

Article

Exploratory Outdoor Assessment of Low-Coverage Silver-Colored Floating Discs: Daytime Water-Level Decline and Water-Temperature Response

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Abstract

Open-water surfaces, including lakes and reservoirs, absorb solar radiation and can experience substantial evaporative water losses. Partial surface coverage with reflective floating elements may reduce both solar heat loading and evaporation, but coverage fraction, water temperature, evaporation, and boundary conditions are strongly coupled. This exploratory study evaluated water-temperature response and daytime water-level decline associated with partial coverage by silver-colored floating polyethylene discs under three reduced-scale outdoor scenarios in Rende, Italy. Three identical water containers (17×15 cm surface area; 10 cm water depth) were tested with 0%, 10%, and 25% nominal projected surface coverage (C_0 , C_{10} , and C_{25} , respectively). Water temperature, air temperature, and relative humidity were recorded hourly, while water depth was measured at the beginning and end of each trial. Reported hourly solar-radiation data for Rende were used only to characterize the meteorological context. Observed mean C_{25} – C_0 temperature differences were $+0.5$ °C in S1, -0.4 °C in S2, and -1.5 °C in S3, with the largest instantaneous separation of -3.1 °C occurring in S3. The mean differences observed in S1 and S2 were of the same order as the nominal combined PT100 measurement uncertainty, whereas the larger separation in S3 exceeded this uncertainty in magnitude. In all three exploratory trials, the covered vessels exhibited smaller daytime water-level declines than the uncovered control; however, several between-treatment differences were comparable with the ± 1 mm water-level measurement resolution. The direction and magnitude of water-temperature differences varied among the three coupled meteorological and support-boundary scenarios. The findings provide preliminary mechanism-screening observations rather than statistically replicated performance validation.

Keywords: silver-colored floating discs; nominal surface coverage; water-level decline; shallow-water temperature; meteorological forcing; exploratory outdoor experiment



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1. Introduction

Evaporation from open-water bodies is a coupled heat and mass-transfer process governed by net radiation, heat storage within the water body, vapor-pressure deficit, and meteorological conditions controlling vapor transfer across the air–water interface [1]. At the lake and reservoir scale, solar radiation, air temperature, atmospheric humidity, wind speed, bathymetry, water depth, and vertical mixing jointly determine the magnitude of evaporation [2]. In arid and semi-arid regions, evaporation losses can reach up to 50% of reservoir storage capacity [3,4]. Recent assessments have quantified substantial evaporation

from small agricultural reservoirs in southern Europe, while experimental and modeling studies show that floating physical covers can modify both radiative and aerodynamic controls on evaporation [5,6]. Forced-convection experiments further demonstrate that evaporation and the mass-transfer coefficient are strongly dependent on airflow velocity, water and air temperatures, and relative humidity [7]. Long-term reservoir observations similarly indicate that substantial evaporation suppression may also be accompanied by changes in dissolved oxygen, nutrients, salinity-related parameters, and biological activity [8]. The design objective is therefore not simply to maximize the covered fraction, because cover geometry, material properties, wind conditions, and cover density can modify both heat and mass transfer. Moreover, high coverage fractions may restrict air–water gas exchange and alter dissolved-oxygen conditions, with potential consequences for aquatic organisms [9,10].

Poós and Varju [7] compared theoretical and empirical mass-transfer correlations and confirmed that water evaporation predictions are highly sensitive to temperature, humidity, and airflow. Chua et al. [11] compared aluminum foil, compact discs, and silver paint and found large differences in reflected-energy performance, providing a material-characterization basis for reflective prototypes. Lehmann et al. [12] tested discs and spheres in a 1.44 m² wind-tunnel basin and obtained evaporation declines of approximately 80% and 70%, respectively, at 91% coverage, while black and white covers generated similar evaporation fluxes because of water thermal decoupling. Rezazadeh et al. [13] investigated polyethylene floating balls under surface water flow and showed that white balls achieved the highest evaporation-suppression efficiency. Shalaby et al. [3] analyzed the impact of white, black, and multicolor floating balls, plastic sheets, and foam sheets on evaporation rate, and their results demonstrated that cover color, geometry, coverage, season, and climate jointly influenced evaporation, water temperature, and microalgal response.

Abdallah et al. [4] reviewed suspended covers and floating elements for evaporation suppression and identified reservoir-scale ecology, economics, material footprint, and wind stability as unresolved constraints, though reservoir-scale evidence remains limited. Wang et al. [14] tested five different sizes of solid expanded polystyrene (EPS) floating balls and found a clear diameter effect in outdoor evaporators, with 40 mm balls achieving 76.31% evaporation-suppression efficiency, whereas the smallest 10 mm balls performed poorly under wind–wave forcing. Hao et al. [15] tested the impact of floating-ball coverage fractions ranging from 0 to 74.98% on evaporation, energy balance, and water quality. Their analysis showed that evaporation reduction was not directly proportional to the covered fraction. Rezaei Jajarm et al. [16] investigated the effect of cover geometry on evaporation suppression and found that water-surface flow, wind conditions, exposed area, and opening perimeter influenced evaporation, with suppression ranging from 33–69% for rectangular openings to 48–75% for circular openings.

Mulero et al. [17] evaluated a 1541 m² experimental irrigation pond covered with a flexible floating-photovoltaic system and reported an annual evaporation reduction of 82.4%, water savings of 2199.3 m³, and electricity generation exceeding 300,000 kWh. Song et al. [18] evaluated the impacts of water-based PV systems on coastal aquaculture ponds and reported that photovoltaic coverage intercepted 89–93% of solar radiation, lowered pond-water temperature by 1.5 °C, reduced wind speed by 41–50%, and substantially altered dissolved oxygen, chlorophyll-a, and nutrient conditions. Han et al. [19] developed and validated a covered-water combination model incorporating opening fetch, wind speed, equilibrium temperature, and modified aerodynamic and radiation terms.

At a broader scale, studies of ocean-albedo modification and other radiative interventions have demonstrated that changing surface or atmospheric reflectivity can alter energy exchange, but they also emphasize strong scale dependence, atmospheric feedbacks, and ecological uncertainty [20–24]. These studies provide conceptual context for

surface-reflectance modification; however, the present work is restricted to reduced-scale water-surface coverage and does not evaluate climatic-scale radiative forcing.

Previous research by the author has examined related interactions among surface optical properties, solar-energy exchange, thermal performance, and water conservation in Mediterranean environments. Pirouz et al. investigated the effect of surface albedo and installation configuration on solar-energy performance and demonstrated that reflected short-wave radiation and surface characteristics can substantially alter the energy response of exposed systems [25]. In subsequent experimental work on bio-solar green roofs, Pirouz et al. showed that modifications of surface configuration can simultaneously influence thermal behavior and water demand, highlighting the importance of evaluating energy and water responses together rather than independently [26]. Earlier work also addressed water-resource conservation through atmospheric water harvesting integrated with green infrastructure, emphasizing the increasing importance of passive and low-energy strategies for reducing freshwater demand under dry climatic conditions [27]. Collectively, these studies provide a broader water–energy framework for the present investigation, which extends the role of surface optical and coverage characteristics from building-integrated systems to partially covered open-water surfaces.

Despite these advances, the available evidence remains dominated by high-coverage floating spheres, continuous sheets, larger modular covers, porous structures, and floating photovoltaic systems.

