LANDSCAPE PERFORMANCE SERIES by the Landscape Architecture Foundation

Environmental and Natural Resources 2 Building (ENR2) Methods

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This investigation was conducted as part of the Landscape Architecture Foundation's 2023 *Case Study Investigation* (CSI) program. CSI matches faculty-student research teams with design practitioners to document the benefits of exemplary high-performing landscape projects. Teams develop methods to quantify environmental, social, and economic benefits and produce Case Study Briefs for LAF's *Landscape Performance Series*.

The full case study can be found at: https://landscapeperformance.org/case-study-briefs/ENR2

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ACKNOWLEDGEMENTS

We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and Indigenous communities through education offerings, partnerships, and community service.

We want to acknowledge and thank all those who provided us with the insight and information that made the completion of this project possible. Your time and support are greatly appreciated.

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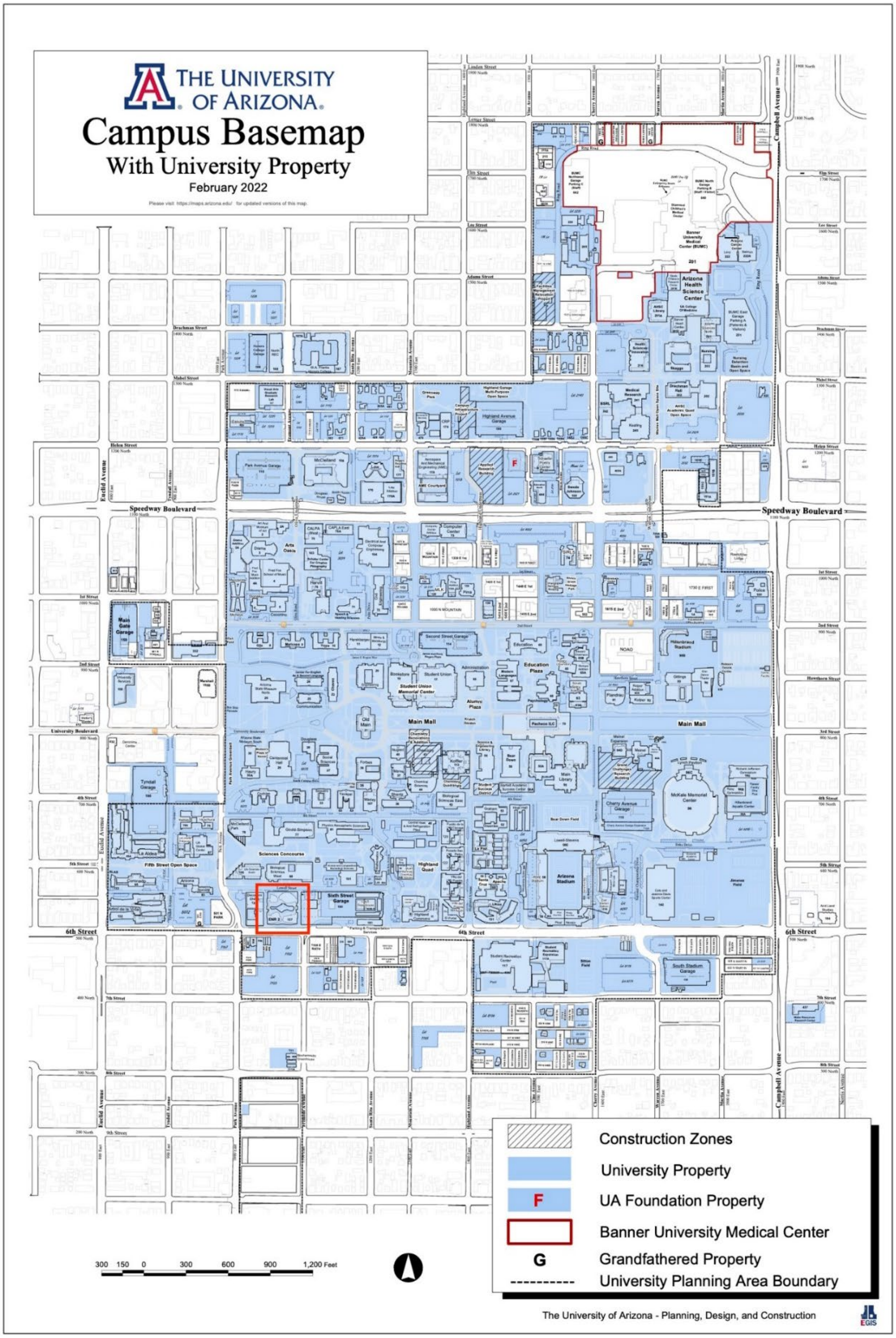


The ENR2 project site is located at the southwest corner of the University of Arizona campus (highlighted with the red box).

RESEARCH STRATEGY

The Environmental and Natural Resources Building 2 (ENR2) made a commitment to achieve LEED Platinum Certification, which required the use of innovative methods to tackle the sustainability needs of a building situated in the hot, arid environment of the Sonoran Desert. The project, earning the status of LEED Platinum in August of 2016, underwent extensive investigation into numerous categories pertaining to sustainability, water efficiency, energy efficiency, materials & resources, and indoor environmental quality.

This case study's findings are heavily reliant on the documentation provided to the US Green Building Council for LEED Certification and are supplemented with current data. Additionally, as a building on a university campus, social benefits were investigated through a survey with participants ranging from daily users of ENR2 to more infrequent visitors. Through this, the building and its landscape's role in campus community and academics was investigated.

Finally, for the purposes of this research and its investigation into ENR2's economic benefits, attempts at specific, measurable benefits gave way to general commentary and anecdotal evidence to provide insight into the building and its landscape's economic impact.

ENVIRONMENTAL BENEFITS

> ***Reduces runoff for a 2-year, 24-hour storm by 55% as compared to pre-project conditions, with the ability to store up to 31,951 gallons of stormwater on-site per month.***

Background:

For ENR2's LEED Platinum certification, points were awarded under the categories of Sustainable Sites and Water Efficiency. Full credit was awarded for the site's stormwater design's quality control and quantity control.

(SSc6.2) Quality control of stormwater management is intended to limit disruption and pollution of natural water flows by managing stormwater runoff. The requirements of this credit are to implement a stormwater management plan that reduces impervious cover, promotes infiltration, and captures and treats stormwater runoff from 90% of the average annual rainfall. Methods used to treat runoff must be capable of removing 80% of the average annual post-development total suspended solids (TSS) load based on existing monitoring reports.

(SSc6.1) Quantity control of stormwater design is intended to limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff, and eliminating contaminants. ENR2, as a site with existing imperviousness of 50% or less, had to implement a stormwater management plan that prevents the post-development peak discharge rate and quantity from exceeding the predevelopment peak discharge rate and quantity for the 1- and 2-year, 24-hour design storms.

The LEED documentation demonstrates a comprehensive approach to stormwater management through the installation of underground water storage systems. In addition, the project has reduced runoff by 54.84% as compared to the pre-project conditions for the two-year, 24-hour design storm.

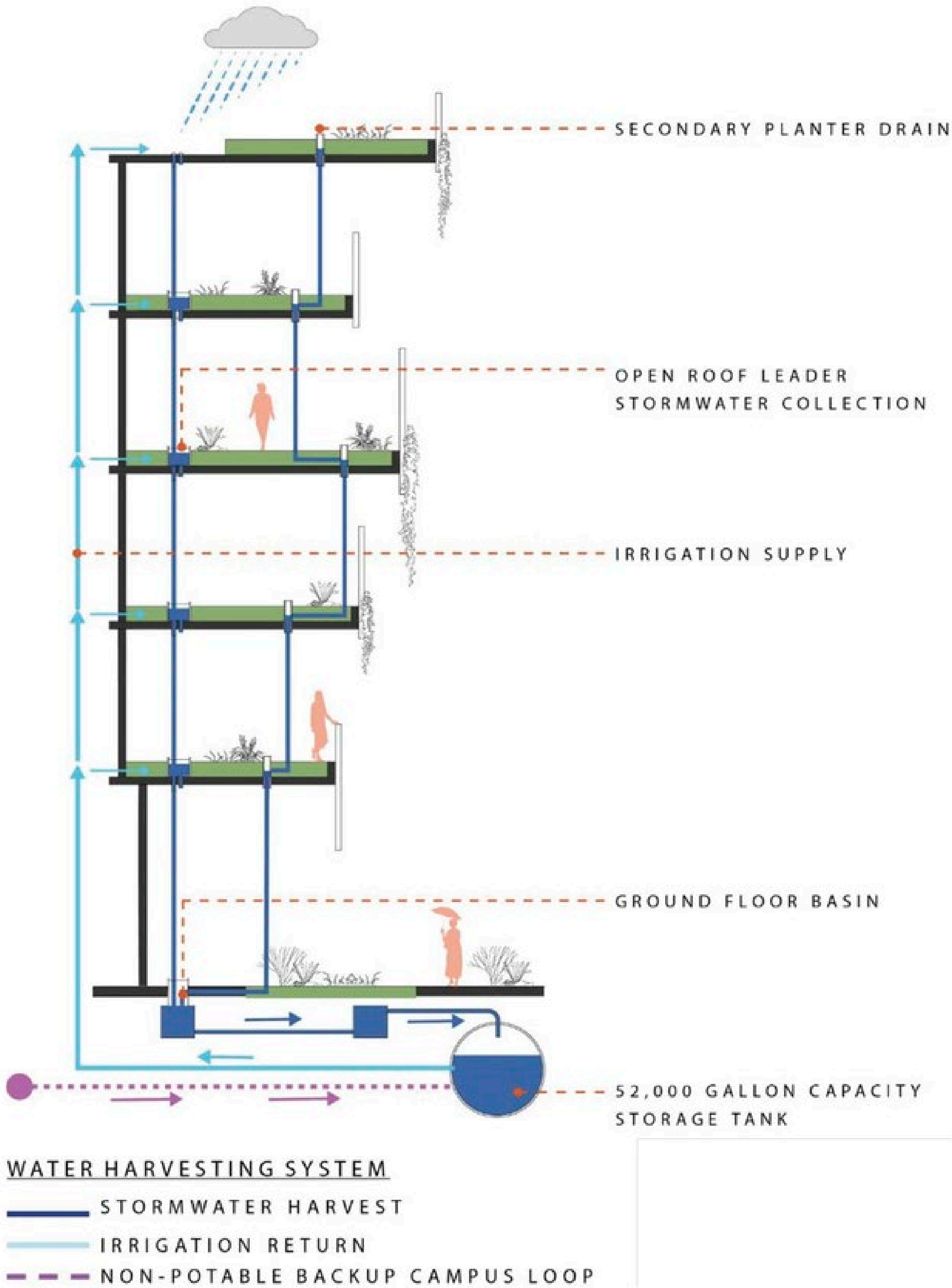


Figure 1: The ENR2 Water Harvesting System collects, reveals, and stores excess runoff through six floors with an open air piping systems. The collected water is redistributed to the multiple levels to irrigate plant material on each deck. (*RICHÄRD | KENNEDY ARCHITECT*S)

Method:

The ENR2 building footprint is 1.13 acres, covering 90% of the site. With the extensive imperviousness, the drainage concept collects runoff into the central canyon from all levels of the of the 5-story building. Stormwater that falls straight through the 0.14-acre roof opening is directed to localized area drains. Three VortSentry® separate hydrodynamic separators receive the runoff and remove a portion of the Total Suspended Solids (TSS). TSS removal efficiency is noted in Table 2 below.

As reported in the Drainage Report Construction Document prepared for LEED, the stormwater runoff from 90% of the average annual rainfall is captured and treated to remove 80% of the average annual post-development TSS. Approximately 1.39 acres of the 1.42-acre site run through one of the three VortSentry® treatment units. Table 2, completed for ENR2's LEED Platinum documentation, lists the TSS removal efficiencies for the Types of management implemented on the project. The table calculates the weighted TSS removal efficiencies for each BMP based on the percentage of the site treated.

Calculations *(from 100% Construction Document Phase Drawings):*

The on-site developed drainage consists of three major watersheds that are divided further into Concentration Points (Figure 2). The descriptions of each Concentration Point are followed by a table of each Concentration Point's peak discharge in various storm events.

Concentration Point 1: combined watershed for sub-basin F (same as pre-development)
Concentration Point 2 (1.38acres): total discharge from the developed site that drains into 6th St
- Concentration Point 2.1 (0.08 acres): drains the revised loading dock
- Concentration Point 2.2 (0.01 acres): drains a small area at the southwest corner of the development that drains directly into the adjacent street.
- Concentration Point 2.3 (0.09 acres): drains the corridor on the west side of the building
- Concentration Point 2.4 (0.34 acres): drains the western portion of the roof and the Canyon area into the western storm drain
  - Concentration Point 2.4A (0.14 acres): represents the roof opening above the Canyon
- Concentration Point 2.5 (0.36 acres): represents the roof drainage from the central area of the building. it is divided by the Canyon area and connected with the underground storm drain
- Concentration Point 2.6 (0.40 acres): represents the rooftop drainage from the eastern roof and a portion of the northern rooftop that drains into the eastern storm drain.
- Concentration Point 2.7 (0.04 acres): represents the area south of the building to 6th St
- Concentration Point 2.8 (0.10 acres): represents the area east of the building and the adjacent parking garage
- Concentration Point 2.9 (0.06 acres): represents the area north of the building on Lowell St

