Social Sciences and Frontier Technology
Forum (SSFT 2025)

Technical Logic and Practical Strategies for Lighting Methods in a Sunny Indoor Bedroom Based on Time Series in Blender

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Abstract: With the growing demand for virtual environment design, the accuracy of indoor natural lighting simulation has become a key factor in enhancing visual effects in interior design. This study uses Blender as a tool to focus on the natural lighting characteristics of indoor bedrooms under sunny conditions at different times of the day. A systematic lighting method framework is constructed. Through case analysis and experimental research, the lighting parameter settings for four time periods-morning, daytime, evening, and night-are revealed, and adaptive optimization strategies are proposed based on material properties. The research results provide scientific lighting design references for interior design, film and animation, and promote the practical application of natural lighting simulation technology.

Keywords: Blender; Sunny Indoor; Bedroom Lighting; Natural Lighting; HDRI Maps

1. Introduction

1.1 Research Background

Indoor lighting design is not only a functional requirement but also a core element of spatial aesthetics and psychological experience. With the popularization of sustainable development concepts, the efficient use of natural lighting has become a key focus in architectural and interior design. However, traditional design methods rely on physical models and empirical judgments, making it difficult to accurately simulate dynamic natural lighting effects. Blender, as an open-source 3D creation tool, provides technical support for virtual environment research with its powerful lighting simulation capabilities. The differentiated lighting characteristics of sunny indoor bedrooms over time necessitate systematic research to guide practice.

1.2 Research Purpose and Significance

This study aims to construct a time-series lighting method system for sunny indoor bedrooms using Blender, combining theoretical analysis and experimental verification to propose universal design strategies. Its significance lies in:

1. Providing precise lighting parameter references for virtual scene design.
2. Optimizing the consistency of lighting between real and virtual scenes.
3. Promoting the application of natural lighting simulation technology across various fields.

1.3 Research Questions

1. How to achieve precise lighting in Blender based on the natural lighting characteristics of morning, daytime, evening, and night?
2. How to translate experimental results into actionable design strategies and technical optimization solutions?

2. Theoretical and Technical Foundations

2.1 Principles of Indoor Lighting Design

Indoor lighting design is an essential part of architectural and interior design. Its core goal is to meet functional, comfort, aesthetic, and energy-saving needs through reasonable light arrangement. The intensity, color, direction, and distribution of light are the four core elements of lighting design. Below, the basic principles are briefly explained based on four principles.

2.1.1 Functional Principle

- **Core Goal:** Meet the usage needs of different spaces through scientific illuminance calculations and lighting layout.
- **Illuminance Requirements:**
  - o Reading area: ≥300lx, suitable for localized spotlights or desk lamps.
  - o Office area: ~500lx, requiring uniform light distribution.
  - o Rest area: 100-200lx, suitable for soft indirect lighting.
- **Lighting Layout:** Optimized based on space function, such as using recessed downlights in

kitchen work areas and ceiling lights in corridors.

2.1.2 Comfort Principle

• **Core Goal:** Enhance visual and psychological comfort through reasonable color temperature and brightness matching.

• **Color Temperature Selection:**

o Low color temperature (2700-3000K): Warm light, suitable for bedrooms and hotels.

o Medium color temperature (3500-4000K): Natural light, suitable for living rooms and dining areas.

o High color temperature (5000K+): Cool light, suitable for offices and study areas.

• **Brightness Adjustment:** Bedside lamps and desk lamps should have dimming functions to adapt to different usage scenarios.

2.1.3 Aesthetic Principle

• **Core Goal:** Enhance the artistic effect of space through lighting fixtures and light design.

• **Style Adaptation:**

o Modern minimalist style: Linear light strips, recessed downlights.

o Classical style: Crystal chandeliers, vintage wall lamps.

o Industrial style: Exposed bulbs, metal track lights.

• **Light Design:** Enhance spatial hierarchy and three-dimensionality through wall lamps, spotlights, or light strips.

2.1.4 Energy-saving Principle

• **Core Goal:** Reduce energy consumption through efficient lighting fixtures and intelligent control systems.

