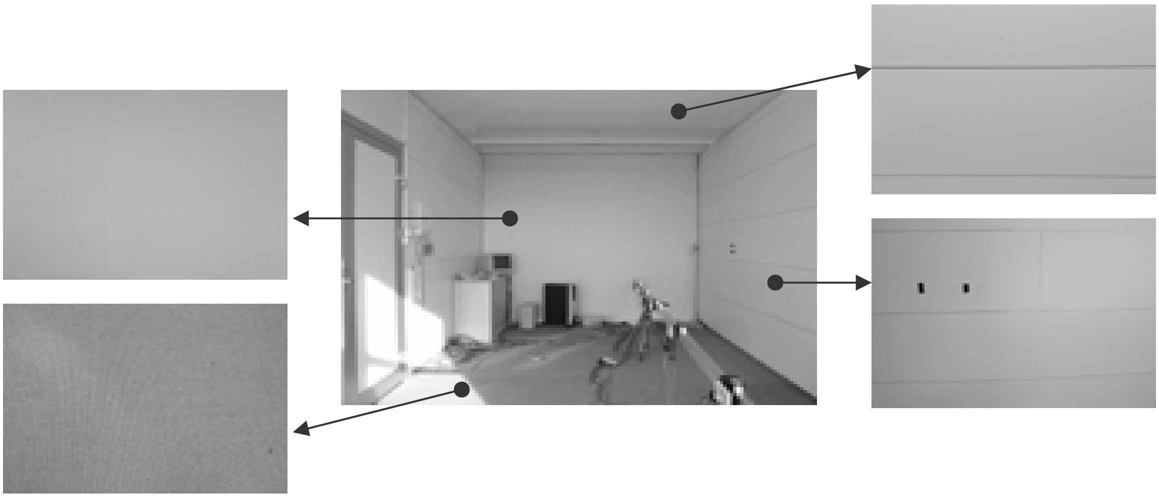

Reflectance
Building
Model 1
Diff. Refl.
Model 2
Building
Daylight factor, D [%]
Work plane Illuminance, E [Lux]
Discrepancy
Daylight factor, D [%]
Work plane Illuminance, E [Lux]
Discrepancy
Relative Divergence (ΔD/D) or (ΔE/E)
Location
Location 1
Location 2
Building
Model 2
Diff. Loc.
Model 2
Building
Daylight factor, D [%]
Work plane Illuminance, E [Lux]
Discrepancy
Daylight factor, D [%]
Work plane Illuminance, E [Lux]
Discrepancy
Relative Divergence (ΔD/D) or (ΔE/E)
Sky View Factor
Location 1
Location 2
Model 2
Building
Model 2
Relative Divergence (ΔD/D) or (ΔE/E)
Luxmeters
BEHA Luxmeter
LMT Luxmeter
Average Divergence

Figure 1

Figure 2



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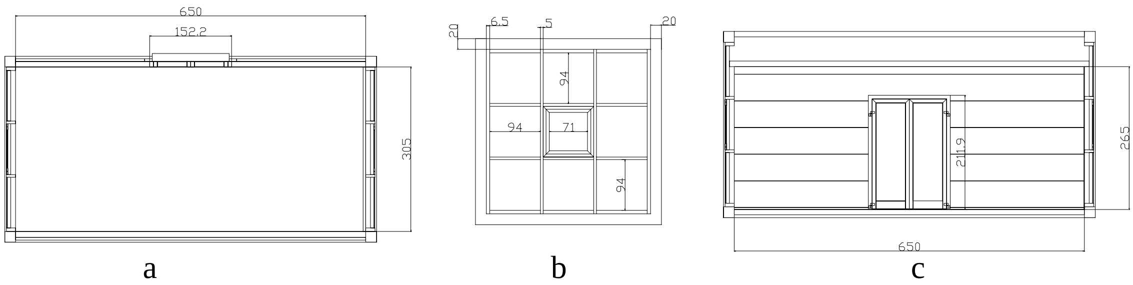
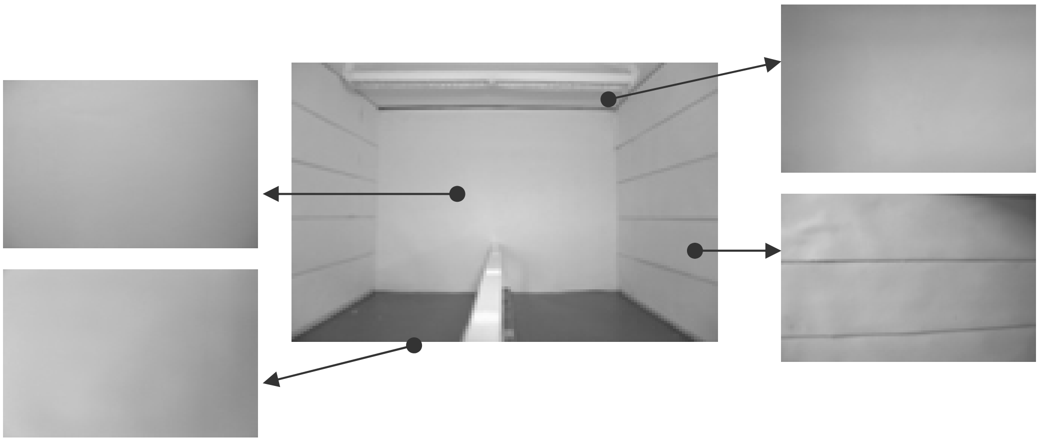


