Experimental study of a small Beam-Down and Direct-Down solar system for water preheating/desalination applications

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Objective

The objective of this study is to assess the feasibility of multiple direct solar configurations for small-scale water preheating and desalination through experimental analysis and complementing the results with a theoretical model.

Materials

Fig. 1 depicts the experimental setup used in the study, consisting of 11 heliostats arranged around a testing basin, a water level controller, and a central mirror for Beam-Down Concentration (BDC) testing.

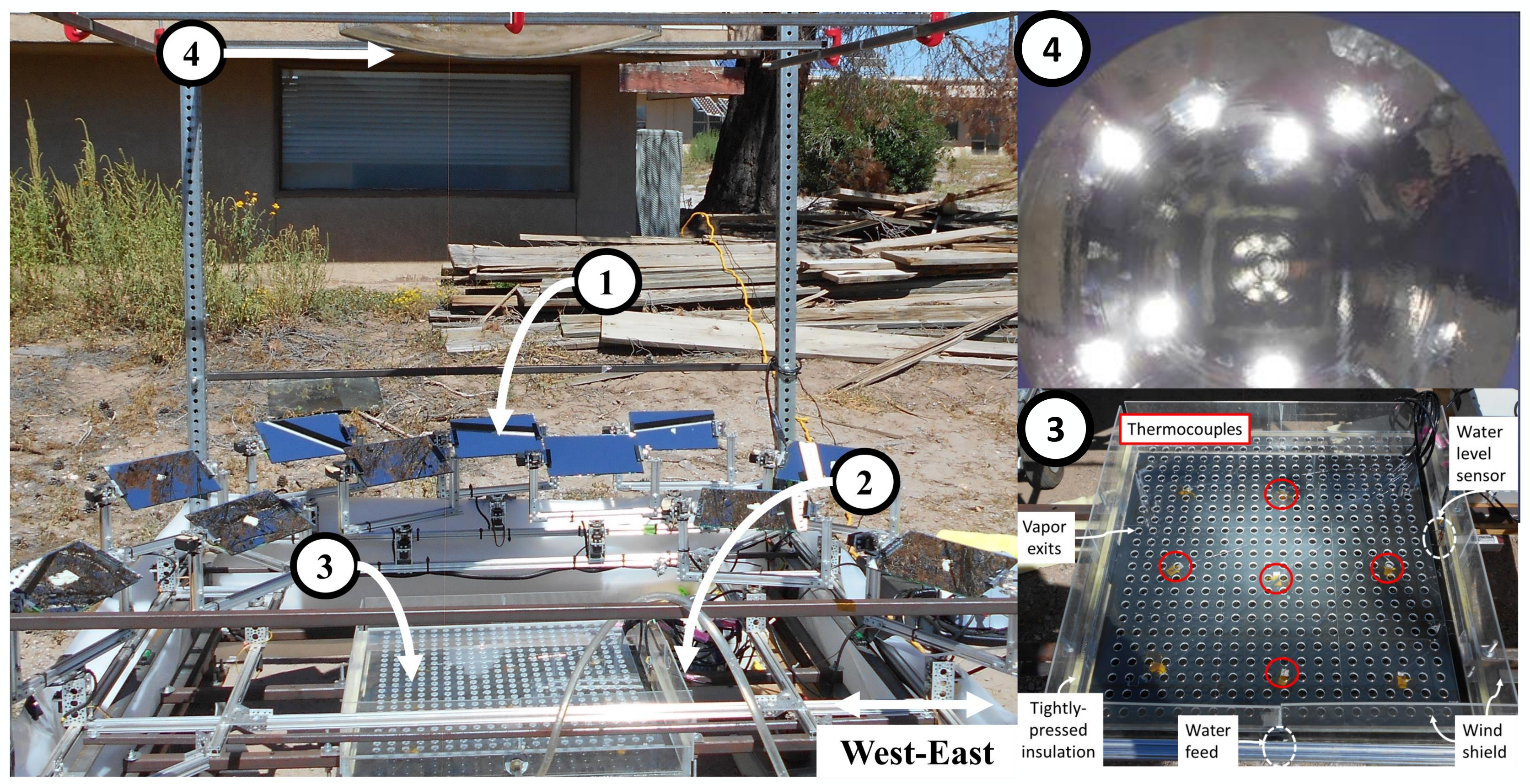

Figure 1. Main components of the experimental setup. 1) Heliostat field distribution, 2) Water level controller, 3) Polycarbonate basin and 4) circular hyperbolic central mirror (for the BDC configuration).

Methods

Three configurations were tested: baseline (BL), Direct-Down concentration (DDC), and Beam-Down solar concentrator (BDC), with the hybrid DDC + BDC configuration also explored. Additionally, an in-house model [1] was used to further analyze the DDC and BDC configurations based on cosine efficiency and solar irradiation.

