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AN ARTIFICIAL SUN FOR BUILDING SYSTEMS RESEARCH

Summary

To address the particular challenges of testing full-scale prototypes and products under global climates in building systems research, a novel Artificial Sun has been developed. A 3.5 m by 2.5 m array of LED sources with attached CPCs produces an irradiance of $\geq 1100\,\mathrm{W\,m^{-2}}$ on the facade of a test chamber. Mounted on a rotating 90° arc-rail, the array can produce directional irradiance in the visible and near-infrared range of the solar spectrum from any direction above the horizon. By controlling the emitted power of three types of LEDs individually, the mixed spectrum can be tuned according to the emulated solar conditions. Systematic testing confirmed the high degree of collimation achieved by the CPCs and the stable provision of the specified irradiance over extended measurement periods. Initial experiments demonstrated applicability in building systems research, e.g., in solar-optical assessments of building envelopes and building-integrated photovoltaics. A current limitation is the spectral match in the near infrared, that may lead to a future modification.

Keywords: Solar simulator, building envelopes, full-scale testing, solar gains, daylight

Field of application for the findings: Development and testing of building systems

Addressed audience: Building scientists, facade industry, architects and engineers

1. Introduction

Response to solar radiation is one key aspect in the design of innovative building systems, aiming for reduced operational energy demand, high occupant satisfaction, and the utilisation of renewable energy sources. The development of novel concepts for such systems and their components into applicable solutions, as well as the planning with existing products under different current and future climates, relies on the thorough testing of prototypes. This imposes particular challenges, i.e., the typical dimensions of full-scale prototypes in building systems research, the wide range of boundary conditions that may significantly diverge from what is specified by standards and norms (Zhang et al., 2025), and the complex interaction with other components of building systems as well as occupants.

A reconfigurable test chamber, equipped with typical state-of-the art systems for heating, cooling, and lighting and with one wall exposed to an artificial climate, was set up to allow for testing under realistic conditions. The artificial climate is controlled in terms of air temperature, humidity, and solar irradiance. The latter is implemented by an Artificial Sun, i.e., a solar simulator that can produce dynamic sunlight conditions in terms of geometry (directionality and incident direction), spectral composition (ratio of infrared and visible light, correlated colour temperature of the latter), and uniform irradiance on the exposed wall of the test chamber (up to $1200\,\mathrm{W\,m^{-2}}$).

2. Design and implementation of the Artificial Sun

The aim to produce irradiance from any incident direction above the horizon and of variable spectral composition led to an early decision for a LED-based design. In contrast to, e.g., Xenon arc-lamps, LEDs enable stable operation during movement and rotation (Tawfik et al., 2018). The combination of LEDs featuring different peak wavelengths allows to tune the emitted spectral composition (Watjanatepin et al., 2023). Other than in illuminators aiming for optimum spectral match and coverage, that can employ dozens of individually controlled spectral channels, a design employing only three types of LEDs was chosen to meet the irradiance requirement on a large area and to limit the complexity of the control system. The phosphor-converted LEDs were selected for emission in wide wavelength ranges in the visible (warm-white and cold-white) and near infrared spectrum.

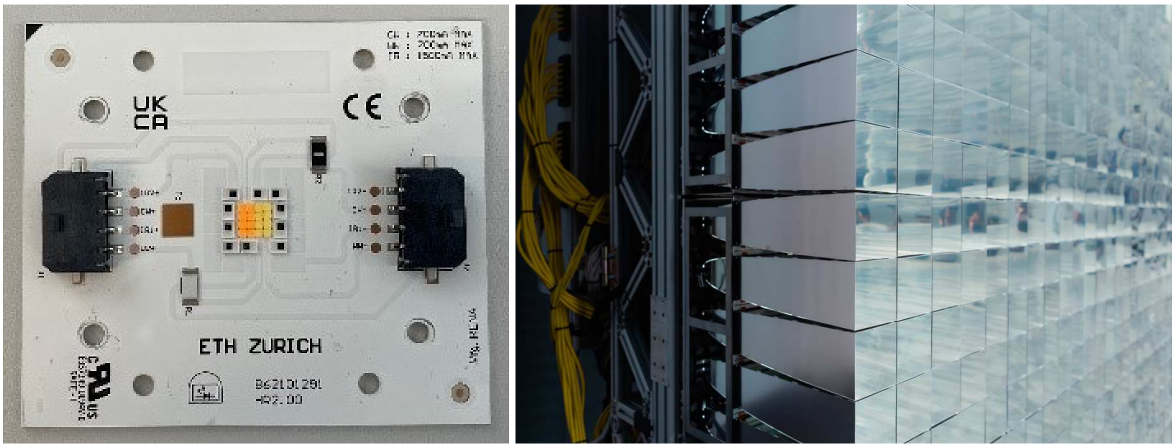

Fig. 1: Left: PCB with 26 LEDs in its centre, emitting in the visible (cold and warm white) and near infrared ranges. Right: Array of C-CPCs with attached PCBs forming the illuminator of the Artificial Sun (image courtesy Girts Apskalns).

