Residential Roof Color, Attic Heat Discharge, and Anthropogenic Heat Loading in the Las Vegas Valley Airshed

A First-Order Engineering Assessment of Solar Absorption, Atmospheric Heat Loading, and Cool-Roof Mitigation Potential

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Abstract

This paper extends the control-volume framework developed in the companion EV/UHI and heat pump papers to estimate the atmospheric heat loading from residential roof surfaces in the Las Vegas valley, quantifying four distinct heat pathways: (1) roof surface longwave radiation and convection to the atmosphere, (2) heated attic air discharged through code-required ventilation openings, (3) ceiling heat conduction into conditioned space driving air-conditioning loads, and (4) AC condenser waste heat rejection to the outdoor atmosphere. The analysis encompasses seven roof assembly types spanning dark asphalt shingles (albedo 0.08) through light-colored concrete tile (albedo 0.45), incorporating the thermodynamic distinction between direct-nailed asphalt shingles and batten-mounted tile roofs whose ventilated air gap reduces heat transfer to the attic by approximately 48% at matched solar reflectance (ORNL field measurements). Using Clark County housing stock data (approximately 580,000 single-family homes with an estimated 69.5 million m² of asphalt shingle and tile roof area), representative solar radiation for the Las Vegas latitude (peak ~1,000 W/m²), and a wind-speed-dependent attic ventilation model coupling stack-effect buoyancy with wind-driven pressure differentials calibrated to the wind rose data from the companion heat pump paper, the analysis estimates that residential roofs collectively contribute approximately 5–6 GW of heat to the urban atmosphere during peak summer hours under the current estimated roof stock distribution—substantially larger than the ICE vehicle fleet transport heat (2.65 GW, 24-hour average) quantified in the companion EV paper. Conversion from the current dark-dominated roof mix to light-colored shingle or tile assemblies could reduce this heat loading by 30–50%, producing a temperature perturbation reduction of approximately 0.5–1.5°F in the control volume depending on wind speed. The analysis further demonstrates that one home with a dark asphalt shingle roof dumps approximately 1.6× the heat of a light asphalt home and approximately 2.8× the heat of a light tile home to the urban atmosphere, while costing the homeowner $125–220 per year more in AC electricity over the cooling season—a cumulative $2,750–4,840 penalty over the 22-year roof life for a color choice that carries zero incremental cost at the point of purchase. A separately documented insulated double-deck roof design employing R-12 isofoam between a new roof deck and the original deck, combined with white and light-tan shingles, is shown to reduce attic temperatures to near-ambient, achieving 85–90% reduction in total atmospheric heat loading from the roof assembly. The paper identifies an insulation code asymmetry: building codes demand R-60 ceiling insulation for an 80°F winter differential (exterior −10°F to interior 70°F) in cold climates, yet require only R-38 for a comparable or larger differential (155°F attic to 78°F interior) in Las Vegas summer, despite identical heat transfer physics. When evaluated as a combined dark-to-light reroof plus insulated-deck measure on asphalt-shingle homes, the roof-attributable AC cost falls from approximately $280/yr to approximately $14/yr, implying about $266/yr savings and simple payback of roughly 11 years for a representative 1,500 sq ft reroof at a $2.00/sq ft incremental deck cost; by contrast, the same intervention is generally not economical for existing tile roofs because the ventilated tile air gap already captures much of the available benefit.

Keywords: *roof albedo, cool roof, asphalt shingles, concrete tile, urban heat island, anthropogenic heat, attic ventilation, Las Vegas, solar absorption, nocturnal heat release, air conditioning waste heat, residential building stock, chill hours, building insulation code*

1. Introduction

The companion papers to this analysis established that direct anthropogenic heat from the internal-combustion vehicle fleet (Brandys, 2026a) contributes approximately 1.07°F of lower-layer warming in the representative 5 m/s ventilation case, and that conversion from gas furnaces to heat pumps (Brandys, 2026b) could extract approximately 2.0 GW from the nocturnal boundary layer on a representative cold winter night. Those analyses focused on active heat sources: engines burning fuel and furnaces combusting gas. This paper addresses a passive heat source that the analysis shows to be the largest single residential contributor to the Las Vegas urban heat island: solar energy absorbed by residential roof surfaces and transferred to the urban atmosphere through multiple heat pathways.

The physical mechanism is distinct from the transport and heating cases. Roofs do not generate heat internally; they intercept solar radiation and convert it to thermal energy through absorption. The fraction absorbed versus reflected is determined primarily by roof color (solar reflectance, or albedo) and secondarily by roof assembly type. A dark-colored asphalt shingle roof with an albedo of 0.05–0.10 absorbs 90–95% of incident solar radiation, heating the roof surface to temperatures of 150–170°F on a Las Vegas summer afternoon. A cool-colored shingle of the same asphalt material, using reflective pigments in lighter colors, achieves an albedo of 0.25–0.40, absorbing 25–40% less solar energy and maintaining surface temperatures 30–60°F cooler under the same conditions. A batten-mounted concrete tile adds a further thermal advantage through its ventilated air gap, which the Oak Ridge National Laboratory has measured as producing a 48% reduction in heat transfer to the attic compared to direct-nailed asphalt shingles at matched solar reflectance.

