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The Geometry of Water: Shaping Terra Cotta for Evaporative Cooling in Urban Heat Islands

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Abstract

Building facades not only serve as protective envelopes for the interior, but critically shape the urban microclimate outside it. Working with US fabricators Boston Valley Terra Cotta, Behnisch Architekten researched the potential of terra cotta facade cladding to improve thermal comfort in the context of urban heat islands (UHI). By combining geometric strategies such as shingling, pleating, folding, dimpling, and capillary geometry with the porosity of terra cotta, the team proposed a market-ready facade system which uses water and vegetation to buffer urban microclimates from heat stress in a four seasons climate. The research was done in collaboration with Transsolar KlimaEngineering (climate engineering), knippershelbig (facade engineering), and Tripyramid Structures (metal fabrication).

Keywords: Urban Heat Islands, Microclimates, Terra cotta, Evaporative Cooling, Digital Fabrication, Pleating, Ceramics, Hydraulic Geometry

1. Introduction

Urban heat islands, a phenomenon caused by the aggregation of heat-trapping materials in the built environment, is one of the most dangerous effects of climate change (Samuelson et al., 2020). With the global urban population projected to rise from the present rate of 55% to 68% by 2050 (UN Department of Economic and Social Affairs, 2018, para. 1), it is essential to understand how building materials can either exacerbate or alleviate urban heat stress.

Public spaces form the social and economic backbone of many urban communities and require comfortable thermal conditions to thrive. Our test case is located in Boston's Chinatown, where a public park serves as a vital gathering place for elderly immigrants from Taishan, China. It supports immigrant, multigenerational communities with free space for socializing, exercise, and childcare. With increasing peak temperatures rising in Boston, this everyday *life between buildings*, especially critical for elderly populations, is at risk (Gehl, 2011, p.50).

Cities around the globe are adapting to increased heat stress by increasing tree canopy coverage, requiring high-albedo surfaces, green roofs, and vegetated façades to mitigate peak heat and storm surges. At the same time, the lateral growth of cities has been supplanted by intense vertical densification (Frolking et al., 2024) often clad in glass due to market and labor efficient-curtain walls and highly-prized views to the outside (Turan et al., 2021). Growing awareness of highly-glazed facades and their dependence on cooling and heating energy has led jurisdictions worldwide to implement energy codes, like the Massachusetts STRETCH code (Velikov et al., 2025), that limit window-wall ratios and prescribe minimum thermal requirements (U-values). Therefore, the thermal properties of opaque surfaces will play an important part in tempering urban heat stress.

Climate change will bring not only rising temperatures but also more rainfall, especially in the U.S. Northeast, where extreme precipitation events have already increased by 60% (Whitehead, 2023,p. 21-1–21-52). The Intergovernmental Panel on Climate Change (IPCC) also projects a precipitation increase of 5–15% (Marvel et al., 2023, p. 2-1 – 2-43) in the coming decades. Slowing and delaying water runoff, while simultaneously retaining excess moisture, would help both excess precipitation and lower urban surface temperatures.

With increasing urbanization, rainfall, and the critical role that urban public spaces play in sustainability and quality of life, our research hypothesizes that the geometric and material configuration of building facades can enhance thermal comfort in public spaces in the context of urban heat islands.

2. Literature Review

This research builds upon climate adaptation strategies from vernacular architecture and urban form, the recent advances around performative ceramics enabled by digital technologies, research on geometry and its relationship to moisture and solar radiation in animals and buildings, and building energy and thermal comfort modeling.

The interrelationship between building materials and geometry and its interaction with natural forces showcases the resourcefulness of societies before the advent of energydependent building systems. The stepped white roofs of Bermudan houses that slow and redirect scarce rainwater while deflecting solar radiation with high albedo limestone, exemplifies the holistic relationship between individual buildings and communal resources, geometry, materiality, color, rainwater and the sun.

The innate ability of earthen materials to passively cool has been deployed by civilizations around the globe since ancient times (Ben-Alon et al., 2022). The Jaliis of India and Mashrabiya of the Middle East and North Africa, are ingenious examples of local adaptations in warm climates before the advent of mechanical cooling. Recent projects have reengaged the potential of passive cooling with terra cotta with intricate geometries enabled by digital tools and fabrication. Examples such as Modulo Continuo by Amelia Gan et al., and Dilara Temel and Lachlan Fahy's TerraCool, maximize surface area for evaporative cooling with topological terra cotta modules, yet are limited to climates above freezing temperatures (Gan et al., 2022). Water expands when frozen and terra cotta with its low tensile strength is highly susceptible to ruptures during freeze thaw cycles. Additionally, geometric ceramic screens are not stand-alone facades, but breeze blocks, which require an additional weather envelope behind it. A complete weather-wall strategy which addresses the multiple requirements of building enclosure (water and vapour control, insulation, fenestration) is needed in four seasons climates such as New England and other similar climates located in Europe, Southern Africa, East Asia, and South America, which experience dramatic swings from hot summers to freezing winters, and vice versa.

Animals also use geometry and water to mitigate heat stress for their survival. In *Textured Building Facades: Utilization Morphological Adaptations Found in Nature for Evaporative Cooling*, the authors tested various parametric permutations exploring the pattern inspired by cracks in elephant skin and found correlations between depth of pattern, thickness, scale of pattern, and color of the material, on the ability of the surface to remain cool after wetting (Peeks, 2021). They also referenced the Namib desert beetle, where the alternating hydrophilic and hydrophobic zones capture and direct water through a gradient of surface roughness, which was a technique that was used in the glazing strategy for our facade prototype. The biomimicry precedents demonstrate how adaptive geometries in nature can be abstracted into scalable architectural systems.

Quantifying the relationship between facades (albedo, thermal mass, color, porosity, reflectivity, vegetation) and human thermal comfort in the public realm, has been extensively researched. Researchers in Indonesia tested various facade types and found that conventional dark red brick walls, metal sheets, and cement-based panels exhibited overheating, while painting them with reflecting coating, and introducing vegetation, lowered the surface temperatures and adjacent air temperatures near the surface (Ornam et al., 2024). The impact of high albedo surfaces in 3 dimensional spaces is researched in a domestic courtyard in Sevilla, and found that painting all sides of the courtyard white lowered surface temperatures of the walls, but increased the mean radiant temperature inside the courtyard due to solar reflection (Lopez-Cabeza, et al., 2022). Therefore, the geometry of the buildings which form the outdoor space needs to be studied in conjunction with surface temperature readings.

The impact of water is largely absent from the studies which extrapolate air temperatures in urban environments with the materiality facades. Dobravalskis et al. demonstrate that 20.96% of wind-driven rain can be collected from vertical surfaces of building façades. (Dobravalskis et al., 2018, p. 9–58). Our geometry employs 7.5° tilted surfaces to enhance the capture of wind-driven rain, which works in conjunction with the techniques mentioned above to provide a multi-pronged solution to lower surface temperatures to enhance urban thermal comfort.