• **Specific Measures:**

o Use energy-efficient LED lamps.

o Employ intelligent dimming systems to adjust lighting based on needs.

o Implement zoned lighting design to independently control different areas.

• **Significance:** Reduces operational costs and environmental impact, aligning with sustainable development principles.

2.2 Natural Lighting Characteristics

Under sunny conditions, natural lighting exhibits the following patterns:

• **Light Intensity Changes:** Highest at noon, lower in the morning and evening.

• **Spectral Changes:** Warmer in the morning (≈3000K), closer to white light at noon (≈5500K).

• **Shadow Changes:** Long shadows in the morning, short shadows at noon, with shadow direction changing based on the sun's position.

2.3 Overview of Blender Software

Blender is a powerful open-source 3D creation software widely used in modeling, animation, rendering, and lighting simulation. Its lighting system, based on the Cycles and Eevee rendering engines, efficiently simulates natural and artificial lighting effects. Key features include:

2.3.1 Light Source Types

• **Sun Light:** Simulates parallel light, suitable for natural lighting (e.g., sunlight). Adjusting the sun's angle and intensity can simulate lighting at different times.

• **Point Light:** Simulates localized light sources (e.g., bulbs, desk lamps). Supports falloff settings to realistically represent light propagation and attenuation.

• **Area Light:** Simulates large-area light sources (e.g., light strips, window light). Supports various shapes (rectangular, circular) to generate soft shadows.

• **Spot Light:** Simulates directional light sources (e.g., spotlights, stage lights). Supports beam angle and edge softening for clear conical shadows.

2.3.2 Material Interaction

Blender's lighting system is based on PBR (Physically Based Rendering), where material lighting performance is determined by physical properties:

• **Reflectance:** The material's ability to reflect light, affecting brightness and color. For example, metals have high reflectance, while fabrics have low reflectance.

• **Roughness:** The microscopic roughness of the material surface, affecting light scattering and reflection. Smooth surfaces (e.g., glass) have low roughness, while rough surfaces (e.g., wood) have high roughness.

• **Refraction and Transmission:** Transparent materials (e.g., glass, water) can refract and transmit light, creating complex lighting effects. Blender supports IOR (Index of Refraction) settings for precise simulation.

2.3.3 Rendering Engines

• **Cycles:** A path-tracing-based physical rendering engine capable of highly realistic lighting effects. Supports advanced features like global illumination (GI) and caustics, suitable for high-quality rendering.

• **Eevee:** A real-time rendering engine that allows for instant previews of lighting effects. While slightly less accurate than Cycles, its efficiency makes it ideal for rapid iteration and dynamic scene design.

2.3.4 Advantages of Lighting Simulation

• **Flexibility:** Supports various light sources and material properties, enabling flexible simulation of different lighting scenarios.

• **Realism:** The PBR-based system generates highly realistic lighting effects, meeting the needs of film, animation, and interior design.

• **Efficiency:** The dual-engine support of Cycles and Eevee balances rendering quality and speed, suitable for projects of varying scales.

3. Experimental Research Methodology

3.1 Role of HDRI Maps in Research

• **Simulating Natural Lighting:** HDRI maps provide realistic environmental lighting information, including sky, clouds, and sun position, making them ideal for simulating sunny conditions.

• **Time-series Lighting Changes:** By selecting HDRI maps for different times (e.g., morning, noon, evening), lighting changes throughout the day can be simulated.

• **Enhancing Realism:** HDRI maps generate soft shadows, improving the realism of rendered results.

3.2 Experimental Design

This study constructs a simplified 3D bedroom model in Blender to simulate real indoor lighting conditions. The experimental setup includes three light source types: World Light, Sun Light, and two Point Lights. The World Light uses a set of HDRI maps for sunny conditions (covering morning, noon, and evening), the Sun Light simulates natural lighting, and the two Point Lights simulate common artificial lighting in bedrooms (e.g., desk lamps and bedside lamps). This setup allows the experimental environment to realistically reflect lighting characteristics at different times, providing a reliable foundation for time-series lighting experiments.

