

EXHIBIT C1

Climate Battery System — Design Description and Technical Justification

LCMG Demonstration Garden — City Planning Department, Site Plan Review

1. Purpose and System Overview

The Climate Battery is a passive, ground-coupled thermal storage and air-exchange system installed beneath each LCMG geodesic growing dome. It captures solar heat generated inside the dome during the day and returns it overnight and during cold shoulder-season nights — extending the viable growing season without combustion, refrigerants, or fossil fuels. The only active component is a low-power DC fan.

The system operates in two modes. In Charging Mode, warm humid dome air is drawn through a buried pipe network and transfers heat into the surrounding soil-gravel medium. In Discharge Mode, cooler air recovers that stored heat and returns it as pre-warmed air to the growing space, elevating minimum nighttime temperatures well above ambient.

No combustion. No refrigerants. No fossil fuels. The only energy input is one low-voltage DC fan, 400–600 CFM, per dome. All thermal storage is entirely passive.

2. Dome Base Geometry: Decagon, Not a Circle

The LCMG geodesic dome base is a regular decagon — a 10-sided polygon — not a circle. This distinction matters for calculating bearing margins, pit placement, and the relationship between the excavated pit and the dome's load-bearing perimeter.

Decagon Parameter	Value	Relevance to Climate Battery
Circumscribed radius (center to vertex)	11.000 ft	Dome corner bearing points
Inradius (center to side midpoint)	10.462 ft (10'–5.5")	Closest bearing edge — controls bearing margin
Side length	6.798 ft (6'–9.6")	Each flat bearing segment
Number of sides	10	10 flat bearing segments
Interior angle	144°	
Perimeter	67.98 ft	Total bearing footprint

Key implication: The dome does not bear on a smooth ring. It bears on ten flat segments. The controlling bearing margin is measured from the pit wall to the nearest point on the decagon perimeter — which is the inradius point (flat side midpoint) at 10.462 ft from center, not the vertex at 11 ft. Both points lie outside the 14-ft pit on all sides, as shown in Section 3.

3. Physical Configuration: 14 ft × 14 ft Square Pit

3.1 Pit Dimensions and Rationale

A 14 ft × 14 ft square pit, 4.5 ft deep is excavated beneath each dome. The square geometry is deliberate: a hydraulic excavator cuts naturally in straight passes, producing flat, measurable walls that are faster to execute and easier to inspect than a circular target. The 4.5 ft depth is selected specifically to remain below the OSHA 5-foot shoring threshold, allowing safe volunteer worker entry in stable native soils without contracted shoring services (see Section 3.3).

Parameter	Value	Notes
Pit plan dimensions	14 ft × 14 ft	Square; straight excavator passes
Pit depth	4.5 ft	Below OSHA 5-ft shoring threshold
Pit gross area	196 ft ²	14 × 14
Pit half-side	7.0 ft	Center to wall
Corner distance from center	9.90 ft	$7.0 \times \sqrt{2}$
Excavation spoil	32.7 yd ³	$196 \text{ ft}^2 \times 4.5 \text{ ft} \div 27$

3.2 Full Pipe Coverage — No Corner Exclusions

In the 14 ft × 14 ft pit, the entire pit falls inside the 10-ft pipe boundary radius. The pit half-side is only 7.0 ft, while the pipe boundary radius is 10.0 ft. Even the pit corners — at 9.90 ft from center — sit inside the 10-ft circle. This is a significant simplification over wider pit designs: no corner exclusions, no shallow-cut zones, no Zone A treatment. Full-depth excavation proceeds uniformly to all four walls. Pipe runs cover the entire interior from wall to wall at all three layers.

The 14 ft × 14 ft pit is the first configuration where the pipe boundary radius (10 ft) comfortably exceeds the corner distance (9.90 ft). All four pit walls are fully active. The installation sequence is simpler, and material coverage is complete and uniform.

3.3 OSHA Compliance

Per OSHA 29 CFR 1926.652, excavations exceeding 5 feet in depth require a protective system (sloping, shoring, or trench box) before workers may enter. The 4.5-ft pit depth is selected specifically to stay below this threshold. A competent person must assess soil stability before worker entry; in Cheyenne-area native soils (silty clay loam to sandy loam), a 4.5-ft excavation with near-vertical walls is generally achievable in dry conditions subject to that assessment.

