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Fractal-Fin, Dimpled Solar Heat Collector with Solar Glaze

Sal Rodriguez, Moises Beato, Graham Monroe, Rob Sharpe, and Ron Hrzich

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

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ABSTRACT

Exterior solar glaze was added to a 3 foot x 3 foot x 3 foot aluminum solar collector that had six triangular dimpled fins for enhanced heat transfer. The interior vertical wall on the south side was also dimpled. The solar glaze was added to compare its solar collection performance with unglazed solar collector experiments conducted at Sandia in 2021.

The east, west, front, and top sides of the solar collector were encased with solar glaze glass. Because the solar incident heat on the north and bottom sides was minimal, they were insulated to retain the heat that was collected by the other four sides.

The advantages of the solar glaze include the entrapment of more solar heat, as well as insulation from the wind. The disadvantages are that it increases the cost of the solar collector and has fragile structural properties when compared to the aluminum walls. Nevertheless, prior to conducting experiments with the glazed solar collector, it was not clear if the benefits outweighed the disadvantages. These issues are addressed herein, with the conclusion that the additional amount of heat collected by the glaze justifies the additional cost.

The solar collector glaze design, experimental data, and costs and benefits are documented in this report.

ACKNOWLEDGEMENTS

The NMSBA is thanked for enabling this work, which culminated in the construction of a complex, fully-passive, glaze window, aluminum fractal fin dimpled solar collector with computer-machined dimpling for enhanced heat transfer. The efforts of the engineers and technicians associated with this project are also gratefully acknowledged.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
CNC	computer numerical control
ROI	return on investment
SNL	Sandia National Laboratories
T	Temperature (K, °F)
TC	thermocouple

1. INTRODUCTION

There is a strong market demand for energy-collecting devices that have few, if any, moving parts and that are economical and environmentally friendly, especially for off-the-grid and rural applications. The hot water can be stored in the solar collector for future use, or piped into a separate tank, and thereafter used for bathing, heating, and other routine homestead and greenhouse applications. The solar-heat collection device discussed in this report consists solely of passive heat transfer mechanisms (solar heat, conduction, and convection), and has no moving parts. This effort represents the culmination of the designs, experiments, and simulations conducted during 2015, 2016, and 2020 [Rodriguez et al., 2015; Rodriguez et al., 2016A; Rodriguez et al., 2016B; Rodriguez, 2020; Rodriguez et al., 2021].

For the final phase of the solar collector, exterior solar glass glaze was added to the 3 foot x 3 foot x 3 foot aluminum collector that was constructed and tested via computer numerical control (CNC) [Rodriguez et al., 2021]. The advantages of the solar glaze include the entrapment of more solar heat and insulation from the wind. The disadvantages are that it increases the cost of the solar collector, and the glass is brittle. Prior to conducting the set of experiments involving the glaze, it was not clear if the benefits outweighed the disadvantages; hence the reason for this undertaking. The solar collector glaze design, experimental data, and costs and benefits are discussed in Sections 2, 3, and 4, respectively.

2. SOLAR COLLECTOR GLAZE DESIGN

Solar glaze was added to the dimpled, fractal-fin solar heat collector to compare its performance vs. the unglazed solar heat collector experiments that were conducted at Sandia in 2021 [Rodriguez et al., 2021]. The original, hand-sketched conceptual schematic of the glaze design is shown in Figure 2-1, which consists of glazed glass panes and structural iron rods.