Comparatively little experimental attention has been given to low fractional coverage using freely floating centimeter-scale elements. The 10% and 25% nominal projected coverage fractions used here were deliberately selected to leave 90% and 75% of the water surface nominally uncovered, respectively, thereby examining a substantially lower coverage regime than continuous sheets, densely packed floating spheres, and many floating-photovoltaic systems reported previously. The resulting experiment was intended as an exploratory assessment of whether such low fractional coverage produces observable water-level and thermal responses while retaining a large, exposed air–water interface.

The present study therefore examines the observed water-temperature response and daytime water-level decline associated with 0%, 10%, and 25% nominal projected coverage by silver-colored polyethylene discs under three reduced-scale outdoor scenarios. Because each scenario was tested on a different date, the study does not seek to isolate substrate effects; instead, S_1 – S_3 are treated as coupled combinations of support-boundary and meteorological conditions. The objective is to provide preliminary mechanism-screening evidence that can inform the design of subsequent replicated experiments rather than to establish reservoir-scale evaporation-reduction performance.

2. Materials and Methods

2.1. Conceptual Design of the Reflective Floating-Disc System

The experimental work was developed as an initial physical assessment of a broader patented floating-disc concept for partial coverage of water surfaces. The patented concept comprises centimeter-scale double-sided discs with a reflective surface intended to reduce absorption of incoming short-wave radiation and an opposite absorbing surface. The conceptual design specifies a reflective-side albedo of at least 0.8, a black-side solar absorptance of at least 0.9, a diameter range of 1–5 cm, and a thickness of approximately 0.05–0.1 mm. These optical and dimensional specifications describe the patented concept and were not measured for the experimental discs used in this study. The present experiment used silver-colored polyethylene discs as simplified prototypes to investigate only the response associated with partial floating-surface coverage. Their optical properties, biodegradability, passive self-selection, anti-aggregation behavior, long-term durability, and ecological

performance were not experimentally evaluated. Accordingly, the present study examines only water-temperature response and daytime water-level decline associated with different nominal coverage fractions and does not validate the additional material or deployment functions of the patented concept. Figure 1 is included only to illustrate the conceptual relationship between the patented design and the simplified experimental prototype.

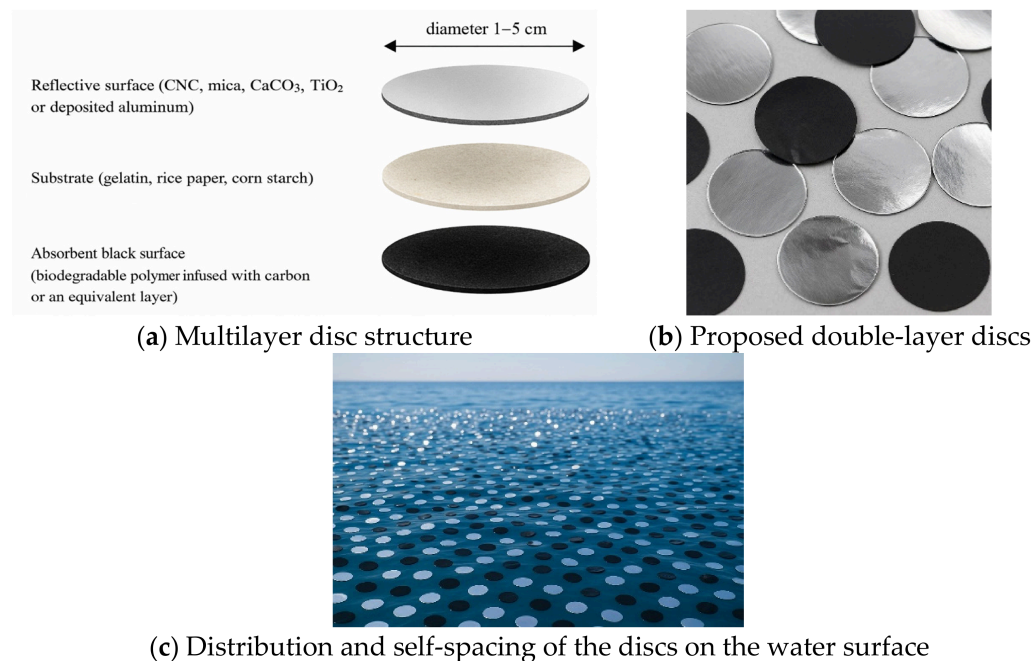


Figure 1. Conceptual illustrations of the patented floating-disc system (Registered Italian patent application No. 102026000013066). The illustrations represent the patented concept only and do not depict experimentally tested field-scale deployment scenarios.

The experimental polyethylene discs were 0.01 mm thick, which is thinner than the 0.05–0.1 mm range specified for the patented conceptual design.

2.2. Reduced-Scale Experimental Prototype and Treatments

The reduced-scale experimental design is shown in Figure 2.

The experiment comprised three one-day reduced-scale outdoor trials conducted in Rende, Southern Italy, during July 2026 under conditions characteristic of the Mediterranean summer. Wind speed and direction were not instrumentally measured; consequently, no quantitative wind classification is assigned to the experimental dates. Three nominally identical vessels were used to establish an uncovered control (C_0) and two low-coverage treatments (C_{10} and C_{25}). The complete vessel dimensions, water volume, disc dimensions, disc number, projected area, and nominal projected coverage fractions are summarized in Table 1. The selected coverage levels were intended to preserve a large, uncovered water-surface fraction while allowing comparison with the uncovered control. The setup was designed to investigate shallow-water treatment responses rather than to reproduce reservoir-scale hydrodynamics. The discs floated freely and were not fixed to predetermined positions. They could therefore migrate, contact vessel walls, overlap, or form temporary clusters during exposure. The quoted 10% and 25% values represent nominal projected coverage calculated from disc number and projected disc area; instantaneous effective coverage, overlap, opening perimeter, and spatial aggregation were not quantified continuously.

