Designing Better Workplaces through Fast Daylighting Simulation with Accelerad

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SDLAB http://mit.edu/sustainabledesignlab/projects/Accelerad/

ABSTRACT

Daylight in buildings is desirable as it is both aesthetically pleasing and a sustainable means of offsetting heating and electric lighting costs. However, misuse or overuse of daylight can lead to veiling glare on monitors and discomfort or disability glare that impedes worker productivity. Short of building elaborate physical mockups, predictions of glare conditions can only be made by time-consuming ray tracing simulation.

This study compares two simulation methods with measurements taken in a physical space. The simulation engines used are **Radiance**, a well-validated CPU-based ray tracing engine originally developed by Greg Ward at Lawrence Berkeley National Laboratory, and **Accelerad**, a GPU-based tool developed by the authors at the Massachusetts Institute of Technology using NVIDIA's OptiX ray tracing engine. **Accelerad** produces image-based visual comfort metrics of daylit scenes with comparable accuracy to Radiance and in much less time. Daylight glare probability (DGP) and monitor contrast ratio (CR) serve as indicators of visual comfort in this study.

Daylighting simulation on the GPU presents several unique challenges. The number of ambient bounces required for ray tracing is high: typically at least 5 bounces to accurately capture the area that will be perceived as daylit by an occupant. To prevent the simulation time from growing exponentially, irradiance caching is employed to allow reuse of previously calculated diffuse lighting values. However, irradiance caching is not easily parallelizable. Instead, **Accelerad** performs iterative irradiance caching as a preprocessing step, employing both CUDA and OptiX kernels to select and evaluate irradiance cache entries.

METRICS

Daylight Glare Probability (DGP)

$$DGP = 5.87 \times 10^{-5} E_v + 0.0918 \times \log_{10}\left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16$$

- E_v vertical illuminance at eye
- L_s brightness of glare source
- ω_s solid angle of glare source
- P Guth position index relating position to sensitivity of human eye