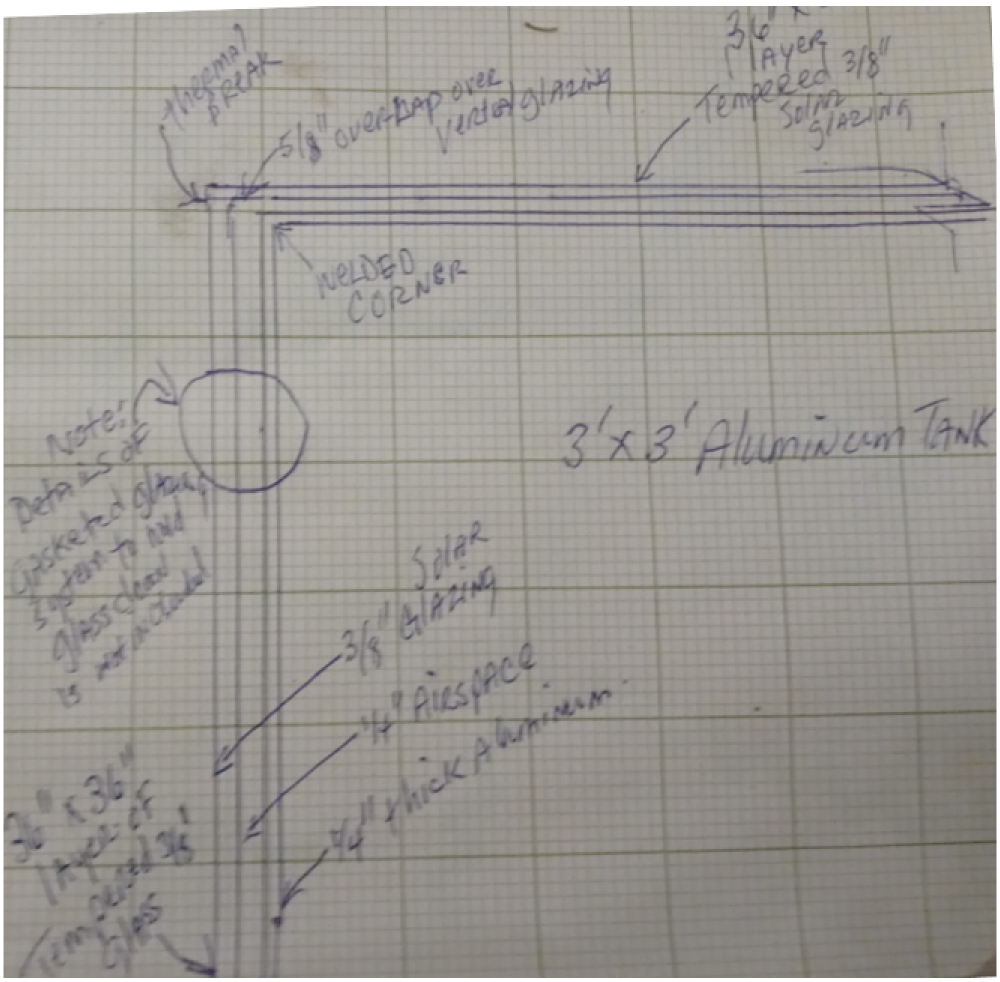

Figure 2-1. Schematic of the glaze structure with respect to the aluminum solar-heat collector.

Note that the glaze was designed to encapsulate the dimpled, fractal-fin solar heat collector, and therefore, had a cubic shape. The glaze encapsulation was constructed to provide an encapsulating layer for the solar collector east, west, front, and top lateral sides, as shown in Figure 2-2. By contrast, the bottom and north sides of the solar collector were insulated to retain heat, as those sides collect a minimal amount of solar energy.

As shown in Figure 2-2, 12 rectangular iron rods were welded together to form a cube, for the purpose of supporting the glaze assembly. There was a ¼ inch air gap between the aluminum solar collector and the glass, which was open to the environment in the sense that the gaskets, iron rods, and insulation at the northern side did not form a perfect seal. The air gap traps the solar heat that passes through the glaze, which is then convected and conducted onto the aluminum walls. Certainly, gases other than air have a higher thermal diffusivity. For example, the thermal diffusivity of air at 350 K is 0.3 $x10^{-4}$ m^2/s, while that of helium is $2.4x10^{-4}$ m^2/s, which is eight times higher. However, the replacement of air will incur higher manufacturing and maintenance expenses, as it requires a pressurized helium gap between the solar collector and glaze.

The glaze consisted of a tempered, low iron, extra clear glass (not UV reflective glass), which has a high energy transmittance and reduced sunlight reflectance. The four glazed glass panes and welded rod frame were manufactured at "Affordable Glass and Mirror", 120 B Menaul Blvd. NW, Albuquerque, NM 87107, (505)-246-2997. The total cost was $2,600, including parts, labor, and taxes.

The thermocouple (TC) placement is shown in Figures 2-7 and 2-8. Figure 2-7 shows the west and north TCs, while Figure 2-8 shows the east and top TCs.

Figure 2-2. Glaze structure showing the glass and support iron rods.