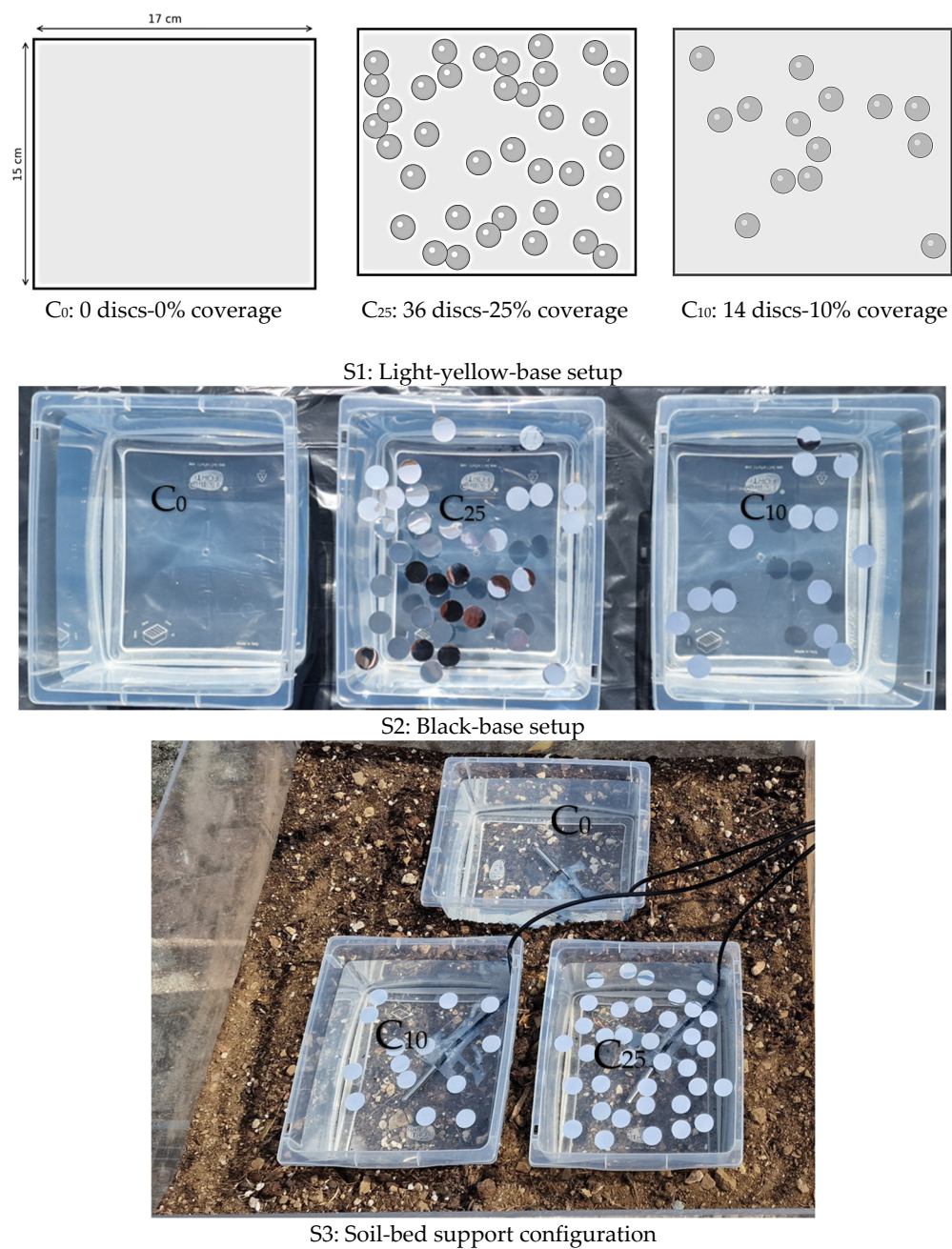


Figure 2. The reduced-scale experiment design.

Table 1. Experimental setup and configuration.

Item	Description	Configuration
Experimental unit	Transparent plastic box	17 × 15 cm internal plan area; total internal height: 14 cm; wall thickness: 2 mm; initial water depth: 10 cm; freeboard: 4 cm; exposed water-surface area: 255 cm ² ; initial water volume: ≈2.55 L; open top, no lid or wind shield.
Floating disc	Circular silver-colored polyethylene discs; optical reflectance and absorptance not measured	Experimental discs: 1.5 cm diameter; thickness 0.001 cm (0.01 mm); projected area 1.77 cm ² .

Table 1. Cont.

Item	Description	Configuration
Water	Municipal tap water	Total dissolved solids (TDS) = 163 ppm
Treatments	C_0 : 0 discs; C_{10} : 14 discs; C_{25} : 36 discs	C_0 : 0 cm ² /255 cm ² , 0.00% C_{10} : 24.74 cm ² /255 cm ² $\approx$ 10% C_{25} : 63.62 cm ² /255 cm ² $\approx$ 25%
Boundary configurations	18 July: S1 19 July: S2 27 July: S3	S1: light-yellow base S2: black base S3: boxes embedded in soil (soil-bed support boundary)
Observation window	Each hour	From 09:00 to 18:00 local time

2.3. Outdoor Experimental Configurations

Experimental details are presented in Table 1. Three one-day outdoor trials were conducted. The light-yellow base trial was conducted on 18 July 2026 (S1), the black base trial on 19 July 2026 (S2), and the soil-bed trial on 27 July 2026 (S3). The soil-bed arrangement reduced the artificial light/dark support contrast of S1 and S2; however, it should not be interpreted as a physical representation of a reservoir or pond because it did not reproduce reservoir depth, vertical mixing, wave action, fetch, or field-scale wind exposure. Because S1, S2, and S3 were conducted on different dates, support-boundary effects are inseparable from day-specific meteorological and initial thermal conditions; the three tests are therefore treated only as distinct coupled experimental scenarios.

2.4. Instrumentation and Measurement Procedure

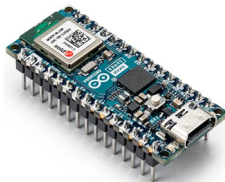
The experimental variables and instrumentation are presented in Table 2. All sensors and instruments were tested before the experiment. Water temperature was measured using PT100 waterproof temperature probes connected to an ESP32-based data-acquisition system. The system was used to acquire one water-temperature reading at each hourly checkpoint from 09:00 to 18:00; continuous temperature logging between the hourly checkpoints was not performed.

One PT100 probe was installed in each vessel with the sensing tip positioned approximately 9.5 cm below the initial water surface, near the horizontal center of the vessel and without direct contact with the vessel bottom, walls, or floating discs. The probes were maintained at the same nominal position and immersion depth throughout each trial. The manufacturer-stated accuracy was ± 0.3 °C. Before deployment, the three probes were immersed simultaneously in the same water bath to verify consistency among their readings. This procedure constituted an inter-probe consistency check rather than calibration against a traceable reference thermometer. Air temperature and relative humidity were recorded hourly using the DHT11 sensor. Hourly solar-radiation values for Rende were obtained from the meteorological source identified in Table 2. Because solar radiation was not measured using an on-site calibrated pyranometer, these data were used to describe the temporal solar-forcing context and were not interpreted as exact irradiance incident on the experimental water surfaces.

The three vessels within each trial were positioned adjacent to one another with unobstructed solar exposure and physical separation between the vessels. Treatment positions were not systematically randomized or rotated during the original experimental campaign; therefore, small positional differences in incident radiation or local airflow cannot be completely excluded. Water depth was measured at 09:00 and 18:00. The directly observed quantity was the daytime water-level decline. Because the vessels had vertical walls and

a constant plan area over the measured depth range, the decrease in water level was interpreted directly as an equivalent evaporation depth. Under the assumption that rainfall, intentional water addition/removal, leakage, splashing, and other external mass-transfer processes were negligible during the test period, the observed water-level decline was used as a water-level-based estimate of evaporative water loss. Accordingly, the resulting values are treated as approximate water-level-based estimates rather than direct high-precision evaporation measurements during the nine-hour daytime test period and should not be interpreted as 24 h daily evaporation rates.

Table 2. Instrumentation accuracy and measurement details.