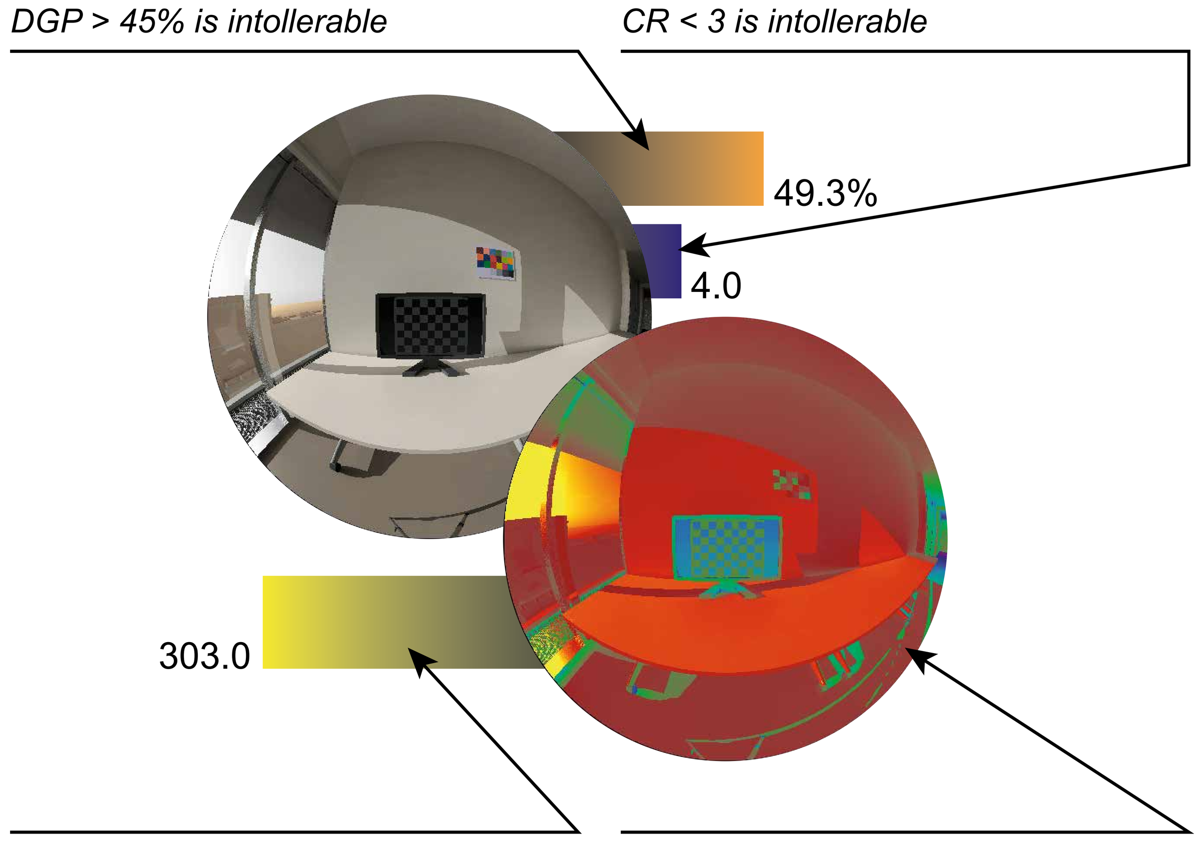
DGP > 45% is intollerable

Monitor Contrast Ratio (CR)

$$CR = \frac{L_H + L_r}{L_L + L_r}$$

- L_H high state luminance
- L_L low state luminance
- L_r amount of reflected light

CR < 3 is intollerable



Simulation Time
shown in minutes

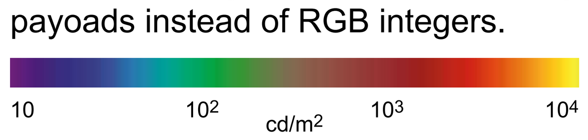
Radiance
3.4 GHz Intel® Core™ i7-4770

Accelerad
2.27 GHz Intel® Xeon® E5520
2 × NVIDIA® Tesla® K40

High Dynamic Range Image (HDR)

HDR photo is a composite of nine images with different exposure lengths.

HDR rendering uses real-valued ray payloads instead of RGB integers.



METHOD

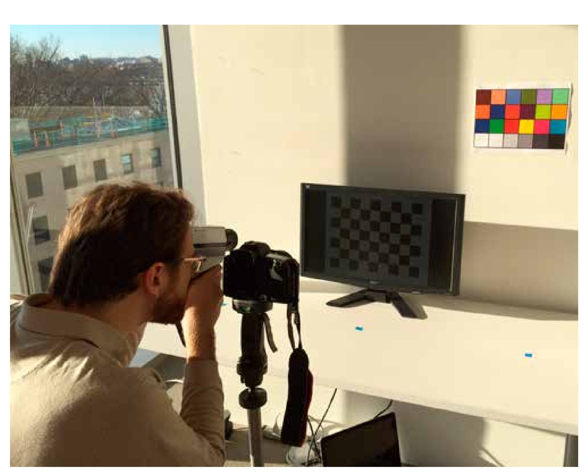
Camera for HDR capture: *Cannon 50D Mark II with Sigma 8mm fisheye lens*