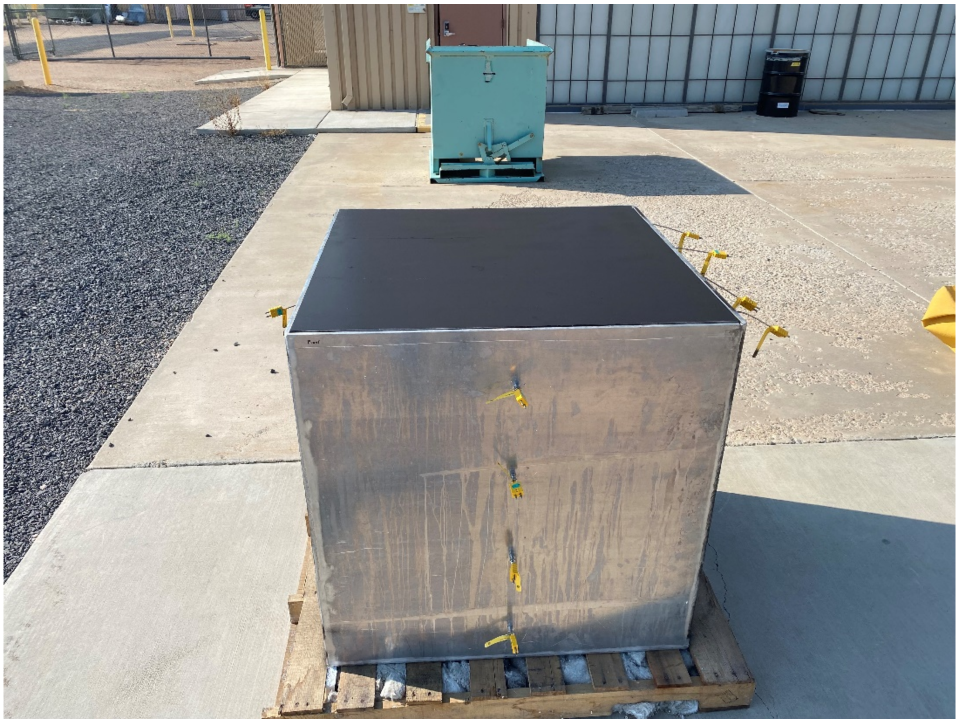

Figure 2-3. Dimpled, fractal-fin solar collector prior to adding the glaze enclosure.

Figure 2-4. Fractal-fin solar collector inside the glaze containment.

Figure 2-5. Instrumentation of the glaze, fractal-fin solar collector assembly.

Figure 2-6. Fully-instrumented glaze solar collector placed outside the assembly building to enable solar heat collection.

Figure 2-7. Configuration of the west and north TCs.

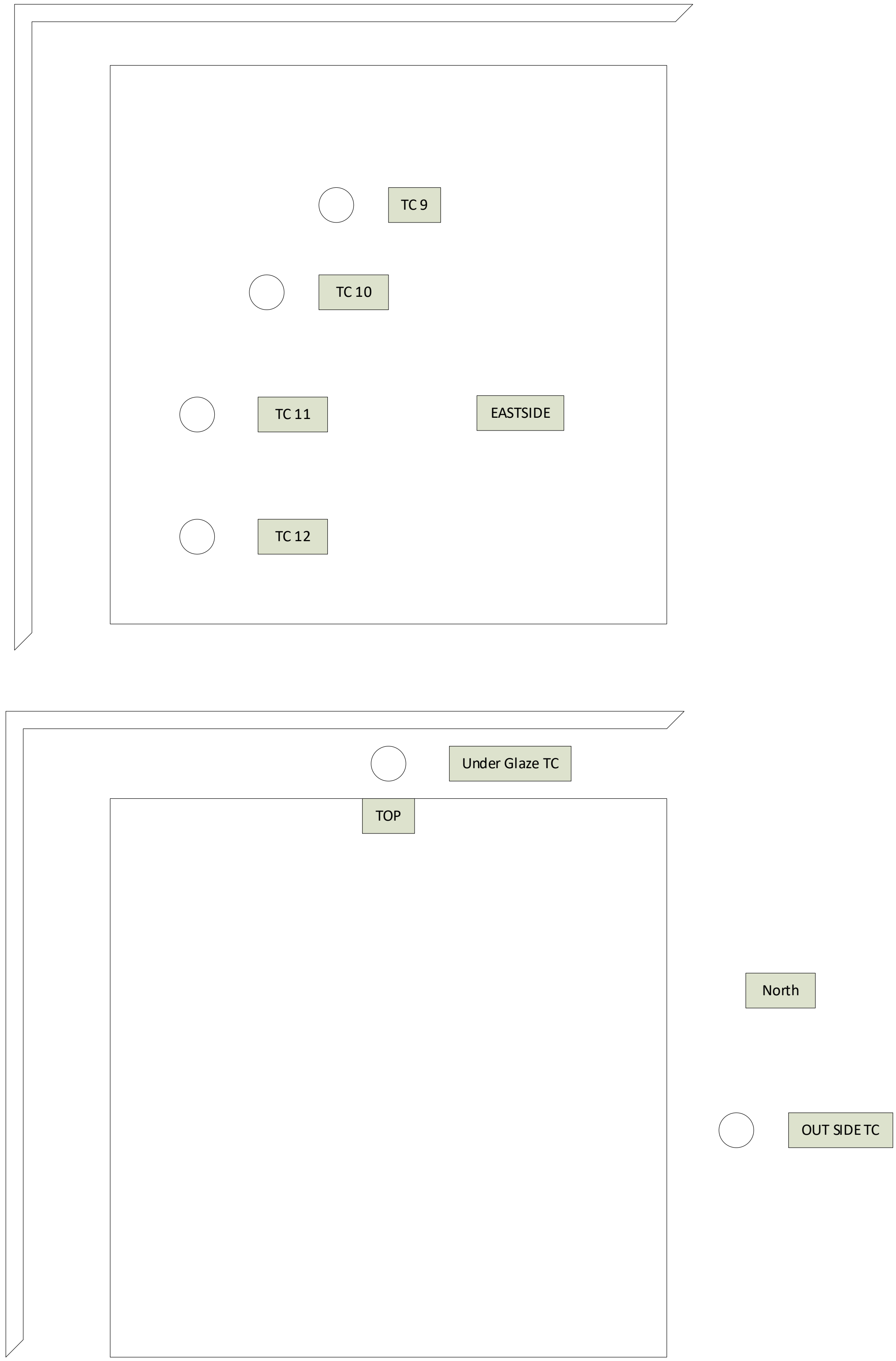

Figure 2-8. Configuration of the east and top TCs.

