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Development and Application of LCA Tool for Cool Pavement

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Outline

- Background & Objective
- Cool Pavement Life Cycle Assessment Tool
- Case Studies for Cool Pavement LCA
- Conclusions

Cool Pavement Basics

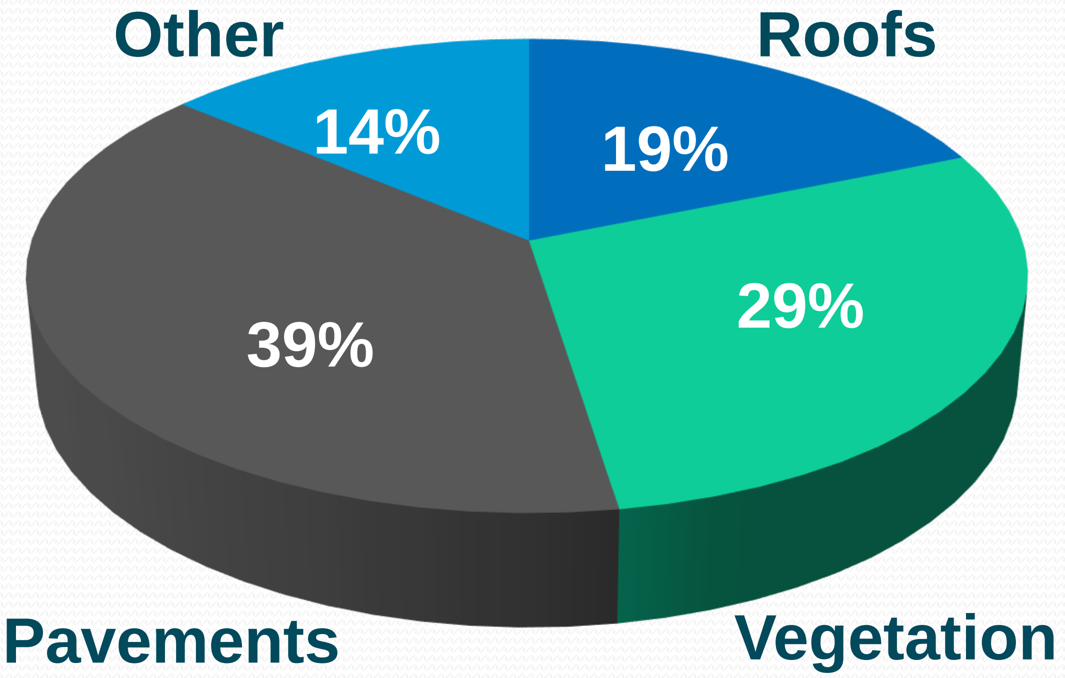
- CA AB296 in 2012, Cool Pavement Research and Implementation Act, to mitigate urban heat island (UHI)
- Albedo is solar radiation reflectivity
  - 0 is completely absorptive
  - 1 is completely reflective
- Typical albedos
  - Asphalt and slurries: 0.05 to 0.1 and lighten to about 0.15
  - Chip seals depend on aggregate reflectivity 0.05 to 0.20
  - Concrete: 0.25 to 0.35 and darkens to about 0.20

Low albedo, high temperature.

Pavements are an important part of the urban environment

Albedo = reflectivity

Question: what is net impact of changing surface materials to change albedo?