Figure 4

Figure 5



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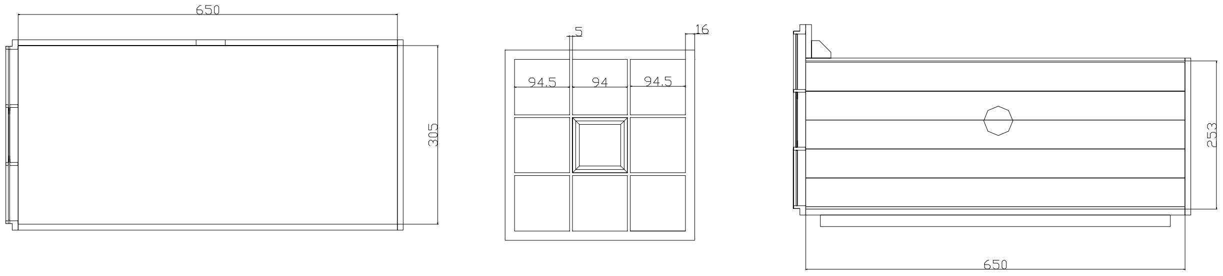
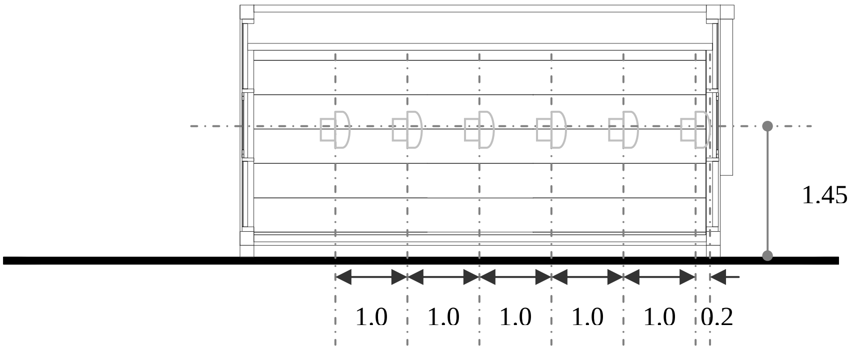


a b c

Figure 7

Figure 8

Figure 9



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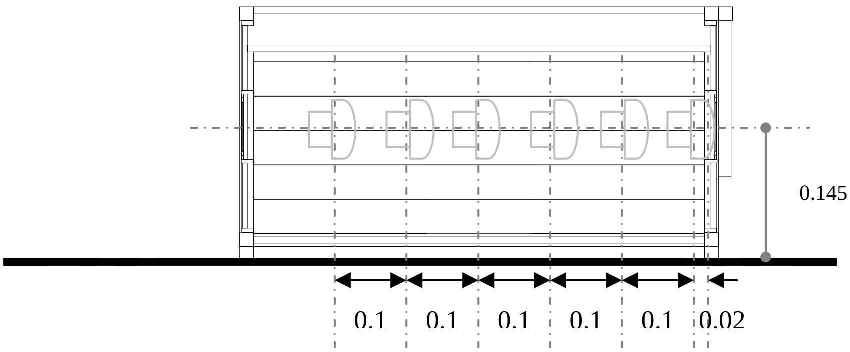


(b)

Figure 10

(a)

(b)

