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Design of a Novel Heliostat for a Large-Scale Desalination System

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Abstract. The optical design and the mechanical structure of a new heliostat is described for application in the Solar Water plc large-scale desalination plant, to be constructed in the Middle East. The heliostat field is required to reflect direct solar radiation onto a section of the desalination dome, requiring the design of a new type of heliostat. A novel dual-tilted dual-axis tracking heliostat is the design selected to meet the optical requirements specification. The supporting structure also requires a unique approach, which we describe in this paper. The optical and mechanical analysis of the heliostat and its operation are also presented

Keywords: CSP, Desalination, Heliostat

1. Introduction

We describe the design of a novel dual-tilted 2-axis tracking heliostat, to be used in conjunction with a parabolic trough or dish concentrator solar field for large-scale thermal desalination systems. The research has been carried out in collaboration with the UK Company Solar Water plc [1], and our collaborative work on the wider desalination system has been described previously [2]. This latest work describes the modelling and design of a new heliostat to supplement the thermal input to the desalination “dome”. A significant proportion of the energy is supplied for desalination is supplied by an external solar field, which is not discussed here.

2. Desalination system design

The basic concept is shown schematically in Figure 1 below. The left image shows the large glass geodesic dome that forms the basis of the thermal desalination system. The thermal energy is provided by a standard CSP field (not shown), supplemented by an arc of heliostats which surround the dome, as shown in the central image. The right image shows the reflected rays that impinge on a “ribbon” absorbing section of the dome (shown in black for clarity)

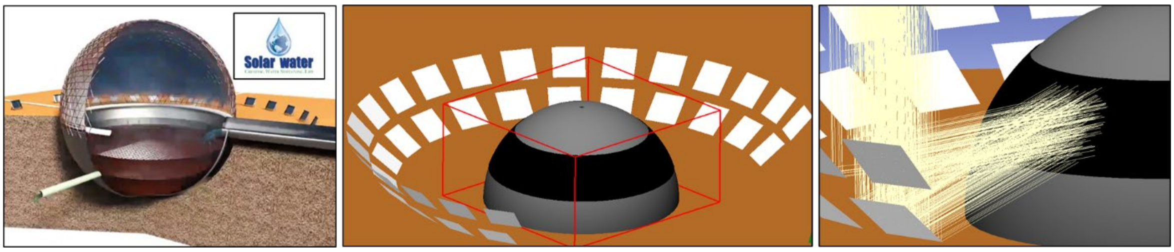

Figure 1. Basic concept for heliostat arc field - main CSP field not shown.

3. Optical system design

The heliostats are 25 m^2 of mirror area each with 4 tilted glass mirror facets creating a focussing effect at the radiator band. This focusses the light onto the band vertically, but not horizontally as the band is extended in that direction (see Figure 2). The number of heliostats is 17, split between inner and outer rows of 8 and 9 heliostats respectively. The radiator band extends from 225 to 113 degrees azimuth, covering a vertical height between 5.8 and 8.5 m from ground level. Ray tracing software Tonatiuh 2.2.4 was used to provide Monte Carlo ray tracing for the optical simulation of the heliostat field. PVGIS DNI data was used as an input to the simulation, which runs hourly for one day per month. Data is then interpolated to give annual outputs of incident energy on the dome. The incident radiation includes both that reflected by the heliostats and the radiation hitting the band directly from the sun. [PVGIS TMY data is downloaded from the online platform https://ec.europa.eu/jrc/en/pvgis]. The target power was adjusted to establish the monthly operational hours that are possible. Figure 3 below shows the expected operating hours for power production of 150, 170 and 190 kW. The system is defined as operating when the incident power from the heliostats exceeds the target value. Figure 3 shows that the system can operate for 6 hours per day for the whole year when the target power is set at 150 kW. During the months of September to March, 190 kW is exceeded for 4 hours per day.