3. Methodology

Our research was conducted at the 2024 Architectural Ceramics Assemblies Workshop (ACAW) hosted by Boston Valley Terra Cotta, a facade contractor that promotes the exploration of architectural terra cotta through the design-build process of full-scale mockups guided by their materials and expertise. The interdisciplinary team including Behnisch Architekten, Transsolar Klimaengineering, knippershelbig, and Tripyramid Structures, created an integrated façade system designed for market viability, efficient fabrication and installation, freeze-thaw resistance, thermal performance, waterproofing, and lifecycle analysis (refer to Figure 3) through weekly workshops which integrated feedback from industry terra cotta experts.

The base design of the module is a shingle, a New England cladding and water management technique but also used throughout the world. The shingle's modular, overlapping system allows it to weatherproof a wide range of geometries made of locally available cedar, which is not only pragmatic, but embodies the landscape, culture, and climate of New England (Scully, 1955).

The base module is installed as a ventilated rainscreen cladding system, where the shingle acts as the primary weather barrier, and is offset for ventilation and mold prevention from the insulated weather wall behind it. Flat rainscreen geometries are advantageous as they allow for efficient manufacturing via hydraulic RAM-press and efficient layout in the kiln. Complex 3D shapes with undercuts need to be made via slip-cast, which is labor intensive, or 3D-printed, which is time intensive. They often require support structures when firing, increasing material use and kiln space, which significantly raises the embodied energy per piece.

Combining the shingle concept with the rainscreen, we designed an 18” tall x 24” wide, 5/8” thick, 7 pound module sized for a single person to install. A horizontal running bond pattern with overlapping vertical and horizontal joints work to keep the insulation dry and ventilated. Within this format, small geometric operations delay water and encourage seepage, balanced against New England winter conditions. A 2.5” relief depth was guided by observing the terra cotta facades in Boston, such as the ornamented Spanish Renaissance Proctor Building (1897) located at 100 Bedford Street, which has resisted mold and freeze-thaw cycles for well over a century.

Each shingle incorporates a folded gutter at the bottom edge that channels water laterally across the facade while shading the tiles below.. Four weep holes assist in the distribution of water. A 7.5° tilt enhances water retention and a 25° peak fold at the center retains water. Tongue-and-groove ship lap joints prevent uplift and direct water downwards.

The integrated facade prototype is made of three tile modules with the following functions:

1. *Shingle Tile*: Positioned on upper stories, slows water flow to allow lower tiles to store moisture, helping reduce surface temperature and mitigate the urban heat island effect.
2. *Evaporative Cooling (EC) Tile*: Placed near walkable surfaces (within 6 feet), maximizes evaporative cooling to improve outdoor comfort in pedestrian zones like streets and terraces.
3. *Screen Tile*: Functions as a horizontal sunshade over glazing or as a breeze screen for semi-enclosed areas. Its geometry cascades water across the façade and supports natural ventilation cooling. A ⅛" stainless steel tensile rope supports the shelves and provides infrastructure for climbing plants to further shade the facade from solar radiation and cool the air via evapotranspiration.

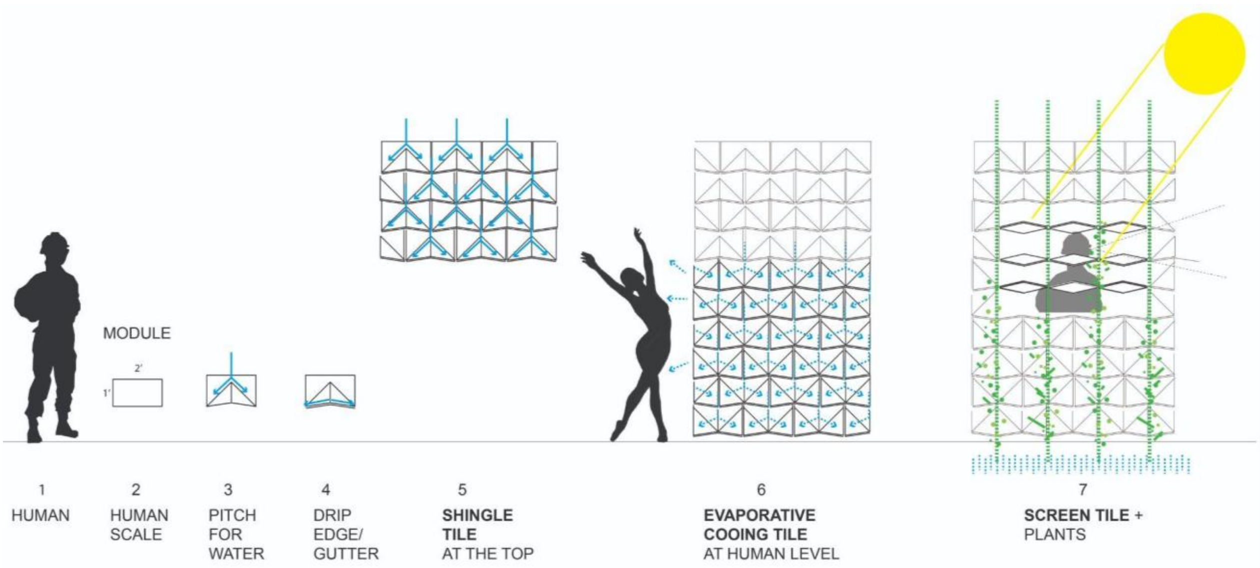

Figure 2: Base module development and tile types.

Figure 3. Left: Wall section with cross-laminated timber (CLT) structure, insulation, rainscreen cladding, and climbing plants. Right: Full-scale facade mockup.

3.1 Surface Texture Methodology

Our geometry was tailored to the constraints of hydraulic RAM press fabrication, which is the most economical and efficient way to produce large quantities of non-linear terra cotta components, at a rate of up to 4 parts per minute with additional post-processing after for edge finishing and mounting detailing. Given the relatively flat geometry required for RAM pressed fabrication, pleating was employed as a key geometric method to channel water diagonally across the terra cotta tile to slow its path to encourage water absorption and increase the surface area of the tile for evaporative cooling.

The pleated geometry was refined through digital modeling, physical prototyping, and performance testing. *Rhinoceros 3D (Robert McNeel & Associates, Version 7, 2020), Grasshopper (McNeel, 2024), and Ladybug (Ladybug Tools, Version 1.7, 2023)* were used to derive and optimize contour lines based on the "pitch for water" (refer to Figure 2). This generated various mountain-valley pleat formations to achieve self-shading high-absorption, unglazed areas, enhance water retention, and guide water flow.

3.2 Pleating and Water Retention

Following shading optimization, we tested pleating strategies to improve water retention and flow. Using *Grasshopper*, the base surface was contoured, and curve lengths organized into lists. Every other contour was offset in the z-direction along surface normals to form mountain-valley ridges. Spacings of 0.00’, 0.02’, 0.0175’, 0.01’, 0.0075’, and 0.005’ (S0–S5) were developed and 3D printed for testing via micropipette droplet method. Three key constraints then guided our design to ensure the tile was ready for fabrication:

1. Master Mold Resolution: mold positives milled with a finishing pass of ¼" ball-end mill which limited feature size and surface detail.
2. Freeze-Thaw Considerations: shallow dimples were adopted over deep pockets to reduce freeze-thaw risks.
3. Edge Fillets: all edges to be filleted to reduce spalling and chipping during de-molding.