3. SOLAR COLLECTOR EXPERIMENTS

The solar collector experimental data are discussed in this section. TC experimental data was collected during five multi-daytime time periods that included both day and night temperature recordings, as follows:

- June 14 – 19, 2022
- July 7 – 11, 2022
- July 11 – 14, 2022
- July 14 – 17, 2022
- July 18 – 21, 2022

The experimental data is shown in Figures 3-1 through 3-5, respectively, for the five time periods. Note that the glaze temperature fluctuated +/- 10 °F, only during the day. This is attributed to small, transient cloud formations, as the skies were generally clear.

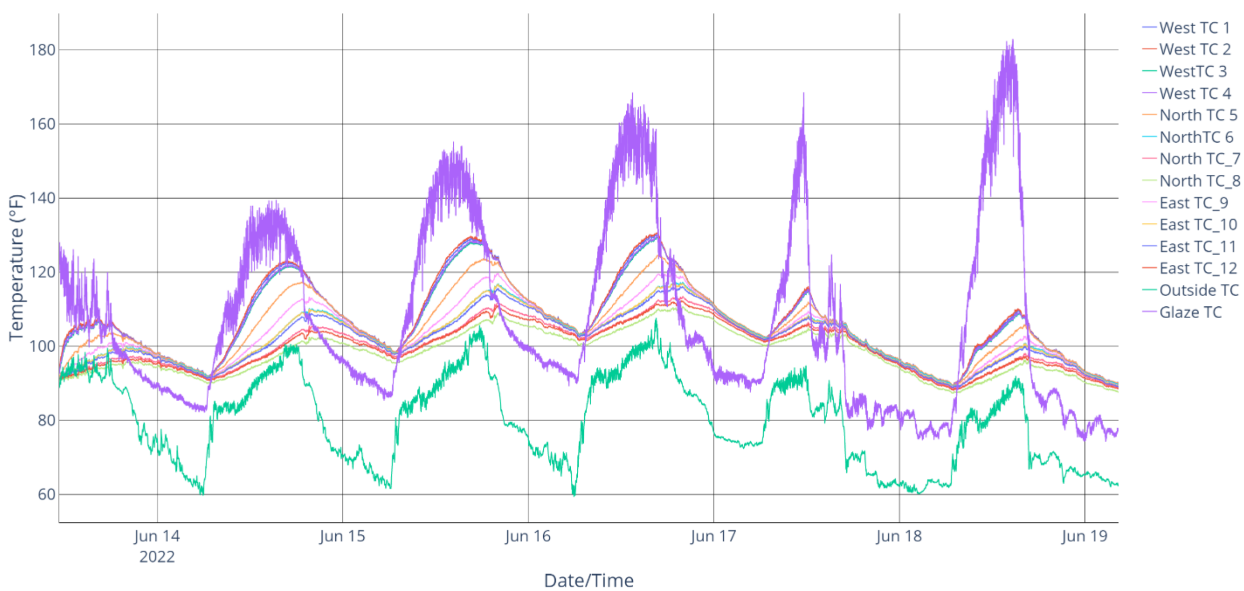

Figure 3-1. June 14 – 19, 2022 TC temperature.