Las Vegas is a particularly compelling case for this analysis. Peak solar irradiance exceeds 1,000 W/m² at solar noon in June–July, among the highest in the continental United States. The residential building stock is dominated by single-story homes with large roof footprints relative to floor area. The average daily global horizontal irradiance in June is 7.18 kWh/m²/day, with approximately 6.4 peak sun hours. And the overwhelming majority of older residential roofs in the valley are covered with dark-colored asphalt shingles—a legacy of aesthetic preferences and building conventions imported from climates where roof color matters far less.

This paper presents a comprehensive analysis of all four heat pathways from the residential roof to the urban atmosphere, develops the black-roof equivalency ratio showing how many light-roofed homes equal the atmospheric heat loading of one dark-roofed home, quantifies the annual AC cost penalty of dark roof choices, and identifies an insulation code asymmetry that under-protects Las Vegas homes against summer heat gain. A separately documented insulated double-deck roof design is analyzed as the optimal engineering solution.

2. Conceptual Framework

2.1. Four Heat Pathways from Roof to Atmosphere

When solar radiation strikes a residential roof, the absorbed energy reaches the urban atmosphere through four distinct pathways, each with different magnitudes, timing profiles, and sensitivity to roof design choices:

Pathway 1 — Roof surface radiation and convection (largest term). The heated roof surface emits longwave (infrared) radiation upward to the sky and transfers sensible heat to the air passing over it by convection. For asphalt shingles, approximately 65% of absorbed solar energy is shed through this pathway. For tile roofs with ventilated air gaps, the fraction is higher (approximately 72%) because the sub-tile air channel carries additional heat away above the deck before it can conduct through to the attic. This is the dominant heat pathway and operates in real time during solar hours, with a delayed component from thermal storage that extends 4–6 hours after sunset.

Pathway 2 — Attic ventilation heat discharge. Building codes require residential attic ventilation at a ratio of 1 sq ft of net free vent area per 150–300 sq ft of attic floor area (IRC Section R806). This ventilation is driven by two forces: stack-effect buoyancy (hot attic air rises and exits through ridge or upper vents, drawing cooler ambient air through soffit vents) and wind-driven pressure differentials (wind creates positive pressure on the windward face and negative pressure on the leeward face). The combined effect pumps heated attic air directly into the urban boundary layer. The discharge rate is proportional to the attic-to-ambient temperature differential and to the wind speed—coupling this heat pathway directly to the wind rose data characterized in the companion heat pump paper.

Pathway 3 — Ceiling heat conduction to conditioned space. Heat conducts from the hot attic through the ceiling insulation into the conditioned living space below. The rate is governed by $q = A \times \Delta T / R$, where A is the ceiling area, ΔT is the attic-to-interior temperature differential, and R is the total thermal resistance (ceiling insulation + air film resistances). This heat is removed by the air conditioning system, converting Pathway 3 into Pathway 4.

Pathway 4 — AC condenser waste heat rejection. The air conditioning system removes the ceiling heat gain (Pathway 3) and rejects it to the outdoor atmosphere through the condenser coil, along with the compressor work energy. At a coefficient of performance (COP) of 3.0, every BTU of ceiling heat gain produces 1.33 BTU of heat rejection to the outdoor air (the original BTU plus 0.33 BTU of compressor work). This amplification effect means that poor ceiling insulation compounds the atmospheric heat loading—the AC system adds energy on top of the solar energy that penetrated the building envelope.

Key insight: All four pathways ultimately deliver the absorbed solar energy (plus AC compressor work) to the urban atmosphere. The only way to reduce the total is to increase roof albedo (reflect more solar energy back to space before it is absorbed) or to intercept heat at the roof deck before it enters the attic (via ventilated tile air gaps or above-deck insulation). Increasing ceiling insulation alone can shift heat from Pathways 3–4 toward Pathways 1–2, but cannot reduce the total because it does not change the amount of solar energy absorbed by the roof surface.

2.2. Asphalt Shingles vs. Tile: The Air-Gap Distinction

The critical thermodynamic difference between asphalt shingle roofs and concrete or clay tile roofs is not primarily albedo—it is the ventilated air gap. Asphalt shingles are nailed directly to

the roof deck (plywood or OSB sheathing), creating intimate thermal contact between the heated shingle and the structural deck. Heat absorbed by the shingle conducts directly through the deck into the attic air space.

Concrete and clay tiles, by contrast, are mounted on batten strips that create a 1–2 inch air channel between the bottom of the tile and the top of the roof deck. This air channel serves as a thermal break and a convective heat removal pathway. As air in the channel is heated by the underside of the tile, it rises along the pitched roof by buoyancy and exits at the ridge, carrying heat away above the deck surface before it can conduct through to the attic. Field measurements at the Oak Ridge National Laboratory (Miller et al., 2005; Olson and Miller, 2013) demonstrated that this above-sheathing ventilation produces a 48% reduction in heat transfer into the attic compared to direct-nailed asphalt shingles at the same solar reflectance and thermal emittance. The ORNL researchers calculated that the air-gap effect is equivalent to approximately 24 points of additional solar reflectance—meaning a dark concrete tile with an albedo of 0.18 thermally performs like a hypothetical asphalt shingle with an albedo of approximately 0.42.