3.3 Shingle Tile - Water Retention and Movement Testing Methodology

To assess the impact of surface textures on water behavior, we reviewed standardized methods such as ISO 4920/AATCC 22 and ASTM D570 and D2842. The behavior of water on textured tiles was assessed using droplet application (similar to ASTM D7334) followed by quantitative absorption and qualitative wetting pattern analysis to enable consistent comparisons of water retention and wettability.

Testing Procedure - Measuring the Retention of Water:

1. Zero scale with water collector only.
2. Place tile in the collector.
3. Evenly apply 5 mL of water droplets along the tile’s top edge using a pipette over 30 seconds.
4. Remove tile; collect runoff water in the vessel below, let tile dry.
5. Repeat Steps 1-5 for each tile.
6. Repeat 30x per tile under consistent conditions.

3.4 Shingle Tile - Water Retention Tests and Pleating Spacing

Tests showed that tighter pleats, increased number of contours (refer to Figure 4 - S4,S5), improved water retention, with the S5 configuration retaining the highest amount (~34.1%). However, this pattern posed challenges in fabrication due to the loss of pleat resolution during the RAM press process. On the other end, the widest spacing (S1) was easier to manufacture but retained significantly less water (~9.3%). Tile S3 was selected as the optimal solution because it offered a balanced performance, providing effective water retention while maintaining the pleat definition required for successful RAM pressed fabrication.

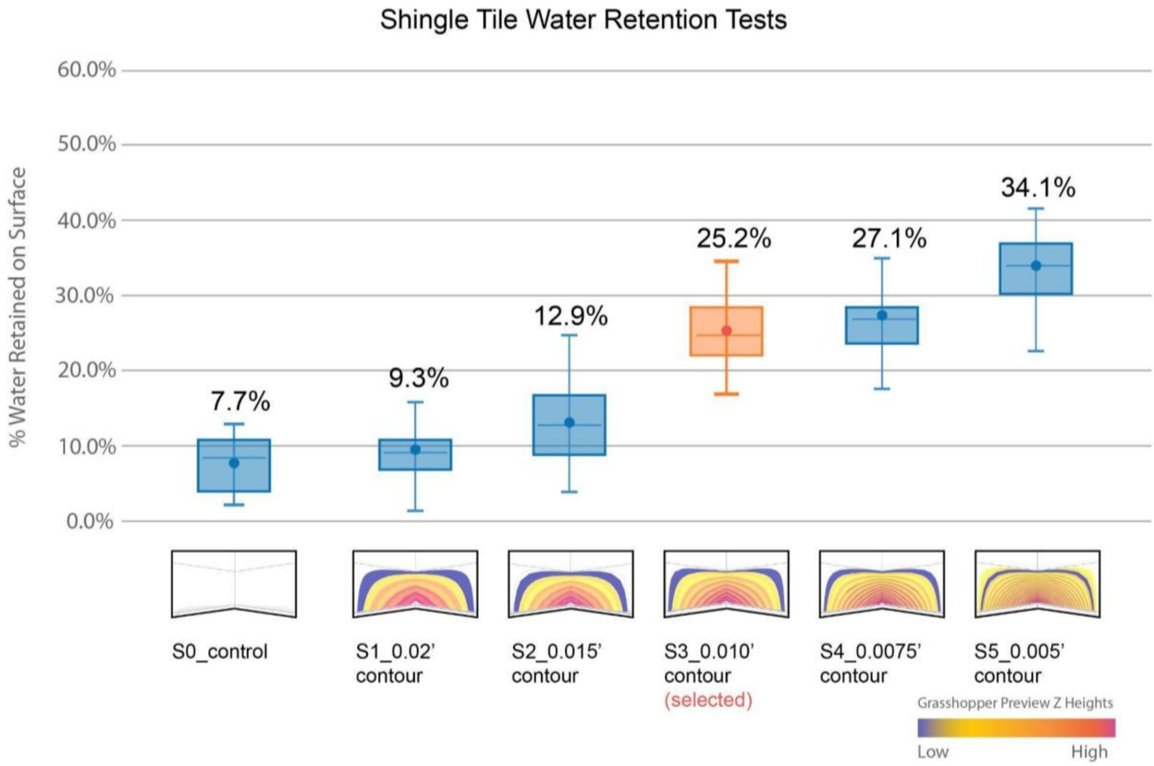

Figure 4: Shingle Tile Water Retention Tests - Increased Number of Pleats Results in Increased % Water Retention.

3.5 Evaporative Cooling Tile - Water Retention and Movement Testing Methodology

The Evaporative Cooling (EC) Tile was designed through digital and physical prototyping to maximize surface area and water retention. This innovation lies in merging global and local geometries—macro pleats for shading and micro dimples tuned to the diameter and behavior of individual water droplets—forming a coupling across scales that translates fluid dynamics into architectural form. The result is a geometry that performs thermally while remaining grounded in fabrication logic. Pleated geometry was refined to enhance capillary action, slowing water flow and improving moisture retention. Unglazed terra cotta was chosen for its natural porosity, allowing gradual evaporation. Based on the Shingle Tile's ribbed form, pleats were inverted into horizontal "shelves" to prioritize water retention. Water tests validated this shift: the Shingle Tile (S3) retained 25.1% of water, while the Evaporative Cooling Tile (E0) retained 36.6% (see Figures 4 and 6).

To improve evaporative cooling, dimpled geometries, based on elephant skin research (Peeks et al., 2021), were introduced to enhance water catchment. Merging pleating and dimpling required a continuous surface to maintain consistent patterning. Discontinuities would distort dimple size and reduce performance. A seamless, radially pleated surface was created, resembling seashells. The *Sweep2 (Rhino)* command was used to smooth sharp protrusions near the top edge, ensuring mold release success. *Sweep2's* control curves extended from the tile center outward and upward, then returned smoothly to the original surface, preserving tile-to-tile contact points (Figure 5).

Once unified, the surface was prepared for parametric dimple variation. Dimples were controlled via parameters for size, distribution, and smoothness. Dimple sizing was set heuristically to capture typical rain droplets, targeting diameters of approximately 1–3 mm (Smith et al., 2009, p. 5). We used a hexagonal texture because its isotropic, equal-neighbor spacing projects uniformly and reduces directional artifacts (Mersereau, R. M., 1979). Key tools included *Surface Morph (Grasshopper)* for hexagonal texture mapping and *Weaverbird'sLaplacian smoothing (Piacentino, Version 0.9.0.1, 2009)* to soften edges. Using *Graph Mappers (Grasshopper)*, the dimple density was highest along the central axis, where water flow is strongest, and gradually decreased toward the edges, creating a gradient that directs water flow while minimizing material use—similar to how erosion shapes natural stone.