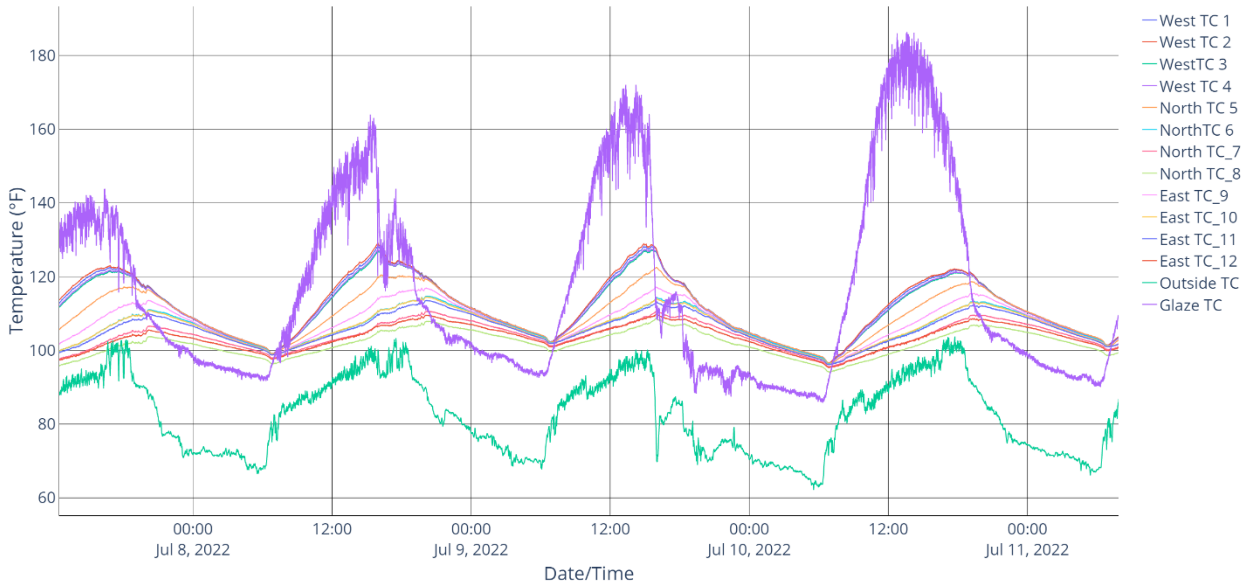

Figure 3-2. July 7 – 11, 2022 TC temperature.

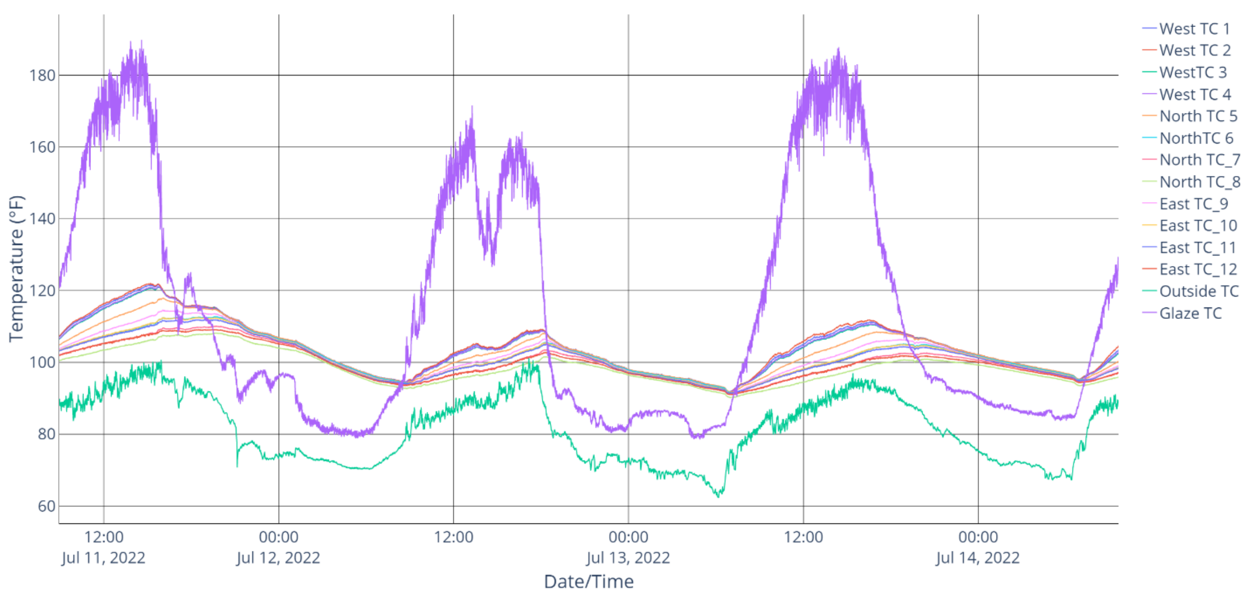

Figure 3-3. July 11 – 14, 2022 TC temperature.