A secondary distinction is thermal mass. Concrete tile has a thermal capacitance of approximately 40 kJ/m²·K, nearly twice the 22 kJ/m²·K of asphalt shingle (LBNL measurements, Fresno study). Higher thermal mass delays and spreads the post-sunset heat release over a longer period at lower intensity. For the nocturnal urban heat island, this means tile delivers a lower peak heat flux during the critical first 2–3 hours after sunset when the boundary layer is collapsing—potentially preferable for chill-hour accumulation because the sharp evening heat pulse from asphalt roofs is attenuated.

2.3. The Insulated Double-Deck Design

The author has installed an insulated double-deck roof system on two Las Vegas residences (each with 1,600 sq ft roof area) that addresses the roof heat loading problem at its source. The design consists of: (1) removal of original shingles down to the existing roof deck, (2) installation of 2 inches of isofoam rigid insulation (R-12) directly on the existing deck, (3) installation of a second half-inch plywood roof deck over the isofoam, and (4) installation of new shingles on the upper deck—white shingles on the rear slope (not visible from the street) and light tan architectural shingles on the front slope for aesthetic consistency.

This design intercepts solar heat at the first surface the absorbed energy encounters—the roof deck—before it can enter the attic air space. The R-12 isofoam between the two decks reduces heat conduction to the lower deck and attic to near-zero. Field observation confirms that attic temperatures in these homes remain within approximately 5°F of outdoor ambient on peak summer days, compared to the 40–55°F above ambient typical of dark asphalt shingle roofs with no deck insulation.

The double-deck assembly is thermodynamically superior to adding more ceiling insulation alone because it simultaneously reduces all four heat pathways: (1) the white/light shingles increase albedo, reflecting more solar energy; (2) the near-ambient attic temperature eliminates the stack-effect driving force for hot air venting; (3) the near-zero attic-to-interior temperature differential eliminates ceiling heat conduction; and (4) with no ceiling heat gain, the AC system has no roof-related load to remove and therefore generates no condenser waste heat from this source. This double-layered insulated roof deck product is commercially available and widely used in Canada, the Midwest, and the Northeast for cold-climate applications—the same physics applies in reverse for hot-climate applications.

The insulated double-deck concept is not a novel invention—it is a direct application of commercially manufactured “nailbase” insulated roof deck panels to the hot-climate residential context. These panels are factory-assembled sandwich products consisting of a polyisocyanurate (polyiso) rigid foam core bonded to an OSB or plywood nailing surface on the top face and a fiber-reinforced facer on the bottom. Major manufacturers include Atlas Roofing (ACFoam Nail Base), GAF (ThermaCAL), Hunter Panels (H-Shield Nail Base), and Petersen/PAC-CLAD (PAC-Shield Nail Base). The panels are available in 4’ × 8’ sheets with foam thicknesses from 1.5” to 4.5”, providing long-term thermal resistance (LTTR) values from R-6 to R-28. They are manufactured to ASTM C1289 Type V and are approved for installation over wood and steel roof decks in both new construction and re-roofing applications. The nailing surface accepts standard asphalt shingles, tile, slate, and standing-seam metal roofing.

It is important to note that polyisocyanurate insulated roof decks are already standard practice in commercial building construction. Virtually every low-slope commercial roof in the United States—including the casino, hotel, and office buildings along the Las Vegas Strip—is insulated with polyiso board installed on top of the structural roof deck, beneath the roofing membrane. This is the same thermodynamic configuration as the residential nailbase panel: insulation above the structural deck, roofing material above the insulation. The commercial roofing industry adopted this approach decades ago precisely because it is the most effective way to manage solar heat gain—intercepting the heat at the first surface before it can enter the building’s interior air space. The residential roofing industry has not adopted this approach at scale, in part because asphalt shingle installation traditions assume direct nailing to plywood sheathing, and in part because residential energy codes have not required above-deck insulation. The nailbase panel solves the installation compatibility problem by providing an integrated product that accepts standard shingle attachment while incorporating the above-deck insulation layer. The author’s field-assembled double-deck design achieves the same result using separately procured isofoam boards and a second plywood deck, at a materials cost under $2.00 per square foot of roof area.

2.4. The Insulation Code Asymmetry

Building energy codes reveal a striking asymmetry in how they treat heat transfer through ceilings. In IECC Climate Zones 6–8 (the northern tier of states), codes require R-49 to R-60 ceiling insulation to resist heat loss from a 70°F interior to exterior conditions as cold as −10°F—a temperature differential of 80°F. The same energy code requires only R-38 ceiling insulation in IECC Climate Zone 3B (Las Vegas), where a dark-shingled attic at 155°F above a 78°F interior produces a temperature differential of 77°F—nearly identical to the cold-climate case.

The physics of heat transfer through a ceiling is identical in both directions. The steady-state heat flux equation $q = A \times \Delta T / R$ does not distinguish between heat flowing up (winter, cold climate) and heat flowing down (summer, hot attic). At R-60, the cold-climate ceiling passes approximately 2,000 BTU/hr for a 1,500 sq ft ceiling. At R-38, the Las Vegas summer ceiling passes approximately 3,000 BTU/hr—roughly 50% more heat flow for a comparable temperature differential, because the insulation is 37% lower.