To evaluate the impact of dimple depth and surface roughness on evaporative cooling, seven tile prototypes were tested, including a control tile E0 with pleating but no additional texture. From E1 to E6, the dimples increased in depth and surface complexity, with E1 featuring the shallowest impressions and E6 the deepest and roughest texture. Among all tests, E6 demonstrated the highest water retention (48%). Notably, the control tile (E0, 36.6% retention) outperformed E1 and E2 (14.7% and 27.4%), suggesting that smoothing texturing reduces retention performance. Visual observation confirmed that smoother surfaces caused water to disperse quickly, while increased roughness helped slow flow and retain moisture. These findings indicate that moderate surface roughness is more effective than smoothness alone in promoting water retention.

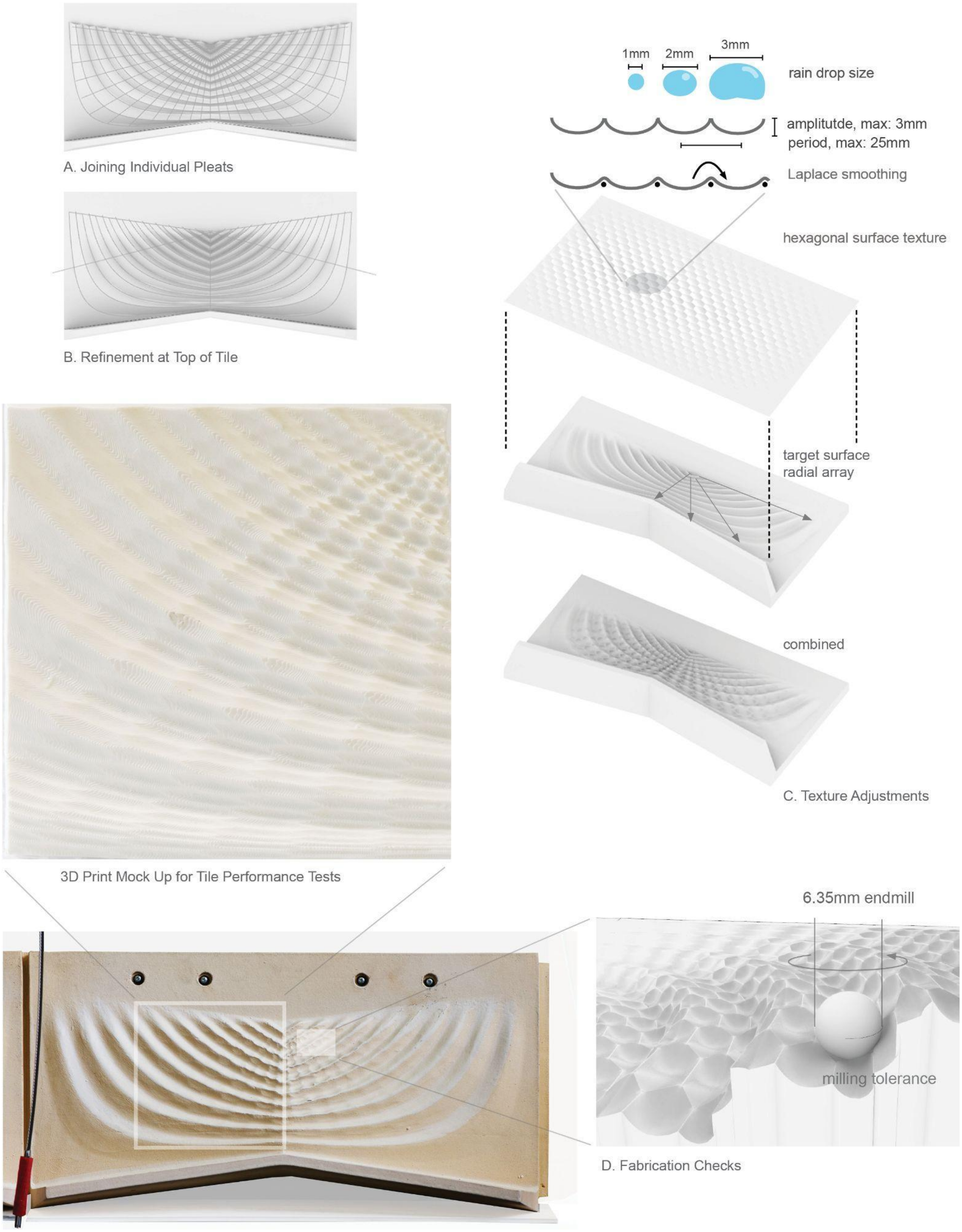

Figure 5: Digital workflow from pleat geometry to surface texture mapping and fabrication workflow from pleat geometry to surface texture mapping.