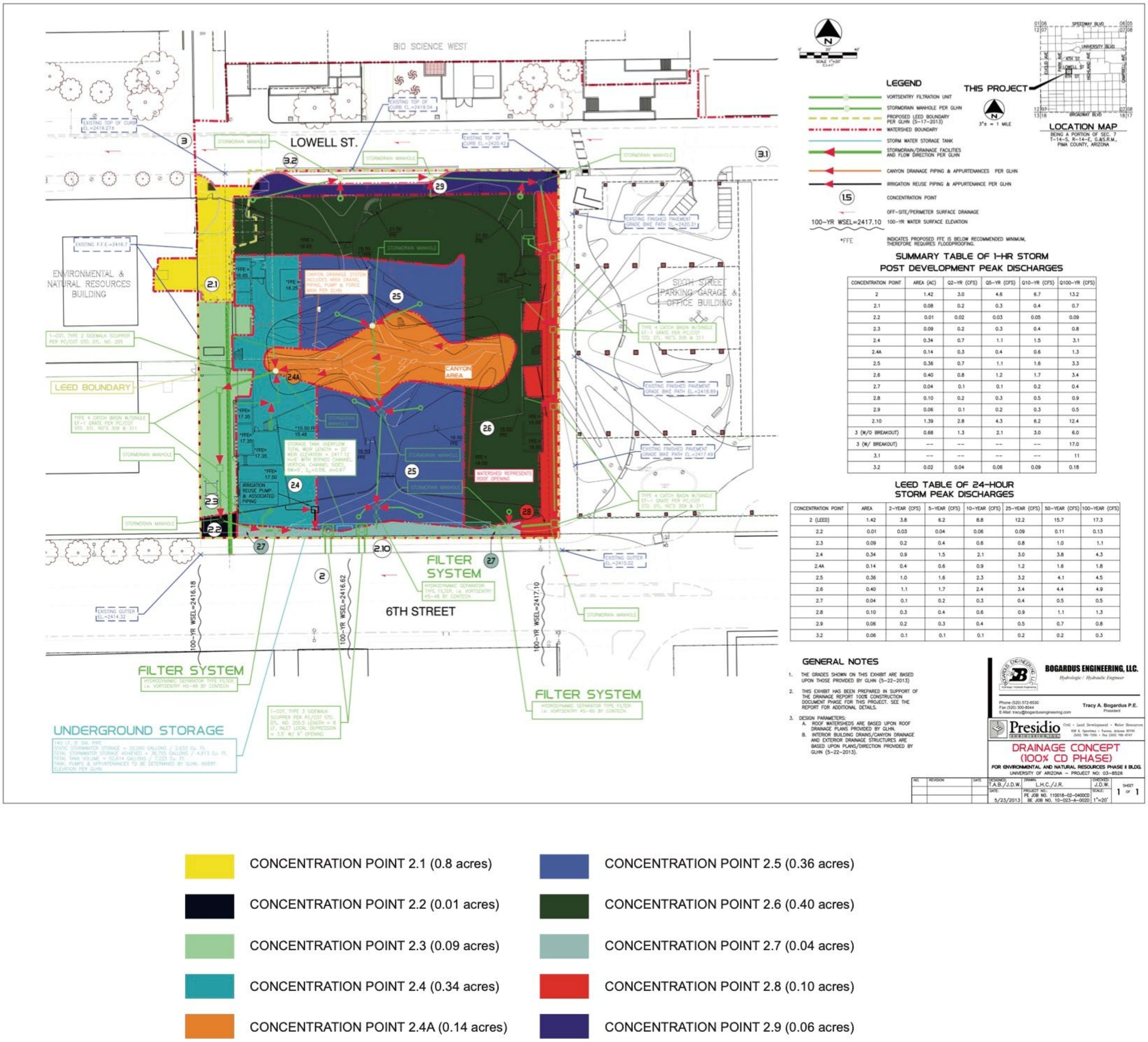
Concentration Point 2.10* (1.39 acres): represents the total stormwater runoff entering the underground storage tank, drains from the rooftop, the Canyon, and the areas east, west, and north of the building. The only on-site areas that are not drained into the storage tank are Concentration Points 2.2, 2.7, and 3.2.

Concentration Point 3 (0.68 acres): represents the watershed draining into Lowell St near the northwest corner of the site

Concentration Point 3.1: represents the breakout flow as determined in the existing conditions

Concentration Point 3.2: represents the area between the roofline of the proposed building and the curb of Lowell St

**The watershed for Concentration Point 2.10, representing all the run-off entering the underwater storage tank, generates a total volume of approximately 14,229 cu-ft (106,440 gallons) for a 100-year storm event.*



SUMMARY TABLE OF 1-HR STORM POST DEVELOPMENT PEAK DISCHARGES

CONCENTRATION POINT	AREA (AC)	Q2-YR (CFS)	Q5-YR (CFS)	Q10-YR (CFS)	Q100-YR (CFS)
2	1.42	3.0	4.6	6.7	13.2
2.1	0.08	0.2	0.3	0.4	0.7
2.2	0.01	0.02	0.03	0.05	0.09
2.3	0.09	0.2	0.3	0.4	0.8
2.4	0.34	0.7	1.1	1.5	3.1
2.4A	0.14	0.3	0.4	0.6	1.3
2.5	0.36	0.7	1.1	1.6	3.3
2.6	0.40	0.8	1.2	1.7	3.4
2.7	0.04	0.1	0.1	0.2	0.4
2.8	0.10	0.2	0.3	0.5	0.9
2.9	0.06	0.1	0.2	0.3	0.5
2.10	1.39	2.8	4.3	6.2	12.4
3 (W/O BREAKOUT)	0.68	1.3	2.1	3.0	6.0
3 (W/ BREAKOUT)	--	--	--	--	17.0
3.1	--	--	--	--	11
3.2	0.02	0.04	0.06	0.09	0.18

LEED TABLE OF 24-HOUR STORM PEAK DISCHARGES

CONCENTRATION POINT	AREA	2-YEAR (CFS)	5-YEAR (CFS)	10-YEAR (CFS)	25-YEAR (CFS)	50-YEAR (CFS)	100-YEAR (CFS)
2 (LEED)	1.42	3.8	6.2	8.8	12.2	15.7	17.3
2.2	0.01	0.03	0.04	0.06	0.09	0.11	0.13
2.3	0.09	0.2	0.4	0.6	0.8	1.0	1.1
2.4	0.34	0.9	1.5	2.1	3.0	3.8	4.3
2.4A	0.14	0.4	0.6	0.9	1.2	1.6	1.8
2.5	0.36	1.0	1.6	2.3	3.2	4.1	4.5
2.6	0.40	1.1	1.7	2.4	3.4	4.4	4.9
2.7	0.04	0.1	0.2	0.3	0.4	0.5	0.5
2.8	0.10	0.3	0.4	0.6	0.9	1.1	1.3
2.9	0.06	0.2	0.3	0.4	0.5	0.7	0.8
3.2	0.06	0.1	0.1	0.1	0.2	0.2	0.3

Figure 2: The ENR2 roof and site are divided into ten concentration points for water collection that pass through each floor and ultimately combine into two sub-surface holding tanks located south of the building.
(*Base plan from Bogardus Engineering, LLC and Presidio Engineering, Inc.*)

Table 1: Summary of peak discharge of each Concentration Point for various storm events. *(from Drainage Report by Bogardus Engineering, LLC and Presidio Engineering, Inc.)*

SUMMARY TABLE OF POST DEVELOPED PEAK DISCHARGES					
Conc. Point	***Area***	***Q2-yr (cfs)***	***Q5-yr (cfs)***	***Q10-yr (cfs)***	***Q100-yr (cfs)***
2	1.42	3.0	4.6	6.7	13.2
2.1	0.08	0.2	0.3	0.4	0.7
2.2	0.01	0.02	0.03	0.05	0.09
2.3	0.09	0.2	0.3	0.4	0.8
2.4	0.34	0.7	1.1	1.5	3.1
2.4A	0.14	0.3	0.4	0.6	1.3
2.5	0.36	0.7	1.1	1.6	3.3
2.6	0.40	0.8	1.2	1.7	3.4
2.7	0.04	0.1	0.1	0.2	0.4
2.8	0.10	0.2	0.3	0.5	0.9
2.9	0.06	0.1	0.2	0.3	0.5
2.10	1.39	2.8	4.3	6.2	12.4
3 (w/o Breakout)	0.68	1.3	2.1	3.0	6.0
3 (w/ Breakout)	-	-	-	-	17.0
3.1	-	-	-	-	11
3.2	0.02	0.04	0.06	0.09	0.2

Table 2: Total Suspended Solids Removal Efficiency *(from LEED 2009, Form-SSc6-2)*

Type of Management	**Description and/or Location**	**Percent Site Treated**	**TSS Removal Efficiency (%)**	**Weighted Average TSS Removal Efficiency (%)**
Vort Sentry	SWT-1	31	98	30.38
Vort Sentry	SWT-2	26	98	25.48
Vort Sentry	SWT-3	43	98	42.14
Total weighted average TSS removal efficiency				98

*****The Types of Management listed in the table are designed to treat stormwater runoff from 90% of the average annual rainfall.

Table 3: Site Runoff: Two-Year, 24-Hour Design Storm *(from LEED 2009, Form-SSc6-1)*

	Quantity (cf/storm)
Predevelopment	8,959
Postdevelopment	4,046
Percent reduction	54.84

Table 4: Nonpotable water supply model and calculations *(GLHN)*

GLHN

Project University of Arizona / ENR-2 / LEED calc's

Proj. No: 1024.00
Date: 07-2016
Computed DCM
Checked: JCM

Stormwater (Roof Drainage) — Yes
Stormwater (Non Roof) — Yes
Stormwater (off site) — No
Condensate Water — Yes
Gray Water — No
Black Water — No
Reclaimed Water — Yes

Precipitation		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
The Arizona Meteorological Network (2011 - 1987)														
Total precipitation (monthly)														
Min	(inch)	-	-	-	-	-	-	0.12	0.63	0.07	-	-	-	
Max	(inch)	5.55	3.83	2.01	1.43	0.83	2.94	6.80	5.59	3.82	4.07	1.81	3.74	
Average	(inch)	0.94	0.97	0.67	0.38	0.16	0.32	2.14	2.09	1.04	0.69	0.61	0.93	10.95
Number precipitation events														
Min	(days)	-	-	-	-	-	-	1	5	1	-	-	-	
Max	(days)	12	11	8	6	5	9	15	13	11	11	5	9	
Average	(days)	4.58	4.57	3.43	2.04	1.00	1.43	8.17	9.00	4.39	3.48	2.57	4.61	
Average Precipitation / event														
Average	(inch)	0.21	0.21	0.19	0.19	0.16	0.22	0.26	0.23	0.24	0.20	0.24	0.20	

Based on a review of the above, use the Arizona Meteorological Network (2011 - 1987) data

Stormwater (Roof and Canyon areas)		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Potential for water harvesting														
Assumes roof top (no green roof) and canyon (courtyard) area														
Weighted runoff coefficient (1)		0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	
Area	(Acres)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Volume V=Cw Pn A /12	(AF)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
	(Gal)	3,065	3,177	2,906	2,803	2,450	3,329	3,909	3,474	3,544	2,948	3,574	3,016	
Number precipitation events		4.58	4.57	3.43	2.04	1.00	1.43	8.17	9.00	4.39	3.48	2.57	4.61	
Volume per month	(Gal)	14,049	14,505	9,981	5,728	2,450	4,777	31,951	31,265	15,561	10,255	9,169	13,899	163,591

(1) Based on City of Tucson, Standard Manual for Drainage Design
90% impervious
100% Type B soil (Imported top soil for landscape areas)
Cw = 0.55 Based on rainfall depth of 0.3" (extrapolated, with small basins and limited ponding)

Using information from the Arizona Meteorological Network and the City of Tucson, this table and its calculations demonstrate the water harvesting potential for ENR2's design. The weighted runoff coefficient was drawn from the City of Tucson, Standard Manual for Drainage Design, where it was determined from the given areas being 90% impervious and entirely Type B topsoil for landscape areas.

The final coefficient of 0.55 was based on a rainfall depth of 0.3", extrapolated, with small basins and limited ponding. Other variables used were based on a review of Arizona Meteorological Network's historical data. For the month of July, these include an average precipitation of 2.14", an average of 8.17 precipitation events, and an average of 0.26" per event. The potential for water harvesting considers the canyon courtyard area and models 31,951 gallons of rainwater available in July, Tucson's rainiest month.

Sources:

"ENR2 Goes Platinum, Gains Highest LEED Certification." University of Arizona News, September 15, 2016. https://news.arizona.edu/story/enr2-goes-platinum-gains-highest-leed-certification.

Drainage Report Construction Document (100%) Phase for Environment and Natural Resources II at The University of Arizona (Prepared by Presidio Engineering, Inc. and Bogardus Engineering, LLC for GLHN Architects and Engineers, May 23, 2013)

Form-SSc6-1: SS Credit 6.1: Stormwater Design – Quantity Control

Form-SSc6-2: SS Credit 6.1: Stormwater Design – Quality Control

LEED BD+C: New Construction – v3 – LEED 2009 – Stormwater design – quantity control (SSc6.1)

LEED BD+C: New Construction – v3 – LEED 2009 – Stormwater design – quality control (SSc6.2)
"University of Arizona Environment + Natural Resources 2." RICHÄRD | KENNEDY ARCHITECTS. Accessed May 4, 2023. https://rkarch.com/projects/university-arizona-environment-natural-resources-2.

Limitations:

- Some numbers provided are calculated as projections using values and models from The Arizona Meteorological Network and the City of Tucson Standard Manual for Drainage Design.
- Models used to demonstrate the sustainable benefits of the water harvesting system represent a design case for the installed system. In reality, technical challenges prevent optimal efficiency in using the site's harvested water. However, the use of reclaimed water supplements the water harvesting system, to the extent needed, to ensure the use of non-potable water.

Reduces potable water use for irrigation by 100% and total water use for irrigation by 51% with installed irrigation systems that use captured rainwater, condensate, and municipally supplied non-potable water.

Background:

ENR2's landscaping and irrigation systems were designed to reduce potable water consumption for irrigation by 100%. This design also led to a reduction of the total water used for irrigation by 51.4%. Installed irrigation systems use on-site captured rainwater, municipally supplied non-potable water, and cooling system condensate.

All landscape beds and the tinaja water feature are irrigated with stored on-site captured rainwater, municipally supplied non-potable water, and cooling system condensate. The water harvesting system's 52,000-gallon underground holding and filtration tank under the building provides water to the irrigation system. The courtyard's canyon floor consists of a sand and stone dry bed that gathers rainwater and leads it to the site's holding and filtration tank. Water is available through municipally supplied non-potable water and the reclaimed water system if harvested water is not available.