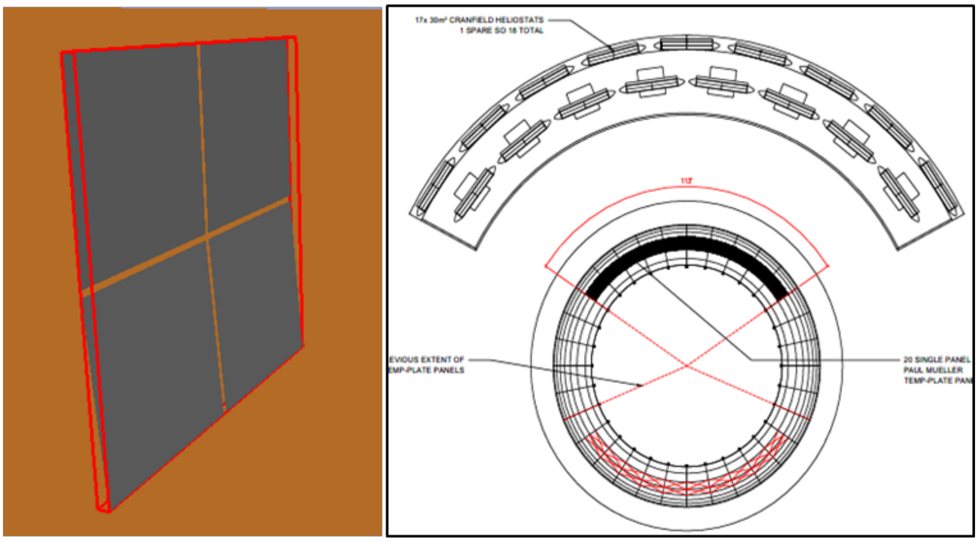

Figure 2. A single heliostat schematic (left) with an aerial view of the heliostat field (right).

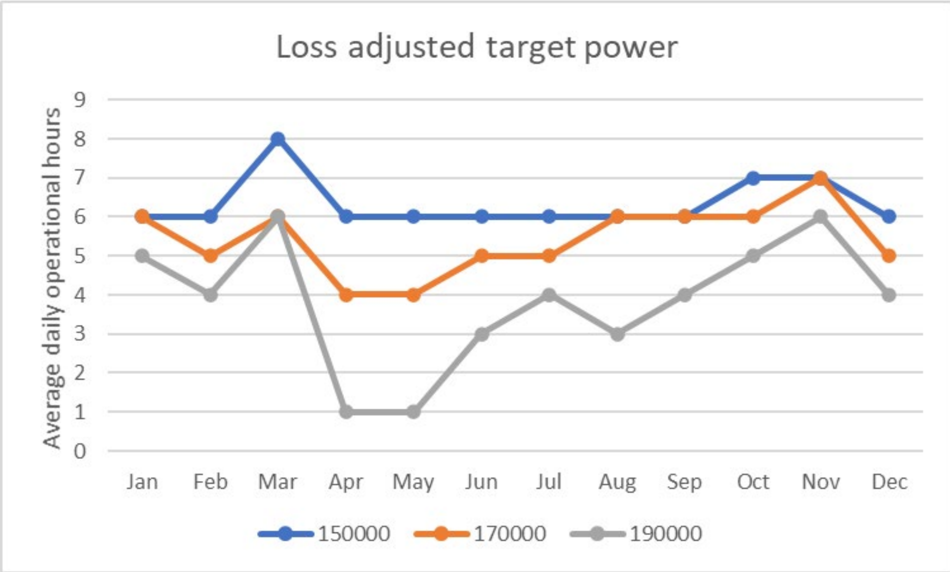

Figure 3. Expected Operating hours for the heliostat field.

4. Mechanical design

The heliostat is a composite design, shown top-level schematically in Figure 4 below. The base for the structure is provided by the dual-axis ST54M3S30 heliostat from SAT CONTROL of Slovenia [4]. This has been adapted to accept an intermediate frame, designed by the authors, which provides the dual-tilt geometry and supports the mirror facets that form the reflecting surface of the linear concentrator. The design enables the mirrors to be assembled, aligned and tested before being secured to the heliostat. The frame design uses existing attachment holes in the SAT CONTROL tracker eliminating the need for any modification. The glass mirror assembly is secured to the tracker frame using a system of bespoke brackets. The mirrors themselves are AGC-SunMax Premium Reflect 4 mm thick back-silvered glass facets [5], 4 per heliostat, with available mirror area per heliostat of 4 x 2850x2248 = 25.6 m^2. The mirror support frame is estimated to weigh 190 kg. With four mirrors having a mass of 252 kg, this gives a total weight on each heliostat tracker base of 442 kg.