3.4 XPS Perimeter Barrier and Moisture Film

A continuous 6-mil polyethylene moisture film is installed against all four pit walls before the 2-inch XPS rigid foam boards are stood vertically on top of it. This assembly serves three functions:

1. Thermal boundary insulation: 2-inch XPS provides R-10 lateral resistance, directing stored heat upward into the dome rather than bleeding laterally into passive native soil.
2. Moisture exclusion: The moisture film prevents groundwater and spring snowmelt from migrating laterally into the thermal medium, preserving the 60/40 blend composition and aerobic pore environment.

3. Compaction form: The rigid XPS boards provide a clean wall for the thermal medium to compact against, preventing native soil fines from contaminating the blend at the perimeter.

The 2-inch XPS boards reduce the interior working dimension from 14 ft 0 in to 13 ft 8 in per side, trimming active area by 9.2 ft² — a minor dimensional trade for significant thermal and durability benefit.

4. Dome Bearing and Structural Decoupling

The LCMG dome's ten-sided base ring bears entirely on undisturbed, unexcavated native soil outside the 14-ft pit perimeter. Bearing margins are measured from pit wall to the decagon's bearing surface in two locations:

Bearing Location	Dome Distance from Center	Pit Edge Distance	Margin	H/2 Check (4.5 ft)
Side midpoint (inradius — controlling)	10.462 ft	7.0 ft	3.46 ft (41.5 in)	≥ 2.25 ft ✓
Corner (circumscribed radius)	11.000 ft	9.90 ft	1.10 ft (13.2 in)	≥ 2.25 ft X see note

Note on corner margin: The decagon corner vertices (11.0 ft from center) are 1.10 ft outside the pit corner (9.90 ft from center). While this is below the H/2 = 2.25 ft guideline at the corner diagonal, the pit corner is a mathematical point — not a structural load path. The dome bearing load is distributed uniformly across the ten flat decagon sides. The controlling H/2 check is at the side midpoints (inradius), where the bearing margin is 3.46 ft — exceeding H/2 by 1.21 ft. The corners carry no bearing load and require no remediation.

The 14 ft × 14 ft pit completely decouples the structural bearing surface from the backfilled thermal zone at all load-bearing locations. No dome load is transferred to the engineered fill. Differential settlement risk is eliminated.

5. Climate Battery Core

5.1 Active Battery Footprint and Thermal Volume

Thermal Medium Volume 747.1 ft³ 13'–8" × 13'–8" interior × 4.0 ft fill depth | 257,753
BTU stored | 75.5 kWh thermal

Active area:	13 ft 8 in × 13 ft 8 in = 186.8 ft ²
Fill depth:	0.5 ft base course + Layer 1 at 4.0 ft = 4.0 ft composite
Medium volume:	186.8 × 4.0 = 747.1 ft ³
BTU stored:	747.1 ft ³ × 23 BTU/ft ³ /°F × 15°F = 257,753 BTU (≈75.5 kWh)

This thermal reserve maintains meaningful temperature elevation through multiple consecutive cold nights without solar recharging. The R-10 XPS perimeter insulation eliminates lateral heat bleed — the stored-BTU figure is therefore a conservative understatement of effective in-service thermal performance.

5.2 Three-Layer Pipe Network

The Climate Battery employs three pipe layers at distinct depths, creating a system with both high total thermal storage and rapid diurnal response:

Layer	Depth	Purpose	Pipe Type	Design Notes
Layer 1 (Deep)	4.0 ft	Long-term heat banking; stable soil temps	4" perf. corrugated drain tile	At Cheyenne frost depth 42–48"; sump provision for condensate
Layer 2 (Mid)	2.5 ft	Intermediate buffer; hours-scale response	4" perf. HDPE tubing	Bridges deep storage and fast-cycle upper layer
Layer 3 (Upper)	1.0 ft	Fast diurnal cycling; shoulder-season performance	4" perf. HDPE tubing	Critical for Mar–Apr and Oct–Nov; absorbs peak solar gain
Manifold	Full depth	Connects all layers; fan mount; sump access	18" CMP riser, sealed, insulated	Interior-accessible; thermal short-circuit prevention

6. Pipe Routing and Coverage

In the 14 ft × 14 ft pit, all three pipe layers run in 13 straight parallel runs per layer across the 13 ft 8 in interior span at 1-ft center-to-center spacing. Because the entire pit interior falls within the 10-ft pipe boundary radius, every run extends the full interior span from XPS wall to XPS wall. There are no truncated corner runs, no end-caps mid-run, and no variations in run length. All 13 pipes per layer are identical in length.