For LEED Platinum certification, all 4 possible points were awarded under the credit (WEc1) Water Efficient Landscaping. The intent of this credit is to limit or eliminate the use of potable water or other natural surface or subsurface water resources available on or near the project site for landscape irrigation. The requirements met for this credit are as follows:

OPTION 1: Reduce by 50% (2 points)
Reduce potable water consumption for irrigation by 50% from a calculated midsummer baseline case or using the month with the highest irrigation demand. Reductions must be attributed to any combination of the following items:

- Plant species, density, and microclimate factor

- Irrigation efficiency
- Use of captured rainwater
- Use of recycled wastewater
- Use of water treated and conveyed by a public agency specifically for nonpotable uses

Method:

The method used to provide LEED documentation, used an evapotranspiration rate (**ET_o**) of 8.3, which is a measurement of the total amount of water needed to grow a reference plant, an irrigation baseline case and an irrigation design case was modeled for the 35,683-sf landscape area. July, the month with the highest irrigation demand, was used. Additionally, controller efficiency (**CE**) was provided from California Sensor Corporation's Manufacturer's Documentation for Controller Efficiency.

Calculations:

Variables used in the baseline case model and the irrigation design model are based on models for July, which is the rainiest month of the year.

The species factor **(ks)** accounts for variation in water needs by different plant species, divided into 3 categories (high, average, and low water need). The appropriate category for a plant species is determined using plant manuals and professional experience. Landscapes can be maintained in acceptable condition at about 50% of the reference evapotranspiration **(ET_o)** value, and thus the average **ks** value is 0.5. The project evapotranspiration **(ETL)** value is 2.32.

The density factor (**kd**) accounts for the number of plants and the total leaf area of a landscape. Sparsely planted areas will have less evapotranspiration than densely planted areas. In mixed plantings, where tree canopies shade understory shrubs and groundcovers, evapotranspiration increases and represents the highest level of landscape density with values between 1.0 to 1.3.

The microclimate factor (**kmc)** accounts for environmental specific to the landscape, including temperature, wind, and humidity. The landscape coefficient (**kL**) indicates the volume of water lost via evapotranspiration and varies with the plant species, microclimate, and planting density. Irrigation efficiencies **(IE)** are 0.625 if sprinkler and 0.90 if drip irrigation.

**Controller Efficiency documented in Manufacturer's Documentation by Calsense, California Sensor Corporation. The Calsense ET 2000e controller with an ET gauge and Tipping Rain bucket has an average documented water savings of 37%, which would yield a controller efficiency of 63%. This water savings is based on central water management reports from government and commercial entities. Calsense ET 2000e controllers tested under the Smart Water Application Technologies (SWAT) program at the Center for Irrigation Technology in Fresno, CA.*

Table 5: Irrigation Baseline Case for July & Irrigation Design Case for July *(from LEED 2009: Form-WEc1)*

WEc1-1. Irrigation Baseline Case (month with the highest irrigation demand)

Landscape Type	Area (sf)	ks	kd	kmc	kL	ET_o	ETL	Irrigation Type	IE	TWA (gal)
Mixed	35,683	0.5	1.1	0.5	0.28	8.3	2.32	Sprinkler	0.625	82,559.39
Total area (sf)	35,683	Baseline Total Water Applied (TWA) (gal)								82,559

WEc1-2. Irrigation Design Case (month with the highest irrigation demand)

Landscape Type	Area (sf)	ks	kd	kmc	kL	ET_o	ETL	Irrigation Type	IE	CE2	TWA (gal)
Shrub	29,487	0.5	1.1	0.5	0.28	8.3	2.32	Drip	0.9	0.7	33,164.33
Mixed	6,196	0.5	1.1	0.5	0.28	8.3	2.32	Drip	0.9	0.7	6,968.7
Total area (sf)	35,683	Baseline Total Water Applied (TWA) (gal)									40,133.03
Nonpotable water used (gal)											40,133.03
Design total potable water applied (TPWA) (gal)											0

Sources:

"ENR2 Goes Platinum, Gains Highest LEED Certification." University of Arizona News, September 15, 2016. https://news.arizona.edu/story/enr2-goes-platinum-gains-highest-leed-certification.

Form-SSc7-1: WE Credit 1: Water Efficient Landscaping

LEED BD+C: New Construction – v3 – LEED 2009 – Water efficient landscaping (WEc1)

LEED Reference Guide for Green Building Design and Construction 2009

Manufacturer's Documentation for LEED Controller Efficiency (CE), *Calsense – California Sensor Corporation*, June 22, 2016

Smart Water Application Technologies. *Center for Irrigation Technology*, Fresno, CA

"University of Arizona Environment + Natural Resources 2." RICHÄRD | KENNEDY ARCHITECTS. Accessed May 4, 2023. https://rkarch.com/projects/university-arizona-environment-natural-resources-2.

Limitations:

- Some numbers provided are calculated as projections using values and models from The Arizona Meteorological Network and City of Tucson Standard Manual for Drainage Design. No on-site measurements were taken by the research team, but the use of models gives an effective representation of the site's irrigation demand.

Reduces volume of air-conditioned space on-site by 24% compared to conventional building practices through open-air "hallway" terraces.

Background:

One of the most notable features of the ENR2 building/landscape is the terraced gardens with open-air "hallway" circulation on each floor oriented toward the interior courtyard. Conventionally, this space would be enclosed within the building envelope to be conditioned. These terraces save on energy costs by reducing the volume of conditioned space in the building with the help of shade and plant materials to provide a microclimate outdoors against the desert heat.

ENR2 uses self-shading and unconditioned outdoor spaces to minimize the impacts of summer heat. Passive systems were implemented in the building design to rely less on non-renewable energy sources and rely more heavily on the inherent structure and design of the building. Oriented on an east-west axis, the building takes advantage of the natural light from the north while being protected from direct sunlight and early morning and late afternoon solar radiation. Vertical metal fins, garden terraces, and balconies forming overhangs work together to maintain comfortable, shaded outdoor spaces with a comfortable microclimate year-round. On these overhangs, large fans help circulate air, and plants temper the building heat through evapotranspiration. Blocking direct sunlight but utilizing the ambient, natural light of ENR2's desert environment, the building's lighting needs are lessened, and thermal heat gain is limited

All these factors lead to a 24% reduction in the building's conditioned space. Per University reports and publications, heat gain and energy costs in the building have been greatly reduced compared to other campus buildings.

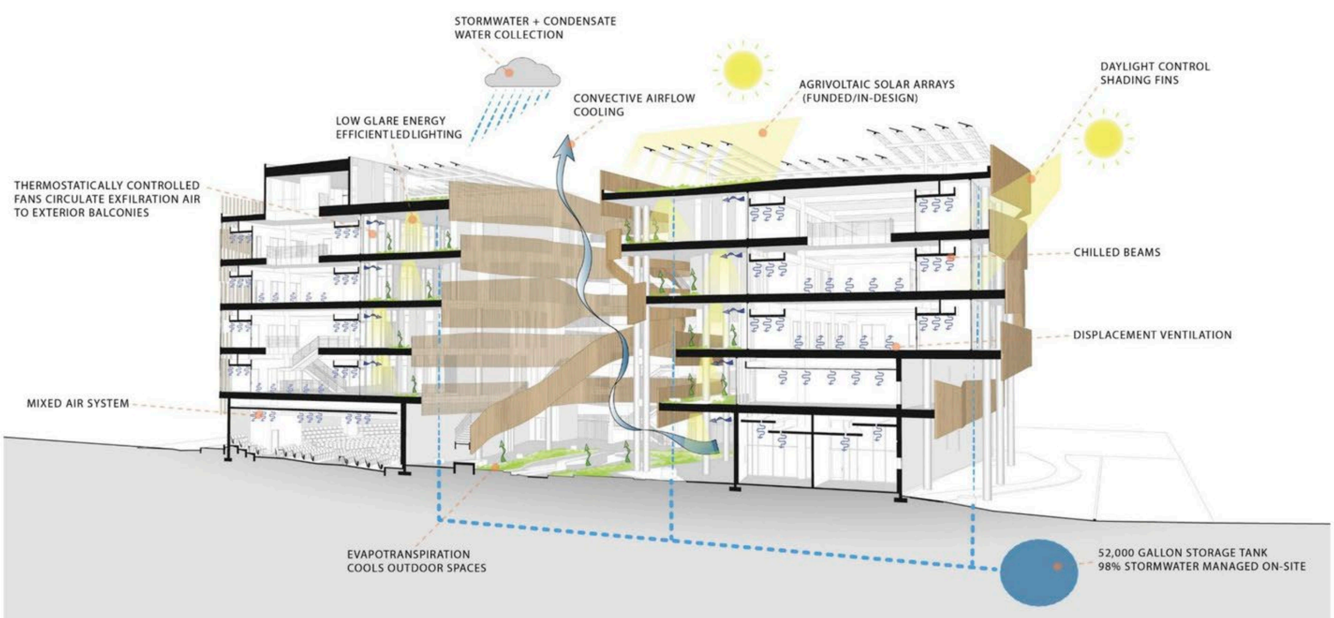


Figure 4: The ENR2 building ventilation and cooling works in concert with outdoor circulation at various levels of the interior courtyard, making comfortable spaces both indoors and outdoors. (*RICHÄRD | KENNEDY ARCHITECTS*)

Method:

Estimate the volume of the outdoor circulation space to establish a conventional baseline, for if the space had been indoors, and compare to the existing volume of conditioned space.

Calculations:

The approximate volume of the existing ENR2 interior space is measured by taking a sum of the area of each floor multiplied by the ceiling heights. Gross floor area is 131,657sf. To determine the volume, the ground floor area (15-foot ceiling height) of 22,689sf is separated from the total area to account for the differences in ceiling height: 131,657 – 22,689 = 108,968sf for Floors 2-5 (10-foot ceiling height). To determine the volume of conditioned space:

22,689 * 15 = 340,335 cubic feet
108,968 * 10 = 1,089,680 cubic feet
340,335 + 1,089,680 = 1,430,015 cubic feet

To estimate a volume of space that conventionally would be conditioned interior space, the approximate volume of the exterior circulation spaces and landscape on each floor is determined by taking a sum of the area of each floor multiplied by the ceiling height of each floor: 17,057 * 15 = 255,855 cubic feet for the ground floor and 19,945 * 10 = 199,450 cubic feet for floors 2-5). For total volume to serve as a conventional baseline, we sum these values with the total existing conditioned volume: 255,855 + 199,450 + 1,430,015 = 1,885,320 cubic feet.

The percent reduction of conditioned space is calculated by comparing the existing conditioned volume to the conventional baseline volume: 1 - (1,430,015/1,885,320) = .2415 or 24.15% reduction in conditioned space.

Sources:

"ENR2 Goes Platinum, Gains Highest LEED Certification." University of Arizona News, September 15, 2016. https://news.arizona.edu/story/enr2-goes-platinum-gains-highest-leed-certification.
"ENR2." ULI Developing Urban Resilience, June 7, 2021. https://developingresilience.uli.org/case/enr2/.
Molleken, Aimee. "Environment and Natural Resources 2 (ENR2)." GLHN, March 21, 2019. https://glhn.com/university-arizona-environment-natural-resources-2-enr2/.
Record Documents for Environment & Natural Resources Phase 2 (ENR2) at The University of Arizona. GLHN Architects & Engineers Inc, March 3, 2016.

Limitations:

- Ceiling heights are estimates and not uniform across the generalized areas of the building.
- Volume calculations do not account for furniture and equipment that may reduce the total volume for the existing or the baseline calculations.

Maintains interior courtyard temperatures that are up to 17°F cooler than building exterior temperature while mitigating urban heat island in 59% of hardscape surfaces with open-grid pavement systems and shading.

Background:

ENR2 minimizes the impacts of summer heat in the interior courtyard by self-shading with a strategically narrowed canyon opening and plant material for evapotranspiration. The building's harshest exposures are on the east and west sides, so the greatest building mass and most limited openings are found on those sides. Additionally, vertical metal fins, garden terraces, and balconies forming overhangs work together to maintain outdoor spaces' comfortable, shaded microclimate year-round.

Contextualized in the desert southwest, a major goal for ENR2 was to minimize the impacts of the urban heat island effect on the site. The project earned LEED credit (SSc7.1) Heat Island Effect – Non-Roof by extensively shading the hardscape by the building and trees (Figure 8), as well as by using permeable decomposed granite as a secondary surface material. The original building's roof also fulfilled LEED credit (SSc7.2) Heat Island Effect – Roof, with 100% of qualifying surfaces having a high Solar Reflectance Index (SRI) value. There has since been an addition of a green roof and solar panels that extensively shade the accessible pavers for enhanced thermal comfort for outdoor uses.

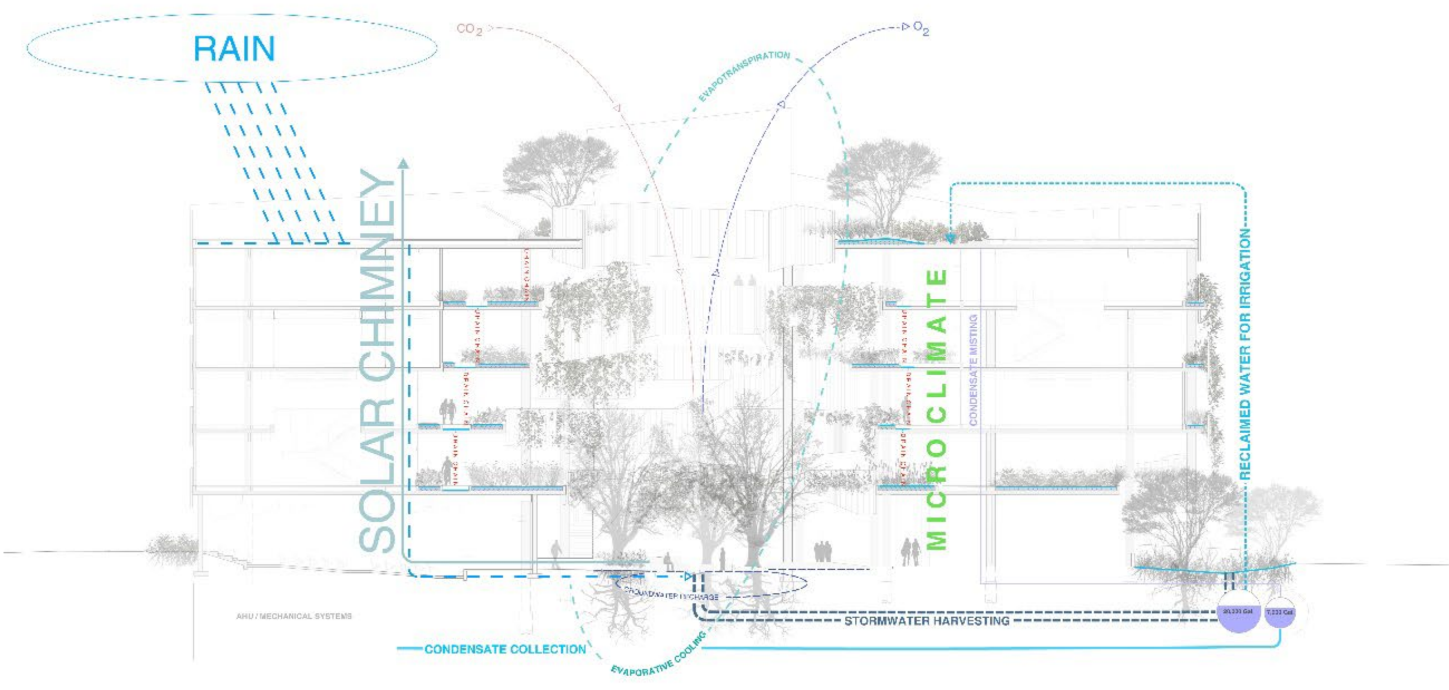


Figure 5: Plant material on each floor of the interior courtyard contribute to a micro climate effect for a comfortable outdoor environment even during extreme heat. (*Colwell Shelor Landscape Architecture*)

Method:

Temperatures comparing ENR2's exterior and interior spaces were taken at 4 public locations throughout the site. A Kestral Heat Stress Meter was used to take 5 temperature reading snapshots at each location on 8 occasions from May to July. The temperatures were taken at various times throughout the day at exterior locations on the North, South, and East sides of the building and the interior courtyard was chosen as a perpetually shaded location in the courtyard on ENR2's ground floor. Each time the measurements were taken, they were taken in the same order: courtyard, south side, east side, and north side. Five temperature measurements were taken, one minute apart, at each location. As the snapshots were captured, Temperature, Heat Index, Relative Humidity, Wet Bulb Temperature, and Globe Temperature were documented. After measurements were taken, the overall lowest and highest temperatures were noted, and each location's average temperature was calculated.

