



Data Article

Assessing museums' daylighting adequacy without annual measurement campaign: Dataset of a confrontation between measured and simulated illuminance values inside the Cetacean Gallery of the Charterhouse of Calci



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ABSTRACT

Lighting Cultural Heritage is a complex task: light is necessary for the act of seeing, it can even enhance the visual experience [1,2], in addition proper lighting can significantly cut down energy consumptions [3], but on the same time it has detrimental effects on exhibits, especially daylight. In order to safeguard the exhibits from damages, national and international standards provide specific recommendations for exhibits' exposure, based on their photosensitivity category. These recommendations are the annual luminous exposure(LO) and the Maximum Illuminance Level (E_{max}), museums' curators have to verify that the display lighting conditions comply with the standards. Historical buildings are often converted into museums but, as their original purpose was different, the lighting conditions are often inadequate (e.g. too much uncontrolled daylight), therefore the lighting conditions' adequacy of the space should be assessed [4]. As the name suggest the annual luminous exposure requires an annual monitoring campaign, unfortunately it often happens that exhibits have been exposed incorrectly for

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prolonged periods, and therefore it is very important to evaluate the need of a fast intervention. In this casuistry a prolonged measurement campaign is not acceptable. Simulations can help running a great number of analysis while reducing the length and expenses of a measurements campaign, however their previsions must be validated. This paper provides the data acquired through measurements and simulations inside the Cetacean Gallery of the Monumental Charterhouse of Calci, near Pisa (Tuscany Region, Italy). The data comprehends horizontal and vertical illuminance measurements, recorded on December the 6th, and simulations run in *Grasshopper* with the plugins *Honeybee+* and *Ladybug*. The data are related to the research article entitled "Application of climate-based daylight simulation to assess lighting conditions of space and artworks in historical buildings: the case study of Cetacean Gallery of the Monumental Charterhouse of Calci", published on the Journal of Cultural Heritage [5].

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Specifications Table

| | |
|--------------------------------|--|
| Subject | Building Engineering |
| Specific subject area | Daylight in buildings |
| Type of data | Tables, Images and Graphs |
| How data were acquired | On-site measurements with luxmeter (Delta OHM 2102.2), simulations run in <i>Grasshopper</i> with <i>Honeybee+</i> and <i>Ladybug</i> . Simulations rely on climate-based data provided by the Pisa Weather Station. |
| Data format | Raw, Analysed |
| Parameters for data collection | Illuminance values were collected in accordance with EN 12,464-1 recommendations [6], for defining measurement grid's dimensions, spacing and minimum number of points. <i>Grasshopper</i> 's simulations precision was ensured referring to the recommended <i>Radiance</i> parameters for accurate analyses [7]. |
| Description of data collection | Illuminance values were measured with Delta Ohm 2102.2 luxmeter, on December the 6th from 10:25 to 12:25. Operators ensured not to cast shadows on the luxmeter sensor using an extension-cable between the sensor and the instrument. Horizontal and vertical illuminances were measured, for the horizontal values a plan placed 1.00 m above the floor level was used, vertical values were measured twice, first facing south and then north, with the sensor placed 1.50 m above the floor level. Annual climate-based simulations were run in <i>Grasshopper</i> using the environmental plugins <i>Honeybee+</i> and <i>Ladybug</i> . Simulations' accuracy was validated though a confrontation with the on-site measurements. |
| Data source location | Natural History Museum of the University of Pisa, housed inside the Monumental Charterhouse of Calci, Pisa (Tuscany Region, Italy), geographic coordinates: 43°43'19"N, 10°31'22"E. |
| Data accessibility | Data are within this article; climate-based data ("epw" file format or others) can be free downloaded at https://energyplus.net/weather-location/europe_wmo_region_6/ITA//ITA_Pisa.161580_IWEC . |
| Related research article | "Application of climate-based daylight simulation to assess lighting conditions of space and artworks in historical buildings: the case study of Cetacean Gallery of the Monumental Charterhouse of Calci", Authors: F. Leccese, G. Salvadori, G. Tambellini, Z.T. Kazanasmaz, Journal of Cultural Heritage [5]. |

Value of the Data

- The data in this article demonstrates that lighting software simulations can substitute prolonged measurement campaign, if the 3D model is well calibrated.