This asymmetry likely persists because energy codes were historically developed with cold-climate heating loads as the primary concern, and the hot-attic problem was addressed through ventilation requirements rather than insulation requirements. The result is that Las Vegas homes are systematically under-insulated against their dominant thermal load—summer roof heat gain—while northern homes are well-protected against their dominant load. The author’s insulated double-deck design (adding R-12 at the roof deck on top of the code-required R-38 at

the ceiling) raises the total system thermal resistance to R-51 and, more critically, reduces the temperature differential by eliminating the superheated attic.

3. Data and Methods

3.1. Residential Roof Stock Inventory

Clark County's 2024 housing unit estimates report approximately 580,839 single-family homes. The Clark County Assessor's Residential Extraction (AORES) dataset includes roofing type for each residential parcel, which would enable a precise inventory of roof materials across the valley. In the absence of a full analysis of the AORES data, this paper uses the following estimated stock distribution based on field observation, local building practices, and the age distribution of the housing stock:

Roof Type	Albedo	Attic ΔT	Est. %	Homes	Notes
Dark asphalt shingle	0.08	+55°F	20%	116,000	Pre-2000 homes, charcoal/black
Medium asphalt shingle	0.18	+38°F	15%	87,000	Gray, weatherwood, brown
Light asphalt shingle	0.30	+25°F	5%	29,000	Light tan, beige (uncommon)
Dark concrete tile	0.18	+28°F	15%	87,000	Dark-brown S-tile, older homes
Medium concrete tile	0.32	+16°F	25%	145,000	Tan/terracotta, newer builds
Light concrete/clay tile	0.45	+8°F	15%	87,000	Light gray, cream, white tile
Flat/metal/other	0.35	+20°F	5%	29,000	Flat roofs, metal, misc.

Table 1. Estimated Las Vegas residential roof stock distribution by type and color. Attic temperature deltas above ambient reflect the ORNL-measured ~48% heat transfer reduction for ventilated tile vs. direct-nailed asphalt at matched albedo.

The weighted average roof footprint is estimated at 1,500 sq ft (141 m²) based on a mix of approximately 60% single-story homes (1,800 sq ft roof footprint) and 40% two-story homes (1,100 sq ft roof footprint). Total residential roof area is approximately 81.8 million m², representing approximately 14% of the 15 mi × 15 mi control-volume plan area.

3.2. Solar Radiation Data

Las Vegas receives among the highest solar radiation of any U.S. metropolitan area. Key parameters: peak clear-sky solar irradiance at solar noon is approximately 1,000 W/m²; June daily global horizontal irradiance is 7.18 kWh/m²/day (NREL); annual average GHI is 5.68 kWh/m²/day; and effective peak sun hours in June are approximately 6.4 hours/day. For the peak-hour analysis, a solar irradiance of 1,000 W/m² is used. For seasonal AC cost calculations, monthly solar profiles are derived from NWS Las Vegas climate normals.

3.3. Roof Albedo and Attic Temperature Assumptions

Albedo values are drawn from the Cool Roof Rating Council (CRRC) product database, U.S. DOE published ranges, and manufacturer specifications from Owens Corning, CertainTeed, and GAF. Dark conventional asphalt shingles (black, charcoal) have albedos of 0.05–0.15; medium tones (gray, brown) achieve 0.15–0.25; cool-colored or light shingles reach 0.25–0.40; and white or high-reflectance products achieve 0.60–0.90. Conventional dark roofs can reach

surface temperatures of 150–170°F; reflective surfaces stay 50–80°F cooler under the same conditions (DOE, EPA).

Attic temperature assumptions are based on published measurements showing dark asphalt shingle attics at 40–60°F above ambient in desert climates, reduced proportionally with increasing albedo and by the ORNL-measured 48% heat transfer reduction for ventilated tile assemblies. The insulated double-deck design produces attic temperatures within approximately 5°F of ambient based on field observation at the author's two Las Vegas installations.

3.4. Attic Ventilation Model

The attic ventilation heat discharge model couples two driving forces: stack-effect buoyancy and wind-driven pressure. The stack-effect pressure differential is calculated as $\Delta P_{stack} = \rho \times g \times h \times (T_{attic} - T_{ambient}) / T_{ambient}$, where h is the ridge height, $\rho = 0.0685$ lb/ft³, $g = 32.2$ ft/s², and temperatures are in Rankine. The wind-driven pressure differential is $\Delta P_{wind} = 0.5 \times (\rho/g) \times C_p \times V^2$, where $C_p = 0.8$ (pressure coefficient differential between windward and leeward faces) and V is wind speed in ft/s. The combined driving pressure is computed as the root-sum-square: $\Delta P_{total} = \sqrt{(\Delta P_{stack}^2 + \Delta P_{wind}^2)}$. Volumetric airflow through the attic is $Q = C_d \times A_{vent} \times \sqrt{(2g \times \Delta P / \rho)}$, where $C_d = 0.60$ (discharge coefficient) and A_{vent} is half the net free vent area (representing either the intake or exhaust side). The vent area assumes a 1/300 code ratio with 60% effectiveness factor for screens, louvers, and installation obstructions. Heat discharge to the atmosphere is $q_{vent} = Q \times \rho \times c_p \times (T_{attic} - T_{ambient})$.