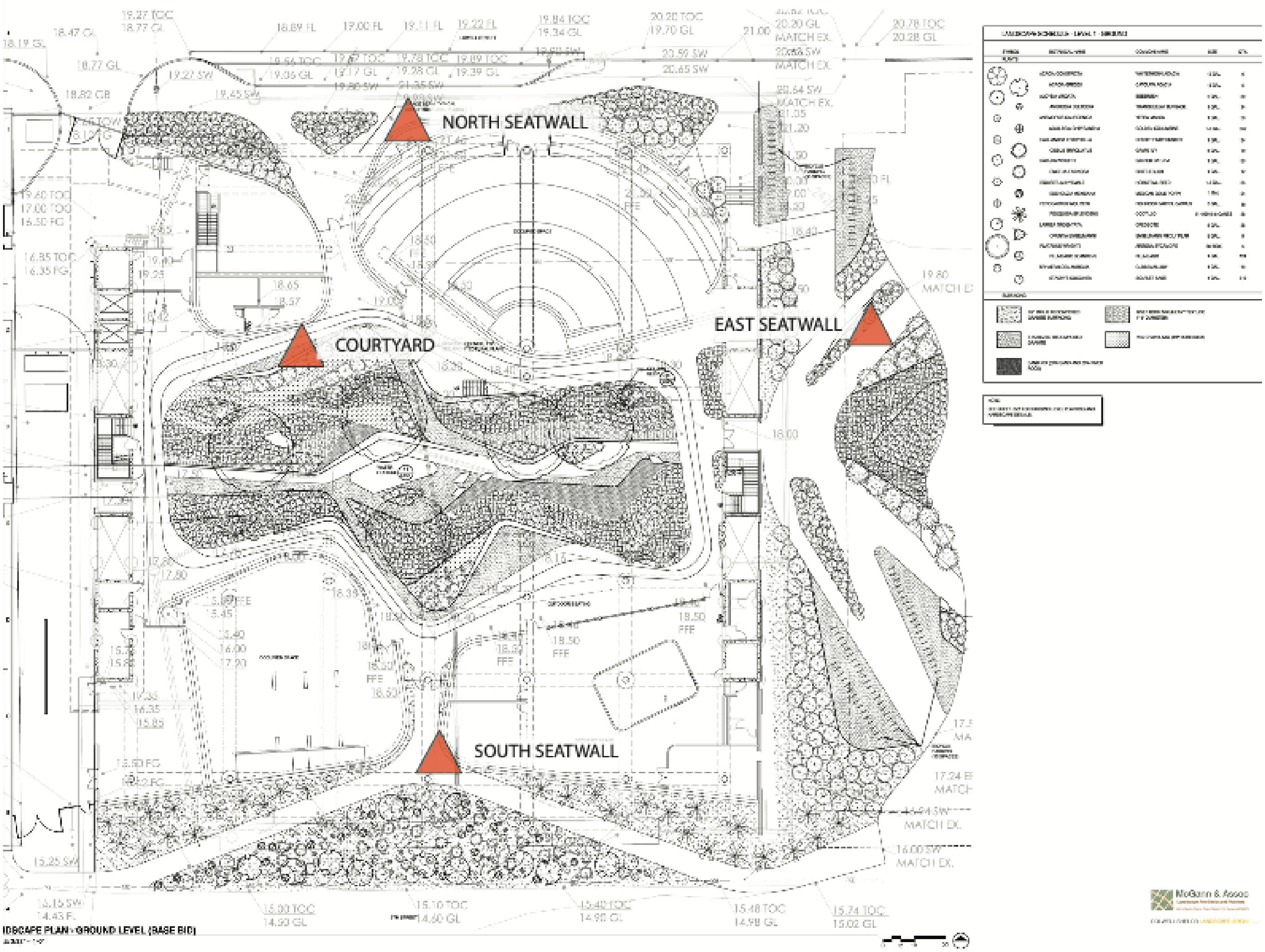


Figure 6: Measurement locations with Kestrel Heat Stress Tracker (*base plan from McGann & Associates*)

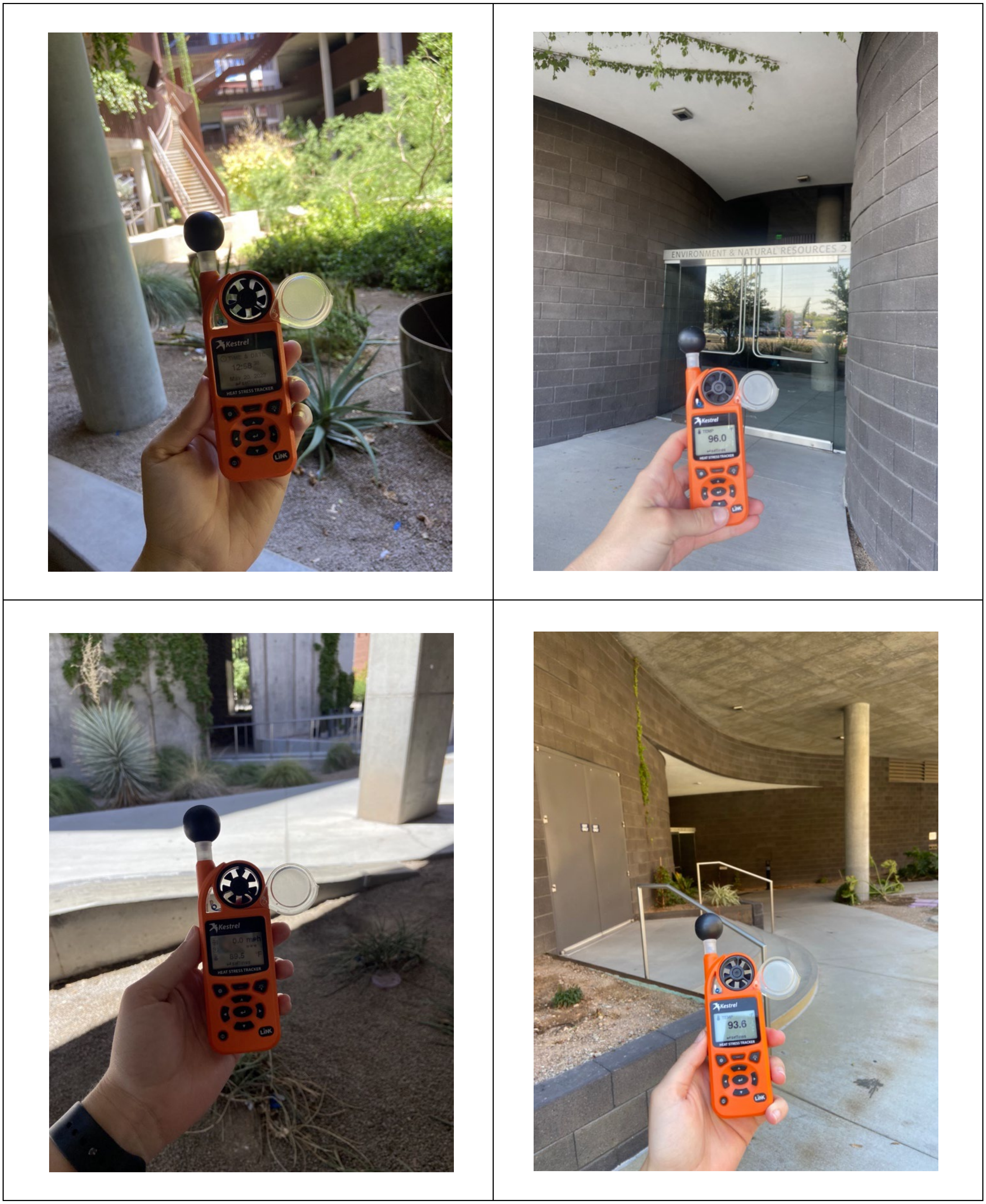


Figure 7: Measurement location with Kestrel Heat Stress Tracker
(Clockwise from upper left: Courtyard, South seatwall, North seatwall, East seatwall)

For Urban Heat Island: ENR2 project documentation for LEED credit 7.1 (See Table 8) complies with Option 1, to "Use any combination of the following strategies for 50% of the site:

- Provide shade from the existing tree canopy or within 5 years of landscape installation
- Provide shade from structures covered by solar panels that produce energy used to offset some nonrenewable resource use
- Provide shade from architectural devices or structures that have a solar reflectance index (SRI) of at least 29
- Use hardscape materials with a Solar Reflectance Index (SRI) of at least 29; Use an open grid pavement system (at least 50% pervious)."

Further, LEED credit 7.2 project documentation complies with Option 1, to "Use roofing materials having a Solar Reflectance Index (SRI) equal to or greater than 78 (according to the requirement for a Low-Sloped Roof) for a minimum of 75% of the roof surface." Original calculations are presented, along with modifications for the addition of the green roof and solar panels relating to Option 3 which incorporates the area of a vegetated roof.

Calculations *(all temperature measurements recorded in degrees Fahrenheit)**:***

Temperature: degree or intensity of heat present
Heat Index: the apparent temperature, what the temperature feels like to the human body when relative humidity is combined with air temperature
Relative Humidity: ratio, expressed in percent, of the amount of atmospheric moisture present relative to the amount that would be present if the air were saturated
Wet Bulb Temperature: representative of the temperature of a parcel of air cooled to saturation by the evaporation of water into it, with the latent heat supplied by the parcel
Globe Temperature: representative of the temperature of the Kestrel Black Globe itself without accounting for air temperature

Definitions from Kestrel Heat Stress Tracker 4400 Manual & NOAA's National Weather Service

Table 6: Temperature measurement snapshots (°F) *(See Appendix D for larger table)*