Figure 11

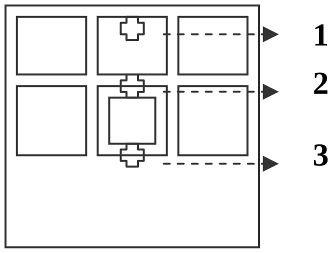
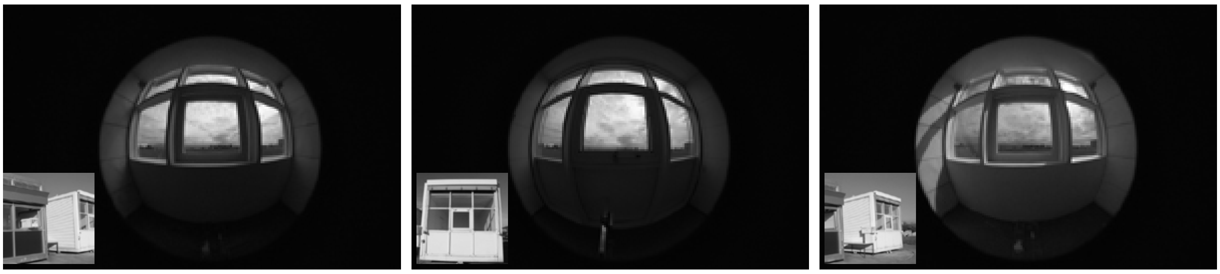


Figure 12

(a)

(b)



(c)

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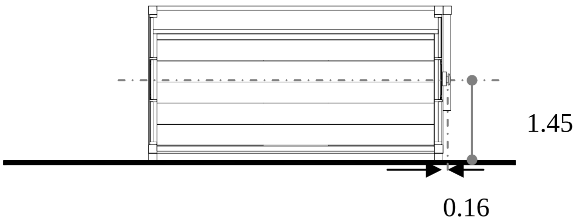

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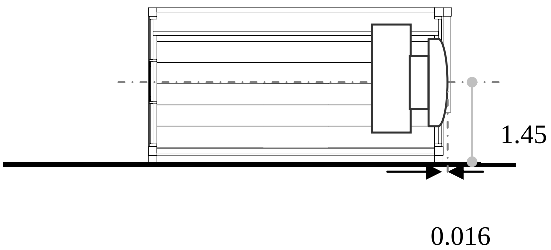

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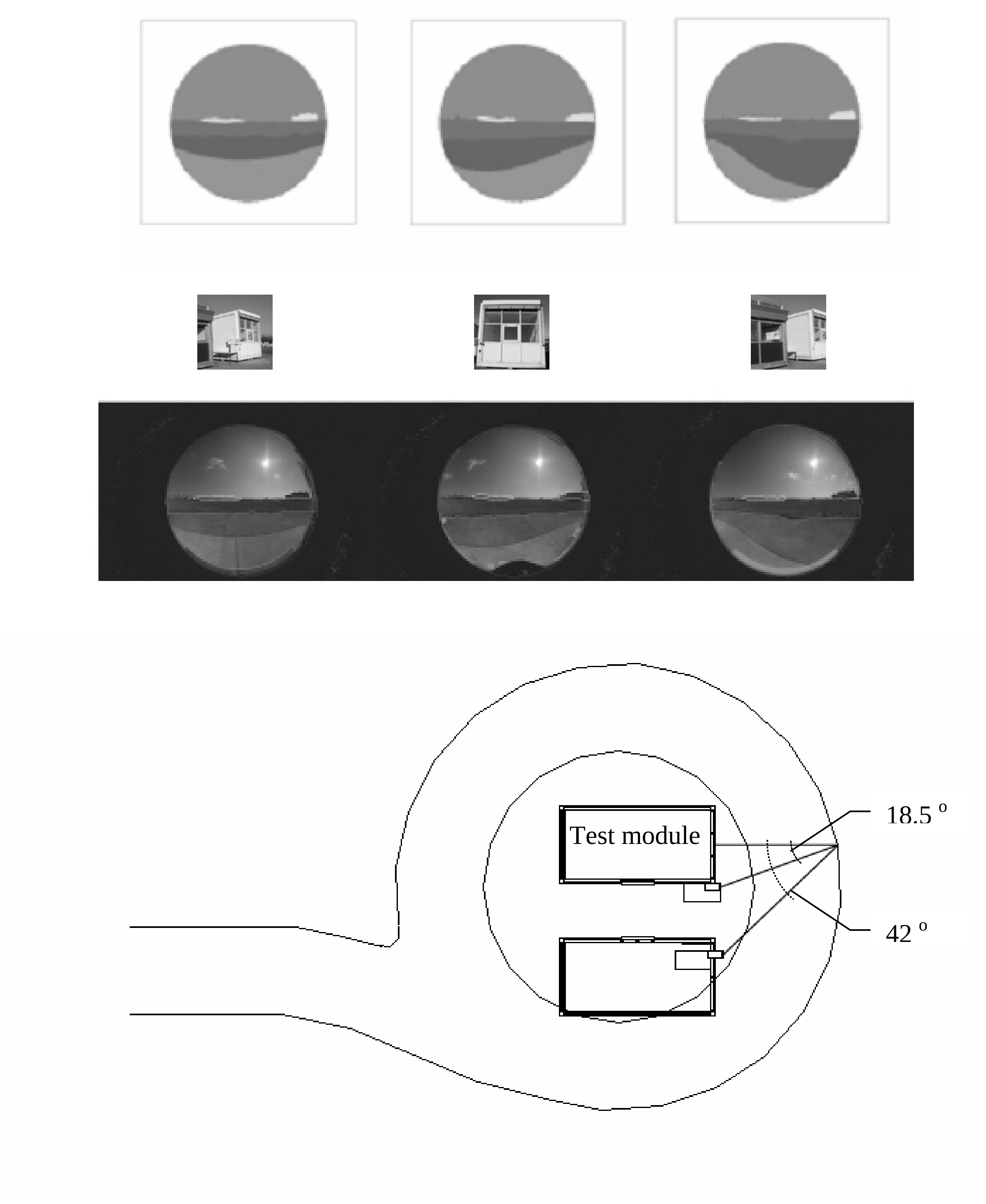