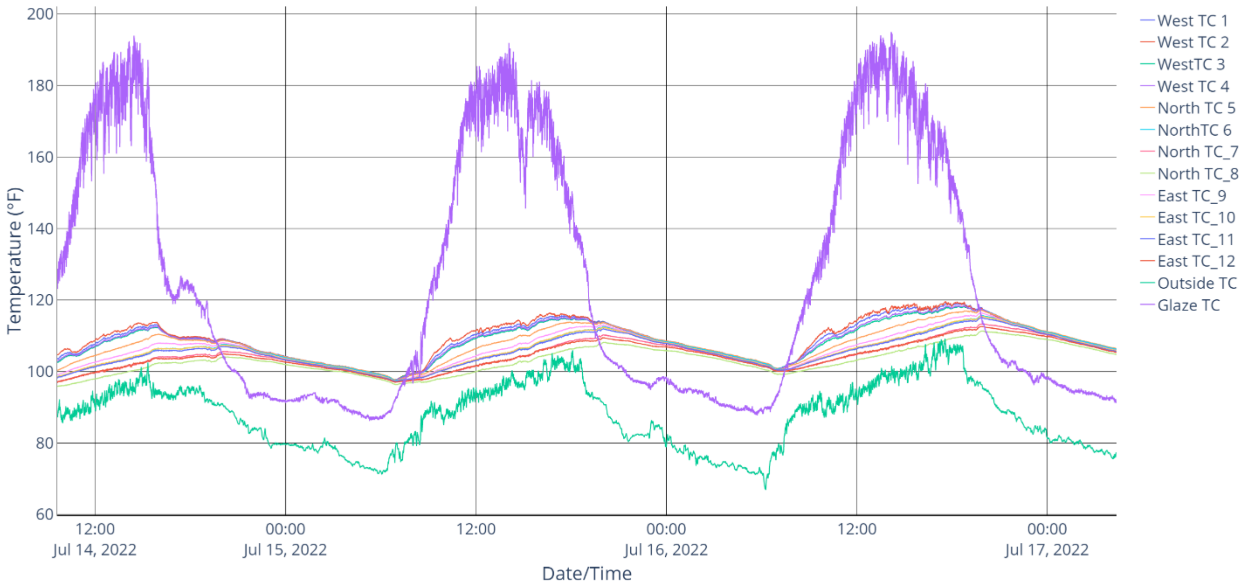

Figure 3-4. July 14 – 17, 2022 TC temperature.

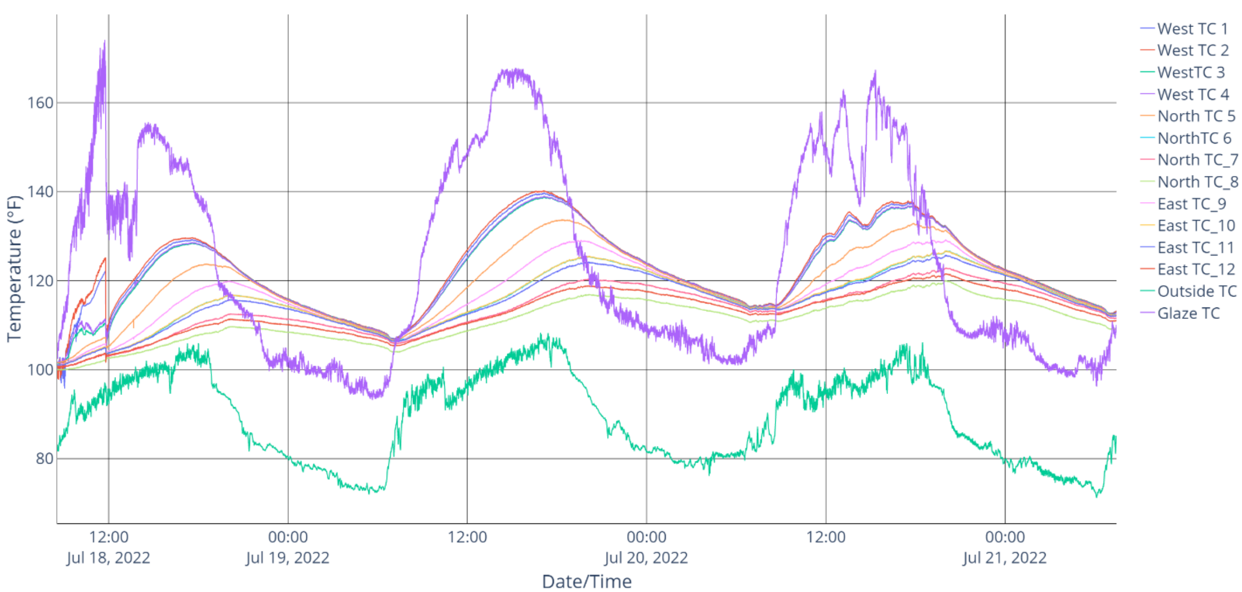

Figure 3-5. July 18 – 21, 2022 TC temperature.

The peak glaze, water, and air temperatures are summarized in Table 3-1, and are compared with the top-performing unglazed 2021 experiment. The table shows that the peak ambient temperature ranged from 99 to 106 °F, reflecting that the data was recorded during some of the hottest days of the year, and with little to no cloud cover and no smoke particulates in the air due to forest fires. This resulted in peak glaze temperatures that ranged from 173 to 193 °F, while the peak water temperatures ranged from 119 to 140 °F. There is a reasonable data correlation and consistency for the first four time periods, while the July 18 – 21 data show a significantly-higher peak water temperature of 140 °F, despite the glaze temperature being one of the lowest. The reason for this is that for the fifth and final experiment (e.g., the July 18–21 experiment), any visible small leakage gaps between the glaze, insulation, and bars were carefully sealed to retain as much heat as possible within the air gap. Hence, more heat was conducted from the glaze, through the air gap, and into the water, thereby reducing the glaze temperature, while increasing the water temperature. *This not only shows the importance of the insulation, but also of having a well-sealed glaze/solar collector system. Thus, the July 18—21 experimental data is more prototypic of the glazed solar collector design. That said, a hermetically-sealed glazed solar collector will probably have an even higher thermal performance than was measured during the fifth experiment.*

Table 3-1. Summary of peak glaze, water, and air temperature.