Wind speed distributions for residential areas are taken from the companion heat pump paper (Section 7), which estimated residential wind speeds from KLAS ASOS data adjusted by a 40–60% urban roughness reduction factor. A representative wind speed of 3.0 m/s is used for the central case, with sensitivity analysis at 1.5, 5.0, and 8.0 m/s.

3.5. AC Load and Waste Heat Model

Ceiling heat flux is calculated as $q_{ceil} = A \times (T_{attic} - T_{interior}) / R_{total}$, where $A = 1{,}500$ ft², $T_{interior} = 78$°F, and $R_{total} = R_{ceiling} + R_{deck} + R_{airfilm}$ (0.68 indoor + 0.17 attic side). The AC system removes this heat and rejects it to the outdoor atmosphere through the condenser: $q_{AC_waste} = q_{ceil} \times (1 + 1/COP)$. A seasonal average COP of 3.0 is used, accounting for COP degradation at high outdoor temperatures typical of Las Vegas summer (COP declines approximately 0.03 per °F above 82°F outdoor). At COP 3.0, every BTU removed from the house produces 1.33 BTU of heat rejection to outdoor air.

3.6. Control Volume and Temperature Model

The analysis adopts the identical control-volume framework as the companion papers: 15 mi × 15 mi plan area (5.83×10^8 m²), 100 ft nocturnal mixing height (30.48 m), ventilated by representative horizontal wind speeds. The temperature perturbation is $\Delta T = \dot{Q} / (\rho\, c_p\, U\, H\, L)$, where $\rho = 1.2$ kg/m³, $c_p = 1005$ J/kg·K, U is wind speed, $H = 30.48$ m, and $L = 24{,}140$ m. Because roof heat is a daytime-absorbed, evening-released phenomenon, the analysis presents both peak-hour instantaneous values and evening thermal release estimates.

4. Results

4.1. Per-Home Heat Loading by Roof Type

At the representative peak summer condition (1,000 W/m² solar irradiance, 110°F ambient, 3.0 m/s wind, R-38 ceiling insulation), the total atmospheric heat loading per home varies dramatically by roof type:

Roof Type	Surface (kW)	Vent (kW)	AC waste (kW)	Total (kW)	BTU/hr	Ratio vs. light asphalt
Dark asphalt	83.4	2.3	5.8	**91.5**	312,200	**1.6×**
Medium asphalt	76.5	1.5	3.9	**81.9**	279,500	**1.4×**
Light asphalt	65.3	0.9	2.4	**68.6**	234,000	**1.0× (baseline)**
Dark tile	73.4	1.0	2.6	**77.0**	262,800	**1.1×**
Medium tile	62.4	0.5	1.2	**64.1**	218,700	**0.93×**
Light tile	50.3	0.2	0.4	**50.9**	173,700	**0.74×**

Table 2. Per-home atmospheric heat loading by pathway and roof type at peak summer conditions. Surface pathway dominates in all cases. Tile assemblies show markedly lower vent and AC pathways due to the air-gap thermal break.

The surface radiation/convection pathway dominates in all roof types, accounting for 85–95% of total atmospheric heat loading. However, the vent and AC pathways, while smaller in absolute terms, carry disproportionate significance for the homeowner (AC costs) and for the nocturnal UHI (the stored thermal energy released after sunset through ventilation coincides with the shallow nocturnal boundary layer).

4.2. The Black Roof Equivalency

One of the most policy-relevant findings is the atmospheric heat multiplier of dark asphalt roofs compared to lighter alternatives. Across all four heat pathways combined:

Comparison	Heat ratio	Meaning
Dark asphalt vs. light asphalt	**1.6×**	Same material, just color
Dark asphalt vs. medium tile	**1.4×**	Most common new LV build
Dark asphalt vs. light tile	**2.8×**	Best practical option

Table 3. Black roof equivalency ratios. One dark asphalt home dumps as much heat as 2.8 light tile homes.

In practical terms, a homeowner who chooses dark asphalt shingles is making a decision that inflicts nearly three times the atmospheric heat burden of the best practical alternative (light tile) on the surrounding neighborhood and the valley at large. Given that this choice typically costs zero additional dollars at the point of purchase—the same retailer sells both colors at the same price point—the only barriers are aesthetic preference and HOA color palette restrictions.

4.3. Valley-Scale Atmospheric Heat Loading

Aggregating across the estimated 580,000 single-family homes using the estimated roof stock distribution (Table 1), the total residential roof heat loading at peak summer conditions is approximately 5.4 GW for the current estimated mix. Under alternative scenarios:

Scenario	Total (GW)	W/m²	ΔT at 3 m/s	vs. current

All dark asphalt (worst)	**7.1**	12.2	+2.9°F	+32%
Current estimated mix	**5.4**	9.3	**+2.2°F**	Baseline
All light asphalt	**4.0**	6.9	+1.6°F	−26%
All medium tile	**3.7**	6.4	+1.5°F	−31%
All light tile	**3.0**	5.1	**+1.2°F**	−44%

Table 4. Valley-scale residential roof heat loading under alternative scenarios. Control volume: 15 mi × 15 mi × 100 ft at 3.0 m/s ventilation.

For context: The current estimated roof heat loading of 5.4 GW at peak summer conditions is approximately 2× the ICE vehicle fleet transport heat of 2.65 GW (24-hour average) from the companion EV paper. The achievable reduction from converting the current mix to all light tile is approximately 2.4 GW—comparable in magnitude to the entire transport heat reduction from full fleet electrification. Roof color change and building electrification are thus comparable in their UHI mitigation potential.