- Lighting designers can use these data as reference for comparing illuminance on-site measurements and simulations' accuracy in similar contexts.
- The data can be used as a basis to further inquire about the daylighting adequacy inside the Natural History Museum.

1. Data

The data shown in this article are related to the research paper entitled "Application of climate-based daylight simulation to assess lighting conditions of space and artworks in historical buildings: the case study of Cetacean Gallery of the Monumental Charterhouse of Calci" [5]. The data validate simulations' previsions with additional confrontations between the measured illuminance values and the software simulated ones; the data are referred to the Cetacean Gallery of the Charterhouse of Calci. The Gallery has a rectangular plan (110×7 m) divided in 21 bays by brick columns. Three of the four vertical surfaces are almost entirely windowed, leading to a ratio of window to floor area of 67%. With its net volume of 3426 m^3 and floor area of 699 m^2 , the Gallery is the largest exhibition room of the Natural History Museum, housed inside the Monumental Charterhouse of Calci, near Pisa. The space corresponds with the monastery's ex-barn and hosts the most important cetacean skeleton collection in Italy, composed by 28 skeletons, 8 fossils, 47 life-sized and scale models, and 9 thematic areas.

Table 1 provides four recommended Radiance parameter settings. The settings vary depending on the level of accuracy required in the simulations. The last row of Table 1 provides a comparison with the parameter settings used in the research. Fig. 1 is a visual representation of the grids used during the measurement campaign. Floor plan and sections are displayed. Measurements points are highlighted in blue, non-accessible area (due to the exhibits' presence) are highlighted in cyan. Table 2, Table 3 and Table 4 provide the comparison between the illuminance values that were measured on-site and those that were obtained through the simulations. Simulations results comprehends four columns of values, depending on how the results were obtained: PIT values were obtained through point-in-time analysis using Climate-Based sky (CB), CIE Clear sky and CIE Overcast sky respectively. Finally results read from annual analysis with Climate-based sky (RFA) are displayed. Fig. 2, Fig. 3 and Fig. 4 are visual representations of the previous tables. The measurements points are placed on the x-axis, the illuminance levels are placed on the y-axis. Results are differentiated with symbols.

2. Experimental Design, Materials, and Methods

Illuminance levels were measured inside the Cetacean Gallery of the Charterhouse of Calci using Delta Ohm 2102.2 lxmeter on December the 6th from 10:25 to 12:25. The measurement grid was defined according to EN 12,464-1 recommendations [6] based on the room's geometry: as the Gallery measures 110×7 m the standard sets the minimum number of points to 20 and their spacing to 5.0 m. The grid used for the on-site measurements is composed by 58 points, spaced 3.00×1.75 m (Fig. 1). Horizontal Illuminance was measured on a horizontal plane

Table 1

Recommended Radiance parameters [7], depending on the required analysis accuracy.

| Required analysis accuracy | ab | aa | ar | ad |
|----------------------------------|----|------|-----|------|
| Minimum | 0 | 0.5 | 8 | 0 |
| Fast | 0 | 0.2 | 32 | 32 |
| Accurate | 2 | 0.15 | 128 | 512 |
| Maximum | 8 | 0.0 | 0 | 4096 |
| Value used in simulations | 2 | 0.1 | 300 | 1000 |

Table 2

Horizontal illuminance values (lx); sensor placed 1.00 m above floor level.

| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 0 | 12:25 | 82 | 2770 | 5119 | 1405 | 621 |
| 1 | 12:24 | 226 | 18,833 | 20,953 | 22,800 | 998 |
| 2 | 12:23 | 393 | 1384 | 1931 | 877 | 1001 |
| 3 | 12:23 | 408 | 1201 | 1387 | 642 | 966 |
| 4 | 12:22 | 463 | 886 | 1260 | 493 | 994 |
| 5 | 12:22 | 352 | 21,823 | 19,059 | 23,927 | 828 |
| 6 | 12:25 | 126 | 1876 | 2264 | 1038 | 812 |
| 7 | 12:24 | 217 | 22,319 | 25,821 | 24,183 | 495 |
| 8 | 12:23 | 280 | 2028 | 2456 | 1161 | 489 |
| 9 | 12:22 | 268 | 21,680 | 21,972 | 23,919 | 474 |
| 10 | 12:25 | 260 | 21,461 | 24,078 | 23,869 | 756 |
| 11 | 12:24 | 144 | 22,741 | 24,587 | 24,378 | 455 |
| 12 | 12:22 | 332 | 20,156 | 22,964 | 23,332 | 502 |
| 13 | 12:25 | 133 | 20,343 | 20,096 | 23,370 | 144 |
| 14 | 12:21 | 381 | 21,185 | 20,417 | 23,652 | 710 |
| 15 | 12:21 | 488 | 2009 | 3134 | 1261 | 851 |
| 16 | 12:21 | 450 | 2826 | 7260 | 1425 | 666 |
| 17 | 12:20 | 185 | 2026 | 2452 | 1078 | 810 |
| 18 | 12:20 | 426 | 2493 | 2948 | 1360 | 725 |
| 19 | 12:20 | 471 | 22,277 | 22,603 | 24,050 | 762 |
| 20 | 12:20 | 443 | 23,253 | 23,951 | 24,471 | 777 |
| 21 | 12:19 | 413 | 1713 | 1955 | 771 | 708 |
| 22 | 12:19 | 462 | 2747 | 2946 | 1258 | 821 |
| 23 | 12:19 | 446 | 2825 | 3083 | 1416 | 665 |
| 24 | 12:18 | 482 | 2953 | 3815 | 1566 | 790 |
| 25 | 12:18 | 437 | 3098 | 3427 | 1564 | 715 |
| 26 | 12:18 | 432 | 2850 | 3590 | 1443 | 746 |
| 27 | 12:18 | 527 | 2515 | 2828 | 1161 | 748 |
| 28 | 12:17 | 421 | 19,686 | 20,255 | 23,193 | 630 |
| 29 | 12:17 | 503 | 19,916 | 20,681 | 23,194 | 766 |
| 30 | 12:16 | 422 | 20,126 | 20,910 | 23,376 | 651 |
| 31 | 12:16 | 438 | 1934 | 2057 | 993 | 745 |
| 32 | 12:16 | 432 | 21,056 | 20,740 | 23,553 | 695 |
| 33 | 12:16 | 340 | 21,333 | 23,222 | 23,804 | 724 |
| 34 | 12:15 | 427 | 630 | 770 | 419 | 754 |
| 35 | 12:15 | 363 | 22,628 | 21,843 | 24,269 | 649 |
| 36 | 12:14 | 423 | 23,376 | 21,347 | 24,625 | 787 |
| 37 | 12:14 | 366 | 4689 | 5965 | 2145 | 696 |
| 38 | 12:14 | 380 | 23,418 | 21,065 | 24,579 | 746 |
| 39 | 12:09 | 186 | 22,136 | 23,095 | 24,106 | 246 |
| 40 | 12:09 | 50 | 23,241 | 21,866 | 24,486 | 134 |
| 41 | 12:08 | 52 | 23,210 | 22,684 | 24,451 | 131 |
| 42 | 12:08 | 77 | 22,644 | 22,518 | 24,172 | 198 |
| 43 | 12:08 | 128 | 23,314 | 23,219 | 24,529 | 206 |
| 44 | 12:12 | 159 | 4143 | 6990 | 2052 | 478 |
| 45 | 12:09 | 166 | 23,224 | 24,535 | 24,542 | 637 |
| 46 | 12:12 | 332 | 22,402 | 18,890 | 24,186 | 559 |
| 47 | 12:10 | 211 | 23,068 | 23,271 | 24,467 | 760 |
| 48 | 12:13 | 349 | 23,044 | 21,872 | 24,441 | 456 |
| 49 | 12:13 | 186 | 22,367 | 25,171 | 24,086 | 556 |
| 50 | 12:13 | 438 | 23,266 | 23,155 | 24,462 | 688 |
| 51 | 12:11 | 173 | 4235 | 4262 | 2061 | 323 |
| 52 | 12:11 | 169 | 23,187 | 24,499 | 24,487 | 339 |
| 53 | 12:11 | 327 | 22,603 | 21,418 | 24,303 | 413 |
| 54 | 12:10 | 110 | 22,755 | 24,259 | 24,318 | 300 |

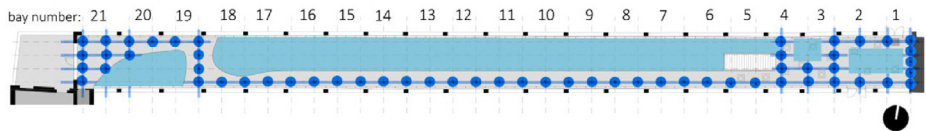
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Table 2 (continued)