	September 9 – 13, 2021 (no glaze)	June 14 – 19, 2022 (glazed)	July 7 – 11, 2022 (glazed)	July 11 – 14, 2022 (glazed)	July 14 – 17, 2022 (glazed)	July 18 – 21, 2022 (glazed; improved gap seal)
T_{glaze} (°F)	N/A	173	187	190	193	175
T_{water} (°F)	116	130	130	122	119	**140**
$T_{ambient}$ (°F)	104	106	102	99	106	106

The final comparison for the glazed vs. unglazed solar collector is shown in Figure 3-6, which shows the thermal performance for the unglazed (left) and glazed (right) solar collectors.

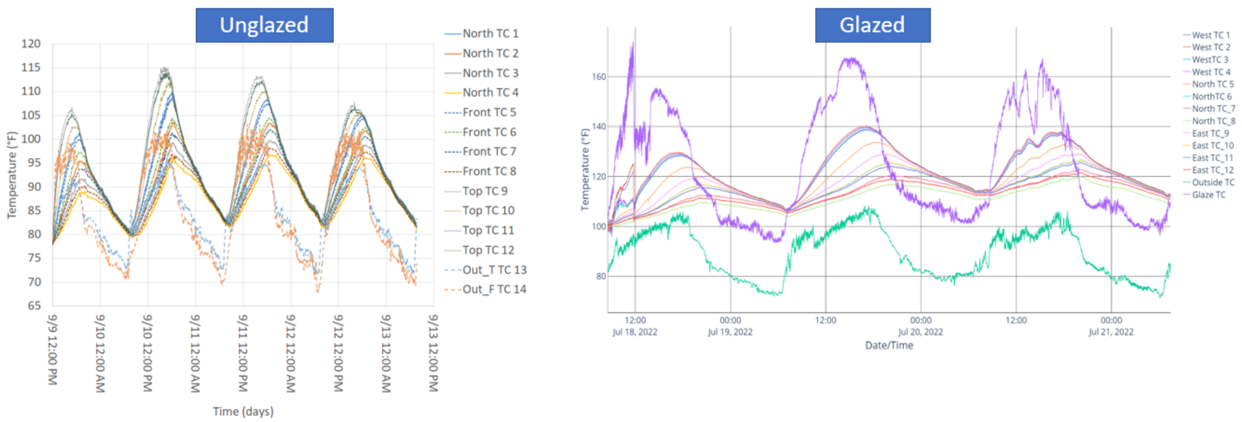

Figure 3-6. Water temperature heat-up performance comparison between the peak-performing, unglazed (left) and glazed (right) solar collectors.

4. BENEFITS, DISADVANTAGES, AND COST OF SOLAR GLAZE

For the unglazed solar collector experiments conducted in 2021 [Rodriguez et al., 2021], the peak water temperature was 116 °F, with a peak ambient temperature of 104 °F. For comparison, the best peak water temperature performance for the glazed solar collector was 140 °F, with a peak ambient temperature of 106 °F. Since both ambient temperatures are relatively close, this facilitates their comparison (albeit at a 2 °F disadvantage for the glazed collector), conservatively showing an additional water temperature increase of 24 °F; adding the 2 °F disadvantage, *the glazed solar collector outperformed the unglazed collector by 26 °F.* This corresponds to a significant water temperature increase, though this increases the cost per unit, and the glass represents a structural weak point.

During the 2021 analysis, it was noted that for the aluminum sheets + *burdened labor* (CNC, welding, machining, and assembly) + miscellaneous items, the cost for one solar collector was $1,320.62 + $2,081.10 + $459.81 = $3,862 [Rodriguez et al., 2021]. The four glazed glass panes and welded rod frame cost $2,600, including parts and labor. Therefore, the total cost rises to $6,462, not including any inflationary costs.

