Synlight - A new Facility for Large-Scale Testing in CSP and Solar Chemistry

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Abstract. As of now the worldwide solar research community has a unique new tool: Synlight is a high-flux solar simulator of a new performance category. It bridges the gap between laboratory scale tests and demonstration, and offers large-scale testing opportunities for up to three independently operating test campaigns. Following the commissioning and opening in March, 2017, the facility has been validated recently. The gained results met or exceeded the expectations from simulation and prototype. In particular, solar radiation powers of up to 310kW with a simultaneous peak flux of 12.5MW/m² could be measured.

MOTIVATION, DESIGN AND CONSTRUCTION

High-flux solar simulators (HFSS) are able to provide consistent and reproducible solar radiation without timely or weather limitations and at low cost. These benefits have made such test facilities to more and more important development tools in CSP and solar chemistry. In the recent years, a large number of HFSS have been erected, mainly with solar radiation powers of 10 to 20kW.

The further development steps of CSP receivers or solar chemical reactors etc., meaningful industrial scale demo applications in solar plants, require typically solar power on a megawatt level and thus a scaling factor of about 100. Therefore, the main motivation for Synlight was to bridge this gap between the laboratory and the full-scale demonstration. Target was a HFSS with a solar power of 200kW, two or three separate test chambers and greatest possible flexibility. The project started in mid-2014 with a simultaneous development of the facility and a special building for it. Valuable operational experience could be used from DLR's 20kW-HFSS [1].

The created and patented (pending) design is strictly modular and consists of 149 equal units. Each module has a three-axially movable reflector with a Xenon short-arc lamp. The reflectors have an ellipsoidal shape with a focal length of 8m. The entire facility is PLC controlled.

Three test chambers are located in opposite of the radiators. They have 4m x 4m large, light and heat proof rolling shatters and a surveillance system with several cameras. The test chambers share the light from the modules which mostly can be directed into two or three of them. This gives a greatest possible flexibility and enables an independent operation of the test chambers. Further, each of them has an own separate control room with exclusive access of the measured data and the respective cameras. Thus, Synlight can be used by up to three independently working test campaigns at the same time.

A rail system inside the building connects the test chambers with the experiment preparation workshop in the ground floor. Manually moveable trolleys enable transport and positioning of test setups up to 2.500kg weight and 2m x 2m x 2m size in an easy and elegant manner. They should be sufficient for the vast majority of experiments.