4.4. Annual AC Cost Penalty

The ceiling heat conduction pathway (Pathway 3) directly drives air conditioning electricity consumption. Over the May–October cooling season, using monthly average highs from NWS Las Vegas 1991–2020 normals and NV Energy's current residential rate of approximately $0.14/kWh:

Roof Type	AC kWh/yr	AC cost/yr	Penalty vs. light asphalt	22-yr cost	22-yr penalty
Dark asphalt	2,000	$280	**+$125/yr**	$6,160	**+$2,750**
Medium asphalt	1,430	$200	**+$45/yr**	$4,250	**+$990**
Light asphalt	1,110	$155	Baseline	$3,410	Baseline
Dark tile	940	$132	−$23/yr	$2,904	−$506
Medium tile	660	$92	−$63/yr	$2,024	−$1,386
Light tile	430	$60	**−$95/yr**	$1,320	**−$2,090**

Table 5. Annual roof-attributable AC cost by roof type, April–October cooling season. Estimates include ceiling conduction and an attic-mounted duct system loss factor of 2.5× (reflecting typical Las Vegas HVAC configuration with ducts and air handler in the attic). Monthly integration uses NWS Las Vegas 1991–2020 average daily high temperatures, COP 3.0, NV Energy rate $0.14/kWh. 22-year values represent the typical roof replacement cycle for asphalt shingles in Las Vegas.

A homeowner choosing dark asphalt shingles over light asphalt pays approximately $125 more per year in AC electricity for a color choice that costs nothing at the point of purchase (approximately $220 per year versus light tile). Over a 22-year roof life, this cumulates to approximately $2,750–4,840 in wasted energy—money that flows directly to NV Energy while simultaneously adding waste heat to the urban atmosphere and accelerating shingle degradation from the higher surface temperatures.

4.5. Insulated Double-Deck Performance

The author's insulated double-deck design (R-12 isofoam + white/light shingles) reduces attic temperature to within 5°F of ambient, producing the following comparison against the standard dark asphalt case:

Metric	Dark asphalt (standard)	Insulated double-deck

Attic temperature	165°F (+55°F)	115°F (+5°F)
Attic vent heat discharge	~7,800 BTU/hr	~600 BTU/hr
Ceiling heat gain	~3,400 BTU/hr	~160 BTU/hr
AC condenser waste heat	~4,500 BTU/hr	~210 BTU/hr
Total to atmosphere	~312,000 BTU/hr	~52,000 BTU/hr
Reduction vs. dark asphalt	—	**~83%**

Table 6. Per-home comparison: standard dark asphalt vs. insulated double-deck design at peak summer conditions.

4.6. Combined Economic Effect of Light-Color Conversion and an Insulated Deck

The insulated double-deck case analyzed in Section 4.5 is a combined measure: it includes both conversion from a dark roof to white/light shingles and the addition of R-12 above-deck insulation. Table 5 shows that color change alone reduces roof-attributable AC cost from approximately $280/yr for dark asphalt to $155/yr for light asphalt, a savings of about $125/yr at essentially zero incremental color cost. Table 6 shows that the combined insulated-deck + light-shingle assembly reduces roof-driven ceiling heat gain and AC waste heat by roughly 95%; applying that reduction to the dark-asphalt baseline yields a residual roof-attributable cooling cost of approximately $14/yr. Relative to the standard dark-asphalt baseline, the combined package therefore saves approximately $266/yr, of which about $125/yr is attributable to the color change and about $141/yr to the near-elimination of attic heat transfer.

Case	Roof AC cost ($/yr)	Savings vs. dark ($/yr)	Representative premium	Simple payback
Dark asphalt baseline	$280	—	—	—
Light asphalt reroof	$155	$125	~$0 color premium	Immediate
Light roof + R-12 insulated deck (vs. conventional dark reroof)	$14	$266	$3,000 ($2/sq ft on 1,500 sq ft)	11.3 yr
R-12 deck premium beyond an already-light reroof	$14	$141	$3,000 ($2/sq ft on 1,500 sq ft)	21.3 yr

Table 7. Combined effect of a dark-to-light reroof and an R-12 insulated deck on annual roof-attributable AC cost for a representative 1,500 sq ft asphalt-shingle home. The last row isolates the deck premium beyond an already-light reroof.

The economic advantage is concentrated in asphalt-shingle reroofs. Existing tile roofs already capture much of the thermal benefit through the ventilated air gap; Table 5 shows roof-attributable AC costs of only $132/yr for dark tile and $60/yr for light tile. Because an above-deck retrofit on a tile roof would require tile removal/reset and more complex flashing and batten detailing, the recoverable savings are generally too small to justify the added cost. For tile roofs, the cost-effective measure is usually color selection at replacement rather than reconstruction of the deck.