Variable	Sensors/Instruments	Accuracy	Measurement Intervals	Image
Water temperature	Waterproof PT100 temperature probe (JUMO GmbH & Co. KG, Fulda, Germany)	$\pm 0.3\text{ }^{\circ}\text{C}$	Each hour	
Ambient air temperature and relative humidity	DHT11 sensor module (ASAIR, Sanc�, France)	$\pm 0.5\text{ }^{\circ}\text{C}$; $\pm 5\%$ RH	Each hour	
Total dissolved solids (TDS)	TDS water tester (MEASURY, Shanghai, China)	$\pm 2\%$	Beginning of each trial	
Water-level decline/water-level-based estimate of evaporative water loss	Water-depth measurement (OTT Hydromet, Kempten, Germany)	$\pm 0.1\text{ cm}$ per reading	Beginning and end of each trial	-
Data acquisition and monitoring	Arduino Nano ESP32 (Arduino S.r.l., Monza, Italy)	-	Each hour	 
Solar radiation	Reported solar radiation from the meteorological network for Rende (W m^{-2})	-	Each hour	[28]

2.5. Thermal-Response Analysis

The thermal response of the silver-colored floating-disc treatments was evaluated from the complete hourly water-temperature trajectories recorded between 09:00 and 18:00. Because C_0 , C_{10} , and C_{25} were exposed simultaneously during each experimental trial, the

uncovered treatment C_0 was used as the concurrent reference for quantifying the effect of partial floating-disc coverage.

For each hourly checkpoint, the covered treatment was compared with the concurrent C_0 vessel using the following equation:

$$\Delta T_i(t) = T_i(t) - T_0(t), \quad (1)$$

Because the stated accuracy of each PT100 probe was $\pm 0.3^\circ\text{C}$, the nominal combined uncertainty of a difference between two independent probes is approximately $\pm 0.4^\circ\text{C}$ by root-sum-of-squares propagation. Consequently, observed mean differences of approximately $0.2\text{--}0.5^\circ\text{C}$ were treated as being of the same order as measurement uncertainty, whereas the larger $1.5\text{--}3.1^\circ\text{C}$ separations observed in S3 were distinguishable in magnitude from nominal sensor accuracy but still cannot be interpreted as statistically validated treatment effects because independent vessel replication was absent.

The thermal behavior was interpreted within a coupled heat-transfer framework in which partial floating-disc coverage can influence two competing processes. First, to the extent that the silver-colored disc surfaces reflect incoming short-wave radiation, they can reduce the amount of solar energy absorbed by the water and underlying boundaries, thereby favoring a cooling response. Second, partial coverage reduces the exposed air–water interface and can decrease evaporative latent-heat loss, thereby weakening an important cooling pathway and potentially favoring heat retention. Moreover, heat exchange with the ambient air and conductive transfer through the transparent vessel bottom and side walls can further modify the response, particularly in the shallow 10 cm water column used in the experiments. The resulting water temperature therefore reflects the net interaction among radiative loading, evaporation, sensible heat exchange with the atmosphere, heat storage within the water, and conductive heat transfer through the bottom and side walls.

These processes were therefore considered qualitatively when interpreting differences among the light-yellow, black, and soil-bed configurations. No quantitative energy balance was calculated because short-wave and long-wave radiative fluxes, sensible and latent heat fluxes, and conductive heat transfer through the vessel boundaries were not measured independently.

2.6. Assumptions and Simplifications

The recorded water temperature was treated as a representative point measurement for comparative analysis. The hourly water-temperature value recorded for each box was assumed to represent the comparative thermal state of that experimental unit at the measurement time. Vertical temperature gradients were not measured, and the measured value was not interpreted as a complete depth-averaged temperature profile. The light-yellow, black, and soil-bed arrangements were treated as complete coupled boundary configurations rather than isolated or quantitatively measured albedo treatments. Comparisons were restricted to treatments measured on the same day, and the three experimental dates were not treated as meteorologically equivalent replicates.

For the water-balance calculations, each box was assumed to have a constant horizontal cross-sectional area of 255 cm^2 . All boxes began with a water depth of 10.0 cm, and the decline in water level between 09:00 and 18:00 was used as a water-level-based estimate of daytime evaporative water loss under the assumptions stated in Section 2.4.

Water-level uncertainty was propagated explicitly because the stated measurement resolution was $\pm 0.1\text{ cm}$ ($\pm 1\text{ mm}$) per reading. For treatment i , the uncertainty associated with the calculated daytime water-level decline E_i was estimated by root-sum-of-squares propagation as follows:

$$uE_i = \sqrt{\left\{ u_{h(i,0)}^2 + u_{h(i,f)}^2 \right\}} \quad (2)$$

where $u_{h(i,0)}$ and $u_{h(i,f)}$ are the uncertainties associated with the initial and final water-depth readings, respectively. With an uncertainty of ± 1 mm for each reading, the resulting uncertainty in E_i was approximately ± 1.4 mm. For the constant exposed water-surface area of 255 cm^2 , this water-depth uncertainty corresponds to an approximate propagated volume-loss uncertainty of ± 36 mL. The nominal relative reduction in daytime water-level decline for treatment i compared with the uncovered control was calculated as follows:

$$Ri (\%) = 100 \left(1 - \frac{E_i}{E_0} \right) \quad (3)$$

where E_i is the water-level decline of C_{10} or C_{25} and E_0 is the corresponding decline of C_0 . The propagated uncertainty of the relative reduction was estimated as follows:

$$uRi(\%) = 100 \sqrt{\left(\frac{u_{E_i}}{E_0} \right)^2 + \left(\frac{E_i u_{E_0}}{E_0^2} \right)^2} \quad (4)$$

These propagated values represent measurement uncertainty rather than statistical confidence intervals because independent experimental replication was not available.

Finally, the silver-colored polyethylene discs were used as prototype floating-cover elements, but their solar-weighted reflectance, absorptance, spectral response, and surface temperature were not measured. The experiment therefore cannot isolate optical reflection from the effects of physical surface coverage, altered latent-heat exchange, or boundary heat transfer. References to the albedo and absorptance of the patented concept should not be interpreted as measured properties of the experimental discs.

3. Results and Discussion

3.1. Meteorological and Experimental Context

The three outdoor experiments exhibited similar daytime solar-radiation patterns but different atmospheric conditions, as shown in Figure 3. The reported solar radiation increased from 09:00, reached its maximum at approximately 13:00, and subsequently declined toward 18:00. Peak values were 917 W m^{-2} for both the light-yellow-base and black base trials and 908 W m^{-2} for the soil-bed trial. Because the external source provided hourly contextual radiation values rather than a calibrated on-site irradiance time series, the values were used descriptively as W m^{-2} profiles and were not integrated to estimate daily irradiation. The black base trial was conducted under the warmest and driest conditions, with a mean air temperature of 34.3°C and mean relative humidity of 25.7%. The light-yellow base trial had a mean air temperature of 31.1°C and mean relative humidity of 28.2%. By contrast, the soil-bed trial was conducted under substantially more humid conditions, with a mean air temperature of 29.6°C and mean relative humidity of 68.9%. Initial water temperatures were equal among C_0 , C_{10} , and C_{25} within each trial, but differed among dates: 23.8°C for the light-yellow base trial, 26.3°C for the black base trial, and 20.9°C for the soil-bed trial. These differences indicate that the three dates represent distinct coupled experimental configurations rather than meteorologically equivalent replicates. Consequently, differences among S1, S2, and S3 cannot be attributed independently to support-boundary type.