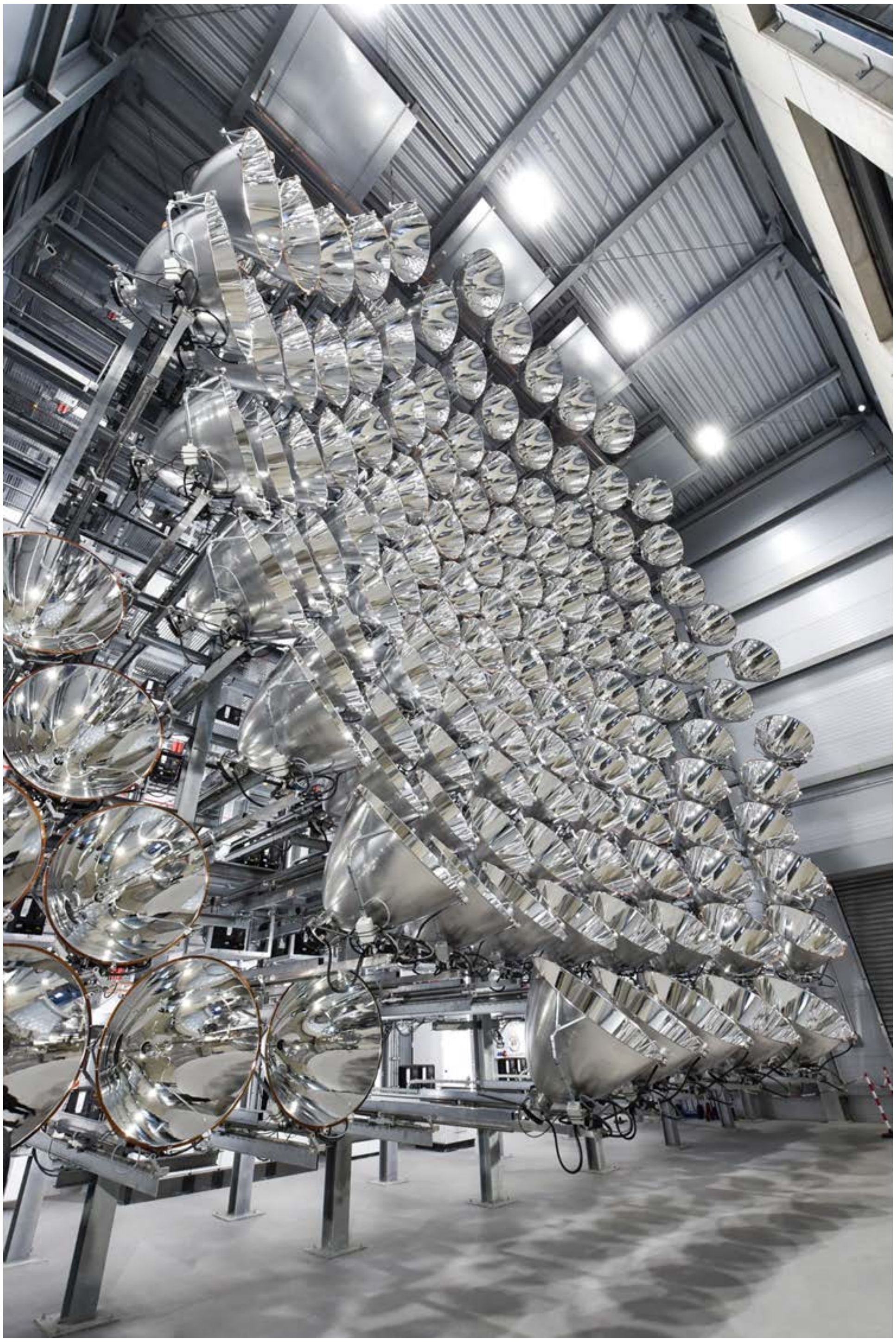


FIGURE 1. Synlight with 121 modules focused on one spot

Synlight can operate with different types of Xenon lamps up to $10kW_{el}$ which means a connected DC load of about $1.5MW_{el}$. The total power demand, including cooling and other devices, is covered by own transformers with a total capacity of 2MVA. The initial equipment uses $7kW_{el}$ lamps, as they are current standard for large cinemas and provide the lowest costs of light. About one third of these lamps emit a higher share of UV light. $10kW_{el}$ lamps have been tested successfully on single modules and can be used for retrofitting at maximum power requirements.

The design concept as well as nearly all EPC work of the facility was done by DLR staff. This enabled a cost-effective design, global sourcing, transparent cost control and finally a larger facility than originally planned. Further information on Synlight's design and its realization is available from earlier conference papers [2] and [3].

Less than 3 years after the project start, Synlight was inaugurated on March 23, 2017. The event and the extraordinary new facility attracted a great attention from the international media. The completed facility is shown in Fig. 1; Fig. 2 depicts a view from a test chamber.

FIGURE 2. A small hydrogen reactor on a trolley in Synlight's central test chamber

COMMISSIONING AND RESULTS OF THE VALIDATION

During the following commissioning phase the number of involved modules was gradually increased. The radiation powers and densities in the three test chambers were regularly verified by using DLRs optical measurement system FMAS [4].

As the test chambers share the radiator resources, their performance parameters are location-dependent. Reference points in each chamber were defined to characterize these parameters for a point-focused irradiation. 121 of the 149 modules can be directed to the reference point of the central test chamber 2. The corresponding module orientation is then as shown in Fig. 1. The reference points of the side chambers 1 and 3 can be reached by 96 modules respectively. The maximum rim angle in all reference points is 48.8°.