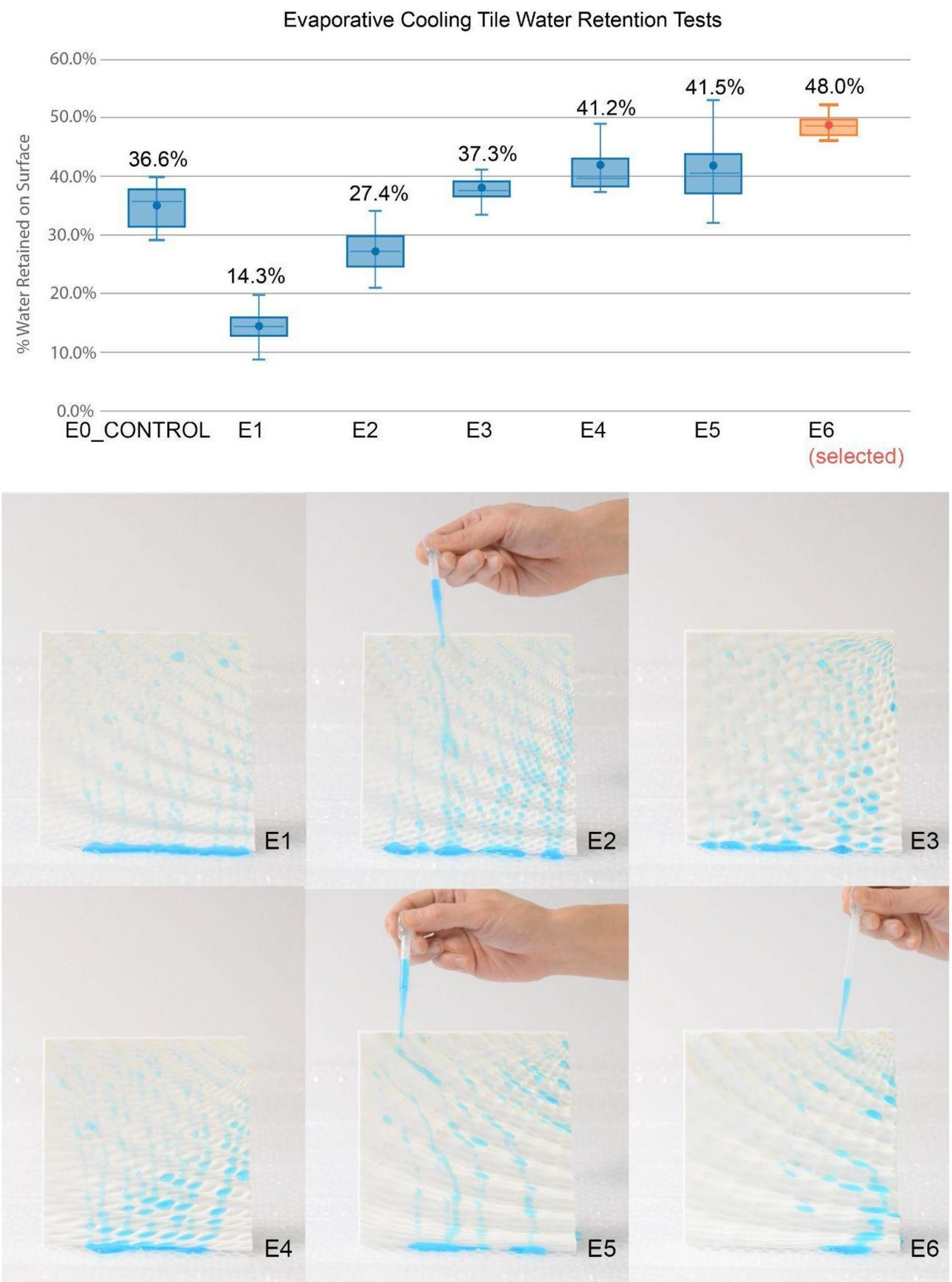

Figure 6: Evaporative Cooling (EC) Tile performance test results and visual inspection stills.

3.6 Screen Tile Design

The Screen Tile module features a horizontal geometry that spans between two vertical cables which double as infrastructure for climbing plants. The shelf is pitched 31° in the center to create a drip edge to direct water. The tile is installed in alternating orientations to create a cascading, see-saw-like flow down the façade. Pleats form terraced channels that slow and guide water from one tile to the next below.

3.7 Glazes and finishes

We researched the standard finishes (clay body colors and glazes) offered by Boston Valley Terra Cotta to understand its impact on surface temperature with and without water when exposed to solar radiation. As expected, a white highly reflective glaze combined with a cream-colored clay body (the highest albedo of the standard clay bodies) registered surface temperatures up to 8°C (14.4 °F) cooler than other standard samples (which ranged from brick color to charcoal combined with glazing options) in dry, sunny conditions. However, it is important to balance reflective glazes with its impact on water absorption, as glazes seal with a layer of thin glass. To address this, a directional spray glazing technique was developed in collaboration with glazing artists at Boston Valley Terra Cotta. By applying glaze only to the peaks of pleated surfaces while masking the valleys, the clay's absorptive capacity was protected in the shaded, low-solar zones. This analog approach, tuned to the geometry of the tile, ensures functional differentiation across the surface and limits glaze coverage to less than 50% to support recycling of the tile into future clay body stock.

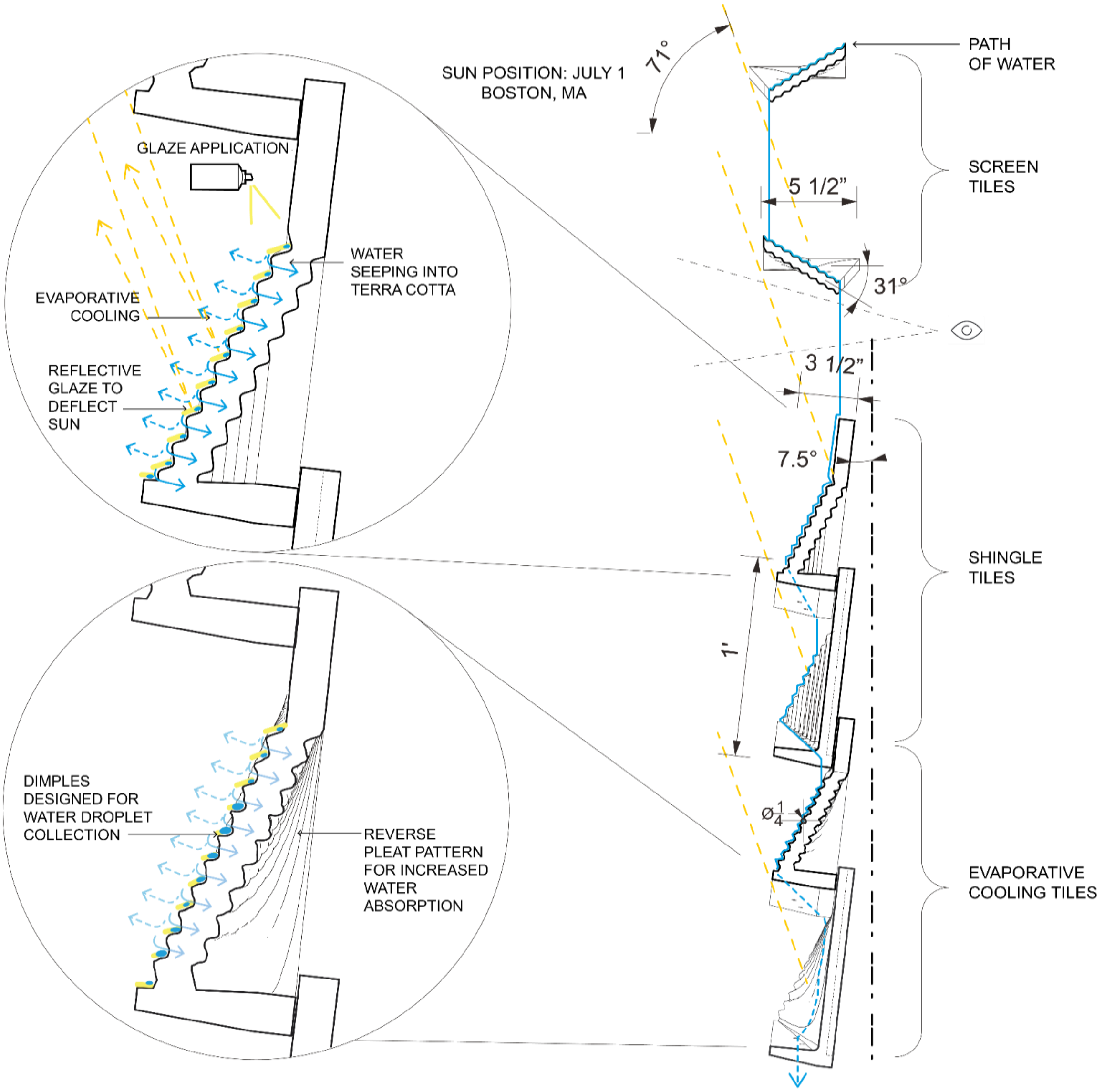

Figure 7: Glazing concept, directional spray - top side of pleat glazed to reflect sun, bottom side of pleat unglazed to absorb water. EC tiles use light deflecting, water penetrable glaze (Matte white glaze).