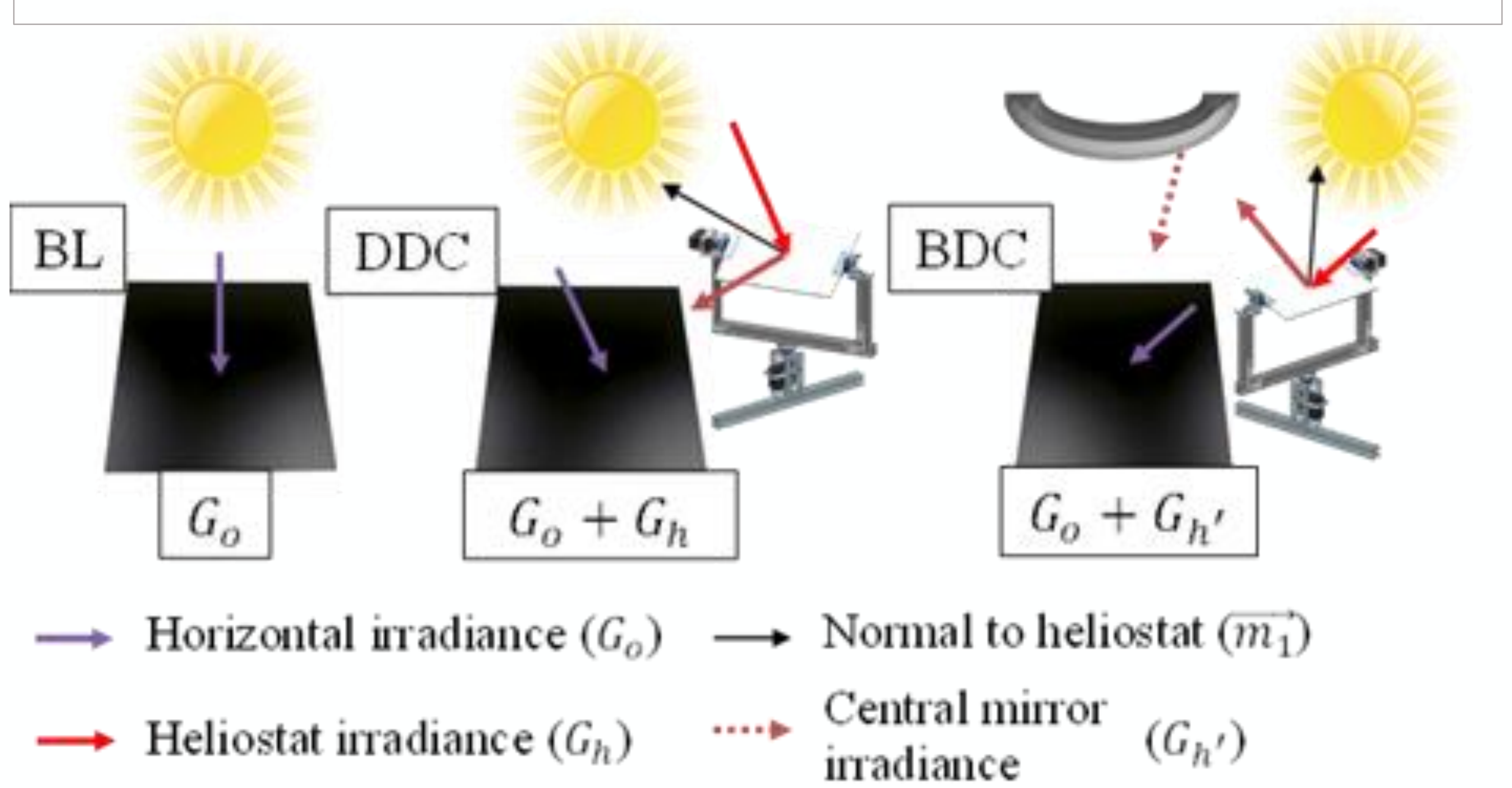

Figure 2. Different configurations tested for water desalination.

Results and discussion

The characterization of the 8 days in which experiments were conducted is presented in Fig. 3. Fig. 3 clearly shows that all days exhibit a certain level of repeatability, with discrepancies between repeated experiments mainly attributed to variations in the wind speed (V_∞).

The results of the 8 experiments (4 configurations repeated twice) are shown in Fig. 4. Fig. 4(a) shows the average temperature ($T_{s,avg}$)) calculated from the five measured surface temperatures. Fig. 4(b) displays the maximum temperature ($T_{s,max}$) among the five surface temperatures, typically corresponding to the central temperature. Fig 4(c) presents the experimental net and normalized water yield per unit area for the different configurations, comparing them against the best-performing baseline run (BL#1).

Comparing the DDC and BDC configurations individually, both have their draw-backs, which are mitigated when combined. The DDC configuration is not significantly affected by the inclusion of the second reflection (lower optical efficiency due to imperfect reflectivity). However, the required positioning leads to more abrupt changes in cosine efficiency, shortening the system's full-operating window. In contrast, the BDC configuration provides greater stability but is susceptible to the impact of imperfect reflectivity in the central mirror. However, by incorporating less efficient heliostats from the DDC configuration into the BDC setup, an enhanced performance is achieved, as evidenced in the hybrid: DDC + BDC configurations.