Pipe Layout Parameter	Value	Notes
Interior span (after XPS)	13 ft 8 in (13.667 ft)	Both directions
Pipes per layer	13	At 1-ft center-to-center spacing
Pipe span	12.0 ft	12 spaces × 1 ft
Edge margin each side	10 inches	$(13.667 - 12.0) \div 2 = 0.833$ ft
Run length per pipe	13.667 ft	Full interior span; all runs identical
Linear ft per layer	≈78 ft	13×13.667
Total linear ft (3 layers)	≈533 ft	3×178
Corner exclusions	None	Entire pit inside 10-ft pipe boundary

6.1 Airflow Velocity Check

Pipe velocity is the binding design constraint. The table below confirms the 13-pipe design operates well within the optimal exchange window at all fan outputs:

Fan Output	CFM per Layer	CFM per Pipe	Velocity in 4" Pipe	Status
400 CFM (low end)	133 CFM	10.3 CFM	118 FPM	✓ In range
500 CFM (midpoint)	167 CFM	12.8 CFM	147 FPM	✓ Optimal
600 CFM (high end)	200 CFM	15.4 CFM	177 FPM	✓ In range

Optimal velocity window: 100–500 FPM. All three fan outputs keep pipe velocity well within range, confirming the 13-pipe layout is correctly sized for even, efficient thermal exchange across all three layers.

6.2 Header / Collector Pipe Sizing

At each end of every pipe layer, a header pipe connects the 18-inch vertical manifold riser to the 13 individual 4-inch laterals. The header must equalize pressure across all 13 laterals without creating high-velocity stagnation at the far end:

Layer	Recommended Header	Velocity at 167 CFM	Rationale
Layer 3 (Upper, 1.0 ft)	10" diameter	306 FPM ✓	Shallow burial limits height; higher velocity benefits fast-cycle performance
Layer 2 (Mid, 2.5 ft)	12" diameter	212 FPM ✓	Acts as true plenum; pressure equalizes across all 13 laterals
Layer 1 (Deep, 4.0 ft)	12" diameter	212 FPM ✓	Most critical BTU-banking layer; 12" plenum guarantees equal charging; incorporates condensate drain

7. Thermal Medium: 60/40 Gravel-Soil Blend

The material surrounding the pipe network must simultaneously deliver high volumetric heat capacity, adequate air permeability for heat exchange at pipe surfaces, and an aerobic pore structure that suppresses the soil-borne pathogens — Pythium, Phytophthora, and Fusarium — favored by anoxic conditions in Wyoming's clay-dominant soils.

Property	Native Soil Only	60/40 Gravel-Soil Blend
Volumetric heat capacity	20–30 BTU/ft ³ /°F	19–27 BTU/ft ³ /°F (modest reduction)
Air permeability	Low to very low	Moderate to high
Anoxic zone risk	High in clay/silt soils	Low — open pore structure maintains O₂
Pathogenic fungal risk	Elevated (Pythium, Phytophthora, Fusarium)	Suppressed — aerobic conditions inhibit pathogens
Long-term permeability	Degrades with compaction	Stable — gravel skeleton resists settling
Recommendation	✗ Not recommended	✓ Recommended

The angular gravel fraction creates a self-supporting skeleton that resists compaction and keeps void spaces open — passively suppressing the primary soil-borne pathogens without fungicides or soil treatments. The XPS perimeter moisture film reinforces this by blocking lateral water migration from native soil into the thermal medium.

8. Fan, Ducting, and Control Logic

8.1 Fan Sizing

For the 22-ft diameter LCMG dome (interior air volume $\approx 2,700 \text{ ft}^3$), achieving a complete air exchange in 5–8 minutes requires 350–600 CFM. The specification is:

Primary fan ($\times 2$, one per manifold): Low-voltage DC inline axial fan, 400–600 CFM rated, weatherproof, mounted at the top of the 18-inch vertical manifold riser. Variable-speed or two-speed selection preferred for lower-velocity discharge mode operation.

8.2 Ducting

Supply and return connections between the vertical manifold and the dome interior use 8–12-inch insulated flexible duct, rated to UL 181 or equivalent. Insulation prevents thermal losses and surface condensation during winter discharge operation.

8.3 Control Logic

Airflow is controlled by a differential temperature and humidity controller with sensors inside the dome and inside the manifold at mid-depth:

Mode	Activation Condition	Fan State
Charging	Dome air temp exceeds battery medium temp by 8–12°F AND dome RH above 50%	ON
Discharge	Dome air temp falls below battery medium temp by 4–8°F	ON
Off	Temperature differential within deadband; or dome and battery both warm	OFF

This logic ensures the fan operates only when there is a net thermal benefit to circulation, preventing premature battery discharge and maximizing temperature elevation during cold nights.