LOCATION / DATE / TIME			MEASUREMENTS 1					2					3					4					5					AVG
			TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	
courtyard	20-May-23	13:00	88.1	84.7	24.0%	62.6	85.2	84.8	81.1	24.5%	60.4	83.4	85.3	81.9	24.9%	61.2	81.4	85.6	81.9	24.0%	61.0	80.8						86.0
S seatwall	20-May-23		87.1	84.4	27.0%	63.1	81.9	88.1	84.0	20.7%	61.0	84.2	87.3	83.3	21.0%	60.6	84.8	87.7	83.3	19.9%	60.4	86.5	87.8	83.5	19.3%	60.2	86.5	87.6
E seatwall	20-May-23		89.2	99.1	59.2%	77.2	89.8	87.9	84.7	25.2%	62.8	92.3	88.1	84.7	23.9%	62.6	91.4	89.0	85.3	21.5%	61.9	90.2	89.3	85.3	19.7%	61.3	89.8	88.7
N seatwall	20-May-23		87.8	84.6	25.4%	63.0	90.7	88.2	84.4	20.9%	61.2	89.8	85.8	81.7	22.1%	60.2	89.5	87.2	83.1	21.5%	60.8	88.5	88.7	84.7	20.0%	61.2	88.0	87.5
courtyard	25-May-23	9:15	77.3	73.4	24.9%	55.6	82.3	78.4	74.8	29.8%	58.1	81.2	77.8	74.1	26.7%	56.6	80.1	77.2	73.4	25.4%	55.6	79.4	77.5	73.6	25.1%	55.7	78.8	77.6
S seatwall	25-May-23		79.4	75.2	22.9%	56.3	79.9	80.2	75.7	21.4%	56.1	80.0	79.8	75.4	21.2%	55.9	80.1	79.9	75.6	21.2%	55.9	79.9	80.8	76.3	20.3%	56.1	79.9	80.0
E seatwall	25-May-23		80.3	76.5	26.0%	58.1	80.8	80.9	76.5	21.3%	56.6	81.8	81.0	76.6	21.4%	56.6	82.5	81.1	76.6	21.1%	56.5	82.9	81.0	76.6	20.7%	56.3	83.2	80.9
N seatwall	25-May-23		83.0	78.3	18.9%	56.8	84.3	83.1	78.6	19.1%	57.0	83.7	82.7	77.9	19.0%	56.8	83.8	83.3	78.4	18.8%	57.0	83.7	83.3	78.6	18.8%	57.0	83.7	83.1
courtyard	1-Jun-23	17:15	85.3	80.3	18.0%	58.6	87.9	85.2	80.2	17.2%	57.5	85.9	85.6	80.6	17.1%	57.7	84.3	83.7	78.8	17.2%	56.6	83.1	83.9	79.0	16.9%	56.6	82.3	84.7
S seatwall	1-Jun-23		85.0	79.7	14.4%	56.1	81.6	84.8	79.5	14.3%	55.9	82.3	84.9	79.5	14.1%	55.9	83.0	84.7	79.3	14.3%	55.9	83.7	84.7	79.5	14.3%	55.9	84.1	84.8
E seatwall	1-Jun-23		85.6	81.1	20.4%	59.2	84.9	85.2	80.1	16.0%	56.8	85.2	85.0	79.9	15.1%	56.5	85.6	85.2	79.9	14.8%	56.3	85.7	85.4	80.1	14.4%	56.3	85.7	85.3
N seatwall	1-Jun-23		85.5	80.2	14.8%	56.5	86.5	85.6	80.2	14.2%	56.5	86.7	85.5	80.2	13.9%	56.3	86.5	85.6	80.2	13.9%	56.3	86.3	85.9	80.6	13.9%	56.3	86.3	85.6
courtyard	9-Jun-23	16:00	85.7	80.4	13.9%	56.5	85.0	85.0	79.7	14.0%	55.9	84.2	83.7	78.4	14.4%	55.4	83.3	83.9	78.6	14.6%	55.6	82.4	83.2	77.9	14.3%	55.0	81.2	84.3
S seatwall	9-Jun-23		85.5	79.9	11.7%	55.0	82.1	86.9	81.0	10.9%	55.6	82.9	87.2	81.2	11.2%	55.9	83.8	87.0	81.1	10.3%	55.4	84.3	86.7	80.8	10.5%	55.2	85.0	86.7
E seatwall	9-Jun-23		87.2	84.4	27.1%	63.3	86.5	87.9	82.4	12.7%	57.0	86.9	87.8	82.0	11.5%	56.3	87.5	88.1	82.2	10.8%	56.1	87.5	87.6	81.9	10.5%	55.7	87.9	87.7
N seatwall	9-Jun-23		88.7	83.5	15.4%	58.8	90.2	89.4	84.0	13.3%	58.1	90.4	88.8	83.1	11.6%	57.0	90.7	88.4	82.6	11.3%	56.5	90.4	87.5	81.7	11.0%	55.9	90.2	88.6
courtyard	16-Jun-23	10:00	82.8	78.1	18.1%	56.5	82.1	82.8	78.1	18.2%	56.5	82.4	82.8	78.1	17.9%	56.5	82.4	83.0	78.1	17.8%	56.5	82.8	82.8	78.1	18.6%	56.6	82.9	82.8
S seatwall	16-Jun-23		83.6	78.6	16.7%	56.5	76.9	85.4	80.2	15.3%	56.8	79.7	84.3	79.2	15.3%	56.1	81.5	85.2	80.1	15.5%	56.8	83.7	85.3	80.2	15.2%	56.6	84.2	84.8
E seatwall	16-Jun-23		87.8	84.7	25.2%	62.8	87.8	86.3	81.5	17.9%	58.6	89.7	87.8	82.9	16.6%	58.8	90.6	87.6	82.6	15.5%	58.3	91.0	86.5	81.5	17.4%	58.4	91.1	87.2
N seatwall	16-Jun-23		90.7	86.0	16.1%	60.2	91.2	89.2	84.0	15.2%	59.0	90.7	88.6	83.3	14.8%	58.6	90.3	89.1	83.8	14.5%	58.6	90.2	90.5	85.3	14.7%	59.5	90.1	89.6
courtyard	25-Jun-23	14:15	84.9	80.4	19.9%	58.6	89.3	84.7	80.2	18.9%	58.4	87.9	84.5	80.1	20.1%	58.4	87.2	84.4	79.9	19.7%	58.3	86.4	83.9	79.3	19.7%	57.9	85.7	84.5
S seatwall	25-Jun-23		97.9	93.6	14.6%	63.7	88.5	98.6	94.1	13.6%	63.5	90.7	99.9	95.4	13.1%	63.9	91.5	94.7	89.8	14.9%	62.1	97.8	94.1	89.6	15.7%	62.2	98.9	97.0
E seatwall	25-Jun-23		98.8	94.6	14.6%	64.2	101.6	98.1	93.7	14.6%	63.9	101.0	98.3	93.9	14.7%	64.2	101.0	100.4	96.1	13.4%	64.6	101.3	99.9	95.5	13.5%	64.2	102.2	99.1
N seatwall	25-Jun-23		101.3	97.0	13.1%	64.8	103.1	102.6	98.4	12.6%	65.1	102.9	102.2	97.7	12.2%	64.6	102.8	100.9	96.3	12.6%	64.2	103.2	100.3	95.7	13.2%	64.2	103.6	101.5
courtyard	28-Jun-23	17:15	85.0	81.7	26.1%	61.3	86.9	85.2	81.7	25.7%	61.3	87	86.1	82.6	24.8%	61.5	87.5	85.6	82	25.1%	61.3	87.4	86.0	82.6	25.4%	61.5	87.7	85.6
S seatwall	28-Jun-23		99.0	96.1	17.1%	65.8	95.2	99.0	95.9	16.9%	65.7	96.5	98.0	94.5	16.5%	64.9	97.4	98.6	95.2	16.8%	65.3	98.3	99.3	96.1	16.7%	65.8	99.2	98.8
E seatwall	28-Jun-23		97.2	94.6	18.7%	65.7	100.6	98.7	96.3	18.9%	66.6	100.3	99.7	97	17.1%	66.2	99.8	100.6	97.9	16.8%	66.7	99.2	99.8	97.2	17.6%	66.6	100	99.2
N seatwall	28-Jun-23		101.6	102.4	22.0%	70.5	101.6	101.4	99.3	17.6%	67.5	102.3	101.9	99.5	16.5%	67.3	103.4	101.6	98.8	16.1%	66.9	103.7	101.7	98.8	15.8%	66.7	103.2	101.6
courtyard	8-Jul-23	11:45	82.6	79.5	30.9%	61.5	85.3	83.2	80.2	30.8%	62.1	85.7	83.1	79.7	29.9%	61.5	85.4	83.7	80.6	29.8%	61.9	85.4	84.1	81	29.2%	61.9	85.4	83.3
S seatwall	8-Jul-23		95.1	94.1	24.1%	67.3	87.3	91.3	89.1	24.4%	64.9	87.6	95.0	93.6	23.1%	66.6	90.1	95.2	93.6	22.2%	66.2	93.4	95.1	93.2	22.1%	66.2	93.0	94.3
E seatwall	8-Jul-23		97.1	94.8	20.0%	66.4	100.2	98.2	96.6	20.2%	67.1	102.5	98.2	96.6	20.0%	67.1	103.0	98.1	96.3	19.9%	67.1	102.7	97.7	96.3	20.8%	67.3	102.0	97.9
N seatwall	8-Jul-23		97.4	95.9	21.2%	67.3	101.6	98.0	96.8	21.5%	67.8	100.0	98.5	97.2	20.9%	67.8	99.8	98.5	97.3	21.1%	67.8	99.5	98.8	97.7	20.9%	68.0	99.3	98.2

Lowest Temperature

Highest Temperature

Table 7 definitions:

Temperature Difference*:* From the data collected, each day there are 5 snapshots at each of the 4 locations. In Table 6**,** the average temperature of each location is calculated for each day and highlighted accordingly. The Temperature Difference column represents the difference between the highest and lowest average.

Tucson Average Daily Temperature: Tucson, Arizona's average recorded temperature on the day of measurement, accessed from National Weather Service

Tucson High Daily Temperature: Tucson, Arizona's highest recorded temperature on the day of measurement, accessed from National Weather Service

Table 7: Temperature comparisons from Table 6 (°F)

Date	Time	Temperature Difference	Tucson, AZ Average Temp	Tucson, AZ High Temp
20-Jun-23	13:00	***2.7***	***78.5°***	***94°***
25-May-23	09:15	***5.5***	***79.5°***	***96°***
1-Jun-23	17:15	***0.9***	***74.5°***	***89°***
9-Jun-23	16:00	***4.3***	***79.5°***	***93°***
16-Jun-23	10:00	***6.8***	***85.0°***	***100°***
25-Jun-23	14:15	***17.0***	***91.0°***	***111°***
28-Jun-23	17:15	***16.0***	***92.5°***	***107°***
8-July-23	11:45	***14.9***	***95.0°***	***108°***

On every visit where temperature snapshots were taken on the ENR2 site, the interior Courtyard had the lowest average temperature of the four locations. A cooler day in May, with a 78.5°F daily average saw an average temperature difference of 2.7°F between the Courtyard's coolest temperature to the average hottest location. The hottest of the four locations was the North seatwall on all but one visit. On hotter days, with the daily average surpassing 90°F in June and July, the difference between the average Courtyard temperature and the average North seatwall temperature ranged from a 14.9°F difference up to a 17.0°F difference.

For Urban Heat Island:

Table 8: Heat Absorption Reduction Strategies *(from LEED 2009: Table SSc7.1-2)*

Area covered by materials with an SRI of at least 29 (sf)	0
Area shaded by current/future tree canopy within 5 years of installation (sf)	4,149
Area shaded by structures covered with energy-producing solar panels (sf)	0
Area 50% pervious and covered by open-grid pavement system (sf)	10,836
Total Area of qualifying non-roof hardscape surfaces	14,985
Total area of all non-roof hardscape surfaces on project site (sf)	25,220
Qualifying non-roof surfaces as a percentage of total non-roof surfaces	59

Non-roof (LEED Credit 7.1, Option 1):

Total area of non-roof hardscape surfaces **(T):** 25,220sf
Total area of open-grid paving and 50% pervious **(O):** 10,836sf
Total area of surfaces with SRI of at least 29 **(R):** 0sf
Hardscape features shaded by trees - arithmetic mean of 10am, 12pm, 3pm on the summer solstice **(S):** 4,149sf

Sum of open-grid paving, high-reflectance paving, and shaded areas **(Q):** Q=(O+R+S)
14,985sf = 10,836 + 0 + 4,149

Comparison of open-grid paving, high-reflectance paving, and shaded areas to non-roof hardscape surfaces for LEED Credit 7.1 requirements **(Q/T):**
14,985/25,220 = .5942 or 59.42%

Roof (LEED Credit 7.2, Option 1):

(see Appendix E for roof model)
Overall Roof Area: 41,707sf
Appurtenances: -2,204sf
Total Roof Area (less Appurtenances): 39,503sf
White Paving (SRI>78): 7,000sf
White Roofing (SRI>78): 32,503sf

(Area Roof Meeting Minimum SRI/Total Roof Area)*(SRI of Installed Roof/Required SRI) ≥ 75%
39,503/39,503 * 78/78 = 1 or 100% ≥ 75%

Roof recalculation (LEED Credit 7.2, Option 3):

(see Appendix E for roof model)

Overall Roof Area: 41,707sf

Appurtenances: -2,204sf

Solar panels: -5,509sf

Total Roof Area (less Appurtenances and Solar Panels): 33,994sf

White Paving (SRI>78): 7,000 - 3,090 (solar panel overlap) = 3,910sf

White Roofing (SRI>78): 32,503 – 4808 (green roof) – 248 (solar panel overlap) = 27,447sf

Green Roof area: 4808 – 2171(solar panel overlap) = 2,637sf

(Area Roof Meeting Minimum SRI/0.75) + (Area of Vegetated Roof/0.5) ≥ Total Roof Area

(27,447/0.75) + (2637/0.5) ≥ 33,994

41,870sf > 33,994sf

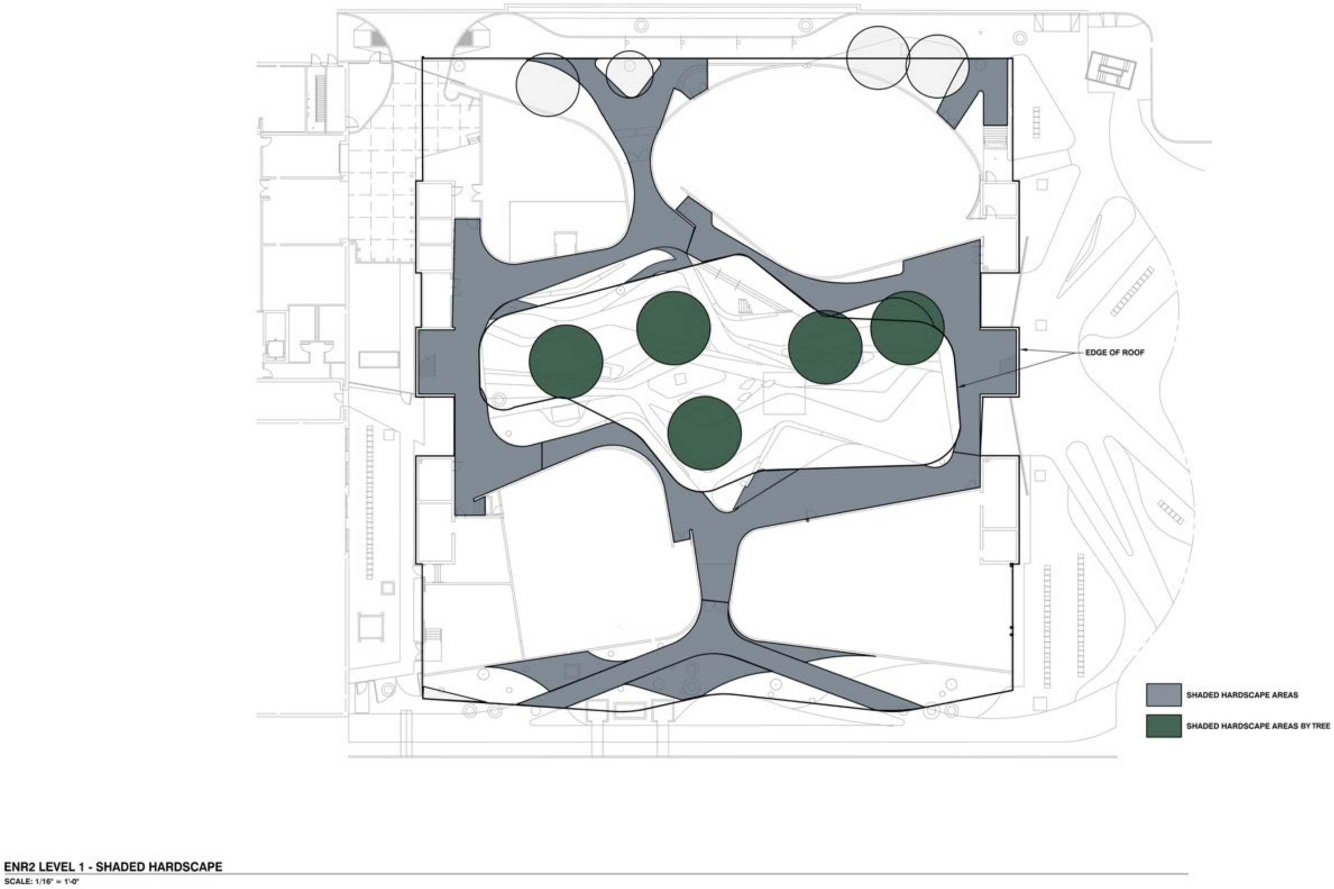


Figure 8: Shaded hardscape as built with canopy projection – ENR2 Level 1 (*from McGann & Associates*)

Sources:

"ENR2." ULI Developing Urban Resilience, June 7, 2021. https://developingresilience.uli.org/case/enr2/.