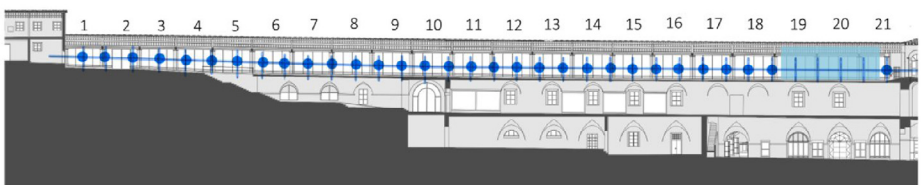
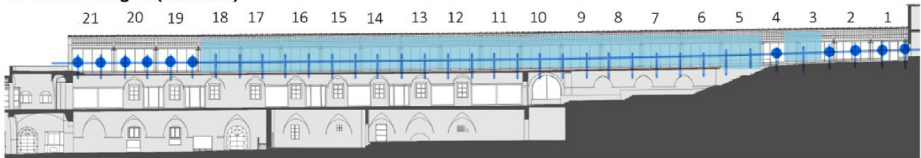
| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------------------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 55 | 12:11 | 184 | 23,161 | 21,805 | 24,493 | 387 |
| 56 | 12:10 | 217 | 21,691 | 21,370 | 23,940 | 624 |
| 57 | 12:11 | 246 | 23,132 | 22,779 | 24,503 | 929 |
| Average illuminance [lx] | | 310 | 14,653 | 15,084 | 15,416 | 625 |
| MD [%] | / | | +46.2 | +47.6 | +48.7 | +1.01 |

placed 1.00 m above floor level, vertical illuminance was measured 1.50 m above floor level both in north and south direction. The measured values (Tables 2-4) were then confronted with software simulations (Figs. 2-4) in order to verify their accuracy. Simulations' grid was denser, with a total of 287 measurements points spaced 1.50×1.75 m. However, to maximize the confrontation's significance, some points were excluded and just the exact same ones of the on-site grid were used for the confrontation. Simulations were run in *Grasshopper* using *Honeybee+* and *Ladybug*, *Radiance*-based environmental plugins (Table 1). The 3D model of the Gallery is based on an architectural survey conducted by the University of Pisa, the geometries were modelled in *Rhinoceros* and then imported in *Grasshopper*. Two kinds of simulation were run: point-in-time (PIT) and annual. PIT simulations are implemented in every lighting software, Annual ones are not. Annual analyses are more accurate, on account of using climate-based data for the sky model creation: the climate-based data provides the TMY (typical meteorological year) for the examined site. The TMY is composed by the succession of the most recurrent weather conditions observed during the recording period [8]. For the data used in simulations the recording

Measurement grid (plan)



Measurement grid (elevation)



● measurement points ● non-accessible areas due to the exhibits' presence

Fig. 1. Cetacean Gallery: measurement grid (plan and elevations).

Table 3

Vertical illuminance values (lx); sensor facing south 1.50 m above floor level.

| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 0 | 10:23 | 146 | 6690 | 10,613 | 3432 | 583 |
| 1 | 10:24 | 207 | 5467 | 7277 | 3122 | 403 |
| 2 | 10:25 | 188 | 4324 | 5374 | 2796 | 273 |
| 3 | 10:26 | 213 | 3494 | 4402 | 2585 | 200 |
| 4 | 10:26 | 304 | 3021 | 4003 | 2102 | 191 |
| 5 | 10:26 | 378 | 51,589 | 55,561 | 55,387 | 1198 |
| 6 | 10:23 | 207 | 4774 | 5062 | 3512 | 303 |
| 7 | 10:24 | 306 | 53,412 | 55,578 | 56,565 | 1333 |
| 8 | 10:25 | 186 | 5592 | 5837 | 4063 | 370 |
| 9 | 10:27 | 572 | 50,682 | 50,418 | 54,980 | 1126 |
| 10 | 10:23 | 293 | 50,070 | 49,093 | 54,614 | 1200 |
| 11 | 10:24 | 270 | 53,702 | 52,120 | 56,207 | 1501 |
| 12 | 10:28 | 1041 | 9944 | 5921 | 5393 | 810 |
| 13 | 10:23 | 49 | 9889 | 9553 | 5253 | 861 |
| 14 | 10:28 | 1412 | 49,932 | 48,696 | 54,935 | 950 |
| 15 | 10:47 | 2253 | 7370 | 8233 | 4729 | 529 |
| 16 | 10:47 | 1718 | 8295 | 8840 | 4978 | 597 |
| 17 | 10:48 | 2289 | 5690 | 6515 | 4090 | 381 |
| 18 | 10:48 | 2117 | 6543 | 7368 | 4489 | 450 |
| 19 | 10:48 | 2195 | 51,112 | 46,082 | 55,087 | 1440 |
| 20 | 10:49 | 2406 | 53,992 | 55,703 | 56,299 | 1535 |
| 21 | 10:51 | 1606 | 2052 | 1868 | 1211 | 308 |
| 22 | 10:51 | 2137 | 5352 | 5634 | 3442 | 403 |
| 23 | 10:52 | 1714 | 6304 | 6547 | 4111 | 437 |
| 24 | 10:52 | 1985 | 6751 | 6941 | 4495 | 478 |
| 25 | 10:52 | 1928 | 6766 | 7084 | 4409 | 452 |
| 26 | 10:53 | 1772 | 6977 | 7390 | 4506 | 475 |
| 27 | 10:53 | 1983 | 3031 | 3229 | 1522 | 595 |
| 28 | 10:53 | 1530 | 7321 | 9544 | 4086 | 527 |
| 29 | 10:53 | 1961 | 8374 | 8718 | 4666 | 602 |
| 30 | 10:54 | 1655 | 8786 | 9968 | 4974 | 653 |
| 31 | 11:34 | 1858 | 1629 | 1591 | 921 | 306 |
| 32 | 11:35 | 1989 | 48,169 | 44,638 | 53,838 | 794 |
| 33 | 11:35 | 1573 | 49,285 | 47,050 | 54,070 | 948 |
| 34 | 11:35 | 1971 | 551 | 566 | 375 | 103 |
| 35 | 11:36 | 1525 | 50,881 | 52,875 | 54,592 | 1260 |
| 36 | 11:36 | 1940 | 53,174 | 51,928 | 55,532 | 1559 |
| 37 | 11:36 | 1415 | 10,228 | 10,298 | 4780 | 1228 |
| 38 | 11:36 | 1811 | 53,273 | 52,044 | 55,536 | 1523 |
| 39 | 11:39 | 467 | 49,627 | 51,386 | 54,101 | 1321 |
| 40 | 11:40 | 235 | 52,998 | 53,999 | 55,284 | 1462 |
| 41 | 11:40 | 161 | 52,866 | 52,464 | 55,095 | 1462 |
| 42 | 11:40 | 119 | 51,012 | 51,325 | 54,573 | 1283 |
| 43 | 11:40 | 110 | 53,509 | 52,391 | 55,590 | 1552 |
| 44 | 11:39 | 581 | 9224 | 3664 | 4219 | 1215 |
| 45 | 11:41 | 162 | 53,285 | 54,623 | 55,662 | 1543 |
| 46 | 11:39 | 942 | 51,082 | 51,182 | 54,772 | 1359 |
| 47 | 11:41 | 203 | 52,774 | 54,094 | 55,294 | 1417 |
| 48 | 11:38 | 1127 | 53,248 | 53,128 | 55,612 | 1527 |
| 49 | 11:38 | 337 | 50,368 | 55,788 | 54,456 | 1219 |
| 50 | 11:38 | 1527 | 53,512 | 56,063 | 55,870 | 1562 |
| 51 | 11:42 | 484 | 9885 | 10,459 | 4884 | 1261 |
| 52 | 11:43 | 411 | 53,441 | 56,871 | 55,913 | 1513 |
| 53 | 11:43 | 673 | 52,404 | 52,554 | 55,268 | 1406 |
| 54 | 11:42 | 286 | 52,467 | 52,383 | 55,566 | 1358 |

(continued on next page)

Table 3 (continued)

| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------------------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 55 | 11:43 | 427 | 53,591 | 52,994 | 55,967 | 1550 |
| 56 | 11:42 | 225 | 49,300 | 52,176 | 54,270 | 1240 |
| 57 | 11:44 | 284 | 53,995 | 57,583 | 56,186 | 1567 |
| Average illuminance [lx] | | 1032 | 29,881 | 30,264 | 30,349 | 960 |
| MD [%] | | / | +28.0 | +28.3 | +28.4 | +0.07 |