However, as noted in the 2021 analysis, the cost of the unglazed unit can be reduced if the solar collector is built in high numbers. Moreover, more than half the cost results from labor; this cost can be reduced if automation is employed, thereby potentially reducing cost by a factor of about 50%. If so, the labor cost per unit is reduced by $1,040.55, resulting in an unglazed unit cost of $2,821. The same arguments can be applied to the glaze structure; for conservativeness, assume that only a 40% reduction in cost can be achieved via automation and high-number production. If so, then the mass-produced glaze confinement is expected to cost $1,300 per unit. ***Under these assumptions, the glazed solar collector costs $2,821 + $1,300 = $4,121 per unit.***

The return on investment (ROI) time period for the glazed fractal fin dimpled solar collector is typical of solar panels, on the order of 11.7 years <u>if performed similarly to the unglazed solar collector</u> (vs. 8 years for the unglazed solar collector); <u>but clearly, the glazed solar collector outperforms the thermal performance of the unglazed solar collector, so this must be factored into the ROI time period</u>. In particular, its ability to heat up the water by an additional 26 °F means that it has a higher thermal output, which is calculated as follows, and reflected onto the ROI time period: the unglazed experiment water temperature rose from 83 to 116 °F (i.e., from 301.5 and 319.8 K, a net rise of 18.4 K), while the glazed experiment water temperature rose from 83 to 140 °F (301.5 and 333.2 K, a net rise of 31.7 K). Hence, the increased performance is 31.7/18.4, or a factor of 1.73. This implies that the glazed solar heater has a ROI time of approximately 11.7/1.73 = 6.8 years. Note that this analysis does not consider potential tax breaks and/or subsidies, so the ROI time period would be lower in such cases.

Moreover, an advantage of the fractal fin dimpled solar collector is its affordability vs. home solar panels. For example, according to ConsumerAffairs, the average cost for home solar panel installation in New Mexico is $16,680 [Parkman, 2021]. Thus, consumers desiring to supplement their energy usage and reduce their environmental footprint via green energy can do so at a much lower cost via the glazed, fractal fin solar collector. Thus, buyers can join the green market at a fraction of the cost for solar panels. For such comparison, the buyers can get up to four glazed dimpled fractal fin solar collectors for the equivalent cost of a single home solar panel.

5. CONCLUSION

A glazed glass exterior containment was incorporated onto the dimpled fractal fin solar collector for the purpose of capturing more solar heat and providing protection from convective wind losses. Then, solar collection experiments were performed to compare its thermal performance against an unglazed, dimpled fractal fin solar collector.

The experimental data shows that the glazed solar collector outperformed the unglazed collector by 24 to 26 °F. The experiments also showed the importance of sealing any visible small leakage gaps between the glaze, insulation, and structural iron bars; providing a hermetic seal is crucial for higher thermal performance. Moreover, by employing a replacement gas instead of air (e.g., helium), the thermal diffusivity could be increased by a factor of eight.

As noted in the 2021 analysis [Rodriguez et al., 2021], if automation and high-volume manufacturing are considered, the glazed collector will cost $4,121 per unit and have a 6.8 year ROI time period, not including tax breaks and/or subsidies.

REFERENCES

Fuego Theory Manual, "SIERRA Low Mach Module: Fuego Theory Manual – Version 5.2", Sandia National Laboratories, SAND2021-12242, 2021A.

Fuego User Manual, "SIERRA Low Mach Module: Fuego User Manual – Version 5.2", Sandia National Laboratories, SAND2021-12243, 2021B.

Holman, J. P., Heat Transfer. McGraw-Hill, Seventh Edition, New York, 1990.

Hurst, J., "How Long Will Your Solar Panel Payback Period Be?", EcoWatch, https://www.ecowatch.com/solar-panel-payback-period-2655204475.html. Accessed on December 1, 2021.

Parkman, K., "How Much Do Solar Panels Cost?", ConsumerAffairs, https://www.consumeraffairs.com/solar-energy/how-much-do-solar-panels-cost.html. Accessed on December 1, 2021.

Rodriguez, S. et al., "Modular Solar Pond Greenhouses", Sandia National Laboratories, 2015.

Rodriguez, S. et al., "Modular Solar Water Tanks with Enhanced Heat Transfer Surfaces", Sandia National Laboratories, 2016A.

Rodriguez, S. et al., "Modular Solar Water Tanks with Enhanced Heat Transfer Surfaces—Final Addendum", Sandia National Laboratories, 2016B.

Rodriguez, S., *Applied Computational Fluid Dynamics and Modeling—Practical Tools, Tips, and Techniques*, Springer Publishing, 2019.

Rodriguez, S., "Dimpled and Undimpled Fractal Fin Solar Heat Collector", Sandia National Laboratories, 2020.

Rodriguez, S. et al., "Fractal-Fin, Dimpled Solar Heat Collector with Solar Glaze Testing", Sandia National Laboratories, SAND2021-15427, 2021.

Wilcox, D. C., *Turbulence Modeling for CFD*, 3rd Ed., DCW Industries, Inc., 2006.

ZipRecruiter, "What Is the Average Machinist Salary by State", https://www.ziprecruiter.com/Salaries/What-Is-the-Average-Machinist-Salary-by-State. Accessed on November 11, 2021.

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