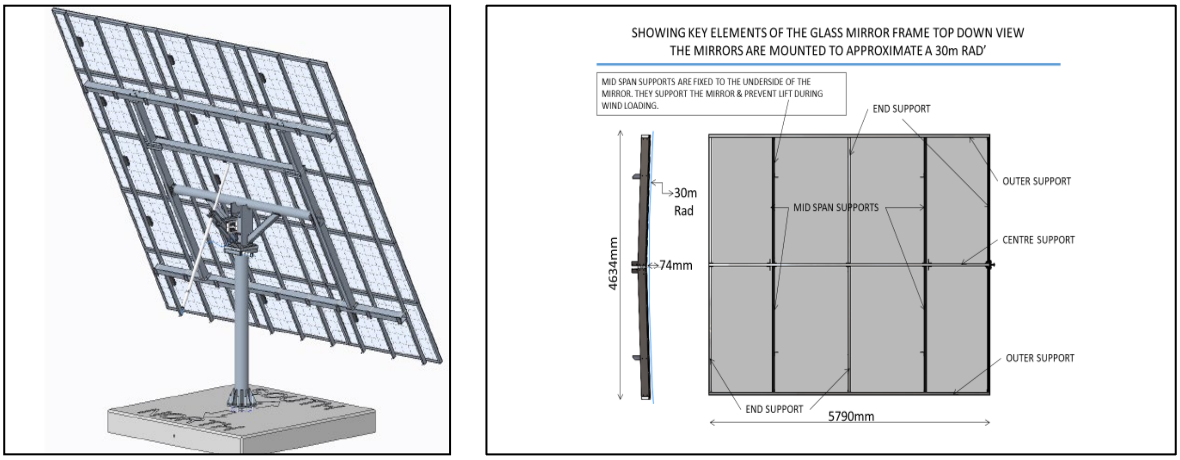

Figure 4. An overview of the structure of the novel heliostat and its constituent parts.

The intermediate frame is made from Aluminium box section extrusions and the mirror facets are held in place by a clamping system designed in the UK by The Standard Patent Glazing Company [6] and shown in Figure 5 below.

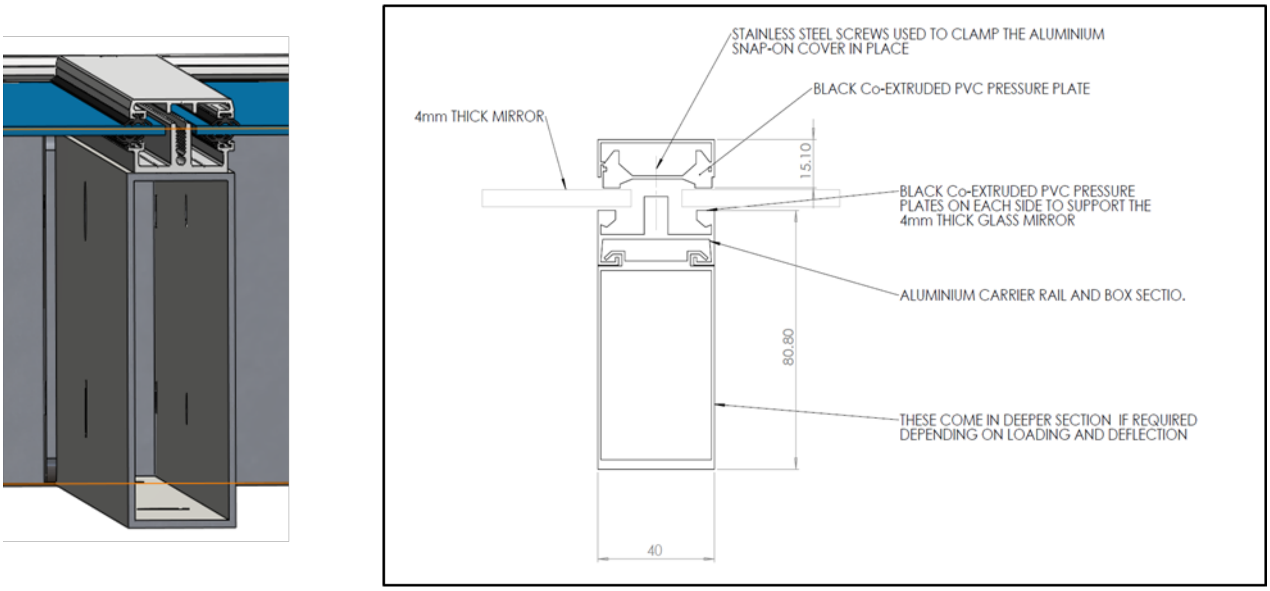

Figure 5. The glass heliostat mirror clamping system.