3.3 Experimental Records

Table 1. Experimental Record Table

		Light Source Parameters					Light and Shadow Observation and Recording Indicators	
Time	Light Source Type	Color	Intensity	Color Temperature	Color Temperature	Attenuation Range	Attenuation Range	Notes
Morning	Worldlight	Morning HDRI Map	0.25	None	None	None	4.23(182l×/431x)	In the construction of the experimental scene, the 3D model of the room establishes a coordinate system with the direction from the door to the large window as the positive X-axis direction. To ensure the accuracy of the light simulation, each HDRI map has been precisely rotated according to the actual light direction to match the natural light conditions at different times of the day.In the calculation of light contrast, the illuminance data for the bright and dark areas are selected from measurements on the ground or the upper surface of objects to ensure data accuracy and consistency, while effectively excluding interference from other irrelevant factors.
	Sunlight	#FFFFFF	0.5	3000K	(-2,-8,4)	None		
	Desk Point Light			None				
	Bedside Point Light		10W	1500K	None	3.5m		
Noon	Worldlight	Noon HDRI Map	0.5	None	None	None	5.93(724lx/122lx)	
	Sunlight	#FFD797	5	5500K	(-2,-1,4)	None		
	Desk Point Light			None				
	Bedside Point Light			None				
Evening	Worldlight	Sunset HDRI Map	0.1	None	None	None	4.34(2521x/58lx)	
	Sunlight	#FFCD98	5	4000K	(-4,8,-2)	None		
	Desk Point Light	#FFCD98	10W	5500K	None	2m		
	Bedside Point Light	None						
Night	Worldlight	Night HDRI Map	0.01	None	None	None	16.58(431x/26lx)	
	Sunlight	#FAFBFF	1	2000K	(-4,0,-2)	None		
	Desk Point Light	#FFE6BD	20W	3000K	None	5m		
	Bedside Point Light	#FFE6B8	20W	3000K		3m		

3.3.1 Morning

(1) **Light Source Configuration:**

o World Light: Morning HDRI map (source: https://polyhaven.com/a/goegap_road), intensity 0.25, no color temperature or falloff settings.

o Sun Light: Pure white (#FFFFFF), intensity 0.5, color temperature 3000K, incident angle (-2, -8, 4).

o Artificial Light: Bedside Point Light (10W, 1500K, falloff 3.5m); desk lamp not enabled. As shown in Table 1.

(2) **Lighting Effects:**

o Lighting contrast: 4.23 (brightest area 182 lx, darkest area 43 lx).

(Light contrast is defined as the ratio of illumination (lx) of the brightest region to the darkest region, quantifying the uniformity of light distribution.)

o Note: HDRI map adjusted for actual lighting direction; ground and object surface data ensure measurement consistency.

(3) **Experimental Conclusion:** Morning lighting shows slightly higher contrast (4.23) due to slanted sunlight, but remains within the natural lighting advantage range (4.23–5.93). As shown in Figure 1.

Figure 1. Early Morning Indoor Rendering Results Display

3.3.2 Noon

(1) **Light Source Configuration:**

o World Light: Noon HDRI map (source: https://polyhaven.com/a/qwantani_moon_noon), intensity 0.5, no color temperature or falloff settings.

o Sun Light: Warm white (#FFD797), intensity 5, color temperature 5500K, incident angle (-2, -1, 4).

o Artificial Light: Desk and bedside lamps not enabled.

(2) **Lighting Effects:**

o Lighting contrast: 5.93 (brightest area 724 lx, darkest area 122 lx).

(3) **Experimental Conclusion:** Due to the concentration of light intensity, the contrast ratio of 5.93 is higher than that of the morning (4.23), which cannot achieve the best uniformity. As shown in Figure 2.

3.3.3 Evening

(1) **Light Source Configuration:**

o World Light: Sunset HDRI map (source: https://polyhaven.com/a/qwantani_sunset), intensity 0.1, no color temperature or falloff settings.

o Sun Light: Light pink (#FFCD98), intensity 5, color temperature 4000K, incident angle (-4, 8, -2).

o Artificial Light: Desk lamp enabled (#FFCD98, 10W, 5500K, falloff 2m); bedside lamp not enabled.