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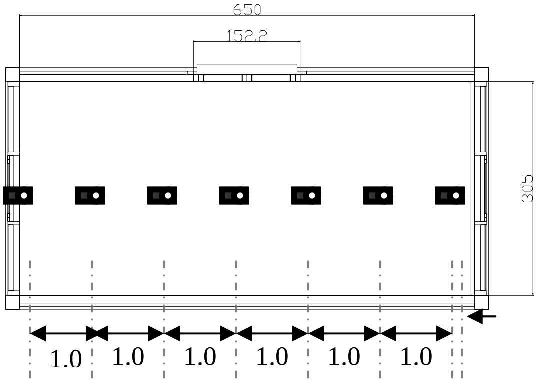

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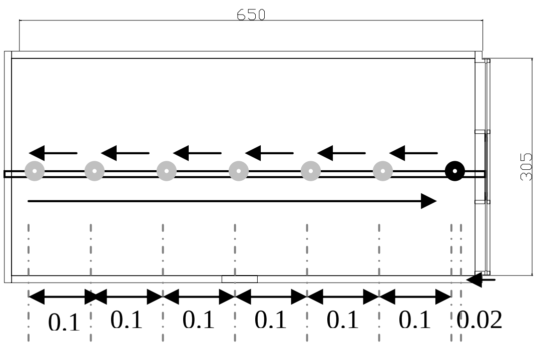
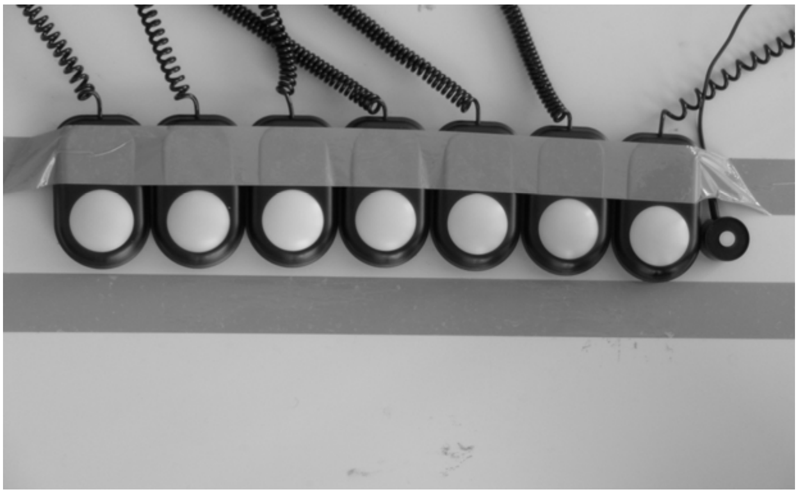


(b)