This system of clamping is designed to accommodate the differential material expansion rates between the Aluminum and glass that will occur due to local ambient conditions that can range between 12 and 43 °C. It should be noted the mirrors are mounted to achieve a nominal 30 m radius to project the reflected rays to the thermal “ribbon” absorbing section of the dome. Alignment of the mirror array is critical for the efficiency of the system and deflection of the individual mirrors must be kept to a minimum to ensure optimum beam alignment. SolidWorks software has been used for the mechanical design including stress analysis of the structure and mirror for safe operation under predicted operational conditions. Design simulations for mirror deflection were conducted and indicated that the initial edge support design required an additional centre support to bring the deflection to within design specification. In addition to gravitational deflection, the mirror array will be subjected to wind loading on either side of the array. The mirror perimeter clamping system is designed for bidirectional pressures, however the centre support required bonding of the mirror. Drilling holes in the mirror for direct clamping was not an option. To achieve a design that allowed for ease of replacing mirrors in service, an intermediate clamping strip was bonded to the underside of the mirror which is then secured to the main frame. The simulations for mirror deflection due to gravitational loading confirms the need for a centre mirror support to reduce the centre deflection from 2 mm to 0.2 mm, as shown in Figure 6. Note that the mirror is only horizonal for maintenance or safety to reduce very high wind loading.

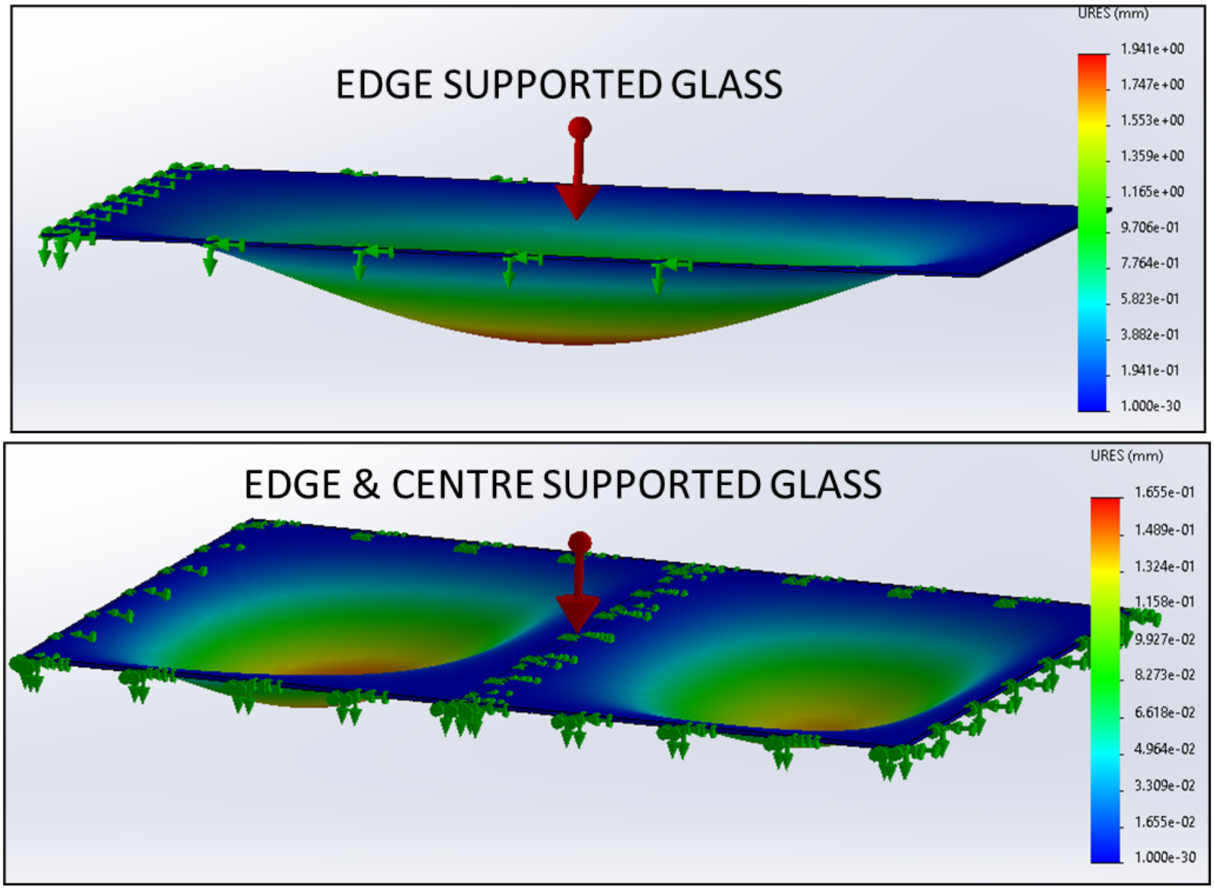

Figure 6. Deflection simulation results for 2850 X 2248 X 4mm glass mirror.