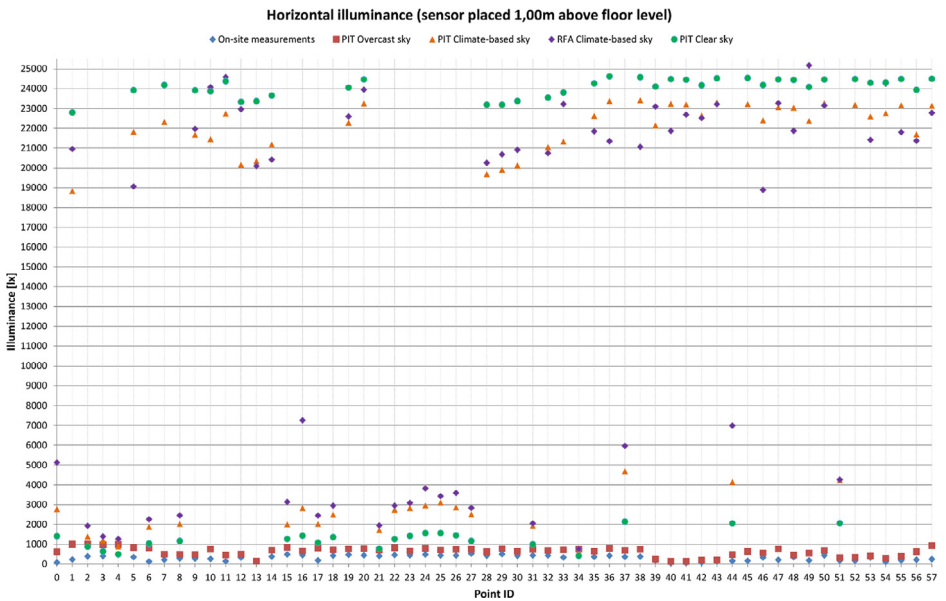


Fig. 2. Horizontal Illuminance values on the selected points' grid.

period is 1982–1997. The mean deviation (MD) is calculated as (Tables 2-4):

$$MD = \frac{\sum_{i=1}^n E_{S, i} - \sum_{i=1}^n E_{M, i}}{\sum_{i=1}^n E_{M, i}} \% \tag{1}$$

where: i (1, 2, ..., n) are the grid points, $E_{S,i}$ the illuminance values obtained through the simulations, $E_{M,i}$ the illuminance values obtained through the on-site measurements.

3. Funding

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Table 4

Vertical illuminance values (lx); sensor facing north 1.50 m above floor level.

| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 0 | / | / | 2193 | 2247 | 1980 | 214 |
| 1 | 10:31 | 416 | 2160 | 2667 | 1857 | 255 |
| 2 | 10:31 | 950 | 1912 | 2256 | 1451 | 342 |
| 3 | 10:31 | 931 | 1778 | 2090 | 1034 | 473 |
| 4 | 10:30 | 990 | 1497 | 1880 | 817 | 425 |
| 5 | 10:30 | 870 | 3102 | 3336 | 2873 | 336 |
| 6 | 10:32 | 87 | 4272 | 4722 | 2293 | 1540 |
| 7 | / | / | 3558 | 3604 | 3192 | 407 |
| 8 | / | / | 4658 | 5565 | 2523 | 1621 |
| 9 | 10:29 | 561 | 3632 | 4451 | 3308 | 411 |
| 10 | 10:32 | 114 | 3676 | 4175 | 3211 | 467 |
| 11 | / | / | 4167 | 4426 | 3620 | 500 |
| 12 | 10:29 | 389 | 3673 | 4268 | 3038 | 537 |
| 13 | 10:33 | 204 | 3923 | 4177 | 3126 | 597 |
| 14 | 10:29 | 303 | 4278 | 4692 | 3510 | 631 |
| 15 | 10:58 | 412 | 3686 | 4271 | 2571 | 850 |
| 16 | 10:58 | 337 | 4380 | 4940 | 3120 | 999 |
| 17 | 10:58 | 286 | 3986 | 4688 | 2193 | 1366 |
| 18 | 10:57 | 294 | 5070 | 5785 | 2736 | 1847 |
| 19 | 10:57 | 337 | 3937 | 4123 | 3323 | 532 |
| 20 | 10:57 | 355 | 3852 | 4036 | 3295 | 487 |
| 21 | 10:57 | 358 | 3280 | 3553 | 1858 | 1217 |
| 22 | 10:56 | 311 | 5605 | 6603 | 3384 | 1909 |
| 23 | 10:56 | 295 | 5370 | 5868 | 3150 | 1845 |
| 24 | 10:56 | 278 | 5302 | 6307 | 3237 | 1796 |
| 25 | 10:56 | 293 | 5643 | 6572 | 3328 | 1939 |
| 26 | 10:55 | 274 | 4714 | 5647 | 2847 | 1533 |
| 27 | 10:55 | 271 | 2723 | 3391 | 1738 | 751 |
| 28 | 10:54 | 294 | 4547 | 4578 | 3294 | 1048 |
| 29 | 10:54 | 283 | 4830 | 5064 | 3502 | 1051 |
| 30 | 10:54 | 276 | 4779 | 5708 | 3605 | 1019 |
| 31 | 11:51 | 180 | 3315 | 3643 | 2073 | 912 |
| 32 | 11:51 | 173 | 4097 | 4543 | 3207 | 670 |
| 33 | 11:50 | 182 | 4599 | 5438 | 3684 | 717 |
| 34 | 11:50 | 184 | 2092 | 2154 | 1474 | 425 |
| 35 | 11:50 | 182 | 4435 | 5315 | 3666 | 565 |
| 36 | 11:49 | 152 | 4513 | 5178 | 3862 | 596 |
| 37 | 11:49 | 132 | 4359 | 5105 | 3617 | 572 |
| 38 | 11:49 | 97 | 4494 | 4628 | 3889 | 598 |
| 39 | 11:47 | 69 | 4333 | 4846 | 3576 | 616 |
| 40 | 11:47 | 83 | 4470 | 4847 | 3829 | 570 |
| 41 | 11:47 | 138 | 4359 | 5213 | 3755 | 588 |
| 42 | 11:47 | 292 | 4376 | 4799 | 3732 | 601 |
| 43 | 11:46 | 428 | 4479 | 5098 | 3780 | 583 |
| 44 | 11:48 | 99 | 4413 | 4996 | 3633 | 575 |
| 45 | 11:46 | 434 | 4581 | 4588 | 3832 | 589 |
| 46 | 11:48 | 129 | 4359 | 4931 | 3622 | 563 |
| 47 | 11:46 | 596 | 4409 | 5036 | 3808 | 592 |
| 48 | 11:48 | 109 | 4377 | 5339 | 3761 | 575 |
| 49 | 11:48 | 108 | 4357 | 5208 | 3663 | 596 |
| 50 | 11:48 | 114 | 4457 | 5079 | 3834 | 560 |
| 51 | 11:45 | 132 | 4255 | 4681 | 3592 | 568 |
| 52 | 11:45 | 128 | 4451 | 4489 | 3788 | 609 |
| 53 | 11:45 | 161 | 4218 | 4465 | 3602 | 565 |
| 54 | 11:45 | 252 | 4347 | 4646 | 3704 | 563 |

(continued on next page)

Table 4 (continued)

| Grid point ID | Hour | On-site measurements | Simulations results | | | |
|---------------------------------|-------|----------------------|-----------------------|-----------------------|-------------------|----------------------|
| | | | PIT Climate-based sky | RFA Climate-based sky | PIT CIE Clear sky | PIT CIE Overcast sky |
| 55 | 11:44 | 313 | 4349 | 4575 | 3702 | 534 |
| 56 | 11:46 | 630 | 4199 | 5102 | 3591 | 546 |
| 57 | 11:44 | 708 | 4312 | 4627 | 3781 | 569 |
| Average illuminance [lx] | | 293 | 4055 | 4556 | 3122 | 775 |
| MD [%] | | / | +12.9 | +14.6 | +9.67 | +1.65 |