Figure 16



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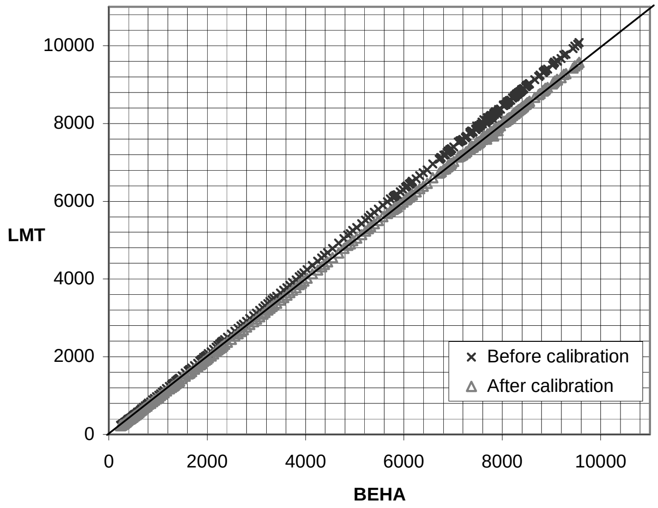
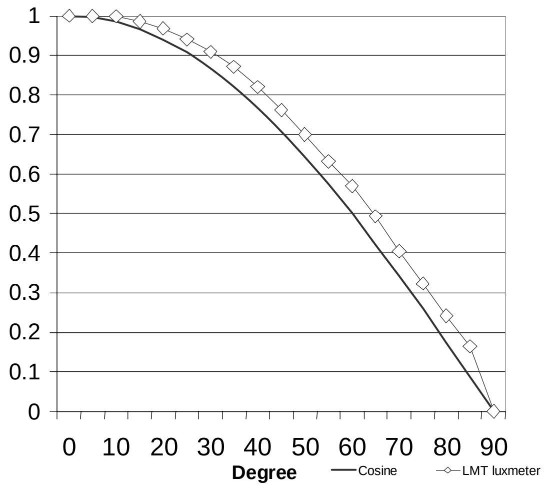


10000
8000
6000
LMT
4000
2000
0
0
2000
4000
6000
8000
10000
BEHA
Before calibration
After calibration

Figure 18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0.8
0.7
0.6
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0.3
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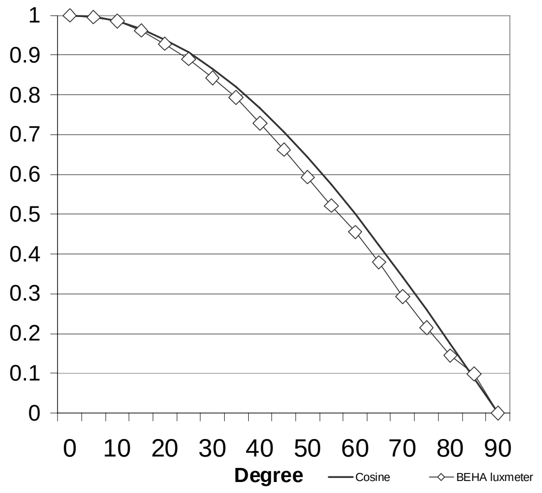
0.1
0
0 10 20 30 40 50 60 70 80 90
Degree
Cosine
LMT luxmeter

(a)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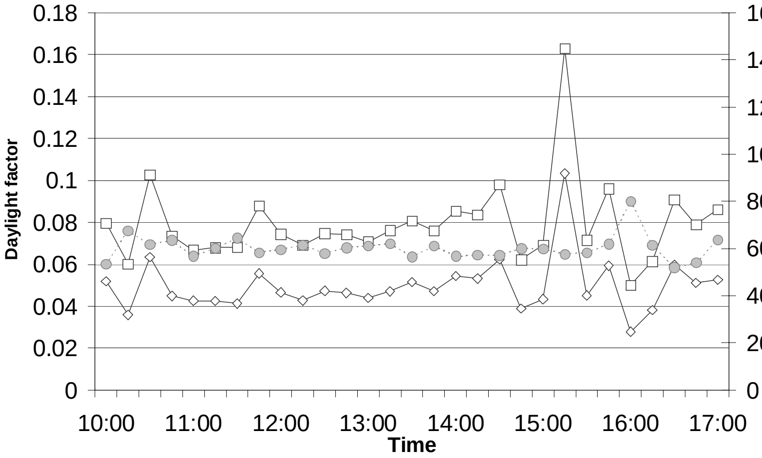
Degree
Cosine
BEHA luxmeter

(b)

Figure 19



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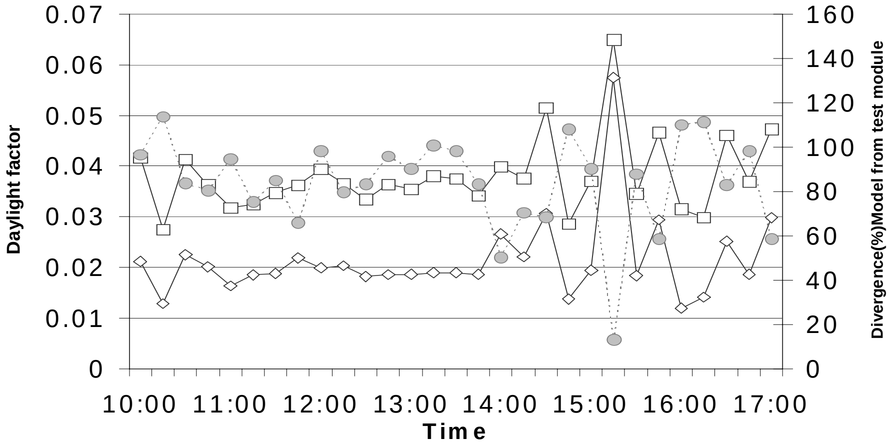