The following Fig. 3 to 5 are screenshots from FMAS, showing the measured powers and flux densities on the reference points of the three test chambers. The radiant powers were determined on reference planes of 55cm x 55cm which seems to be representative for the scale of the anticipated test specimen. The gained values show a remarkable fit with the previous expectations of 300kW_{rad} and 240kW_{rad} gained from simulations and the module prototype which were published in [3]. The radiant power in the central test chamber exceeds its expectation slightly.

The peak flux targets of 11MW/m² and 8MW/m², published in [3], were exceeded in all cases.

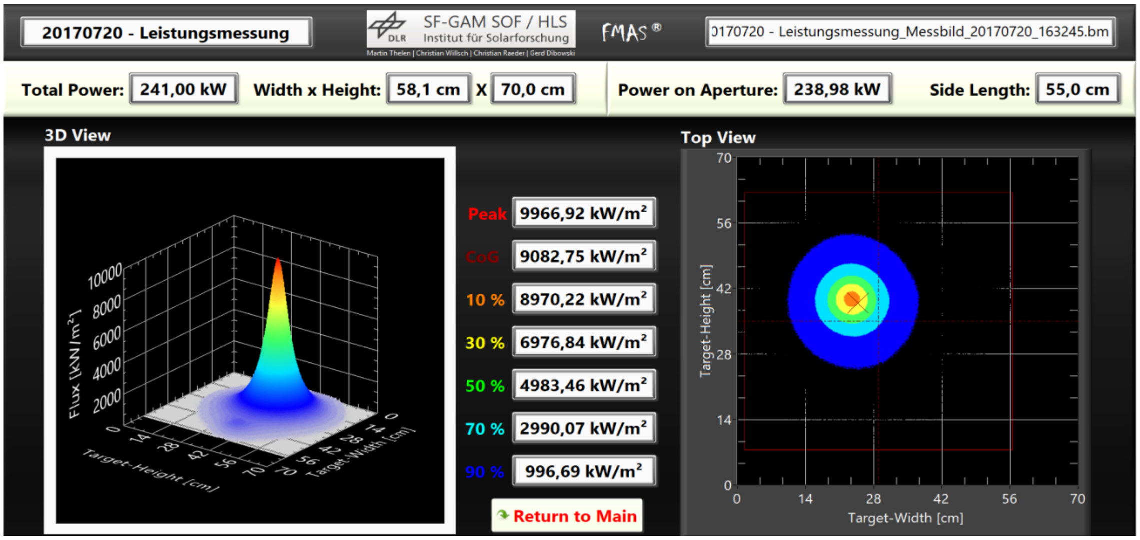


FIGURE 3. Measured radiation and flux distribution on the reference point in test chamber 1