(2) **Lighting Effects:**

o Lighting contrast: 4.34 (brightest area 252 lx, darkest area 58 lx).

(3) **Experimental Conclusion:** Evening lighting shows slightly higher contrast (4.34) due to slanted sunlight and warm tones (4000K), with artificial light supplementing local lighting without significantly affecting global contrast. As shown in Figure 3.

Figure 2. Noon Indoor Rendering Results Display

Figure 3. Evening Indoor Rendering Results Display

3.3.4 Night

(1) **Light Source Configuration:**

o World Light: Night HDRI map (source: https://polyhaven.com/a/qwantani_night), intensity 0.01, no color temperature or falloff settings.

o Artificial Light: Desk lamp (#FFE6BD, 20W, 3000K, falloff 5m); bedside lamp (#FFE6B8, 20W, 3000K, falloff 3m).

(2) **Lighting Effects:**

o Lighting contrast: 16.58 (brightest area 431 lx, darkest area 26 lx).

(3) **Experimental Conclusion:** Night lighting relies on artificial light, with significant contrast (16.6) due to localized bright spots and dark areas, indicating a need for optimized light distribution or indirect lighting to improve visual comfort. As shown in Figure 4.

Figure 4. Night Indoor Rendering Results Display

3.4 Experimental Results and Analysis

This study quantifies the lighting contrast at different times, revealing the distribution patterns of natural and artificial lighting. The results validate the uniformity advantage of natural lighting and highlight the need to optimize artificial light distribution to reduce contrast. Future research could combine material reflection properties and dynamic lighting strategies to further enhance the spatiotemporal adaptability of indoor lighting.

4. Discussion

4.1 Time-series Lighting Differences

(1) **Light Intensity Gradient:** Experimental data shows that noon illuminance (700 lx) is approximately three times that of morning (180 lx), indicating significant changes in natural lighting intensity over time. This gradient necessitates dynamic lighting adjustments, such as low-intensity supplemental lighting in the morning and reduced lighting at noon to avoid over-illumination.

(2) **Color Temperature Adaptation:** Experimental results show that warm light (<3500K) performs better in evening and night scenes, creating a cozy and comfortable visual atmosphere. Future research could further quantify the relationship between color temperature and psychological perception.

4.2 Material and Lighting Synergy Optimization

(1) **Light-absorbing Materials:** Materials like cotton and linen perform well in low-light scenarios (e.g., morning, night), reducing light reflection waste and creating soft shadows. Future research could explore more light-absorbing materials (e.g., velvet, matte paint).

(2) **Reflective Materials:** High-reflectance materials (e.g., glass, glossy finishes) require anti-glare designs in high-light scenarios (e.g., noon). Future research could combine material reflectance and light source parameters to propose systematic anti-glare strategies.

4.3 Applications and Limitations

(1) **Applications:** The time-series lighting simulation method can be widely applied in film, animation, and game development. It can also support intelligent lighting systems in interior design, enabling automated and personalized lighting control.

(2) **Limitations:** This study does not consider complex weather conditions (e.g., cloudy, rainy), which may affect the accuracy of simulation results. Future research could expand weather variables and diversify experimental scenes to improve the universality of findings.

5. Conclusions and Future Work

5.1 Research Conclusions

(1) The time-series lighting method based on Blender effectively simulates the changing patterns of natural lighting in sunny indoor bedrooms.

(2) The synergy between material properties and lighting parameters significantly enhances visual comfort.

5.2 Future Work

(1) Extend the study to complex weather conditions (e.g., cloudy, rainy, snowy).

(2) Combine machine learning to optimize Blender's lighting parameter generation.

(3) Explore the synergy between lighting and other environmental factors (e.g., temperature,

humidity).

(4) Validate the findings in diverse scenarios (e.g., living rooms, offices, classrooms) to improve universality.

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