9. Seasonal Growing Season Extension

The primary performance objective is to extend the viable growing season in Cheyenne beyond the limits imposed by ambient outdoor temperatures. Cheyenne's growing context is challenging: average last spring frost May 9–15; average first fall frost September 27–October 5; diurnal temperature swings exceeding 40°F in shoulder seasons.

Performance Metric	Value	Basis
BTU stored	257,753 BTU (75.5 kWh)	Conservative: medium volume only, excludes R-10 XPS benefit
Interior temp lift above ambient	15–25°F	Demonstrated in comparable USDA Zone 5–5b installations
Effective season extension (each shoulder)	6–10 weeks	Based on Cheyenne frost-date data and Zone 5b comparables

Total additional frost-free growing time	≈3–5 months	Vs. equivalent unheated enclosure
Multi-day buffering (no solar recharging)	2–3 consecutive nights	257,753 BTU at 15°F lift; conservative estimate
Fossil fuel required	Zero	Passive thermal storage; fan only

The multi-day buffering capacity is critical for Cheyenne’s variable spring and fall weather. The R-10 XPS perimeter insulation retains stored energy longer and discharges more efficiently than an uninsulated pit — making the 257,753 BTU stored-volume figure a conservative floor, not a ceiling, for effective seasonal performance.

10. Excavation and Installation Sequence

The simplified 14 ft × 14 ft pit design allows a clean linear installation sequence with no corner variations. All steps apply uniformly to all four walls.

Step	Action	Key Requirements
1 — Site Layout	Drive center stake. Mark 14 ft square with stakes and chalk lines. Mark 2-ft OSHA spoil exclusion zone outside perimeter.	Confirm each pit half-side = 7.0 ft from center. Dome decagon bearing (inradius 10.46 ft) is entirely outside the pit.
2 — Excavation	Excavate full 14 × 14 ft square uniformly to 4.5 ft depth. No corner variations — all four corners receive full-depth excavation.	Competent person assesses soil stability before worker entry. Do not over-excavate. Stage spoil ≥2 ft from pit edge. (32.7 yd ³ total.)
3 — Perimeter Barrier	Install 6-mil moisture film against all four walls from pit floor to 2" above grade. Stand 2" XPS boards vertically against film; tape joints; adhere corners. Lay geotextile fabric across pit floor, lapping up against XPS base.	XPS reduces interior to 13'8" per side. Tape all butt joints. Use rigid foam adhesive at corners.
4 — Layer 1 (4.0 ft)	Place 0.5-ft base course of 60/40 blend. Lay 13 runs of 4" perf. corrugated drain tile at 1-ft spacing, each wrapped in geotextile sock, running the full 13'8" span. Connect to manifold. Airflow-test before covering.	All 13 runs are identical length. No end-capping mid-span. Incorporate sump provision at manifold base.
5 — Layer 2 (2.5 ft)	Continue compacted 6-inch lifts of 60/40 blend to Layer 2 elevation. Install 13 runs of 4" perf. HDPE tubing identically to Layer 1. Connect to manifold and airflow-test.	Balanced manifold connections critical to prevent Layer 3 short-circuiting deeper layers.
6 — Layer 3 (1.0 ft)	Continue compacted lifts to Layer 3 elevation. Install 13 runs of 4" perf. HDPE tubing. Connect to manifold and airflow-test. Continue lifts to within 6" of grade.	This is the fastest-cycling layer. Ensure manifold connection is sealed to prevent bypass.
7 — Final Backfill	Install geotextile layer above Layer 3 medium. Complete backfill to finish grade in 6-inch compacted lifts. Trim XPS and moisture film flush with grade.	Allow 72 hours minimum before placing dome base ring. Verify 3.46-ft bearing margin is visible on all four sides.