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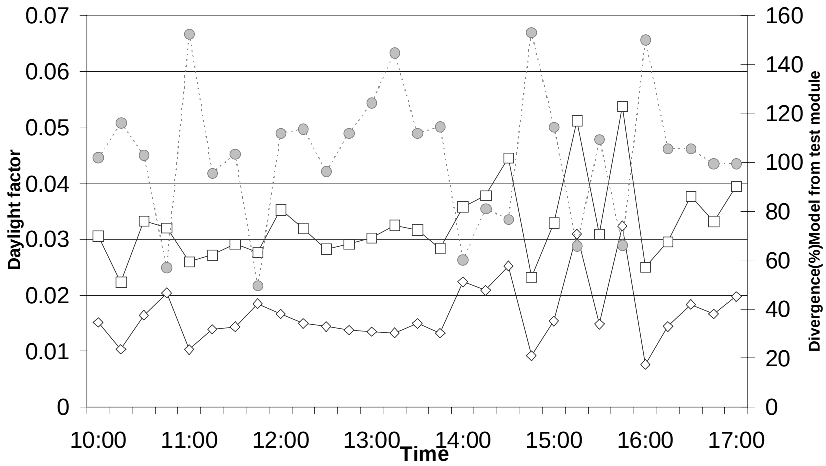

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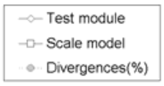

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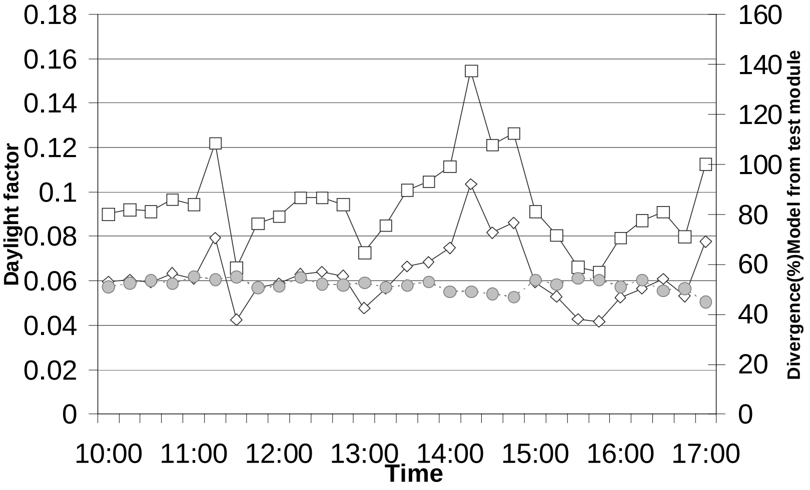

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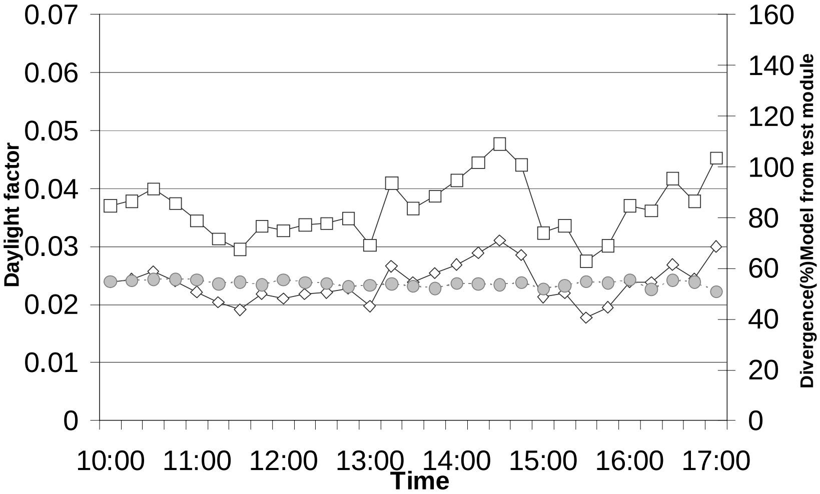