For the purpose of this design, the wind speeds are taken from https://weatherspark.com giving average weather in Riyadh, Saudi Arabia by way of an example location and are shown below in Figure 7. When the prevailing wind is stopped by a mirror, the dynamic energy in the wind is transformed to pressure. Using the higher average wind speed of 5 m/s from the chart, the resultant pressure acting on the surface can be calculated.

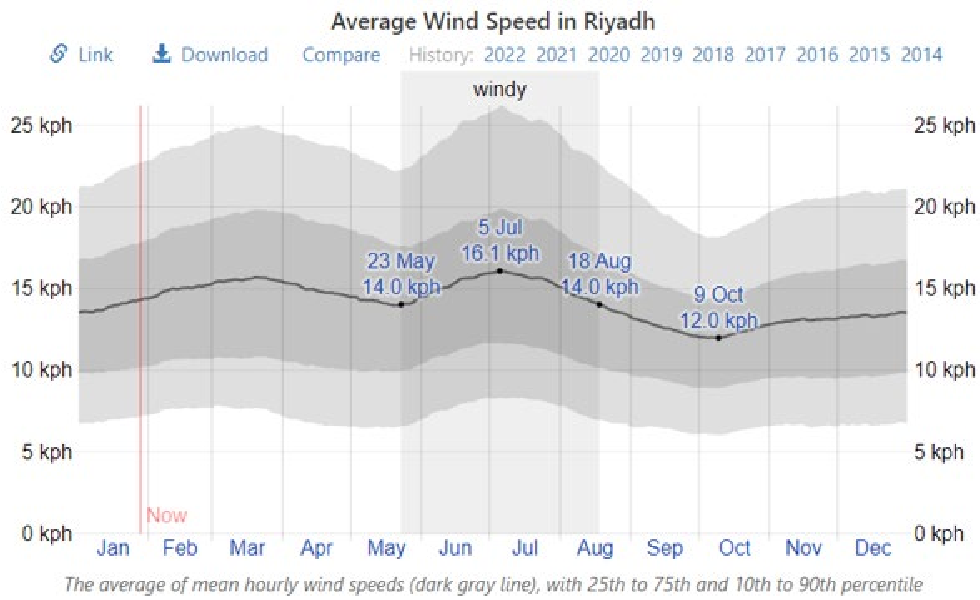

Figure 7. Average wind speeds at 10m above the ground in Riyadh.

The dynamic energy in the wind is transformed to pressure, Pd = ½ ρv2

Where

Pd = Dynamic pressure (N/m^2 (Pa))
ρ = Density of air (kg/m^3) = 1.2
V = Velocity (m/s) = 5

Hence Pd = 15 N/m^2

A dynamic pressure of 15 N/m2 results in a 0.02 mm maximum mirror deflection as shown in Figure 8 below. This ensures minimal deflection of the optical surface and therefore minimises optical losses.

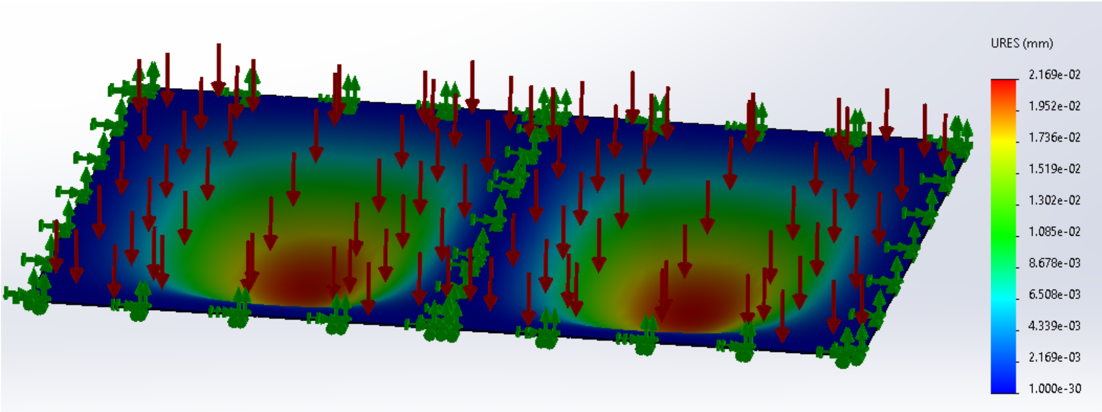

Figure 8. Wind load deflection simulation results for a dynamic wind pressure of 15 N/m^2.