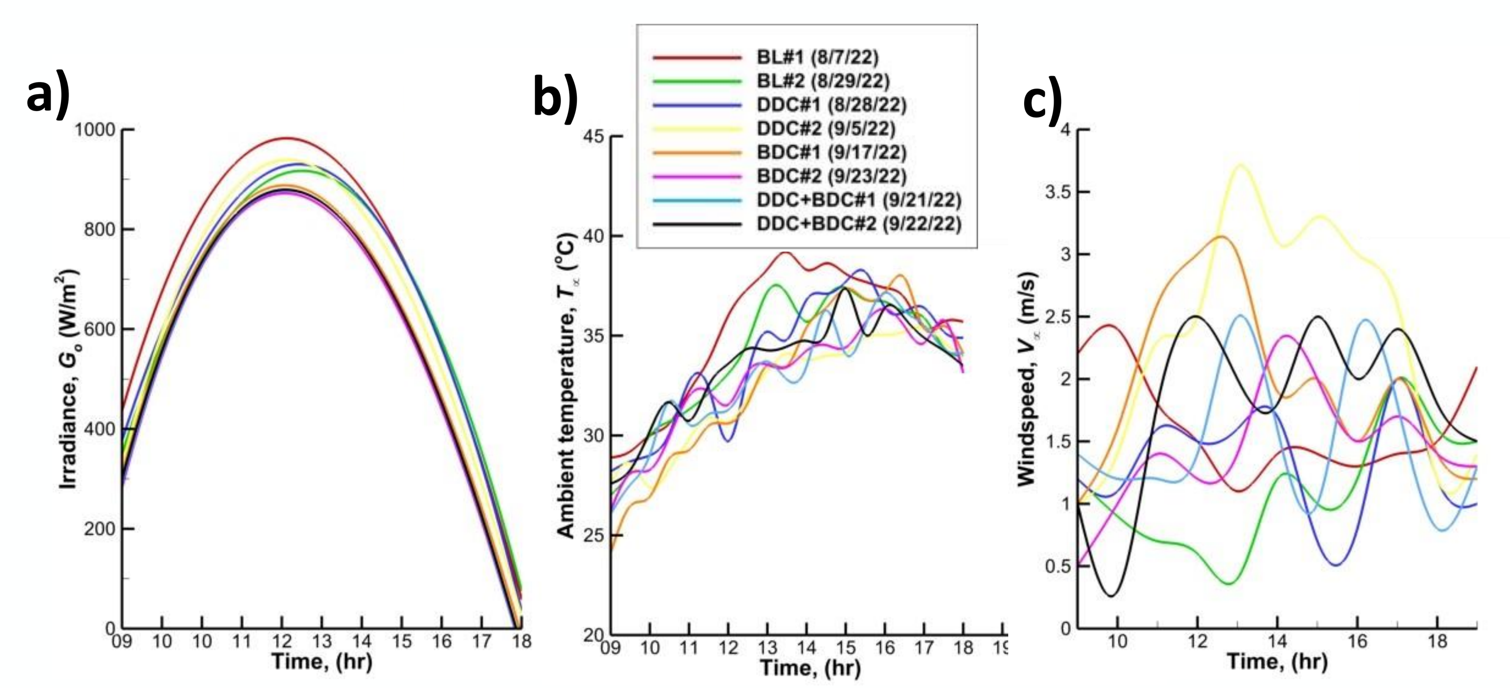

Figure 3. Characterization of days in which experiments were conducted. (a) Irradiance, (b) ambient temperature and (c) windspeed,