Kestrel Instruments Support & FAQs. Accessed July 11, 2023. https://kestrelinstruments.com/support/manuals-and-downloads/.

Form-SSc7-1: SS Credit 7.1: Heat Island Effect - Nonroof

"University of Arizona Environment + Natural Resources 2." RICHÄRD | KENNEDY ARCHITECTS. Accessed May 4, 2023. https://rkarch.com/projects/university-arizona-environment-natural-resources-2.

National Oceanic and Atmospheric Administration. (2022, March 3). *Past Weather NOWData*. National Weather Service. https://www.weather.gov/wrh/climate.

Limitations:

- Temperatures around the site were only taken during 3 of the hottest months on average in Tucson, AZ. Mitigating the extreme heat experienced throughout a large portion of the year is crucial when designing outdoor spaces in a desert environment, but ENR2's performance in creating comfortable outdoor spaces for the cooler winter months is not addressed.
- Tree canopy coverage exists as an estimate and does not account for the variance of canopy coverage resulting from tree removals and additions, as well as the growth and seasonal change.
- Though no SRI values were independently verified by the research team, it is unsure whether the pavers installed on the roof meet the SRI value of 78 or higher. However, with the recalculation that includes the installed green roof and solar panels, the pavers were omitted from being classified as a qualified surface and the cumulative roof measures still meet the requirement for the Heat Island Effect – Roof LEED credit 7.2.

SOCIAL BENEFITS

Landscape Performance Survey

> ***Provides a satisfying outdoor experience according to 85% of 76 surveyed users, with 95% of regular users reporting that ENR2 and its landscape have a positive impact on their health and well-being.***
>
> ***Provides aesthetic value, with 94% of 75 surveyed users rating ENR2's aesthetic value higher than other buildings on campus.***

Background:

The survey was created with three target respondent groups of Faculty & Staff, Student, and Visitor. Questions were formulated to inquire about respondents' experiences and opinions regarding recreational & social value, health & well-being, educational value, and aesthetic perception.

Method:

This data was collected through an Institutional Review Board (IRB) approved survey distributed through various Departments and groups throughout the University of Arizona. Survey users were asked to self-identify as a Student, Faculty or Staff Member, Visitor, or Other. Based on their response to this initial question, certain questions pertaining to that user group were asked. There were certain questions posed to all survey respondents, regardless of identification. The goal of this survey was to identify the respondent's relationship with ENR2’s outdoor spaces and then look into their experiences and perceptions of time spent there. Through the survey’s online distribution, 76 responses were collected.

A copy of this survey and written comments from survey respondents are included in Appendix A.

Calculations:

Reason for being at ENR2:

- 27% faculty & staff
- 62% student
- 11% visitor

Satisfied with experience in ENR2’s outdoor spaces:

- 85% yes
- 4% no
- 11% undecided

Out of faculty & staff, those with ENR2 as primary workspace:

- 42% yes
- 58% no

Out of faculty & staff who do not have ENR2 as a primary workspace, those who have teaching or work duties in the building:

- 27% yes
- 73% no

For those who do not have ENR2 as a primary workspace, do you use ENR2 for class instruction?

- 70% yes
- 3% no

For instructors: compared to others, how often do you use ENR2 or its features as an example for class instruction?

- 0% less than
- 17% the same
- 83% more than

Regular users (non-visitors), to what extent do ENR2’s outdoor spaces have a positive effect on your health & well-being?

5% none
23% a little
26% a moderate amount
29% a lot
17% a great deal

Rating of ENR2's aesthetic compared to other buildings on campus:
94% more aesthetic
4% the same
0% less

For students: compared to others, how often have ENR2 or its features been used for lessons in any of your classes?

(Note: Wording on this question might have led to responses not representative of the question's intent. The intent was to identify if the building or its landscape was used as a 'case study' to enhance understanding of a topic presented in class. There is potential that respondents understood the question as asking if their class was scheduled to meet and be instructed in the building.)

30% less than
19% the same
51% more than

Visitors (8 identified):
2 first-time visitors, both reported that they would recommend ENR2 to others
6 non-first-time visitors (4 respondents reported visiting a few times in the past 12 months)

Sources:

Recorded responses to the distributed survey.

Limitations:

- Survey participants did not represent all departments and fields of study within the University.
- Campus IRB restrictions prevented surveyors from approaching survey candidates on-site.

ECONOMIC BENEFITS

As mentioned under research strategy, efforts to identify specific, mensurable benefits gave way to general commentary and anecdotal evidence surrounding the project's economic impact. Attempts were made to identify various metrics such as increasing property value and catalyzing an increase in research funding involving ENR2 and its sustainable features.

ENR2's design replicates natural sequences and systems to address complex environmental issues. With its focus on sustainability, the CSI research team looked into research that included ENR2 and its landscape. The hope was to compare funding for sustainability or biodiversity-related research projects across the university, before and after the construction of ENR2. This investigation did not find enough current or historic records of such studies taking place on the University of Arizona campus.

Another aim of the research team was to identify a specific increase in property value or notable trends in property values surrounding the project site. Not only was this unattainable due to parcel records dating back to 2016 at the earliest, but the project site lies within a larger parcel that covers a notable part of the University of Arizona's Main Campus. After discussions with the University of Arizona's Planning, Design & Construction (PDC), which plans, designs, and constructs the physical campus and manages the campus real estate, it became clear that, although not necessarily numeric value, ENR2 continues to be a majorly popular building amongst the many buildings PDC has completed recently. As a pinnacle example of developing outdoor spaces and incorporating landscape inside a building, the building serves as a showcase that is requested to be viewed by many. With this popularity and distinctive character, ENR2 serves a sizeable function as a recruitment tool for faculty, staff, and students.

LESSON LEARNED – ADDITIONAL INFORMATION

Effect of high salinity levels in water used for irrigation

The use of drip irrigation of reclaimed water throughout the site led to high levels of salinity experienced by plants on all levels of ENR2. Plant choices *(see full plant list in Appendix A)* were made with this consideration in mind, but plant vitality was still impacted by the reclaimed water used for irrigation. The nature of ENR2's plantings prevented natural flushing of salt through the soil, especially in the covered areas unable to be reached by rain.

Some plants that have been attempted to be used and have ultimately been unable to handle the salinity included elderberry (*Sambucas spp.*), lilac (S*yringa spp.*), panicled hydrangea (*Hydrangea paniculata*), oakleaf hydrangea (*Hydrangea quercifolia*), *Ilex heterophylla*, penstemon, English lavender *(Lavandula angustifolia*), *Justicia spp.*, and firebush (*Hamelia patens*). It should be noted that other factors could have contributed to their inability to exist in that space, such as lack of light in some of the landscaped areas. Plants that have survived include purple heart (*Tradescantia pallida)*, sage (*Salvia spp.), Philodendron spp.*, *Agave spp.,* jacaranda (*Jacaranda mimosifolia), Sansevieria*, and 'Silver Streak' flax-lily (*Dianella tasmanica).*

Water samples were taken from the building's underground water storage tank and one of the open-air water columns found in the interior courtyard. Irrigation Suitability Tests were performed on both samples by IAS Laboratories. The tests (see full results in Appendix B) resulted in a United States Department of Agriculture (USDA) classification of C3 – S1 and showed a high salinity hazard and low sodium hazard (Figure 9). it was recommended that both water samples should only be used on soils with no restricting layers so the leaching of salts can be accomplished.

The USDA Agriculture Handbook 60 classifies the water as **High Salinity Water (C3)** that "cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected," and **Low Sodium Water (S1)** that "can be used for irrigation on most soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive plants may accumulate injurious concentrations of sodium. This classification bears relevance to ENR2, as the various successes and failures of sustaining different plant species are suspected to be partly attributed to high salinity levels present in the water used for irrigation, as well as salinity accumulation in the specific soil manufactured for the site.

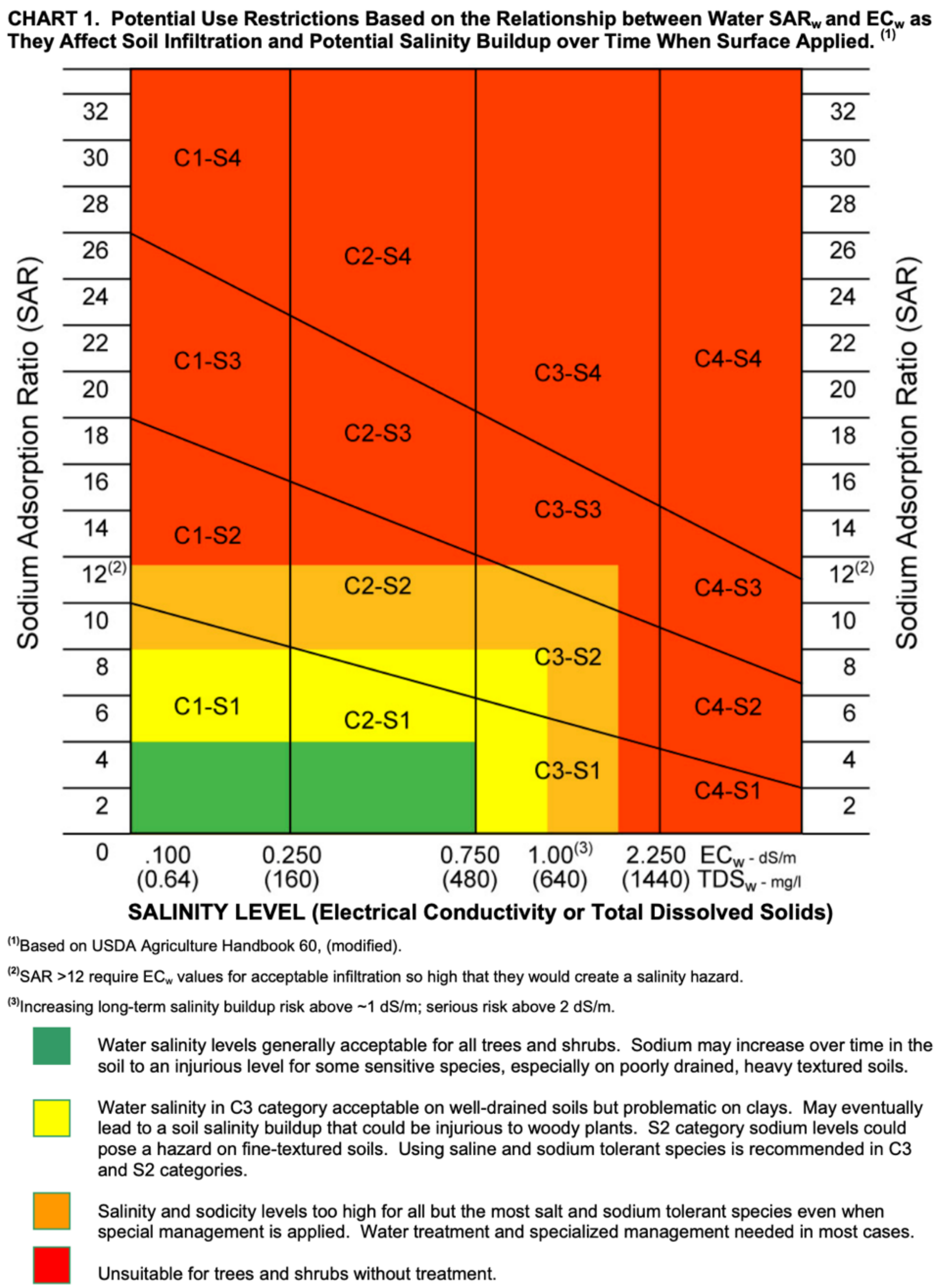


Figure 9: Salinity Levels & Soil Classifications *(from USDA Plant Materials Technical Note MT-61)*

Water with a salinity hazard is toxic to plants and these high concentrations of salt in the soil can lead to a "physiological" drought condition. This can be seen through instances where plants begin to wilt even though the bed appears to have plenty of moisture because the roots become unable to absorb the water. Water with a sodium hazard, if continually used, can lead to a breakdown in the physical structure of the soil, as the sodium is absorbed and attaches to soil particles. The soil then can become hard and compact, leading it to be impervious to water penetration.

Sources:

Fipps, Guy. "Irrigation Water Quality Standards and Salinity Management Strategies." *AgriLife Communications, The Texas A&M System*, April 30, 2003.

Scianna, Joseph, Tom Pick, and Robert Logar. "Testing and Interpreting Salt-Affected Water for Tree and Shrub Plantings." *Plant Materials Technical Note* MT-61 (September 2007).

United States Salinity Laboratory Staff. "Diagnosis and Improvement of Saline and Alkali Soils." *Agriculture Handbook* 60 (February 1954).

COST COMPARISON

The interior courtyard with the over-deck gardens on each floor is a key element in creating the canyon effect of the building and landscape. While estimated to cost an additional $425,000 as compared to a conventional, enclosed building, the over-deck gardens offer significant value through an array of environmental and social benefits including habitat creation, microclimate, biophilic benefits, reduced energy costs, and architectural recognition and acclaim for blurring the line between building and landscape.

Background:

A significant feature of the ENR2 building/landscape is the terraced over-deck gardens on each floor, with open-air "hallway" circulation oriented toward the interior courtyard. A conventional building as part of the bigger project would be more routine, as it is standardized and without the landscape, it is a lower cost per square foot. The construction of an over-deck landscape is a more significant investment. Such landscapes have additional construction costs compared to a ground-level landscape. This is due to the structural reinforcement needed to support the weight of materials for proper drainage and the weight of material delivery and equipment access for completing the work.