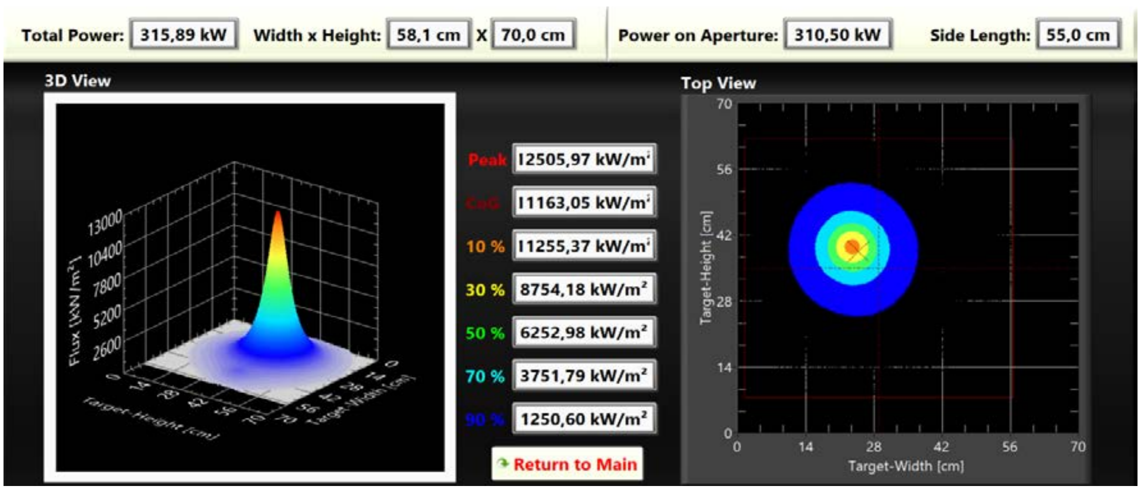


FIGURE 4. Measured radiation and flux distribution on the reference point in test chamber 2

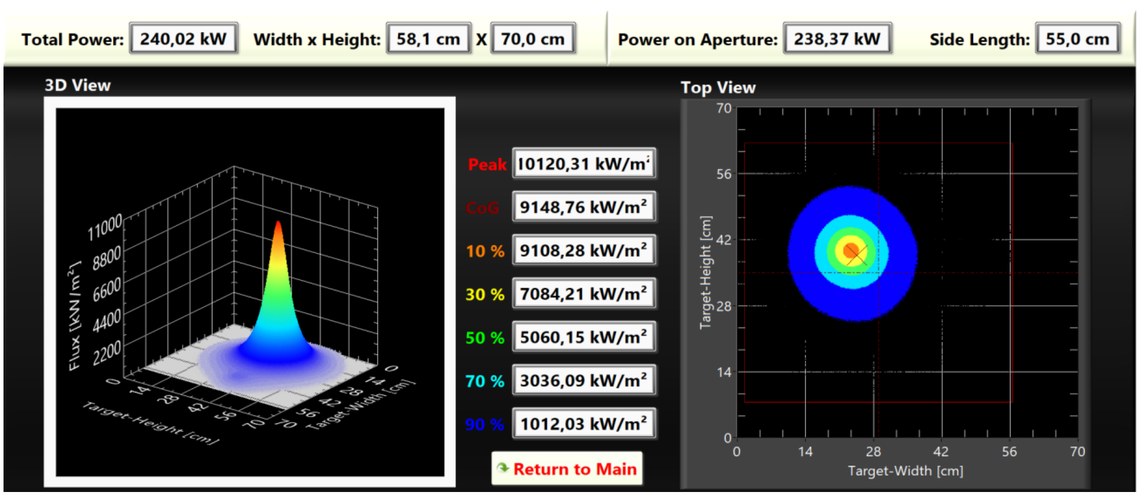
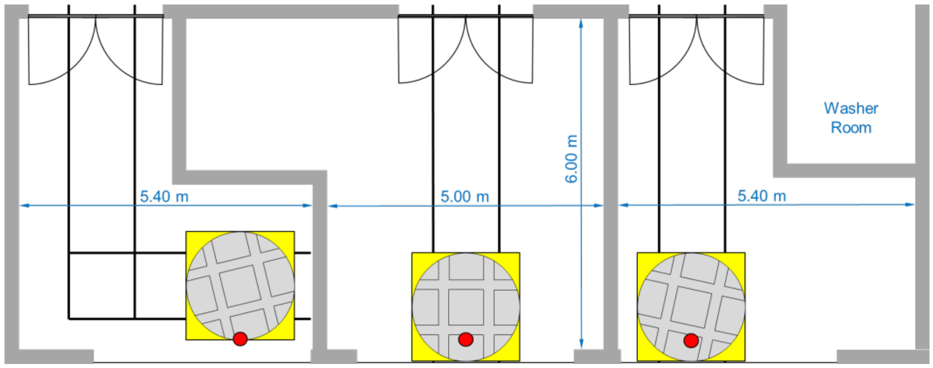


FIGURE 5. Measured radiation and flux distribution on the reference point in test chamber 3

TESTING OPPORTUNITIES

A summary over the measured performance data (in rounded form) and the other technical parameters of the test chambers as well as a floor plan are given in Table 1. The red dots in the floor plan indicate the reference points. The rails and typical positions of the trolleys are drawn as well.