Urban fabric above tree canopy in Sacramento, California

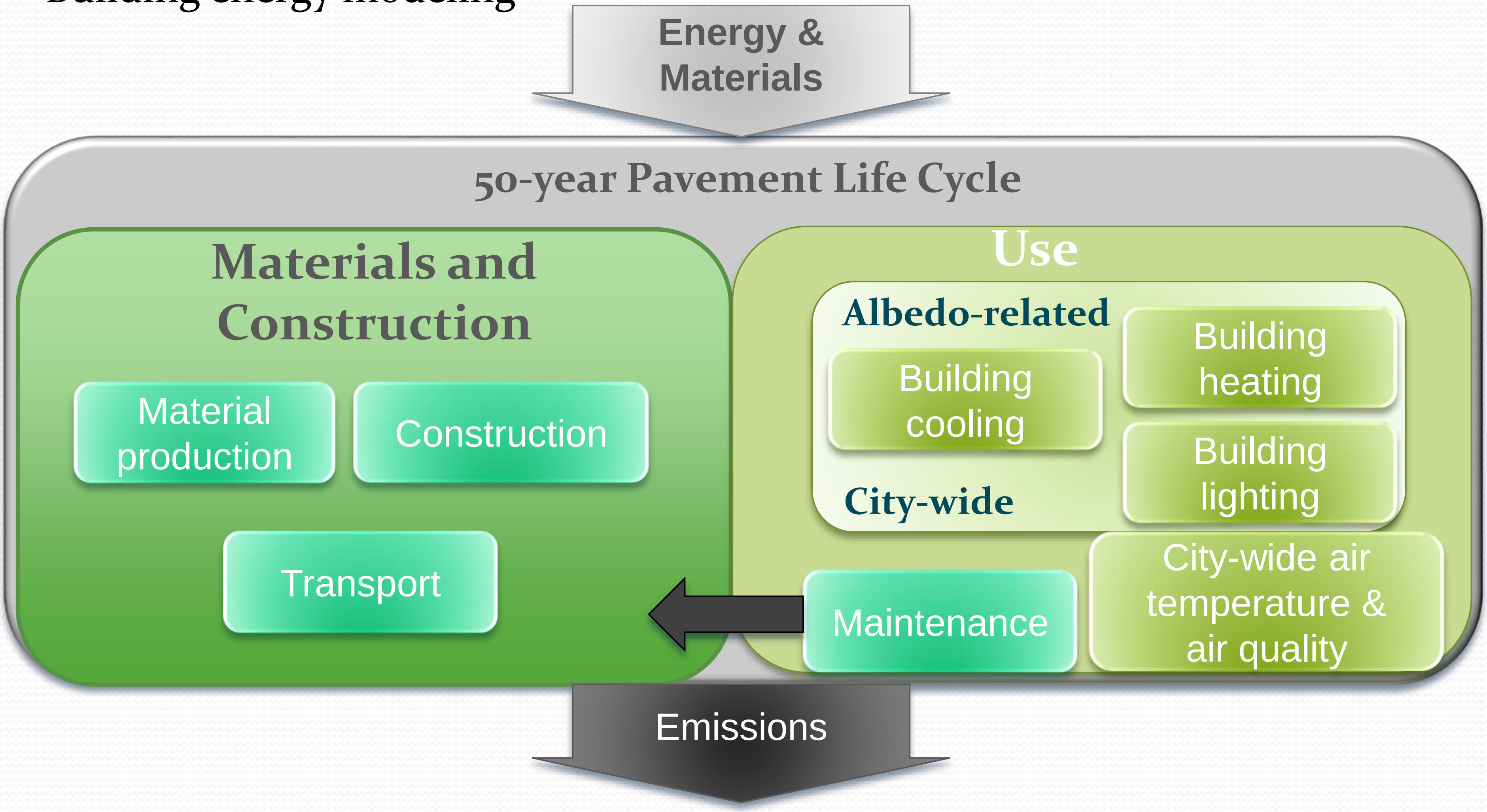
Objectives

- Develop model and tool for estimating the 50-year life cycle environmental effects of various pavement treatment scenarios of modifying pavement albedo

- Case studies

The scope of the pLCA tool includes the non-use and use phases of the pavement life cycle

- Pavement materials and construction models
- State-wide WRF climate change model response to albedo
- Building energy modeling



What are the life cycle benefits/penalties from the adoption of cool pavements? examples

- Apply the pavement life cycle assessment (pLCA) tool to evaluate business-as-usual and alternative pavements

Routine maintenance

Rehabilitation (Regular & Long-life)

➢ **Δ = (alternative pavement) – (business-as-usual pavement)**

Methodology

- Development of the pavement strategy guidance tool involved,
  - Assessment of local government pavement management practices in California
  - Assessment of pavement albedo
  - Calculation of life-cycle inventories for pavement materials and energy sources in California
  - Assessment of building stock in California
  - Urban climate modeling in California
  - Ozone temperature sensitivities in California
  - Building energy modeling in California
  - Tool coding
  - Tool input and output quality assurance

Local Government Pavement Management Practice

City	Portion of Each Treatment Used in Total Network Treated					
	A. Slurry Seal	B. Sand Seal	C. Chip Seal	D. Cape Seal	E. Asphalt Overlay	F. Reconstruction (AC, RAC, FDR, CIR)
City of Bakersfield	-	75%	-	-	13%	12%
City of Berkeley	31%	-	-	-	41%	28%
City of Chula Vista	28.3%	-	46.4%	0.5%	21.8%	3%
City of Fresno [a]	-	-	-	-	100%	-
City of Los Angeles	60.7%	-	-		35.4%	3.9%
City of Richmond	47.1%	-	0.7%	0.5%	45.9%	5.9%
City of Sacramento	82.4%	-	-	-	17.6%	-
City of San Jose	80%	-	-	-	20%	-
Average	***41.2%***	***9.4%***	***5.9%***	***0.1%***	***36.8%***	***6.6%***