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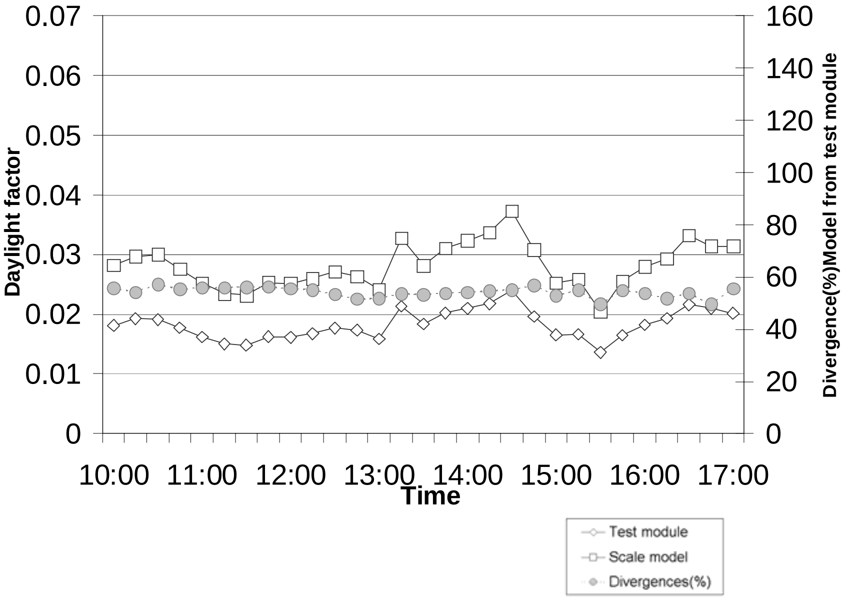

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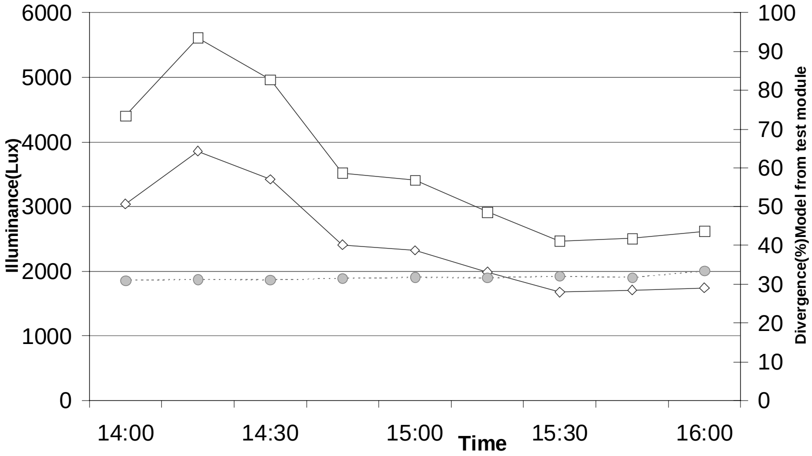
Figure 21



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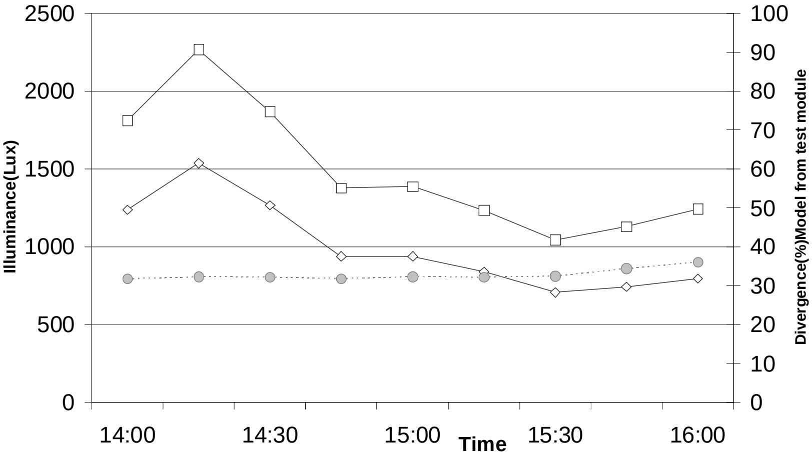

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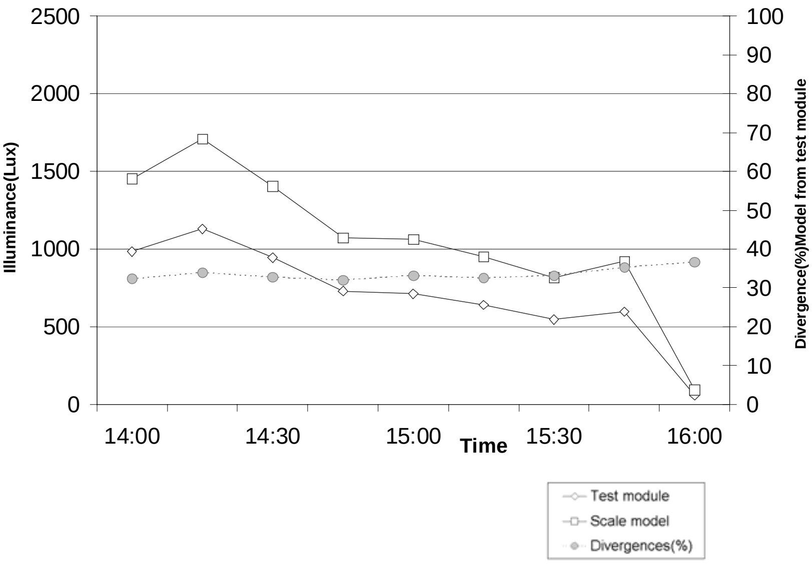