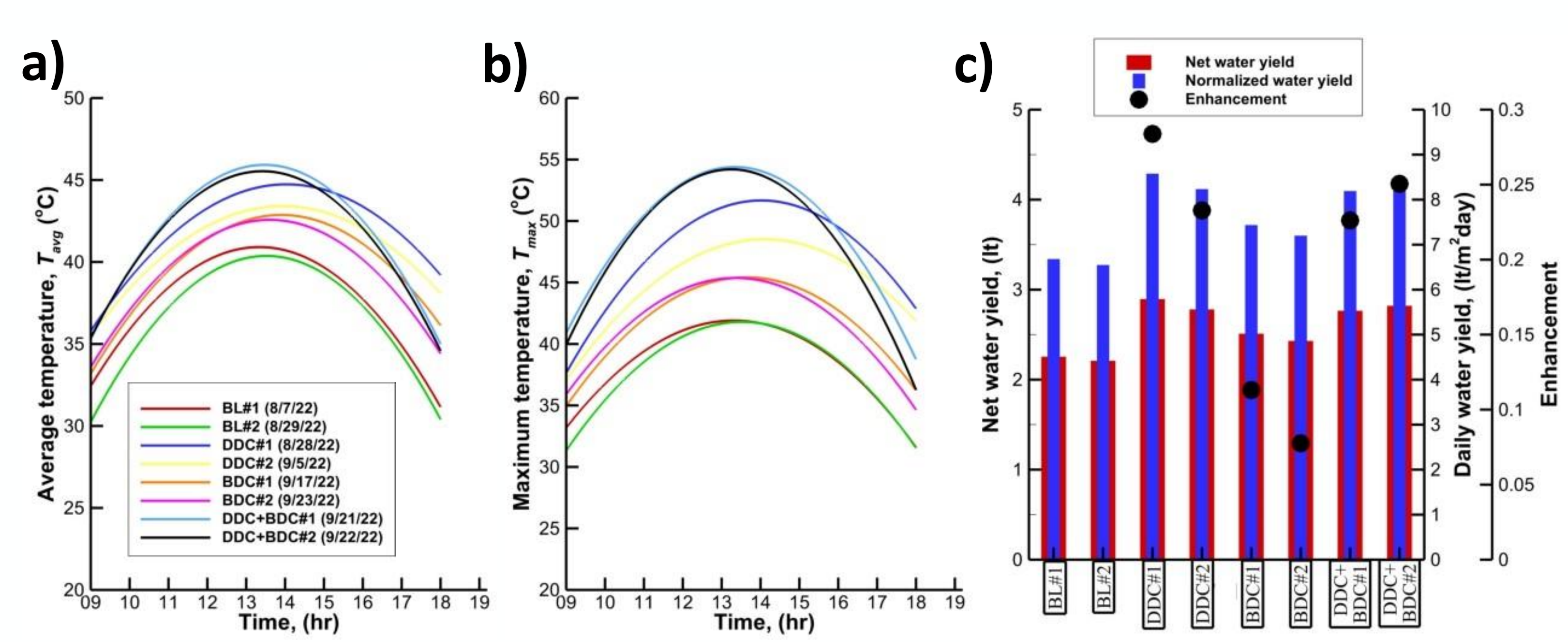

Figure 4. Experimental results for the tested configurations. (a) Average water temperature, (b) maximum water temperature and (c) water yield.

Conclusions

The present study successfully tested and compared three different configurations utilizing direct solar thermal energy for water desalination. The results demonstrated significant improvements in water yield and surface temperature. However, certain limitations were observed for each configuration.

Beam-Down solar concentrator (BDC) configuration:

1. Showed higher and less varying cosine efficiency.
2. Operated throughout the day except for shading constraints.
3. Experienced additional shading effects that hindered performance.
4. Required a minimum central mirror reflectivity for inclusion.
5. Magnified irradiance did not significantly increase water temperature or achieve high evaporation rates compared to Direct-Down concentration (DDC).
6. Emphasized the importance of cohesion between the central mirror, basin, and heliostat to maximize useful heat and collection efficiency.
7. Enabled more design options and applications through the inclusion of a second reflection.
8. Demanded higher precision servomotors to maintain expected collection efficiency.
9. Considered easily scalable.

Direct-Down concentration (DDC) configuration:

1. Exhibited lower and highly varying cosine efficiency.
2. Had a limited full operating window due to heliostat limitations in reflecting sunlight towards the basin, especially for heliostats located in the west and east demi circles.
3. Experienced lesser shading effects due to the absence of certain structural elements.