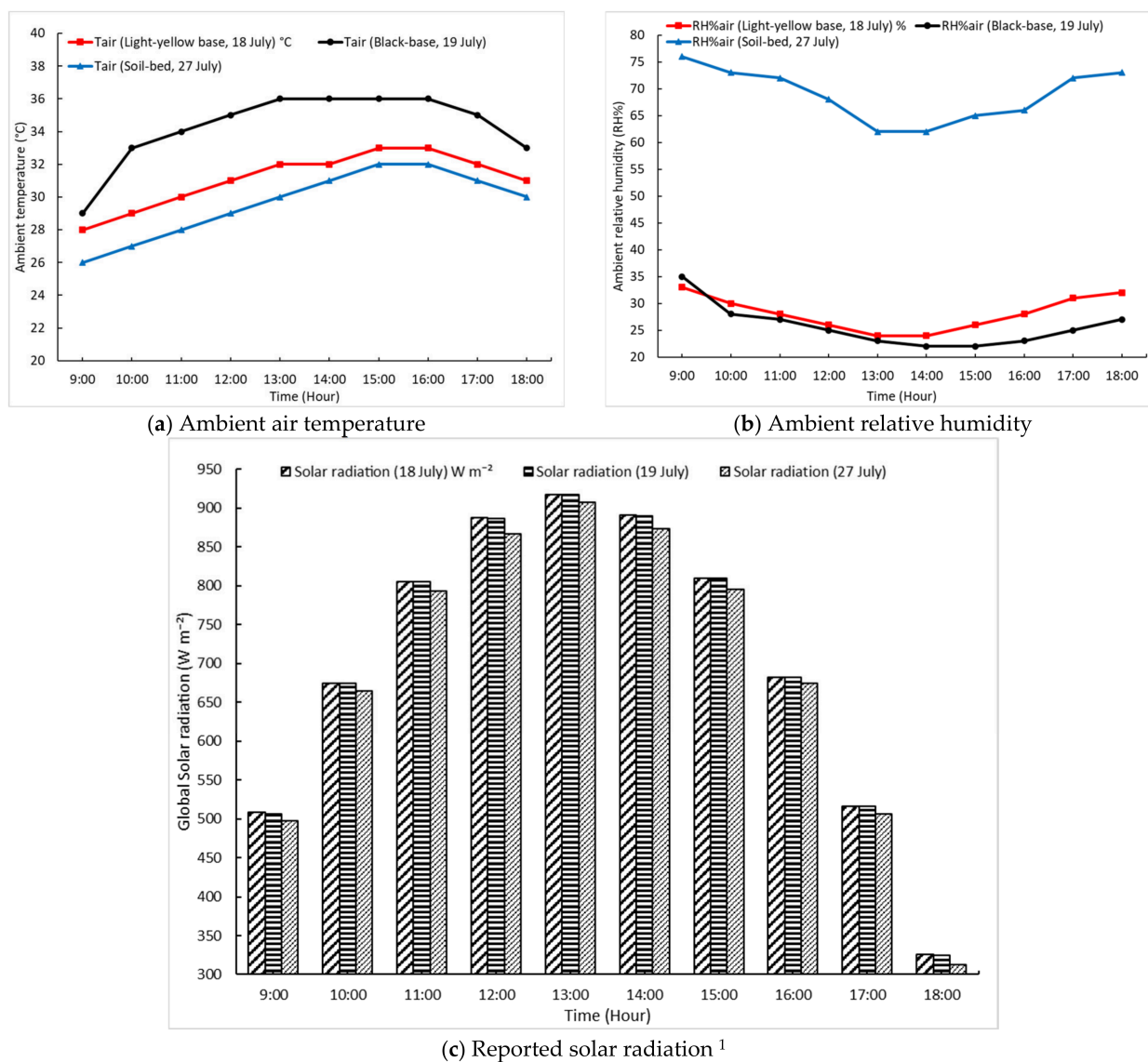


Figure 3. Meteorological conditions during the three outdoor experimental trials. ¹ The solar radiation values were obtained from the meteorological source described in Section 2 and do not represent calibrated irradiance measured directly at the experimental vessels.

3.2. Observed Water Temperature Response

Water-temperature trajectories for C_0 , C_{10} , and C_{25} under three different bases are presented in Figure 4.

3.2.1. Light-Yellow Base Trial

All three treatments began at a water temperature of 23.8 °C at 09:00. Water temperature increased rapidly during the morning and reached its maximum at 14:00, when C_0 , C_{10} , and C_{25} attained 37.1, 37.4, and 37.7 °C, respectively. Subsequently, water temperatures decreased in all treatments. The mean temperatures over the ten hourly observations were 31.7 °C for C_0 , 31.9 °C for C_{10} , and 32.2 °C for C_{25} . The mean differences relative to C_0 across the ten hourly observations were +0.2 °C for C_{10} and +0.5 °C for C_{25} . The largest C_{25} – C_0 difference was +1.0 °C at 17:00, while the final differences at 18:00 were +0.3 °C for C_{10} and +0.9 °C for C_{25} .

The observed mean C_{10} – C_0 and C_{25} – C_0 differences were +0.2 and +0.5 °C, respectively. These values are small relative to the stated PT100 accuracy and should not be interpreted

as established thermal treatment effects. They nevertheless indicate that, within this exploratory trial, the covered vessels did not exhibit a clear cooling response. Possible contributions from altered evaporative cooling, bottom/side-wall heat transfer, and sensor offset cannot be separated. The result therefore indicates competing radiative and latent-heat pathways rather than evidence of an inherent warming effect of partial floating-disc coverage.