However, the investment in these landscaped terraces is meaningful to ENR2's overall building concept of a canyon refuge. The landscape terraces save on energy costs by reducing the volume of conditioned space in the building and by utilizing plants and shade materials to provide an outdoor microclimate combatting the desert heat. Additionally, the landscape terraces have a notably public orientation, for all building occupants to utilize and view from all building levels. They contribute in a major way to the recognition and acclaim of this campus landmark that obscures the line between building and landscape.

Method:

Aggregated cost comparison using price per square foot for construction of a conventional building/landscape compared to an open-air courtyard with terraced landscape.

Calculations:

The total area of the over-deck landscape on Floors 2-6 is 24,783sf.

The cost per square foot was estimated in 2020 values by referencing an Audit for the U.S. General Services Administration (GSA) Green Roof Maintenance and Safety Practices. Extensive Green Roofs were estimated to cost $24.50 per square foot compared to $15.51 for a traditional roof. No estimate was provided for an Intensive Green Roof, but the difference in maintenance between the two types is 33.33% higher. This difference was used to calculate an estimate for construction cost difference: $24.50 * 1.3333 = $32.67 per square foot for an intensive Green Roof system.

This value was applied to all over-deck landscaping for the project to estimate a total cost of the over-deck landscape: 24,783 * $32.67 = $809,660.61
A more traditional comparison without intensive landscape used the traditional roof cost: 24,783 * $15.51 = $384,384.33

The estimated cost difference is $809,660.61 - $384,384.33 = $425,276.28

Sources:

Office of Inspector General, Audit of the Public Buildings Service's Green Roof Maintenance and Safety Practices § (2020).

Record Documents for Environment & Natural Resources Phase 2 (ENR2) at The University of Arizona. GLHN Architects & Engineers Inc, March 3, 2016.

Limitations:

- Actual construction costs that itemized the cost of over-deck construction and standard building construction were not available for use in calculating the over-deck landscape cost comparison.
- Estimates were based on values used for GSA public buildings and are not specific to Southern Arizona or campus construction. No value was provided for intensive Green Roofs and the adjusted value was applied uniformly to all over-deck landscapes.

MASTER SOURCES

Drainage Report Construction Document (100%) Phase for Environment and Natural Resources II at The University of Arizona (Prepared by Presidio Engineering, Inc. and Bogardus Engineering, LLC for GLHN Architects and Engineers, May 23, 2013).

“ENR2: A New Model for Sustainability.” University of Arizona News, November 3, 2015. https://news.arizona.edu/story/enr2-a-new-model-for-sustainability.

“ENR2 Goes Platinum, Gains Highest LEED Certification.” University of Arizona News, September 15, 2016. https://news.arizona.edu/story/enr2-goes-platinum-gains-highest-leed-certification.

“ENR2.” ULI Developing Urban Resilience, June 7, 2021. https://developingresilience.uli.org/case/enr2/.

Fipps, Guy. “Irrigation Water Quality Standards and Salinity Management Strategies.” *AgriLife Communications, The Texas A&M System*, April 30, 2003.

Form-SSc6-1: SS Credit 6.1: Stormwater Design – Quantity Control

Form-SSc6-2: SS Credit 6.1: Stormwater Design – Quality Control

LEED BD+C: New Construction – v3 – LEED 2009

LEED Reference Guide for Green Building Design and Construction 2009, USGBC, January 1, 2009

LEED Reference Guide for Green Building Design and Construction with Global Alternative Compliance Paths, version v2009, USGBC, January 1, 2009

Molleken, Aimee. “Environment and Natural Resources 2 (ENR2).” GLHN, March 21, 2019. https://glhn.com/university-arizona-environment-natural-resources-2-enr2/.

National Oceanic and Atmospheric Administration. (2022, March 3). *Past Weather NOWData*. National Weather Service. https://www.weather.gov/wrh/climate.

Office of Inspector General, Audit of the Public Buildings Service’s Green Roof Maintenance and Safety Practices § (2020).

Record Documents for Environment & Natural Resources Phase 2 (ENR2) at The University of Arizona. GLHN Architects & Engineers Inc, March 3, 2016.

Scianna, Joseph, Tom Pick, and Robert Logar. “Testing and Interpreting Salt-Affected Water for Tree and Shrub Plantings.” *Plant Materials Technical Note* MT-61 (September 2007).

United States Salinity Laboratory Staff. “Diagnosis and Improvement of Saline and Alkali Soils.” *Agriculture Handbook* 60 (February 1954).

“University of Arizona Environmental and Natural Resources 2.” COLWELL SHELOR LANDSCAPE ARCHITECTURE, June 30, 2022. https://colwellshelor.com/works/university-of-arizona-environmental-and-natural-resources/.

“University of Arizona Environment + Natural Resources 2.” RICHÄRD | KENNEDY ARCHITECTS. Accessed May 4, 2023. https://rkarch.com/projects/university-arizona-environment-natural-resources-2.

APPENDIX A: Survey Questions & Written Responses

Survey Questions

**Note: survey followed logic where not all questions were posed to all groups of survey respondents*

What best describes your reason for being at ENR2?

Faculty/Staff   Student   Visitor   Other

Are you satisfied with your experience in ENR2's outdoor spaces? Y/N/Undecided

Is your primary workspace ENR2? Y/N

Do you teach or have work duties here? Y/N

Do you use ENR2 for class instruction? Y/N

Compared to other buildings in which you have taught, how often do you use ENR2 or its features as an example for class instruction?

Less than   The same   More than

Compared to other buildings on campus, how often have ENR2 or its features been used for lessons in any of your classes?

Less than   The same   More than

To what extent do ENR2's outdoor spaces have a positive effect on your health & well-being?

None   A little   A moderate amount   A lot   A great deal

How do you rate ENR2's outdoor spaces compared to other buildings on campus?

More aesthetic   The same   Less aesthetic

What would you change about ENR2's outdoor spaces to improve your experience?

Written responses, see next page

Please share any other thoughts you may have on ENR2's architecture and outdoor spaces.

Written responses, see next page

Survey Written Responses

What would you change about ENR2's outdoor spaces to improve your experience?

> *"Needs to feel a little less private"*
> *"I would like to see it more throughout campus"*
> *"Replace sparse ornamental plantings with native plant communities, edible gardens, and ethnobotanical landscapes"*
> *"Add vegetation to ground level."*
> *"More seating"*
> *"There is no shield from the wind. In the winter, it's brutal trying to sit outside. I'd love some kind of protection from the wind."*

Please share any other thoughts you may have on ENR2's architecture and outdoor spaces.

"We need more tables and places to sit outside on all of the levels."
"Best building on campus. It's always calming and cool in the canyon of the building and the classrooms are great."
"ENR2 gives me hope that one day all buildings can and will create a better world."
"I think the ENR2 landscape should feature more educational components and there should be more emphasis around the university to educate the students and the community about sustainable design."
"The shady microclimate of the main courtyard is an undervalued asset perfect for intensive planting of water-needy crops and native plant habitat. The trail-like stairways and terraces that wind above the courtyard are inviting and exciting to explore, yet provide little reason to linger. The vertical steel slats and sparse terrace planters are unrealized opportunities to demonstrate urban gardening strategies and create micro-habitats. The original intent of ENR2 as a learning landscape can be fully realized by reimagining its marginal landscape as a flourishing campus garden that invites students to put their hands in the dirt and inspire a lifelong ethic of care through cultivation."
"I give thanks to the wonderful courtyard EVERY DAY I COME TO WORK. The interior spaces are less successful, particularly for folks with direct sun coming in their windows."
"I really enjoy the building and landscape architecture of ENR2! It is an incredibly peaceful and calming place to sit in between classes and while doing schoolwork."
"Very pretty"
"I love this building and all that it has done for my mental health being a student at the U of A!"
"The landscape features are cool, the rainwater harvesting and connection of the indoor and outdoor landscapes has a string connection. The facade gives a rustic feeling and blends well with the exiting spaces. The layout of the plan seems geometrical but the passive heating and cooling techniques makes it unique, directly focusing on the health and well being. This building at the U of A has set an example to be more sustainable and environment sensitive"
"Great space to do works"
"This is my favorite building in Arizona. Since it was built, we make a yearly pilgrimage to ENR2 during the monsoons to watch the rain come through and it is close to a religious experience. It feels like a gothic cathedral, cool in temperature, peaceful and revenant in atmosphere and truly glorious to sit quietly in and contemplate."
"It's gorgeous and, I think, fairly sustainable. I love it when I get a chance to visit."

“I think ENR2 is one of the more distinctive buildings and spaces on campus. I'd like to see more!”
“ENR2 is my favorite building on campus”
“ENR2 is a highlight of the already very beautiful campus of University of Arizona. As a current student, my only wish is we had more opportunities to spend time at ENR2 and enjoy its rooftop.”
“I really appreciate that the outdoor spaces are comfortably occupiable most of the year- there is enough shade to see my laptop screen, places that feel safe to sit in for a while, and multiple options for seating proximity to plants. I love it when it rains in ENR2. Only complaint is it is difficult to cross straight through from north to south or to get to the west stairs.”
“Wonderful, innovative design enjoyed by many. Great use of outdoor space and ecological presence. Blurring the lines between indoor and outdoor in a beautiful way. Inspiring.”
“It is really nice to visit and I enjoy taking the ramp up to the meeting rooms”
“I love the canyon feel and the temperature inside the courtyard. It's beautifully designed!”
“Best building on campus hands down”
“Make more like it”
“ENR2 gives campus a more green feel, coming from a state surrounded constantly by green and the changing of trees I often feel 'dead' by the same monotone colors found all over campus. ENR2 is the one place I feel slightly more at home with all the greenery and options for sitting outside and embracing nature. I wish I there was more places and buildings like this one on campus!”
“It’s really cool, the architecture and the nature surrounding and in it as well”
“My favorite building on campus. Took my graduation photos there! Love to be there when it rains. Have enjoyed the progress of the landscape over the past several years. It is a great building I use in a few of my courses (teach at Pima College)”
“Sensory architecture”
“Innovative, thought-provoking, a good template for other buildings on campus”
“Incredible. By far the best building on campus.”
“It’s cool and interesting there”
“The sustainability is inspiring”
“It is beautiful and my favorite building on campus. I have learned so much about it and it’s LEED certification supported my academic journey and final professional career choice.”
“Probably the most aesthetic building on campus”
“Peaceful space that makes me want to hang out in the building more often”
“The architecture is really cool but the well being of the vegetation does not seem to have been considered. There is insufficient sunlight in the patio area to support much vegetation.”
“Fantastic building both indoor and outdoor spaces. Love the design and landscaping, shade and sustainability”
“Slot canyon idea is great”
“Needs more outdoor seating”
“Love the natural shade. Love all the plants. Wish there were tours”

APPENDIX B: Irrigation Suitability & Evaluation

IAS Laboratories
2515 East University Drive
Phoenix, Arizona 85034
(602) 273-7248
Fax (602) 275-3836

Report Number:	23F0425	**Submitted By:**	Kirk Dimond
Lab Number:	23F0425-01	**Report To:**	U of AZ School of Land Arch
Sample ID:	1	**Project:**	Water
Date Received:	06/20/2023	**Crop:**	No Crop

COMPLETE WATER TEST W4: Irrigation Suitability & Evaluation

Elements and Compounds	mg/L	meq/L	Lbs/Acre-ft
Calcium (Ca)	68.5	3.42	186.2
Magnesium (Mg)	12.0	0.99	32.7
Sodium (Na)	119	5.17	323.2
Potassium (K)	9.83	0.25	26.7
Carbonate (CO3)	0.0	0.00	0.00
Bicarbonate (HCO3)	146	2.40	398.2
Chloride (Cl)	232	6.54	631.0
Sulfate-S (SO4)	57.41	1.20	156.1
Nitrate-N (NO3-N)	5.15	0.08	14.0
Phosphate-P (PO4-P)	0.23	0.01	0.62
Boron (B)	0.37	0.01	1.00

Chemical Properties

pH, units:	8.27
Electrical conductivity, dS/m:	1.05
Total soluble salts, ppm:	651.7
Cation/Anion ratio:	0.96

Sodium adsorbtion ratio (SAR):	3.48
SAR adjusted:	3.83
Adjusted RNa:	3.91
Soluble sodium percentage (SSP):	52.6
Salt applied per acre-foot, lbs:	1772.6
Sulfuric acid required (gal 95% acid/ac-ft to neutralize 90% carbonate + bicarbonate):	20.2
Calcium + Magnesium hardness (mg/L):	220.5
Gypsum required (lb of 100% gypsum/ac-ft) to reach a desired SAR of 5.00:	0.0
Leaching required (% additional irrigation) for leaching of salts:	11.8
Salinity hazard is high. Sodium hazard is low.	
U.S.D.A. classification of this water is C3 - S1	

Comments

This water should be used only on soils with no restricting layers so the leaching of salts can be accomplished.

IAS Laboratories
2515 East University Drive
Phoenix, Arizona 85034
(602) 273-7248
Fax (602) 275-3836

Report Number:	23F0425	**Submitted By:**	Kirk Dimond
Lab Number:	23F0425-02	**Report To:**	U of AZ School of Land Arch
Sample ID:	2	**Project:**	Water
Date Received:	06/20/2023	**Crop:**	No Crop

COMPLETE WATER TEST W4: Irrigation Suitability & Evaluation

Elements and Compounds	mg/L	meq/L	Lbs/Acre-ft
Calcium (Ca)	112	5.61	305.8
Magnesium (Mg)	24.5	2.02	66.6
Sodium (Na)	152	6.62	413.8
Potassium (K)	8.74	0.22	23.8
Carbonate (CO_3)	0.0	0.00	0.00
Bicarbonate (HCO_3)	298	4.88	809.7
Chloride (Cl)	255	7.19	693.6
Sulfate-S (SO_4)	88.26	1.84	240.1
Nitrate-N (NO_3-N)	3.26	0.05	8.87
Phosphate-P (PO_4-P)	0.14	0.00	0.38
Boron (B)	0.35	0.01	0.95

Chemical Properties

pH, units:	7.71
Electrical conductivity, dS/m:	0.84
Total soluble salts, ppm:	943.3
Cation/Anion ratio:	1.04

Sodium adsorbtion ratio (SAR):	3.39
SAR adjusted:	4.46
Adjusted RNa:	4.44
Soluble sodium percentage (SSP):	45.7
Salt applied per acre-foot, lbs:	2565.9
Sulfuric acid required (gal 95% acid/ac-ft to neutralize 90% carbonate + bicarbonate):	41.3
Calcium + Magnesium hardness (mg/L):	381.6
Gypsum required (lb of 100% gypsum/ac-ft) to reach a desired SAR of 5.00:	0.0
Leaching required (% additional irrigation) for leaching of salts:	9.1
Salinity hazard is high. Sodium hazard is low.	
U.S.D.A. classification of this water is C3 - S1	

Comments

This water should be used only on soils with no restricting layers so the leaching of salts can be accomplished.