TABLE 1. Floor plan and parameters of the three test platforms

	Test Chamber 1	**Test Chamber 2**	**Test Chamber 3**
Floor plan			
# of Xenon lamps to be focused on reference point	96	121	96
Max. solar radiation power with $7kW_{el}$ standard lamps	$240kW_{rad}$	$310kW_{rad}$	$240kW_{rad}$
Expected max. radiation power with $10kW_{el}$ lamps	$320kW_{rad}$	$400kW_{rad}$	$320kW_{rad}$
Peak flux with $7kW_{el}$ standard lamps	10.0MW/m²	12.5MW/m²	10.0MW/m²
Maximum aperture size of a test object	4m x 4m[1]	4m x 4m[1]	4m x 4m[1]
Maximum weight of a test object	4,000kg[1]	6,000kg[1]	4,000kg[1]
Test chamber dimension	25m² x 4.5m	38m² x 4.5m	26m² x 4.5m
Special feature	High UV proportion	Connection to washer room for solar chemical applications	

[1] Single objects up to 2,500kg and 2m x 2m x 2m can be transported by and positioned on the trolleys

Every chamber has an ventilation air flow of up to 5m³/s, providing cooling and explosion protection. Water is available up to 100 liters/min per chamber. Furthermore, all chambers have AC power supplies of 400V/63A, 400V/32A and 230V/16A as well as 1Gbit/s Ethernet connections to the corresponding control room.

Synlight can thus offer a new quality of testing and qualification of critical CSP components and solar chemical processes. Their scaling risks towards large demo or commercial plants can be reduced significantly. Their time to market should reduce significantly.

Further applications might be UV aging tests of large components for use in desert conditions or use cases with extreme temperature requirements.

An overview on all known HFSS with at least 10kW of solar radiation power is given in Tab. 2. The data are collected from the most recent literature and to the author's best knowledge. As mentioned above, most of these facilities were commissioned in the recent years. All of them use Xenon lamps with exception of Swinburne University whose metal halide lamps which provide a lower flux density.

TABLE 2. Globally known and operating HFSS with point-focusing solar radiant powers ≥10kW ([3], updated)

Operator and facility	Commis-sioning	Electric Power [# x kW]	Type of Lamps	Solar Power [kW]	Peak Flux [MW/m²]
DLR, Synlight, Jülich	2017	149 x 7 (149 x 10*)	Xe	310 (400*) 240 (320*) 240 (320*)	12.5 10.0 10.0
PSI, Zürich [5]	2005	10 x 15	Xe	50	11.0
Niigata University [6]	2013	19 x 5	Xe	30	3.2
Aristotle Univ., Thessaloniki [7]	2013	11 x 6	Xe	20	4.8
DLR, HLS, Cologne [1]	2007	10 x 6	Xe	20	4.2
North China El. P. Univ., Beijing [8]	2015	7 x 10	Xe	20	4.0
KTH Stockholm, Solar Lab [9]	2014	12 x 7	Xe	19.7	6.7
University of Florida [10]	2011	7 x 6	Xe	14	4.2
IMDEA, Madrid [11]	2013	7 x 6	Xe	14	3.6
Swinburne Univ., Melbourne [12]	2015	7 x 6	MH	12	0.9
EPFL, LRESE, Lausanne [13]	2015	18 x 2.5	Xe	11.3	21.7
Australian Nat. Univ., Canberra [14]	2015	18 x 2.5	Xe	10.6	9.5
Univ. of Colorado, Boulder [15]	2016	18 x 2.5	Xe	10*	*

* Design values, not yet been demonstrated / published

Even if the solar power data was measured on various reference planes and include more or less of scatted light, the overview outlines the special position of Synlight. The solar power which is available in its smaller side chambers is equivalent to the cumulated powers of the other listed facilities. And further upgrades with $10kW_{el}$ lamps will be possible on demand.

The authors hope that Synlight can make an important contribution to the development of the concentrated solar technologies in the coming years.

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