5. Discussion

5.1. Roofs as the Dominant Residential Heat Source

The central finding of this analysis is that residential roof surfaces are the largest single anthropogenic heat term in the Las Vegas valley residential sector—substantially larger than transport heat or building heating waste heat. The current-mix estimate of approximately 5.4 GW at peak conditions exceeds the 24-hour-average ICE fleet transport heat of 2.65 GW by approximately 2×. While the roof peak is instantaneous and the transport average is 24-hour, the practical comparison is reinforced by the temporal alignment: much of the roof heat stored during the day releases during the evening and early nighttime hours, when the nocturnal boundary layer is shallowest and the companion papers show maximum UHI sensitivity.

This means that roof color policy may be the single most effective UHI mitigation lever available in the residential built environment—requiring no new technology, no behavioral change, and minimal or zero incremental cost at the point of normal roof replacement.

5.2. Comparison Across the Four Companion Papers

The control-volume framework now encompasses four major anthropogenic heat terms in the Las Vegas valley, each addressed in a separate paper. Ranking by approximate peak magnitude: (1) residential roof heat, approximately 5–6 GW at peak; (2) ICE vehicle fleet transport heat, approximately 2.65 GW 24-hour average; (3) heat pump atmospheric extraction (winter cooling benefit), approximately 2.0 GW on a cold winter night; and (4) gas furnace flue waste heat (eliminated by heat pumps), approximately 0.17 GW on a cold winter night. The combined mitigation potential—cool roofs, EV fleet electrification, and heat pump adoption—addresses all four terms simultaneously.

5.3. Tile vs. Asphalt: Policy Implications

The tile air-gap effect measured by ORNL (48% heat transfer reduction at matched albedo) has profound policy implications for Las Vegas building standards. A dark concrete tile thermally outperforms a medium asphalt shingle, and a medium concrete tile approaches the performance of a light asphalt shingle—entirely from the passive air gap. New construction in Las Vegas increasingly specifies concrete tile, which is a positive trend for UHI mitigation. However, the existing stock of older homes with dark asphalt shingles represents the largest single opportunity for improvement, because these homes sit at the worst-performing end of the spectrum and will cycle through roof replacement over the next 10–25 years.

5.4. Roof Replacement as a Mitigation Pathway

Asphalt shingle roofs in Las Vegas have a typical service life of 20–25 years due to extreme UV degradation. This means that approximately 4–5% of the residential roof stock is replaced annually—roughly 23,000–29,000 homes per year. Unlike EV adoption or heat pump conversion, which require active investment in new equipment, the cool-roof substitution can occur at the point of normal replacement at minimal incremental cost. A Clark County cool-shingle ordinance or incentive program applied only at the point of replacement could achieve 50% fleet conversion within 10–13 years and near-complete conversion within 20–25 years, without requiring any homeowner to replace a functioning roof prematurely.

Table 7 shows that the economics improve materially when roof replacement is framed as a combined measure rather than as deck insulation alone. A homeowner replacing a dark asphalt

roof with light shingles immediately captures approximately $125/yr of savings at essentially no color premium; adding an R-12 insulated deck to that same reroof lowers the residual roof-attributable AC cost to approximately $14/yr and yields total savings of approximately $266/yr relative to the dark baseline. At an incremental deck premium of $2.00/sq ft on a representative 1,500 sq ft roof, simple payback is approximately 11 years; if the premium is closer to $1.00/sq ft, payback falls to roughly 6 years. The same logic generally does not extend to existing tile roofs, whose ventilated air gap already removes much of the available heat before it reaches the attic.

5.5. Albedo Aging and Weathering Effects

CRRC three-year weathering data from exposure sites in Arizona (hot-dry, most relevant to Las Vegas), Florida (hot-humid), and Ohio (temperate-polluted) reveals that roof solar reflectance changes substantially after installation, with implications for long-term cost and heat loading calculations (Berdahl et al., 2012; Sleiman et al., 2014). White and high-reflectance materials suffer the largest absolute drops: initial albedo of 0.70–0.80 can fall to 0.55–0.65 within one to three years, primarily from dust and soot deposition and UV-induced yellowing of polymer binders. In the Arizona hot-dry climate most analogous to Las Vegas, soiling is predominantly mineral dust rather than biological growth, and infrequent rainfall limits natural washing. Cool-colored asphalt shingles (initial 0.25–0.35) show moderate drops of 0.03–0.08, reaching three-year aged values of 0.22–0.30. Notably, dark asphalt shingles can actually increase slightly in reflectance over time, as UV degrades the oily asphalt films covering the ceramic granules, exposing the more reflective mineral surface beneath—a new dark shingle at albedo 0.08 may age to 0.10–0.12 after three years. Concrete and clay tile show the best aging resistance due to their hard, non-porous surfaces, with drops of only 0.02–0.04 from soiling. Aging narrows the albedo gap between dark and light products but does not close it. Since most roofs in the Las Vegas stock are well past three years old, the aged albedo values should be used as the primary assumption for fleet-average calculations. A California field study found that 70% of the reflectance drop for white roofs occurred within the first two months of exposure, with small additional losses after the first year.