Although the central mirror support is required for mechanical reasons, to reduce the centre deflection from 2 mm to 0.2 mm, it is also of interest to determine the impact of a 2mm centre deflection on the optical performance of the heliostat (this is a hypothetical “worst case” since the heliostat will never be operational in the horizontal position). To investigate this the 2mm centre deflection was simulated by replacing a flat facet with a spherical facet of 500m radius. The resultant performance graph is shown in Figure 9 and can be compared with the flat facet graph of Figure 3. In fact, the performance of the heliostat increases slightly when the deflection is added. Total annual working hours increases by 1.3% from 2313 to 2343 hrs and the total energy output increases by 1.7% from 578 to 588 MWh. This is an indication of the trade-off between the focussing advantage of the curved reflector and the simpler and lower cost design of the flat glass heliostat.

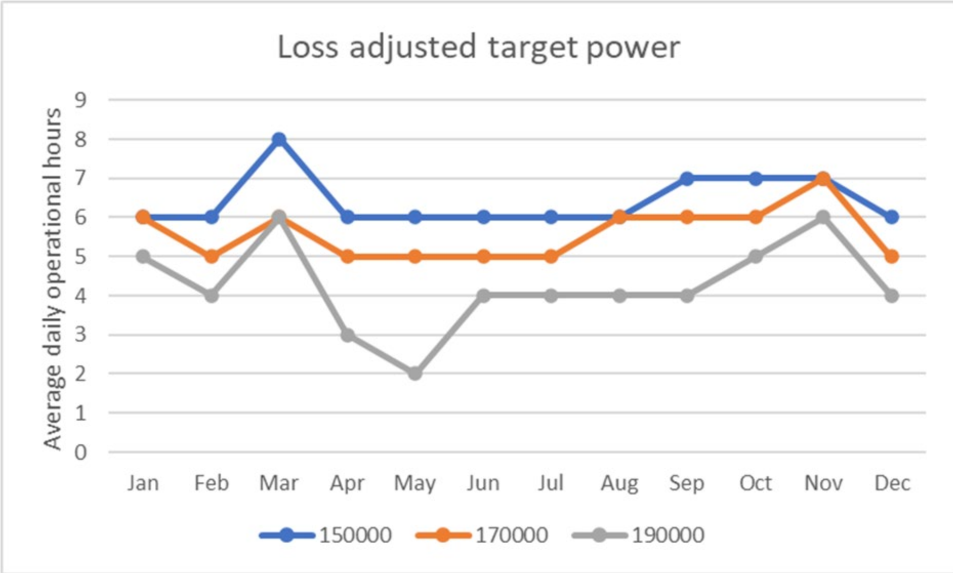

Figure 9. Expected Operating hours for the heliostat field (with a 2mm centre deflection).

5. Summary and Conclusions

In this work we explain the concept, modelling and detailed design (both optical and mechanical), components selection, and parts manufacture of a novel dual-tilt two-axis tracking heliostat for a large-scale desalination application Details of how to assemble the heliostat are also described. The heliostat has been designed for Solar Water plc large-scale desalination dome systems, where the radiation reflected from the heliostats is targeted at a “ribbon” around the circumference of the spherical dome surface. The optical and mechanical requirements have led to a unique design of heliostat with a correspondingly innovative supporting structure. Particular emphasis is given to ease of assembly and in-situ testing when designing the structural assembly. The performance of the heliostat is predicted for Riyadh in KSA, and its resistance under wind loading is also assessed. The heliostats are planned to be installed at a Solar Water plc desalination plant, currently at the advanced planning stage in KSA.

Author contributions

C Sansom was responsible for conceptualization, funding, resources, supervision, project administration, methodology, and writing the original draft. P King was responsible for conceptualization, data curation, formal analysis, investigation, optical analysis software, and validation. K Carlisle was responsible for conceptualization, data curation, formal analysis, investigation, drawings, mechanical analysis software, and validation,

Competing interests

The authors declare no competing interests.

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