4. Induced higher water temperature and achieved higher evaporation rates without the magnification provided by the central mirror.
5. Required less accurate servomotors due to the absence of the second reflection.
6. Lacked versatility in design and low-temperature applications.
7. Suited for smaller-scale systems when the basin is located below the helio-stats' z-plane and all heliostats are in the same z-plane.

Hybrid DDC + BDC configuration:

1. Proved advantageous when central mirror reflection was not very high.
2. Offered potential to mitigate the limitations of individual configurations, such as the limited full operating window of DDC and the inclusion of the imperfect second reflectivity in BDC.
3. Required careful selection of heliostats based on cosine efficiencies and central mirror reflectivity.
4. Enabled the use of larger basins with regions of higher evaporation rates by combining the "high" irradiance over a smaller area (DDC configuration) with the magnified irradiance over a larger area (BDC).

This study provides valuable insights into the performance and characteristics of the BDC, DDC, and hybrid DDC + BDC configurations for direct solar thermal water desalination and other low-thermal applications. These findings can inform the development of optimized and efficient systems for various scale applications in the future.

Publication and References

➢ [1] E. Moreno Resendiz et al., “Analysis of a small-scale modified beam-down solar concentrator system for low temperature applications,” Renewable Energy, vol. 215, p. 119007, 2023. doi:10.1016/j.renene.2023.119007

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