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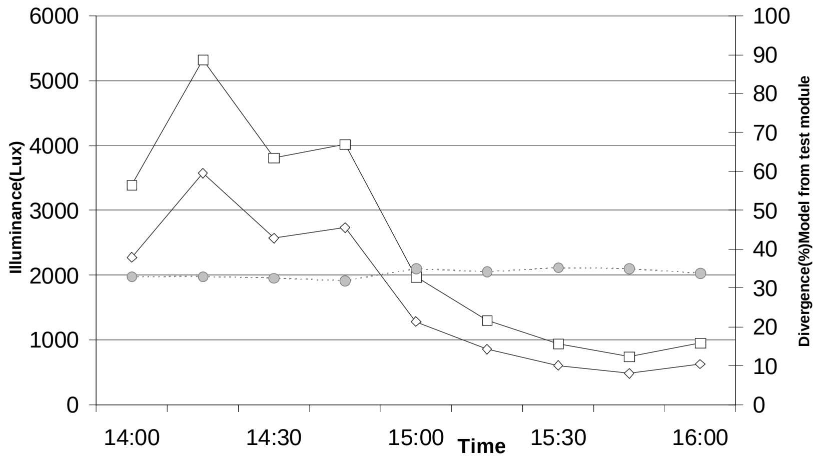

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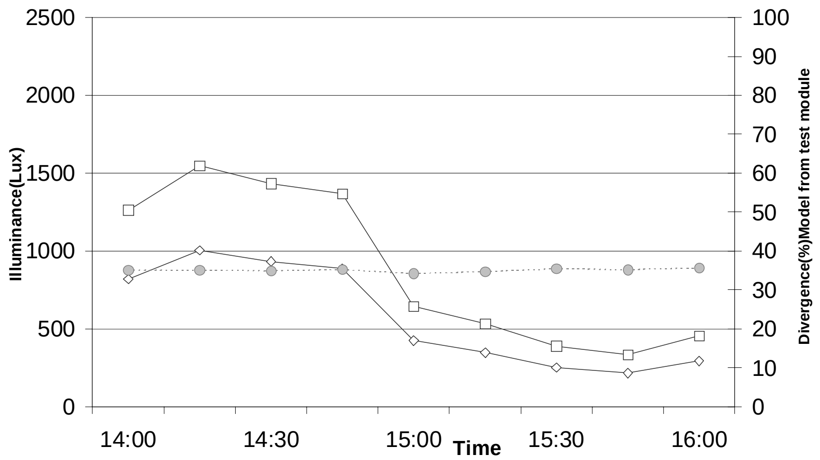

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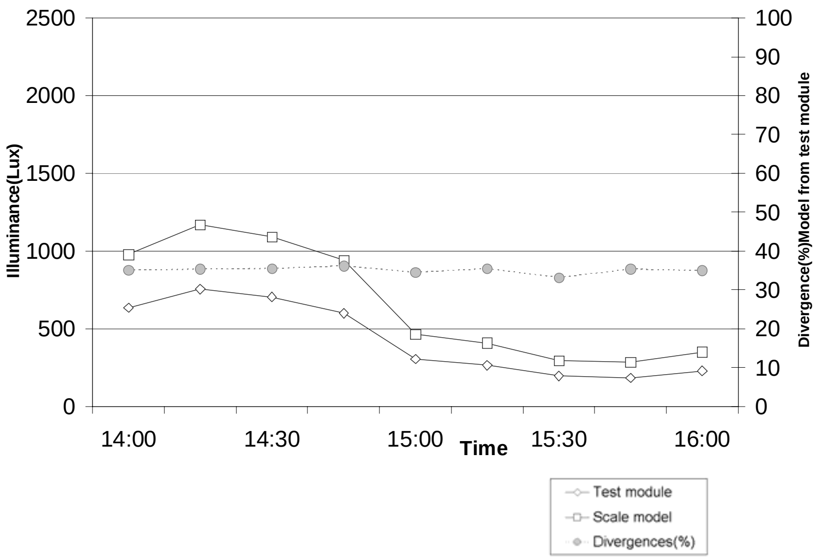

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Figure 23