3.8 Full-Scale Mockup

Performance tests were conducted on a full-scale mockup of the facade which measured 4 feet wide and 6 feet tall, and consisted of (5) EC tiles, (7) Shingle Tiles, and an opening with (6) Screen Tiles to simulate the position of a window. On August 14th, 2024, we conducted outdoor tests with unobstructed western sun exposure, from 4:00 pm to 8:00 pm at the University of Buffalo, New York. Air temperature during the test ranged from 23.7°C to 37.9°C (74.6°F to 100.2°F).

Surface temperatures were recorded for each tile type under dry conditions, and two test wetting conditions, which simulated natural rain and active wetting via irrigation of the facade. Concurrently, temperatures were recorded for the tan colored concrete masonry unit (CMU) wall behind the mockup and a ¼ inch steel plate as a baseline comparison to other conventional facade materials. Five surface temperatures were recorded with a handheld infrared thermometer and a center of mockup temperature using a FLIRE8-XT thermal camera, capturing thermal images every 5 minutes. Two HOBO data loggers tracked air conditions at the wall and 15' away, alongside a radiation wattage meter measuring solar radiation (W/m2).

The "Wetting Test" simulated active wetting used to mitigate extreme heat using excess condensate from air conditioning or stored rain water, irrigating the wall at 1 GPM for 50 minutes with 36.4°C water using a gutter system with 1/16 in holes spaced every inch. The second "Rain Event Test" used 23°C water to simulate rain for 10 minutes directly wetting all surfaces. Data was recorded for 2 hours and 40 minutes after the event, with testing facing due west starting at 5:20PM.

3.9 Outdoor comfort modeling

To evaluate the local outdoor comfort impact of the facade, we simulated the Standard Effective Temperature (SET) in a courtyard and street located in Boston Chinatown. SET is a thermal comfort metric that accounts for factors beyond air temperature, including mean radiant temperature from adjacent surfaces.

These simulations focus on one hour, using the recorded data from the full-scale mock-up at 6:20PM, the time when materials reached a peak in temperature after the second test, the “Rain Event Test”. Surface temperatures of the EC tile, CMU wall, and steel plate as well as air temperature (30.8°C) and humidity (34%RH) match the conditions of the physical test. We kept all other factors constant and typical: still air conditions of 0.1 m/s, clothing value of 0.61 CLO (trousers and long sleeve shirt), metabolic rate of 1.1 MET (seating in active conversation, or standing still), and disregarded the impact of the floor, keeping floor temperature equal to air temperature. We further assume uniform façade temperatures for each scenario to reduce complexity; while not reflective of field conditions, this approximation clarifies the modeled effects.

Two urban settings were analyzed: an open courtyard (partially shaded) and a narrow street canyon (high façade view factor); and we included shaded and unshaded sections in the courtyard using radiation data from the site’s closest weather file, International Airport

Boston weather file, under the sunniest day condition July 25th at 3PM and morphed to 2080 (climate scenario SSP3) to show the extreme scenario.

This test aims to understand the impact of our design at the scale of the spaces that inspired this research, outdoor public spaces that people use in our community in Boston's Chinatown. Four façade types were compared: EC Tile, light-colored CMU, metal panel, and a hypothetical reflective surface that has the surface temperature equal to air temperature, assuming a high-performing material that could reflect 100% of solar radiation and be adiabatic to air conditions.

4. Results

4.1 Dry conditions

In dry conditions, the facade mockup's surface temperature was similar to the CMU wall, except in the glazed pleated eyebrows and the unglazed water absorption channels which they shaded. The EC Tile, with more radiation absorbing surface area and less reflective glaze, heated up faster than the Shingle Tile, and showed more uniform temperatures, similar to the CMU wall. As expected, the steel plate due to its low-albedo and thermal conductivity heated up faster than the CMU and terra cotta.

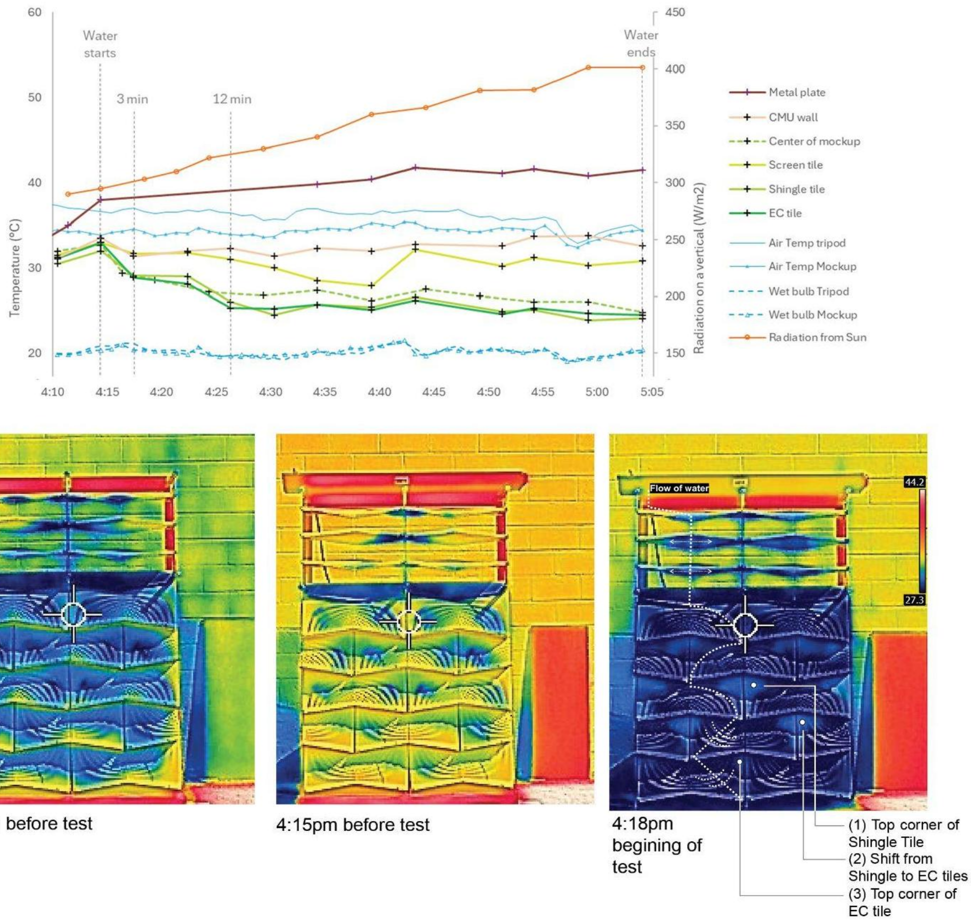

Figure 8. Thermal images (FLIR0020 at 4:00 PM and FLIR0023 at 4:15 PM) showing dry baseline surface temperatures before testing. Wetting Test 1 thermal images and graphs summarize key data points including surface temperatures, test conditions, and fluctuations over the 50-minute period.