APPENDIX C: LEED Scorecard

1000026441, Tucson, Arizona

Environment and Natural Resources Ph 2

LEED BD+C: New Construction (v2009)

PLATINUM, AWARDED AUG 2016

SUSTAINABLE SITES — AWARDED: 24 / 26

SSp1	Construction activity pollution prevention	REQUIRED
SSc1	Site selection	1/1
SSc2	Development density and community connectivity	5/5
SSc3	Brownfield redevelopment	0/1
SSc4.1	Alternative transportation - public transportation access	6/6
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1/1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	3/3
SSc4.4	Alternative transportation - parking capacity	2/2
SSc5.1	Site development - protect or restore habitat	0/1
SSc5.2	Site development - maximize open space	1/1
SSc6.1	Stormwater design - quantity control	1/1
SSc6.2	Stormwater design - quality control	1/1
SSc7.1	Heat island effect - nonroof	1/1
SSc7.2	Heat island effect - roof	1/1
SSc8	Light pollution reduction	1/1

WATER EFFICIENCY — AWARDED: 7 / 10

WEp1	Water use reduction	REQUIRED
WEc1	Water efficient landscaping	4/4
WEc2	Innovative wastewater technologies	0/2
WEc3	Water use reduction	3/4

ENERGY & ATMOSPHERE — AWARDED: 22 / 35

EAp1	Fundamental commissioning of building energy systems	REQUIRED
EAp2	Minimum energy performance	REQUIRED
EAp3	Fundamental refrigerant Mgmt	REQUIRED
EAc1	Optimize energy performance	11/19
EAc2	On-site renewable energy	2/7
EAc3	Enhanced commissioning	2/2
EAc4	Enhanced refrigerant Mgmt	2/2
EAc5	Measurement and verification	3/3
EAc6	Green power	2/2

MATERIAL & RESOURCES — AWARDED: 7 / 14

MRp1	Storage and collection of recyclables	REQUIRED
MRc1.1	Building reuse - maintain existing walls, floors and roof	0/3
MRc1.2	Building reuse - maintain interior nonstructural elements	0/1
MRc2	Construction waste Mgmt	2/2
MRc3	Materials reuse	0/2
MRc4	Recycled content	2/2

MATERIAL & RESOURCES — CONTINUED

MRc5	Regional materials	2/2
MRc6	Rapidly renewable materials	0/1
MRc7	Certified wood	1/1

INDOOR ENVIRONMENTAL QUALITY — AWARDED: 11 / 15

EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0/1
EQc2	Increased ventilation	1/1
EQc3.1	Construction IAQ Mgmt plan - during construction	1/1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1/1
EQc4.1	Low-emitting materials - adhesives and sealants	1/1
EQc4.2	Low-emitting materials - paints and coatings	1/1
EQc4.3	Low-emitting materials - flooring systems	1/1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1/1
EQc5	Indoor chemical and pollutant source control	1/1
EQc6.1	Controllability of systems - lighting	1/1
EQc6.2	Controllability of systems - thermal comfort	0/1
EQc7.1	Thermal comfort - design	1/1
EQc7.2	Thermal comfort - verification	1/1
EQc8.1	Daylight and views - daylight	0/1
EQc8.2	Daylight and views - views	0/1

INNOVATION — AWARDED: 6 / 6

IDc1	Innovation in design	0/1
IDc2	LEED Accredited Professional	0/1

REGIONAL PRIORITY CREDITS — AWARDED: 4 / 4

EAc2	On-site renewable energy	1/1
SSc2	Development density and community connectivity	1/1
SSc4.4	Alternative transportation - parking capacity	1/1
SSc7.1	Heat island effect - nonroof	1/1
WEc1	Water efficient landscaping	0/1
WEc3	Water use reduction	0/1

TOTAL 81 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

APPENDIX D: TEMPERATURE SNAPSHOTS

LOCATION / DATE / TIME			MEASUREMENTS 1					2					3					4					5					AVG
			TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	TEMP	HEAT INDEX	REL HUMID	WET BULB	GLOBE TEMP	
courtyard	28-May-23		88.1	84.7	36.8%	62.6	85.2	84.8	81.1	34.5%	60.4	83.4	85.3	81.9	34.9%	61.2	81.4	85.6	81.9	34.8%	61.0	80.8						86.0
S sidewall	28-May-23	13:00	87.1	84.4	37.8%	63.1	81.9	88.1	84.8	38.7%	61.8	84.2	87.3	83.9	31.0%	60.6	84.8	87.2	83.9	29.9%	60.4	85.5	87.8	83.5	19.9%	60.2	85.5	87.6
E sidewall	28-May-23		80.2	99.1	59.3%	77.2	80.8	87.9	84.7	35.3%	60.8	92.9	88.1	84.7	29.9%	60.6	94.4	89.0	85.9	31.5%	61.9	90.2	89.3	85.9	19.7%	61.9	80.8	88.7
N sidewall	28-May-23		87.8	84.6	35.4%	63.0	90.7	88.2	84.4	30.9%	61.2	88.8	85.8	81.7	32.2%	60.2	89.5	87.2	83.1	31.5%	60.8	88.5	88.7	84.7	30.0%	61.2	88.8	87.5
courtyard	25-May-23		77.3	73.4	34.9%	55.6	80.9	78.4	74.8	30.0%	58.1	81.2	77.8	74.1	36.7%	56.6	80.1	77.2	73.4	35.4%	55.6	79.4	77.5	73.6	35.3%	55.7	78.8	77.6
S sidewall	25-May-23	9:15	79.4	75.2	32.9%	56.9	79.9	80.2	75.7	31.4%	56.1	80.8	79.8	75.4	31.9%	55.9	80.1	79.9	75.6	31.3%	55.9	79.9	80.8	76.9	30.9%	56.1	79.9	80.0
E sidewall	25-May-23		80.3	76.5	36.0%	58.1	80.8	80.9	76.5	31.9%	56.6	81.8	81.0	76.6	31.4%	56.6	80.5	81.1	76.6	31.1%	56.5	80.9	81.0	76.6	30.7%	56.9	80.2	80.9
N sidewall	25-May-23		83.0	78.9	31.9%	56.8	84.5	83.1	78.6	29.1%	57.0	83.7	82.7	77.9	19.0%	56.8	83.8	83.3	78.4	30.0%	57.0	83.7	83.3	78.6	18.0%	57.0	83.7	83.1
courtyard	1-Jun-23		85.3	80.9	31.8%	58.6	87.9	85.2	80.2	17.9%	57.5	85.9	85.6	80.6	17.9%	57.7	84.9	83.7	78.8	17.9%	56.6	83.1	83.9	78.8	16.9%	56.6	82.9	84.7
S sidewall	1-Jun-23	17:15	85.0	79.7	14.4%	56.1	81.6	84.8	79.5	14.9%	55.9	82.9	84.9	79.5	14.1%	55.9	83.8	84.7	79.5	14.9%	55.9	83.7	84.7	79.5	14.9%	55.9	84.1	84.8
E sidewall	1-Jun-23		85.6	81.1	18.4%	59.2	84.9	85.2	80.1	16.0%	56.8	85.2	85.0	79.9	15.1%	56.5	85.6	85.2	79.9	14.8%	56.9	85.7	85.4	80.1	14.4%	56.9	85.7	85.3
N sidewall	1-Jun-23		85.5	80.9	14.8%	56.5	86.5	85.6	80.2	14.9%	56.5	86.7	85.5	80.2	13.9%	56.9	86.5	85.6	80.2	13.9%	56.9	86.9	85.9	80.6	13.9%	56.9	86.9	85.6
courtyard	9-Jun-23		85.7	80.4	13.9%	56.5	85.8	85.0	79.7	14.8%	55.9	84.2	83.7	78.4	14.4%	55.4	83.9	83.9	78.6	14.6%	55.6	82.4	83.2	77.9	14.9%	55.0	81.2	84.3
S sidewall	9-Jun-23	16:00	85.5	79.9	11.7%	55.0	82.1	86.9	81.0	10.9%	55.6	82.9	87.2	81.2	11.9%	55.9	83.8	87.0	81.1	10.9%	55.4	84.9	86.7	80.8	10.5%	55.2	85.0	86.7
E sidewall	9-Jun-23		87.2	84.4	17.1%	60.9	86.5	87.9	82.4	13.7%	57.0	86.9	87.8	82.0	11.5%	56.9	87.5	88.1	82.2	10.0%	56.1	87.5	87.6	81.9	10.5%	55.7	87.9	87.7
N sidewall	9-Jun-23		88.7	83.5	15.4%	58.8	90.2	89.4	84.0	13.9%	58.1	90.4	88.8	83.1	11.0%	57.0	90.7	88.4	82.6	11.9%	56.5	90.4	87.5	81.7	11.0%	55.9	90.2	88.6
courtyard	16-Jun-23		82.8	78.1	18.1%	56.5	80.1	82.8	78.1	18.1%	56.5	80.4	82.8	78.1	17.9%	56.5	80.4	83.0	78.1	17.0%	56.5	80.8	82.8	78.1	18.0%	56.6	80.9	82.8
S sidewall	16-Jun-23	18:00	83.6	78.6	16.7%	56.5	76.9	85.4	80.2	15.9%	56.8	79.7	84.3	79.2	15.9%	56.1	81.5	85.2	80.1	15.5%	56.8	83.7	85.3	80.2	15.3%	56.6	84.2	84.8
E sidewall	16-Jun-23		87.8	84.7	15.3%	60.8	87.8	86.3	81.5	17.9%	58.6	88.7	87.8	82.9	16.0%	58.8	88.6	87.6	82.6	15.5%	58.9	90.8	86.5	81.5	17.4%	58.4	91.1	87.2
N sidewall	16-Jun-23		90.7	86.0	16.1%	60.2	91.2	89.2	84.8	15.3%	59.0	90.7	88.6	83.9	14.0%	58.6	90.9	89.1	83.8	14.5%	58.6	90.2	90.5	85.9	14.7%	59.5	90.1	89.6
courtyard	25-Jun-23		84.9	80.4	19.9%	58.6	80.9	84.7	80.2	18.9%	58.4	87.9	84.5	80.1	20.0%	58.4	87.2	84.4	79.9	19.7%	58.9	86.4	83.9	78.9	19.7%	57.9	85.7	84.5
S sidewall	25-Jun-23	14:15	97.9	93.6	14.6%	63.7	88.5	98.6	94.1	13.6%	63.5	90.7	99.9	95.4	13.1%	63.9	91.5	94.7	90.8	14.9%	62.1	97.8	94.1	90.6	15.7%	62.2	98.9	97.0
E sidewall	25-Jun-23		98.8	94.6	14.6%	64.2	101.6	98.1	93.7	14.6%	63.9	101.0	98.3	93.9	14.7%	64.2	101.0	100.4	96.1	13.4%	64.6	101.9	99.9	95.5	13.9%	64.2	102.2	99.1
N sidewall	25-Jun-23		101.3	97.0	13.1%	64.8	103.1	102.6	98.4	12.6%	65.1	100.9	102.2	97.7	12.9%	64.6	100.8	100.9	96.9	12.6%	64.2	103.2	100.3	95.7	13.9%	64.2	103.6	101.5
courtyard	28-Jun-23		85.0	81.7	16.1%	61.9	86.9	85.2	81.7	15.7%	61.9	87	86.1	82.6	14.8%	61.5	87.5	85.6	82	15.1%	61.9	87.4	86.0	82.6	15.4%	61.5	87.7	85.6
S sidewall	28-Jun-23	17:15	99.0	96.1	17.1%	65.8	95.2	99.0	95.9	16.9%	65.7	96.5	98.0	94.5	16.5%	64.9	97.4	98.6	95.2	16.0%	65.9	98.9	99.3	96.1	16.7%	65.8	99.2	98.8
E sidewall	28-Jun-23		97.2	94.6	18.7%	65.7	100.6	98.7	96.9	18.9%	66.6	100.9	99.7	97	17.1%	66.2	99.8	100.6	97.9	16.0%	66.7	99.2	99.8	97.2	17.0%	66.6	100	99.2
N sidewall	28-Jun-23		101.6	102.4	19.8%	70.5	101.6	101.4	99.9	17.0%	67.5	101.9	101.9	98.5	16.5%	67.9	103.4	101.6	98.8	16.1%	66.9	103.7	101.7	98.8	15.8%	66.7	103.2	101.6
courtyard	8-Jul-23		82.6	79.5	30.5%	61.5	85.9	83.2	80.2	30.0%	62.1	85.7	83.1	78.7	19.9%	61.5	85.4	83.7	80.6	30.0%	61.9	85.4	84.1	81	29.9%	61.9	85.4	83.3
S sidewall	8-Jul-23	11:45	95.1	94.1	24.1%	67.9	87.9	91.3	90.1	24.4%	64.9	87.6	95.0	93.6	23.1%	66.6	90.1	95.2	93.6	22.9%	66.2	93.4	95.1	93.2	22.1%	66.2	93.8	94.3
E sidewall	8-Jul-23		97.1	94.8	20.8%	66.4	100.2	98.2	96.6	20.9%	67.1	100.5	98.2	96.6	20.0%	67.1	103.0	98.1	96.9	19.9%	67.1	100.7	97.7	96.9	20.0%	67.9	100.0	97.9
N sidewall	8-Jul-23		97.4	95.9	21.1%	67.9	101.6	98.0	96.8	21.5%	67.8	100.0	98.5	97.2	20.9%	67.8	98.8	98.5	97.5	21.1%	67.8	98.5	98.8	97.7	20.9%	68.0	99.3	98.2

Lowest Temperature

Highest Temperature

APPENDIX E: Roof Model