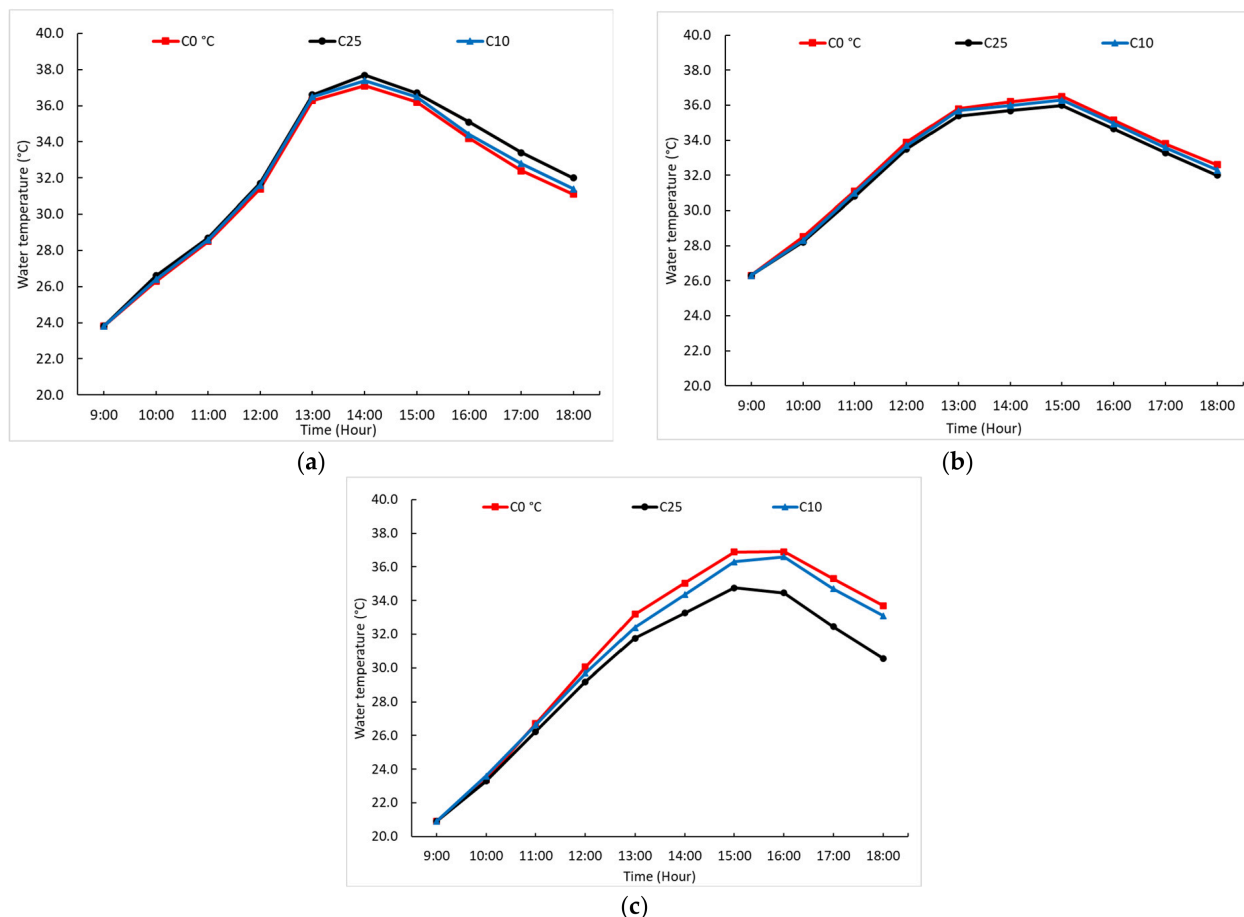


Figure 4. Hourly water temperature trajectories for C_0 , C_{10} , and C_{25} under (a) the light-yellow base configuration, (b) the black-base configuration, and (c) the soil-bed configuration.

3.2.2. Black Base Trial

All treatments began at 26.3 °C. Maximum temperatures occurred at 15:00 and were 36.5 °C for C_0 , 36.3 °C for C_{10} , and 36.0 °C for C_{25} . From 10:00 onward, the temperature ordering was consistently $C_0 > C_{10} > C_{25}$. The corresponding mean temperatures were 33.0, 32.8, and 32.6 °C for C_0 , C_{10} , and C_{25} , respectively. Mean differences relative to C_0 across the ten hourly observations were -0.2 °C for C_{10} and -0.4 °C for C_{25} . At 18:00, C_{10} and C_{25} were 0.3 and 0.6 °C cooler than C_0 , respectively. Although the observed ordering after 10:00 was $C_0 > C_{10} > C_{25}$, the mean differences of approximately -0.2 and -0.4 °C are comparable with the nominal combined probe uncertainty. The result is therefore reported as an observed ordering in this individual trial rather than evidence of a causal cooling effect of coverage.

3.2.3. Soil-Bed Trial

The initial water temperature was 20.9 °C in all treatments. The soil-bed configuration produced the strongest and most persistent separation among the coverage levels. C_{25} was cooler than C_0 from 10:00 onward, while C_{10} was generally intermediate. C_0 reached a

maximum of 36.9 °C at 15:00–16:00, C_{10} reached 36.6 °C at 16:00, whereas C_{25} reached a lower maximum of 34.8 °C at 15:00. The mean temperatures were 31.2 °C for C_0 , 30.8 °C for C_{10} , and 29.7 °C for C_{25} . The mean differences relative to C_0 across the ten hourly observations were −0.4 °C for C_{10} and −1.5 °C for C_{25} . The temperature differences among treatments increased during the afternoon. The C_{25} – C_0 differences were −2.1, −2.5, −2.8, and −3.1 °C at 15:00, 16:00, 17:00, and 18:00, respectively. At the end of the test, at 18:00, temperatures were 33.7 °C for C_0 , 33.1 °C for C_{10} , and 30.6 °C for C_{25} . The S3 trial produced the largest observed separation, with a mean C_{25} – C_0 difference of −1.5 °C and a final difference of −3.1 °C. These differences exceed the nominal ± 0.4 °C combined sensor uncertainty in magnitude; however, because only one vessel represented each treatment, they remain exploratory observations and cannot establish a statistically robust treatment effect. Reduced heat accumulation is one possible interpretation, but differences in boundary conditions and day-specific meteorology cannot be separated from the coverage response.

3.3. Observed Water-Level Decline and Water-Level-Based Estimates of Evaporative Water Loss

Across the three exploratory trials, the final measured water depth followed the same descriptive ordering, $C_{25} > C_{10} > C_0$. Accordingly, the covered vessels exhibited smaller observed daytime water-level declines than C_0 , as shown in Figure 5. Because several between-treatment differences were only 1–2 mm and the stated reading resolution was ± 1 mm, the magnitude of the derived reductions is highly uncertain and should not be interpreted as a precise estimate of evaporative water-loss reduction. During the light-yellow base trial, the final water depths were 9.2, 9.3, and 9.4 cm for C_0 , C_{10} , and C_{25} , respectively. Relative to the equal initial depth of 10.0 cm, the observed daytime water-level declines were 8, 7, and 6 mm. These values correspond to estimated volume losses of 204.0, 178.5, and 153.0 mL and nominal relative reductions in water-level decline of 12.5% for C_{10} and 25.0% for C_{25} .

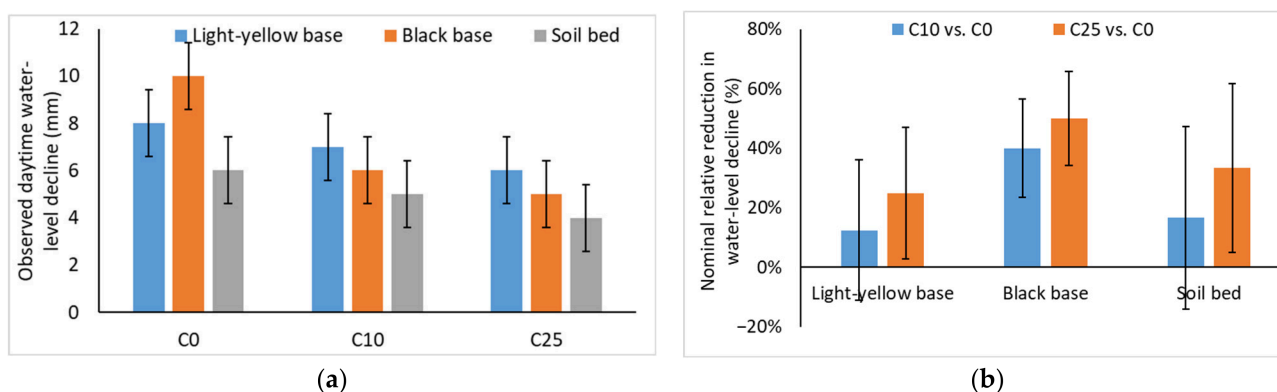


Figure 5. Observed and derived water-level responses: (a) observed daytime water-level decline for C_0 , C_{10} , and C_{25} ; and (b) nominal relative reduction in water-level decline for C_{10} and C_{25} compared with C_0 . Error bars represent propagated measurement uncertainty based on the ± 1 mm uncertainty of individual water-depth readings and are not statistical confidence intervals.