4.2. Active Wetting Test Results

As intended, the façade diverted water in a zigzag path across the three tile types. After three minutes of consistent water flow, all surface temperatures dropped: EC Tile cooled by 4.1°C, Shingle Tile cooled by 2.9°C,and Screen Tile cooled by 1.3°C.

The EC Tile showed the most even cooling, which was expected as the geometry was designed to retain and absorb water. In both EC and Shingle Tiles, corner areas revealed key performance differences. The Shingle Tile's top corner remained warmer, suggesting poor absorption, while the EC Tile's top corner cooled evenly, confirming the effectiveness of flipped channels and porous horizontal shelves in directing water into those zones.

At the transition row between Shingle and EC Tiles, a noticeable “shift row” formed. The EC Tile corner there absorbed less water due to the glazed drip edge of the Shingle Tile above, which restricted flow except through weep holes.

Testing showed three cooling phases for the Shingle and EC Tiles. In the first 3 minutes, they cooled rapidly at 1.0°C and 1.4°C per minute, respectively. By 12 minutes, the rate slowed to 0.4°C per minute, then dropped further to 0.05–0.02°C per minute over the next 38 minutes. These results suggest that active wetting or a short rain event lasting 3 to 12 minutes delivers the most effective cooling.

The Screen Tile cooled steadily at just 0.04°C per minute over 50 minutes, showing no significant trends apart from radiation response.

4.3 Rain Event Test Results

The impact of a 10 minute rain event was recorded over 2-hour 40-minutes to evaluate passive cooling under natural drying and temperature fluctuations. The EC Tile showed strong evaporative cooling, averaging 1.22× and reaching as low as 1.08× the ambient wet bulb temperature. In contrast, the Shingle Tile exhibited limited cooling due to low water absorption and rapid drying, while the Screen Tile performed comparably well to the EC Tile, aided by high absorption and reduced solar exposure from time of the test, from 5:10PM to 8:00PM .

Throughout the 3-hour test, the mockup remained wet, indicating the need for extended-duration studies. Notably, the EC Tile maintained significantly lower surface temperatures compared to conventional materials. Peak temperature recordings showed the metal panel reaching 45.0°C, the CMU wall at 31.1°C, the Screen Tile at 27.8°C, the Shingle Tile at 29.5°C, and the EC Tile at just 25.6°C.

Despite falling ambient temperatures, the thermal mass of the CMU wall retained heat due to its thermal mass, remaining 12.5°C warmer than the EC Tile. Peak temperature differences included 20.8°C between the metal panel and EC Tile, and 13.2°C between the CMU wall and EC Tile. These results highlight the EC Tile's effectiveness as a passive cooling surface in urban conditions.

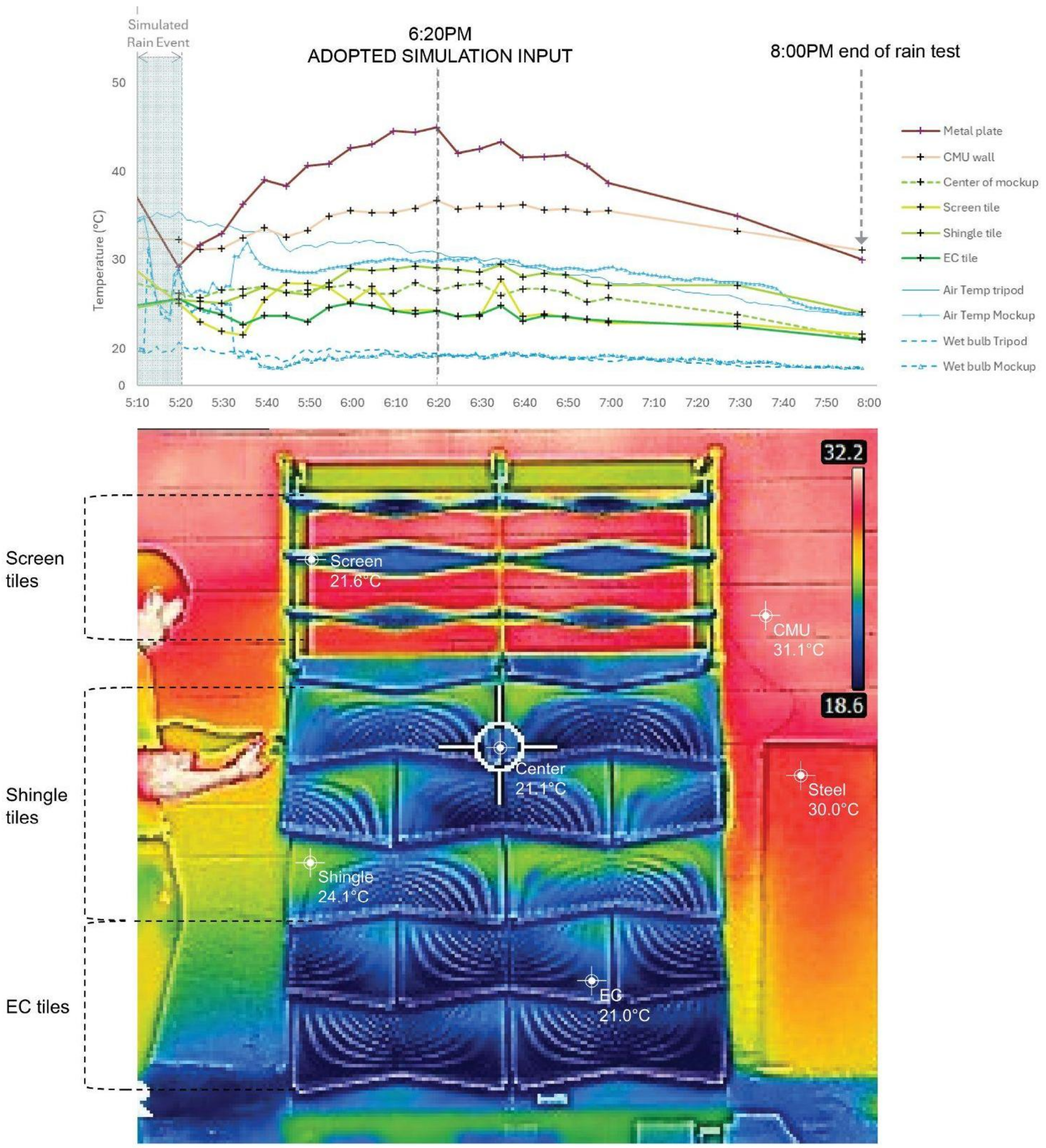

Figure 9: Rain event test end - comparative analysis of CMU and steel plate with the terra cotta tiles.

4.4 Outdoor comfort modeling results

The urban simulations show that surface temperature of facades impacts thermal comfort. This comparison, which uses recorded information from the full-mockup, shows that the EC tile reduces the SET by 3.3°C (6°F) in the shaded street canyon (high façade view factor). The courtyard shows the high variability of SET temperatures depending on position and view factors to the facades and the sky. The range of cooling varied from a reduction in SET of 2.2°C (4°F) in the shade and 1.8°C (3.2°F) in full sun.