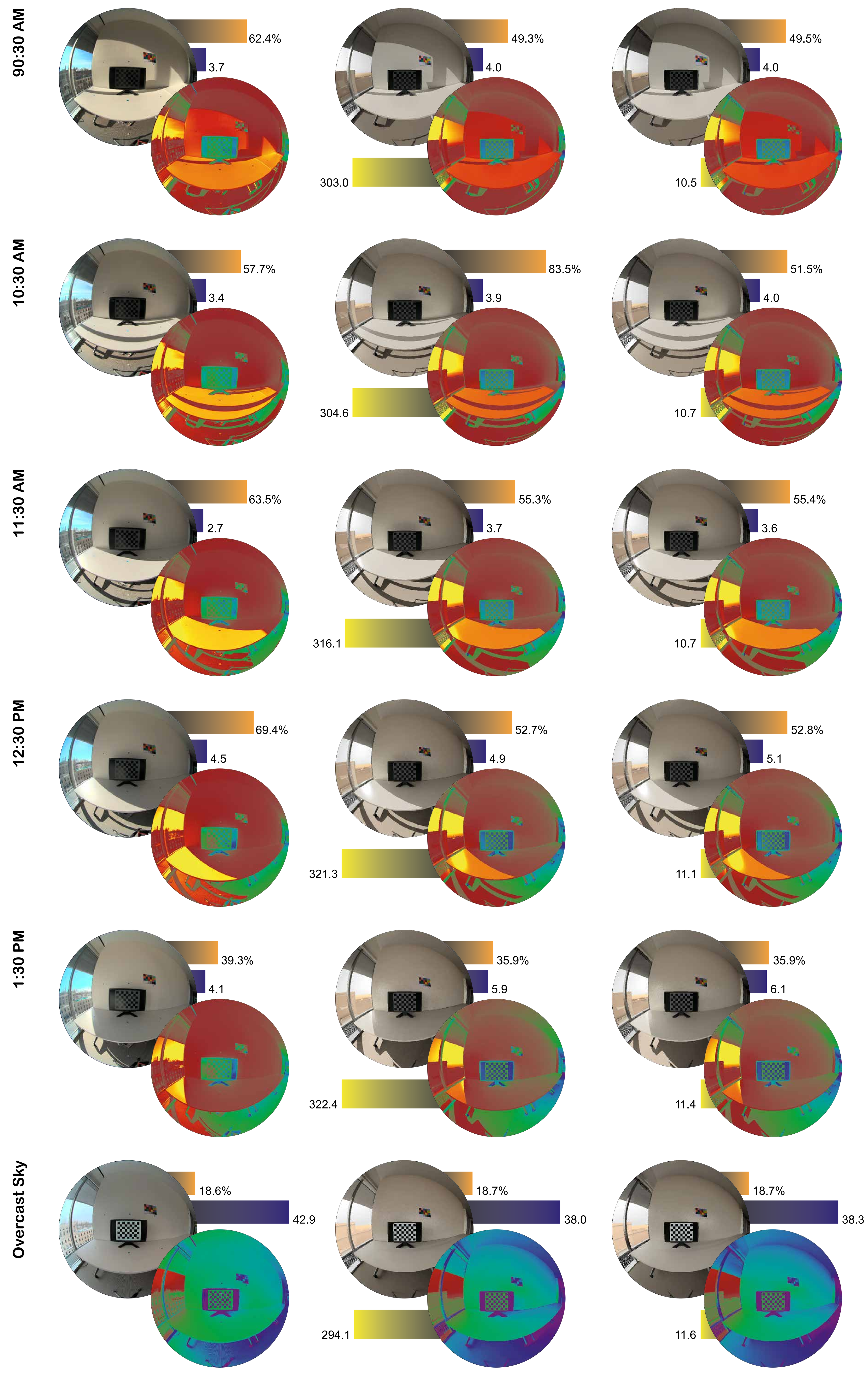
Luminance meter for monitor luminance measurements: *Konica Minolta LS-110*

Illuminance meter for workplane measurements: *Konica Minolta TL-1*

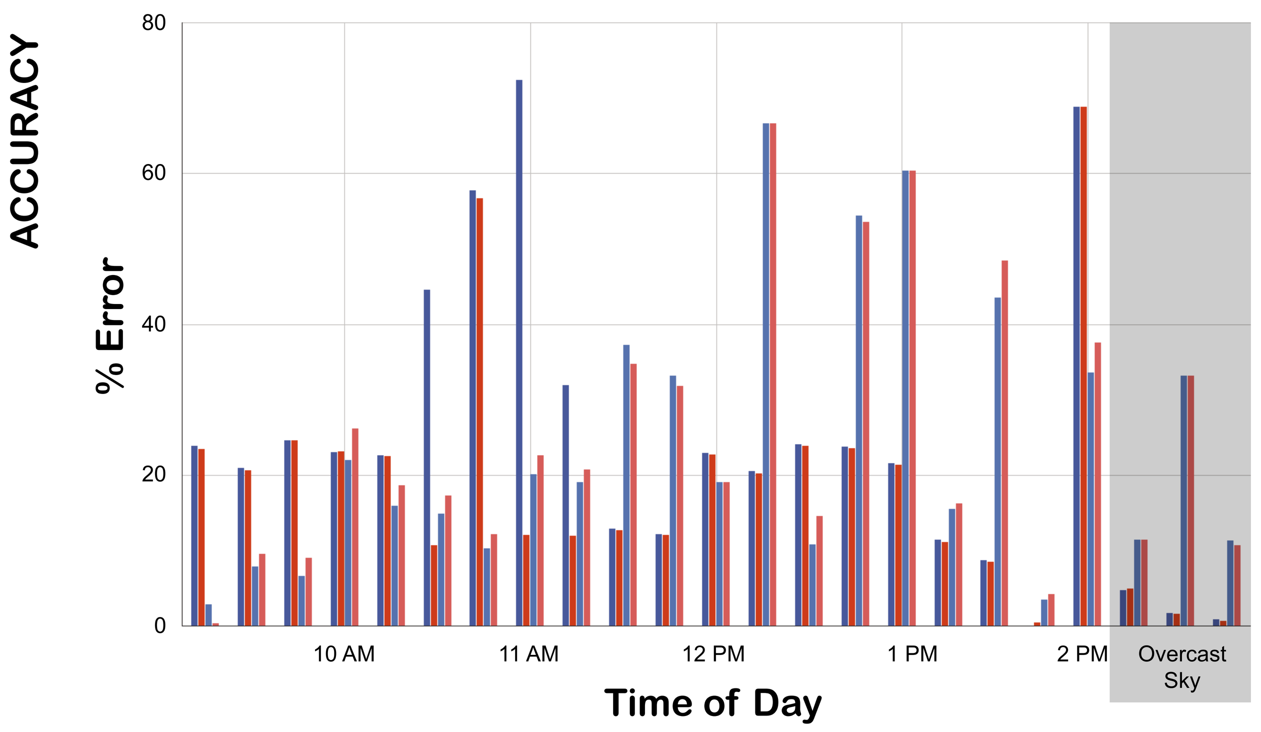
Spectrophotometer for reflectance measurement: *Konica Minolta CM-2500d*