In the black base trial, final water depths were 9.0 cm for C_0 , 9.4 cm for C_{10} , and 9.5 cm for C_{25} . The corresponding observed daytime water-level declines were 10, 6, and 5 mm, equivalent to volume losses of 255.0, 153.0, and 127.5 mL. The nominal relative reductions in water-level decline were 40.0% for C_{10} and 50.0% for C_{25} . In the soil-bed trial, final depths were 9.4, 9.5, and 9.6 cm for C_0 , C_{10} , and C_{25} , respectively, corresponding to observed daytime water-level declines of 6, 5, and 4 mm. These values are equivalent to volume losses of 153.0, 127.5, and 102.0 mL, corresponding to nominal relative reductions in water-level decline of 16.7% for C_{10} and 33.3% for C_{25} relative to C_0 . The corresponding propagated

measurement uncertainties in the nominal relative reductions were approximately ± 24 , ± 22 , ± 17 , ± 16 , ± 31 , and ± 28 percentage points for S1-C₁₀, S1-C₂₅, S2-C₁₀, S2-C₂₅, S3-C₁₀, and S3-C₂₅, respectively. These values represent propagated measurement uncertainty and should not be interpreted as statistical confidence intervals.

The repeated ordering of the final water levels across the three trials is consistent with smaller water-level-based estimates of daytime evaporative water loss in the covered vessels. However, because the trials were unreplicated and several differences approached the measurement resolution, this pattern should be regarded as preliminary observational evidence rather than a quantitative demonstration of evaporative water-loss reduction. This pattern is consistent with the reduction in exposed air–water interfacial area and with changes in radiative and aerodynamic exchange reported for floating-cover systems [12,19]. The magnitude of the reduction was not strictly proportional to nominal coverage. Increasing coverage from 10 to 25% produced different nominal reductions in observed water-level decline among the three configurations. Hao et al. [15] similarly found that evaporation decline did not increase in direct proportion to floating-ball coverage because coverage altered the distribution of energy between latent, sensible, and stored-heat fluxes. Rezaei Jajarm et al. [16] and Wang et al. [9] further showed that opening geometry and wetted perimeter influence evaporation even when the total covered fraction is held constant. The differences between C₁₀ and C₂₅ may also depend on vessel geometry, disc arrangement, opening perimeter, and atmospheric conditions rather than on nominal coverage alone.

3.4. Relationship Between Water-Level Decline and Water-Temperature Response

Within the three exploratory trials, the observed water-level and temperature responses did not vary in a fixed parallel manner. Covered vessels consistently showed smaller water-level declines, while the sign and magnitude of temperature differences varied among scenarios. Because the nominal relative reductions in water-level decline and the smaller temperature differences carry substantial measurement uncertainty, this observation is interpreted mechanistically rather than as a statistically established treatment relationship. In all three trials, the observed daytime water-level decline was smaller for C₁₀ and C₂₅ than for C₀, whereas the water-temperature response changed direction among scenarios. In S1, C₂₅ exhibited a smaller daytime water-level decline than C₀, nominally corresponding to a 25.0% relative reduction, while its mean water temperature was 0.5 °C higher. Thus, a smaller observed water-level decline did not coincide with cooling in this trial. In S3, C₂₅ likewise exhibited a smaller water-level decline than C₀, nominally corresponding to a 33.3% relative reduction, together with a mean C₂₅–C₀ water-temperature difference of –1.5 °C. Given the propagated water-level measurement uncertainty and the absence of independent replication, these percentages are used only to describe the magnitude of the observed differences and not as precise evaporation-suppression efficiencies. These contrasting observations are consistent with competing radiative and latent-heat pathways associated with partial floating coverage.

In principle, a reflective floating surface can reduce the solar energy entering the water, which tends to lower water temperature; at the same time, it can reduce the exposed water area and suppress latent-heat removal through evaporation, which can increase heat retention. The subsequent temperature response depends on which mechanism dominates under the prevailing atmospheric and boundary conditions. Han et al. [19] demonstrated that evaporation under floating coverage cannot be described adequately using conventional uncovered water formulations because coverage changes effective fetch, aerodynamic exchange, radiation partitioning, equilibrium temperature, and thermal layer.

Although the individual energy-balance components were not measured, an order-of-magnitude comparison illustrates why radiative reflection and suppression of evaporative

cooling can plausibly compete in the reduced-scale system. Using the observed C_0 – C_{25} difference in daytime water-level decline as a water-level-based estimate of the difference in evaporative water loss, the corresponding difference in mean latent-heat flux can be approximated from the latent heat of vaporization. Across the three trials, the C_0 – C_{25} water-level differences were approximately 2–5 mm over the nine-hour observation period, corresponding to an indicative latent-heat-flux difference of approximately 150–375 W m^{-2} . Because each calculated water-level decline has an uncertainty of approximately ± 1.4 mm, the uncertainty in a C_0 – C_{25} difference is approximately ± 2.0 mm by root-sum-of-squares propagation, corresponding to roughly ± 150 W m^{-2} in this illustrative latent-heat-flux estimate. For comparison, at a contextual peak solar-radiation value of approximately 900 W m^{-2} , approximately 225 W m^{-2} of incident short-wave power falls on the nominally disc-covered fraction when normalized to the total water-surface area. Because the solar-weighted reflectance of the experimental discs was not measured, the fraction of this incident power actually reflected away from the system is unknown. Nevertheless, the estimated radiative and latent-heat terms are both of order 10^2 W m^{-2} , illustrating the physical plausibility that these mechanisms can compete. This calculation is intended solely as an order-of-magnitude sensitivity comparison and not as closure of the experimental energy balance.

The findings of the present study similarly indicate that water temperature should not be used as a proxy for reduced evaporative water loss, because lower water temperature does not necessarily imply lower evaporative water loss. This distinction is operationally important. For irrigation reservoirs, the primary performance indicator may be water conservation, whereas aquaculture ponds and multi-purpose reservoirs may require simultaneous control of evaporation, water temperature, dissolved oxygen, nutrients, and biological productivity. Previous studies have shown that floating covers can substantially suppress evaporation but also modify dissolved oxygen, conductivity, nutrient concentrations, and biological activity [3,8,29]. Cover design should therefore be selected according to the intended water use rather than evaporation reduction alone.

3.5. Influence of Meteorology and Support-Boundary Conditions

The largest water-level-based estimate of evaporative water loss for the uncovered control occurred during the black base trial, which also had the highest mean air temperature and the lowest relative humidity. By contrast, the soil-bed trial produced smaller water-level-based estimates of evaporative water loss under substantially higher humidity. This pattern is consistent with the role of atmospheric vapor pressure demand in controlling open water evaporation. Poós and Varju [7] showed that evaporation and mass-transfer coefficients depend strongly on air velocity, water temperature, air temperature, and relative humidity. Similarly, the results of another study demonstrated that a 5 °C increase in surface-water temperature produced an average evaporation increase of 3.5 mm d^{-1} , although the magnitude varied with meteorological conditions [30]. At lake and reservoir scale, heat storage, vertical temperature gradients, mixing, bathymetry, and seasonal thermal memory strongly influence evaporation. Zhao et al. [2] showed that explicitly representing water-column heat storage improved the simulation of lake evaporation and its seasonal variation.

The present results therefore suggest that atmospheric forcing interacted with partial physical coverage; however, the contributions of individual meteorological variables cannot be separated because wind speed and water-surface vapor pressure were not directly measured. For the present geometry, the plan area is only 0.0255 m^2 and the water volume is approximately 2.55 L. The resulting high wall/bottom boundary area relative to water volume, together with a 10 cm water depth, makes conductive wall exchange, bottom heat transfer, and edge effects proportionally more important than in large water bodies. Because

no insulated control or boundary heat-flux measurement was included, these contributions cannot be quantified separately or corrected retrospectively. The light-yellow, black, and soil-bed support configurations may therefore affect the complete heat-transfer environment rather than functioning solely as isolated albedo treatments.