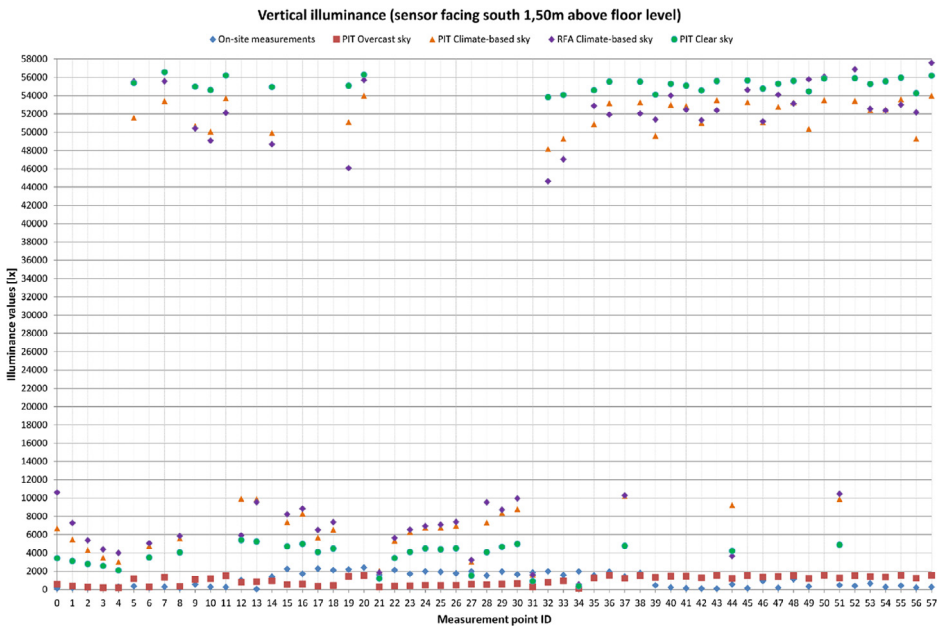


Fig. 3. Vertical illuminance values (facing south) on the selected points' grid.

List of abbreviations

- ab ambient bounces, it sets the number of diffuse bounces computed in the indirect illuminance calculation
- aa ambient accuracy, it influences the error from indirect illuminance interpolation
- ar ambient resolution, it sets the density of the ambient for the interpolation
- ad ambient divisions, it influences Monte Carlo's error during indirect illuminance calculation
- $E_{S,i}$ illuminance values obtained through the simulations
- $E_{M,i}$ illuminance values obtained through the on-site measurements
- MD mean deviation, deviation between simulated and measure illuminance values
- PIT Point In Time, illuminance values obtained through point in time analyses simulations
- RFA Read From Annual, Illuminance values obtained through annual, climate-based simulations

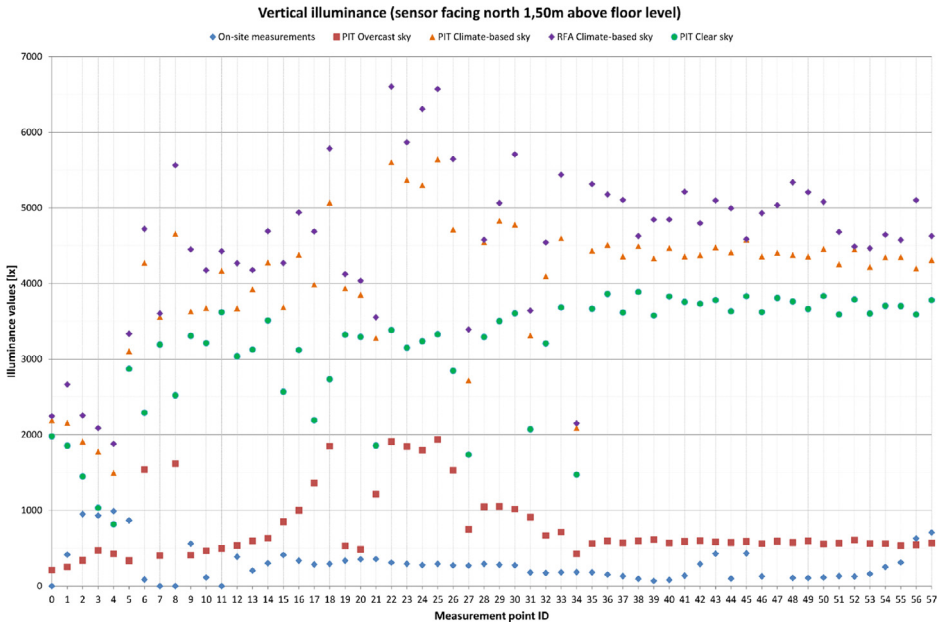


Fig. 4. Vertical illuminance values (facing north) on the selected points' grid.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which could have influenced the work reported in this article.

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