5.6. Thermal IR Imagery as a Data Source for Effective Roof Albedo

The estimated roof stock distribution in Table 1 could be replaced with measured data through two complementary thermal infrared data sources. First, NASA’s ECOSTRESS instrument on the International Space Station provides 70-meter-resolution surface temperature maps with a 3–5 day revisit frequency. The June 10, 2022 Las Vegas overpass (already cited in the companion irrigation paper) captured surface temperatures at 5:23 PM showing pavement exceeding 122°F and suburban neighborhoods averaging 14°F cooler. At 70-meter pixels, individual roofs blur into two to three per pixel in typical Las Vegas subdivisions, but neighborhood-average roof temperature is well captured. A time series of ECOSTRESS summer passes over Las Vegas could directly measure the neighborhood-average effective roof temperature—which is the thermal equivalent of the effective aged albedo, integrating color, material type, weathering, and dust accumulation into a single physically meaningful measurement. Second, a drone-mounted FLIR thermal camera at 200–400 feet altitude could directly image individual roof temperatures across representative neighborhoods during a summer afternoon, producing a parcel-level census of roof thermal performance. A systematic survey of 500–1,000 homes across different-age neighborhoods would ground-truth the estimated roof stock distribution at a cost under $3,000 in equipment. The critical advantage of thermal IR over visible-light color assessment is that IR measures the thermal outcome directly—a medium-colored tile at 125°F and a light asphalt at 130°F may look similar in a photograph

but are thermodynamically distinguishable in IR, and the IR measurement represents what the atmosphere actually receives.

5.7. Connection to Chill-Hour Restoration

The nighttime thermal release from dark roofs persists for 4–6 hours after sunset, directly overlapping with the nocturnal chill-hour accumulation period analyzed in the companion heat pump paper. The achievable temperature reduction of 0.5–1.5°F from cool-roof conversion operates during these same hours and thus directly contributes to the marginal-band chill-hour restoration mechanism. The combined effect of EVs + heat pumps + cool roofs could push the total nocturnal temperature reduction to 1.5–3.0°F under moderate wind conditions—potentially restoring chill-hour accumulation to the early 1990s level or better, particularly in the western residential neighborhoods where all three effects compound.

6. Limitations and Simplifications

The roof stock distribution is estimated from field observation rather than measured from the Clark County AORES parcel database. The surface-to-atmosphere fraction for each roof type is a first-order estimate calibrated to the ORNL tile air-gap measurements; a full energy balance model with measured roof surface temperatures would strengthen these assumptions. The attic ventilation model assumes code-compliant vent installations with 60% NFA effectiveness; actual installations may have lower effectiveness due to clogged soffits, missing baffles, or improper ridge vent installation—the author is not aware of field data confirming that code-required vent areas actually achieve the intended air exchange rates. The daytime convective boundary layer is substantially deeper than the 100 ft nocturnal layer assumed in the control volume, diluting the instantaneous peak-hour temperature perturbation; the nocturnal values (during stored thermal release) are the proper comparison to the companion papers. The AC COP of 3.0 is a seasonal average; actual COP degrades significantly above 110°F outdoor temperature, amplifying the AC waste heat pathway during the hottest conditions. Commercial and multifamily roofs are excluded from this residential analysis but represent an additional significant heat source.

7. Conclusion

Residential roof surfaces are the largest single addressable heat source in the Las Vegas valley residential sector, with an estimated peak atmospheric heat loading of approximately 5–6 GW under the current roof stock distribution—exceeding the entire ICE vehicle fleet transport heat by a factor of two. The heat reaches the atmosphere through four pathways: roof surface radiation and convection (dominant), attic ventilation discharge, ceiling heat conduction driving AC loads, and AC condenser waste heat rejection. Each pathway is sensitive to roof color and assembly type.

One home with a dark asphalt shingle roof dumps approximately 1.6× the atmospheric heat of a light asphalt home and approximately 2.8× the heat of a light tile home—while costing the homeowner approximately $125–220 per year more in AC electricity for a color choice that carries zero incremental cost at the retailer. Over a 22-year roof life, this cumulates to approximately $2,750–4,840 in unnecessary energy expenditure. The insulated double-deck design (R-12 isofoam between decks + white/light shingles), as implemented at the author’s two Las Vegas residences, reduces total atmospheric heat loading by approximately 83% by intercepting solar heat at the roof deck before it can enter the attic. Evaluated as a combined dark-to-light reroof plus R-12 above-deck insulation on a representative 1,500 sq ft asphalt-shingle roof, the roof-attributable AC cost falls from approximately $280/yr to approximately $14/yr, implying approximately $266/yr savings and simple payback of roughly 11 years at a $2.00/sq ft incremental deck premium. Existing tile roofs generally do not offer enough remaining recoverable load to justify the same intervention.

The insulation code asymmetry—requiring R-60 for an 80°F winter differential in cold climates but only R-38 for a comparable summer differential in Las Vegas—systematically under-protects desert homes against their dominant thermal load. Correction of this asymmetry, combined with cool-roof requirements at the point of replacement, represents a policy opportunity that requires no new technology, minimal cost, and leverages the natural 4–5% annual roof replacement cycle to achieve near-complete fleet conversion within a generation.

When combined with the transport electrification (companion EV paper) and building heating electrification (companion heat pump paper) findings, cool-roof conversion represents the third

pillar of a comprehensive strategy to reduce the anthropogenic heat burden on the Las Vegas valley. The convergence of the three analyses—showing that roof color, vehicle fleet, and building heating each contribute multi-GW heat terms that are addressable through technology substitution at the point of normal replacement—argues for integrated urban heat policy that evaluates roofing standards, vehicle electrification, and building electrification as a coordinated package rather than as isolated initiatives.

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