The simulated hour has an air temperature of 30.8C, which lies in the “warm” section of the SET scale, outside of the comfort target. Having cool facade surfaces improves the thermal comfort condition and brings the SET to 28.6°C in the street and up to 28.8°C in the shaded courtyard, well within the target comfort state. However, the EC tile walls are not sufficient to comfort in fully exposed sun as the SET lies well above the comfort threshold.

The hypothetical no-mass reflective wall performed worse than the EC tile, with street areas measuring 1°C warmer and sun-exposed locations 0.5°C hotter than the design scenario. Compared to metal and CMU walls, the EC tile again showed superior performance: the metal and CMU walls scenarios peaked at 31.9°C and 30.6°C in the shade respectively. In full sun, all models exceeded comfort levels, but the EC tile recorded the lowest SET temperature. These results confirm that the EC tile reduces heat stress more effectively than high-mass or reflective façades, enhancing comfort and mitigating local comfort in urban conditions, particularly in shaded courtyards and streets.

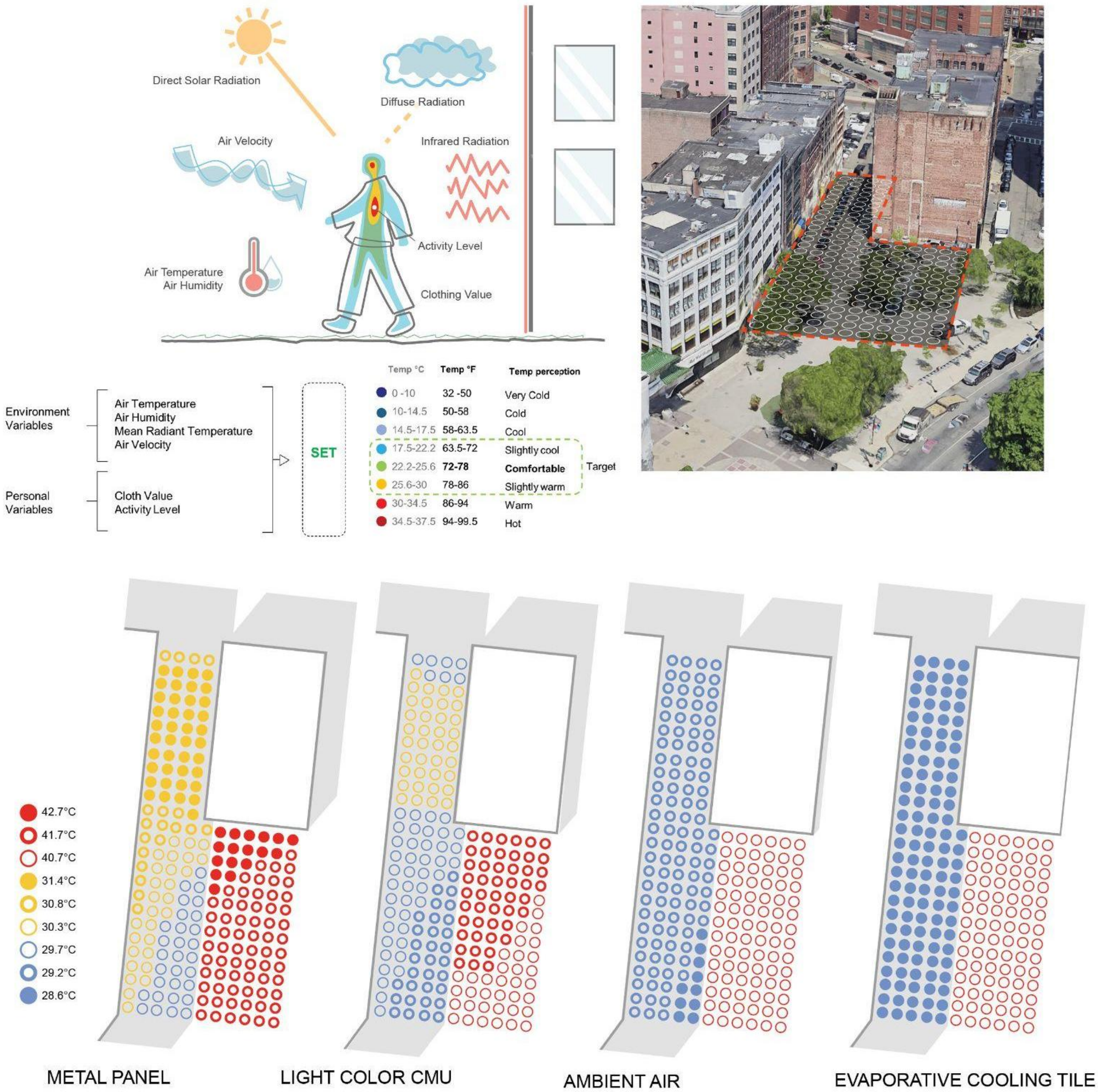

Figure 10. SET model definition and temperature range for comfortable standard and comparative facade materials results.

5. Discussion

5.1 Future Work

Our research focused on the design of a market-ready facade cladding system to mitigate urban heat stress for continental climates with special resistance to freeze thaw within the capabilities of industry fabricator Boston Valley Terra Cotta. Future work is needed to evaluate the impact of the tiles outside the peak summer heat days, optimize for passive solar heat gain in the winter months, and develop approaches to orientations with limited solar exposure. The research gives a snapshot of the potential benefit of shaping terra cotta tiles to lower urban surface temperatures and mitigate heat discomfort in urban heat islands from the perspective of human comfort. The technique of shingling with terra cotta combined with a screen module supported by vertical cables which integrate climbing plants is developed for the unique requirements of the four seasons climate, which are under unique constraints of freezing winters, and increasingly uncomfortably hot summers.

Future areas of improvement include the optimization of tile thickness and water absorption. Thinner tiles use less material but hold less water and are more vulnerable to freeze thaw damage. This research focuses on identifying the ideal thickness to balance cooling performance and durability. This will also guide refinements to overarching surface geometry and surface features for more efficient structural capacity and water flow.

5.2 Conclusion

Public space is a valuable asset and unique feature of cities, and the microclimate upon which it depends on for resilience is critical. Our research shows that by combining small-scale architectural geometry with widely-used methods of rainscreen cladding, façades can temper the effects of extreme heat and precipitation. In both dry and wet scenarios on a hot summer day, our performance testing for a market-ready integrated façade system yielded cooler surface temperatures than other typical facade types: 20.8°C (37.4°F) lower than the steel plate cladding, and 13.2°C (23.8°F) cooler than a CMU wall after a rain event. Extrapolated onto a simulated urban environment, our research shows that the radiant surface temperatures of vertical surfaces can influence the experienced thermal comfort of a human, with a SET difference of around 2°C (3.6°F) between steel plate cladding and a geometric terra cotta rain screen. These results showcase the facade’s potential as a passive cooling surface in local urban conditions in the context of urban heat islands.

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