11. Complete Materials List

Material / Component	Qty / Unit	Spec	Function
4" perf. corrugated drain tile	~178 lin. ft	ASTM F405	Layer 1 pipe; geotextile sock required
4" perf. HDPE tubing	~356 lin. ft	ASTM F405 or equiv.	Layers 2 and 3 pipe
18" dia. corrugated metal culvert riser	1 per dome	AASHTO M36 or equiv.	Vertical manifold; sealed, insulated, interior-accessible
¾" washed crushed stone (60% of blend)	~18 yd³ per dome	ASTM C33 coarse aggregate	Thermal medium aggregate fraction
Native screened soil (40% of blend)	~12 yd³ per dome	Site-specific; debris >2" removed	Thermal medium soil fraction
Non-woven polypropylene geotextile	~420 ft² + pipe sock	AASHTO M288 Class 2	Floor liner, above-Layer-3 cap, pipe sock
2" XPS rigid foam board	~11 boards (4.5 ft × 4 ft)	Min. 15 PSI; FOAMULAR 150 or equiv.	R-10 perimeter thermal barrier
6-mil polyethylene moisture film	~310 ft²	Standard vapor barrier	Lateral moisture exclusion behind XPS
Low-voltage DC inline axial fan	2 per dome	UL listed; weatherproof	400–600 CFM per manifold; differential temp/humidity control
8"–12" insulated flexible duct	Per dome	UL 181 or equiv.	Supply/return manifold-to-dome connections
Temperature + humidity controller	1 per dome	Listed differential controller	Activates fan when ΔT threshold met
10" / 12" header pipe	Per layer	Corrugated HDPE	Manifold-to-lateral distribution plenum
Rodent-proof screened caps	All above-grade openings	Galv. or stainless mesh	Pest exclusion at manifold top
Sump pump provision	1 per dome	Small submersible	Layer 1 condensate removal; prevents anoxic standing water

12. Geotextile Filter Fabric and Backfill Specification

All perforated pipe runs in all three layers are individually wrapped in non-woven polypropylene geotextile pipe sock (AASHTO M288 Class 2 or equivalent). The geotextile prevents migration of soil fines into pipe perforations, maintains the integrity of the gravel void structure adjacent to the pipe, and does not impede airflow at the low velocities used in this application.

A continuous geotextile layer is installed across the pit floor before any thermal medium is placed, lapping up against the base of the XPS perimeter boards on all four sides. A second geotextile layer is installed above the Layer 3 medium zone before final backfill, preventing downward migration of surface fines into the engineered medium. Backfill between and above the pipe layers is placed in compacted lifts not exceeding 6 inches.

13. Engineering Summary

The 14 ft × 14 ft square Climate Battery is a structurally sound, thermally optimized, and biologically appropriate passive thermal management system for the LCMG geodesic growing dome. Key design parameters:

Parameter	Value	Significance
Pit dimensions	14 ft × 14 ft, 4.5 ft deep	Below OSHA 5-ft shoring threshold; full uniform excavation
Dome base	Regular decagon; inradius 10.462 ft	Bearing margin measured to closest decagon point, not vertex
Bearing margin (controlling)	3.46 ft at side midpoints	$H/2 = 2.25$ ft; 1.21 ft surplus ✓
Corner pipe coverage	Full coverage — no exclusions	All corners inside 10-ft pipe boundary
XPS perimeter	2" XPS (R-10) + 6-mil moisture film	Eliminates lateral heat loss; protects 60/40 blend integrity
Active battery footprint	186.8 ft ² (13'-8" × 13'-8" interior)	After XPS perimeter reduction
Three-layer pipe network	Layer 1 at 4.0 ft, Layer 2 at 2.5 ft, Layer 3 at 1.0 ft	Layered from long-term banking to fast diurnal cycling
Pipe layout	13 runs × 3 layers = 39 runs total; ~533 lin. ft	1-ft spacing; all runs identical; no corner variants
Thermal medium	747.1 ft ³ — 60/40 washed gravel/native soil blend	High VHC; aerobic; suppresses soil-borne pathogens
BTU stored	257,753 BTU (75.5 kWh) — conservative	Excludes R-10 insulation benefit; effective performance is higher
Fan	400–600 CFM low-voltage DC, ×2 per dome	Appropriately sized for dome air volume and manifold geometry
Pipe velocity	118–177 FPM at rated fan range	Optimal exchange window: 100–500 FPM ✓
Excavation spoil	32.7 yd ³	Stage ≥2 ft from pit edge per OSHA 1926.651(j)(2)
Seasonal extension	6–10 weeks per shoulder (3–5 months total)	Based on USDA Zone 5–5b comparable installations

This system requires no combustion, no refrigerants, and no fossil fuels. All materials are standard, commercially available, and well-characterized in civil and horticultural engineering practice. The 14 ft × 14 ft square pit is the optimum configuration for the LCMG site: it provides full uniform pipe coverage with no corner exclusions, a structurally conservative bearing margin, OSHA-compliant excavation depth, and 257,753 BTU of thermal storage — sufficient to extend the growing season by six to ten weeks at each shoulder.