Modeling environment: *Trimble SketchUp and su2rad*





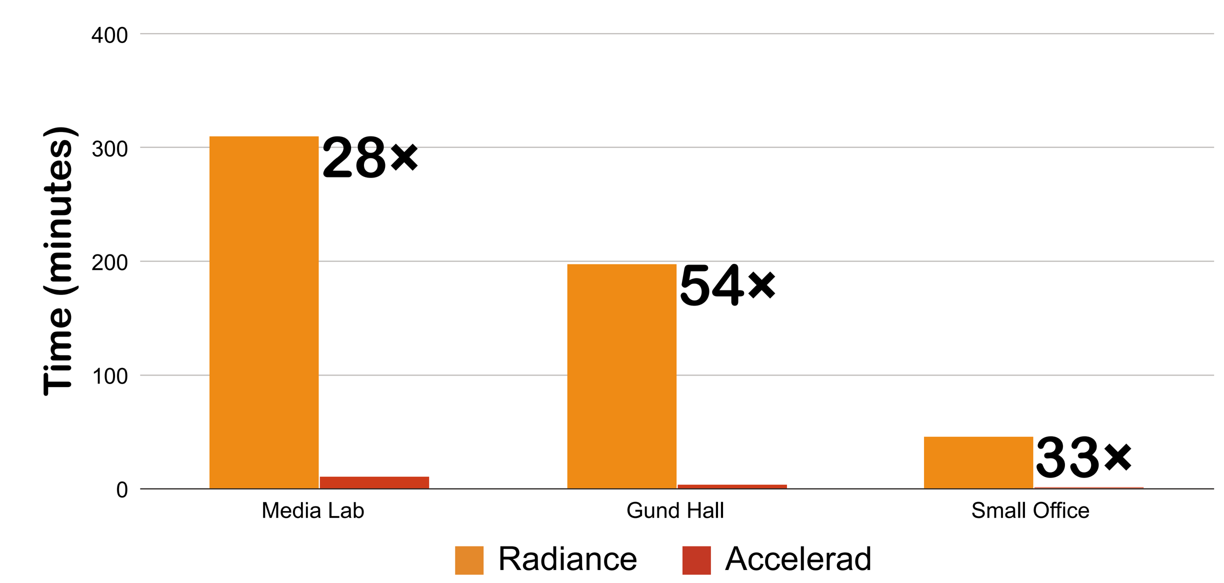
ACCURACY



Average Error in DGP	
Radiance	24%
Accelerad	19%

Average Error in CR	
Radiance	24%
Accelerad	25%

SPEED



FUTURE WORK

Accelerad shows that ray tracing with irradiance caching and multiple ambient bounces performed on the GPU can be as accurate as traditional Radiance methods for predicting visual comfort conditions in a workplace.

Furthermore, **Accelerad** generates five-bounce solutions up to 50 times faster than Radiance. Even with accurately modeled materials that cause poor warp coherence, a speedup of more than 4 times is possible. These results are expected to scale up on new generations of GPUs.

These speed increases open the way for new types of building performance simulation that currently require excessive computation times on CPUs. These opportunities include:

Annual simulation Simulations performed over the occupied hours of a building will allow architects to identify and respond to problematic lighting conditions that occur at certain times of year.

Spatial glare mapping Today's cutting edge lighting studies, called adaptive glare analysis, add rotational and small translational components to glare analysis images to simulate the adaptive response of a single office worker to glare conditions. However, generation of a large set of HDR images using a camera grid will allow the design of workplaces where areas with high glare probability are assigned alternate functions.

Spectral analysis Certain wavelengths of blue light are associated with regulation of the body's alertness level. Simulations that break light into many spectral bands, rather than traditional RGB values, will allow the design of buildings that encourage attentiveness and productivity.

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