This scale limitation also reflects the broader complexity of natural water systems, in which hydrodynamics interact with morphology, sediment transport, ecological processes, and boundary conditions over much larger spatial and temporal scales. For example, Zhi et al. [31] used an integrated numerical framework to examine coupled river-flow, sediment-deposition, wetland-morphology, and vegetation responses in the Yellow River Delta. Although their study concerns coastal-wetland restoration rather than evaporation control, it illustrates why responses observed in small experimental vessels cannot be transferred directly to natural water bodies without considering interacting hydrological and ecological processes. The importance of considering multiple atmospheric drivers is also supported at broader scales by Jin et al. [32], who showed that actual evapotranspiration variability reflects multiple environmental controls and identified wind speed as an important contributor to global AET trends. Although their analysis concerns terrestrial evapotranspiration rather than open-water evaporation, it reinforces the general point that meteorological variability can substantially confound comparisons performed on different dates.

3.6. Experimental Uncertainty, Scale Limitations, and Future Research Priorities

The principal uncertainty of the present exploratory study arises from the absence of independent spatial replication. One vessel represented each coverage treatment within each experimental scenario, and the ten hourly temperature observations therefore constitute repeated temporal measurements of the same experimental units rather than independent replicates. No inferential statistical tests are consequently applied, and the observed treatment differences should not be interpreted as statistically established effects. Measurement uncertainty is also important. The PT100 probes have a stated accuracy of ± 0.3 °C, giving an approximate root-sum-of-squares uncertainty of ± 0.4 °C for a difference between two independently measured temperatures; several mean treatment differences in S1 and S2 were of this same order. Similarly, the ± 1 mm water-depth reading uncertainty produces an estimated ± 1.4 mm uncertainty in calculated daytime water-level decline, which is substantial relative to several 1–2 mm treatment differences. Accordingly, all differences reported in the present study are interpreted as scenario-specific preliminary observations that motivate further testing, rather than as performance metrics that can be generalized beyond the present experimental setup.

Additional uncertainty arises from incomplete characterization of the environmental and boundary conditions. Wind speed and direction were not measured, solar-radiation data were obtained from an external meteorological source rather than an on-site pyranometer, and the three support configurations were tested on different dates. Consequently, meteorological variability and support-boundary effects cannot be separated. Furthermore, the shallow 10 cm water column, transparent walls, small plan area, short fetch, and high boundary-area-to-volume ratio may amplify bottom, wall, and edge heat transfer relative to natural water bodies. The optical properties and time-dependent spatial distribution of the silver-colored discs were also not quantified. These factors restrict the present findings to reduced-scale mechanism screening and preclude direct extrapolation to reservoir-scale performance.

Future studies should therefore employ replicated experimental units for each coverage level, randomized vessel positions, and gravimetric measurements of water loss with simultaneous water-level verification. Continuous on-site monitoring of solar irradiance,

wind speed and direction, air temperature, relative humidity, and water temperature at multiple depths would allow a more rigorous assessment of the coupled thermal and evaporative response. For larger-scale assessments, such in situ measurements could be complemented by multisource remote sensing and data-driven monitoring frameworks. Guan et al. [33], for example, combined multisource ocean observations with clustering and machine-learning methods to estimate mixed-layer depth, demonstrating the potential of integrated observation frameworks for characterizing spatially heterogeneous thermal conditions in large water bodies. Similar approaches could complement field measurements in future scale-up studies of floating-cover systems.

Direct optical characterization of the silver-colored prototype discs, including solar-weighted reflectance and absorptance, together with measurements of substrate thermal and spectral properties, would further help separate the effects of surface reflection, evaporation suppression, and boundary heat transfer. For subsequent scale-up, experiments should be extended to larger and deeper water bodies and repeated under contrasting meteorological conditions and over longer periods. Moreover, additional investigations should address disc aggregation and spatial distribution, wind-wave stability, and long-term material durability. For any future biodegradable implementation, biodegradation rate alone should not be treated as evidence of ecological safety; degradation products, fragmentation, freshwater/marine ecotoxicity, bioaccumulation potential, and material fate would require dedicated assessment.

Future surface design may also consider controlled microstructuring as an additional means of modifying interfacial heat and mass transfer. For example, Li et al. [34] demonstrated that engineered copper-foam microstructure and surface treatment can substantially alter vapor-phase transport and condensation behavior in a solar water-production system. Although that process differs from the present floating-cover application, it illustrates how engineered surface morphology could become a design variable in future studies aimed at managing the evaporation–temperature trade-off.

4. Conclusions

A reduced-scale exploratory outdoor experiment was conducted to examine water-temperature response and daytime water-level decline associated with 0%, 10%, and 25% nominal projected coverage by silver-colored floating polyethylene discs under three coupled meteorological and support-boundary scenarios. The principal preliminary observations from these exploratory trials are as follows:

- Across the three unreplicated exploratory trials, the covered vessels exhibited smaller measured daytime water-level declines than the uncovered vessel. The derived relative reductions were highly sensitive to the ± 1 mm water-level measurement uncertainty and are therefore interpreted as approximate water-level-based estimates rather than precise estimates of evaporative water-loss reduction. In every experimental configuration, final water depth followed the order $C_{25} > C_{10} > C_0$.
- The direction and magnitude of observed water-temperature differences varied among the three coupled scenarios. The small mean differences in S1 and S2 were comparable with nominal probe uncertainty, whereas the larger S3 separation reached -1.5 °C on average and -3.1 °C at 18:00; nevertheless, these observations remain unreplicated.
- The exploratory data indicate that water-level decline and water-temperature response should be evaluated as separate observables: a smaller water-level decline did not necessarily coincide with a lower water temperature in every tested scenario. Therefore, water temperature should not be used as a proxy for reduced evaporative water loss.
- Across the three tested reduced-scale scenarios, C_{10} and C_{25} exhibited smaller observed daytime water-level declines than C_0 . However, because the experiments were

unreplicated and the derived reductions are sensitive to water-level measurement uncertainty, the present results do not establish an optimum coverage fraction or field-scale water-conservation performance. They instead provide a basis for designing replicated experiments with improved water-mass, meteorological, optical, and thermal measurements.

Overall, the study provides exploratory experimental observations showing that low fractional coverage by freely floating silver-colored discs was associated with differences in both daytime water-level decline and shallow-water temperature under the tested outdoor conditions. The observations also indicate that these two responses need not vary in parallel and that their interpretation is sensitive to meteorological forcing, measurement uncertainty, and reduced-scale boundary effects. The findings should therefore be regarded as mechanism-screening observations that support the design of subsequent replicated experiments, rather than as direct validation of evaporative water-loss reduction or reservoir-scale performance.

5. Patents

The concept described in this manuscript is the subject of a Registered Italian patent application No. 102026000013066.

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Abbreviations

The following abbreviations are used in this manuscript:

AOAM	Arctic Ocean albedo modification
CESM	Community Earth System Model
MCB	Marine cloud brightening
RH	Relative humidity
TDS	Total dissolved solids

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