The emission of groups of 26 LEDs, that share one PCB, is mixed and collimated by an attached Crossed Compound Parabolic Concentrator (C-CPC) (Sellami and Mallick, 2013) and forms one unit. In total, 875 of such units are assembled in a source array (Figure 1, right) that is attached to a 90 degrees arc-rail to form the Artificial Sun (Figure 2).

3. Testing and first applications of the Artificial Sun

To test the absolute irradiance, its spectral composition, and its distribution, a reflective target was installed between the illuminator and the test chamber (Figure 2). Pyranometer measurements confirmed that the illuminator outperformed the target irradiance of $\geq 1100\,\mathrm{W\,m^{-2}}$ during stable operation over extended periods, and allowed to calibrate image-based irradiance maps on the target for the subsequent characterization of the spatial distribution and uniformity of the irradiance, as well as the collimation achieved by the C-CPCs. Spectrophotometric measurements monitored the spectral composition for different combinations of set points controlling each LED channel.

After the confirmation of the stable operation of the Artificial Sun, first experiments demonstrated the applicability of the setup. An experimental study on outward-effects of solar irradiation on Building-Integrated Photovoltaics (BIPV) was conducted employing the Artificial Sun and the controlled thermal environment of the emulated climate. A second study included the test chamber to assess the solar-optical properties of 3D-printed facades (Piccioni et al., 2024). Finally, the Artificial Sun has been employed as a source for calorimetric measurements on building components.

4. Conclusions, future applications and modifications

While the expansion of the laboratory's capabilities and in particular the tuning of the Artificial Sun are ongoing, it has already become a central infrastructure for building systems research. After an initial focus on the thermal effects of solar irradiation, the application of the laboratory in daylight research, including subject studies, are envisioned.

Besides purely academic research, the laboratory offers unique opportunities for research and development collaborations that go beyond small-scale experiments. The current configuration in particular lends itself for the accelerated testing of full-scale components of building envelopes under controlled conditions, that would required extended measurement periods to arrive at representative results under outdoor conditions.

Despite the demonstrated applicability of the Artificial Sun to building systems research, limitations that mostly result from deliberate design decisions are addressed by the development of possible future enhancements. One example is the spectral mismatch in the infrared, that was accepted to improve the efficiency of the illuminator and to reduce complexity but is problematic in BIPV research and could be addressed by small changes within the design.

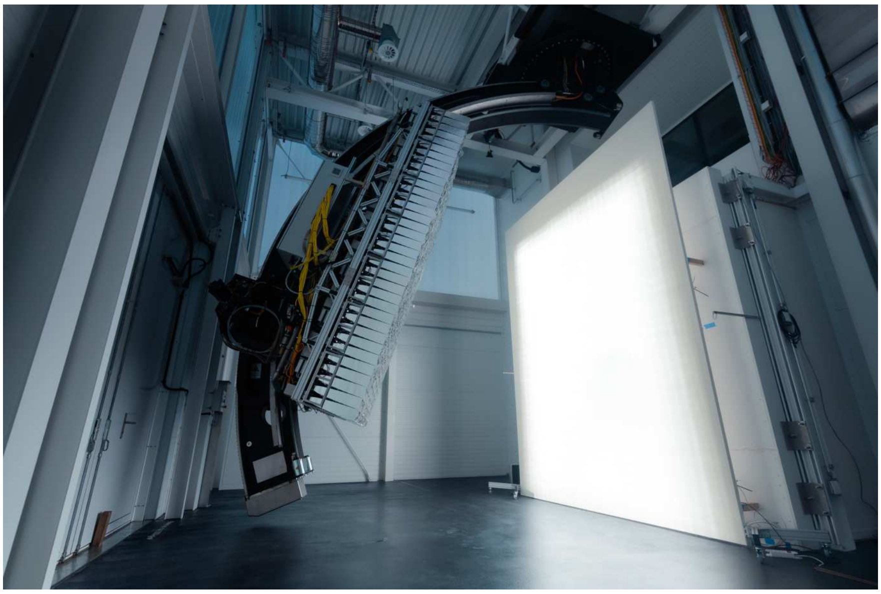

Fig. 2: The artificial sun, comprising the illuminator mounted on a rotating 90 degrees arc-rail, illuminates a screen in front of the test chamber during testing (image courtesy Girts Apskalns).

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