[a] 40 centerline miles asphalt overlay up to 2009, then 20 cen

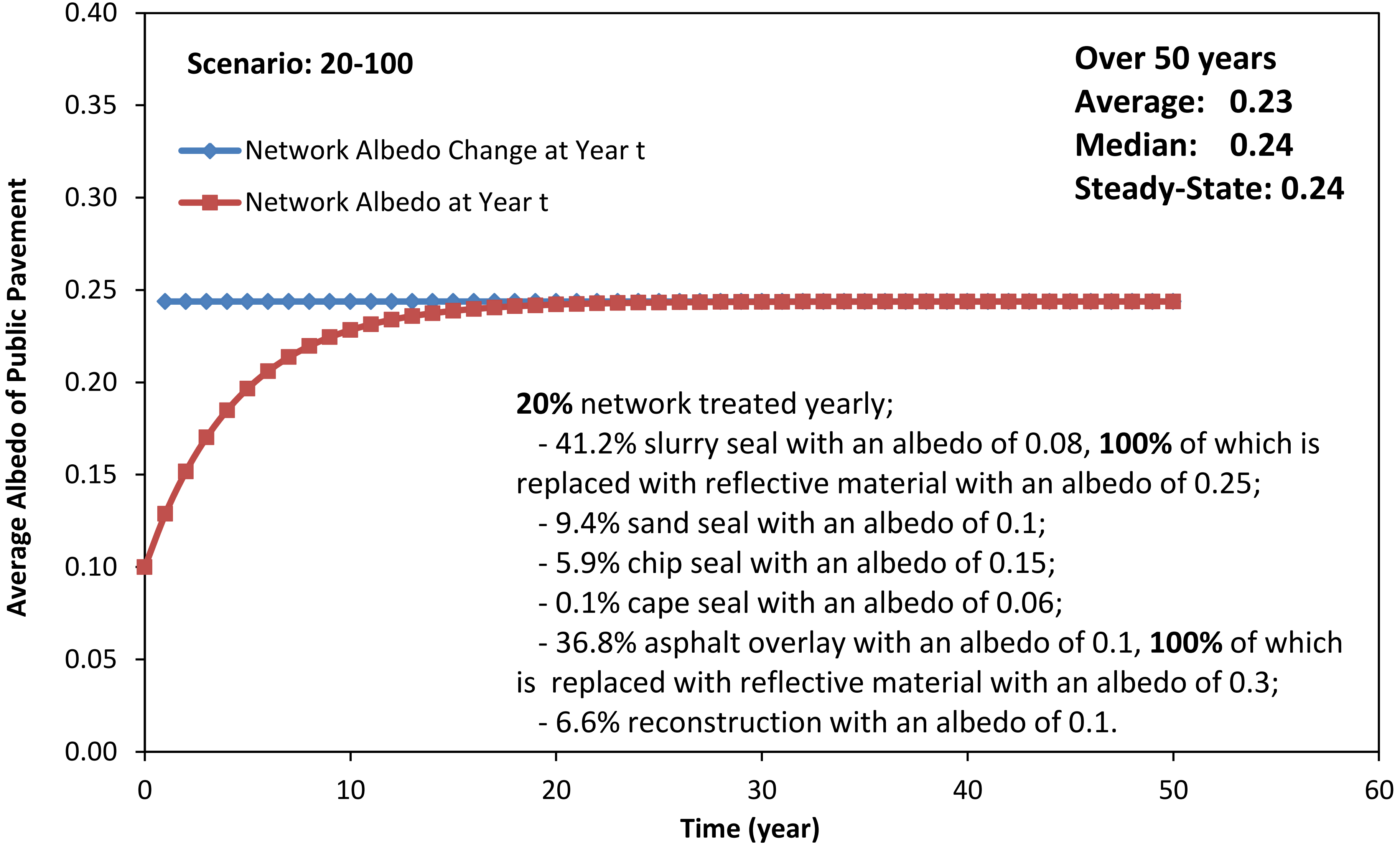
[b] use multiplier 2.2 to convert centerline miles to lane miles.

Pavement Albedo

Material Type	Albedo (Typical)	
	Range	Avg.
Asphalt Concrete or Overlay	0.05 - 0.15	0.1
Asphalt Concrete or Overlay with Reflective Coating	0.2 - 0.3	0.2
Chip Seal	0.1 - 0.24	0.15
Slurry Seal	0.07 – 0.1	0.08
Cape Seal	0.05 – 0.15	0.06
Fog Seal	0.04 – 0.07	0.06
Sand Seal	0.07 – 0.1	0.08
Portland Cement Concrete	0.15 - 0.35	0.25
Conventional Interlocking Concrete Pavement	0.25 – 0.3	0.26
Permeable Asphalt Pavement	0.08 – 0.12	0.1
Permeable Concrete Pavement	0.18 – 0.28	0.25
Permeable Interlocking Concrete Pavement	0.25 – 0.3	0.26
Gravel	0.12 – 0.22	0.18
Soil	0.21 – 0.23	0.22
Grass	0.18 – 0.20	0.19

Albedometer with dual-pyranometer

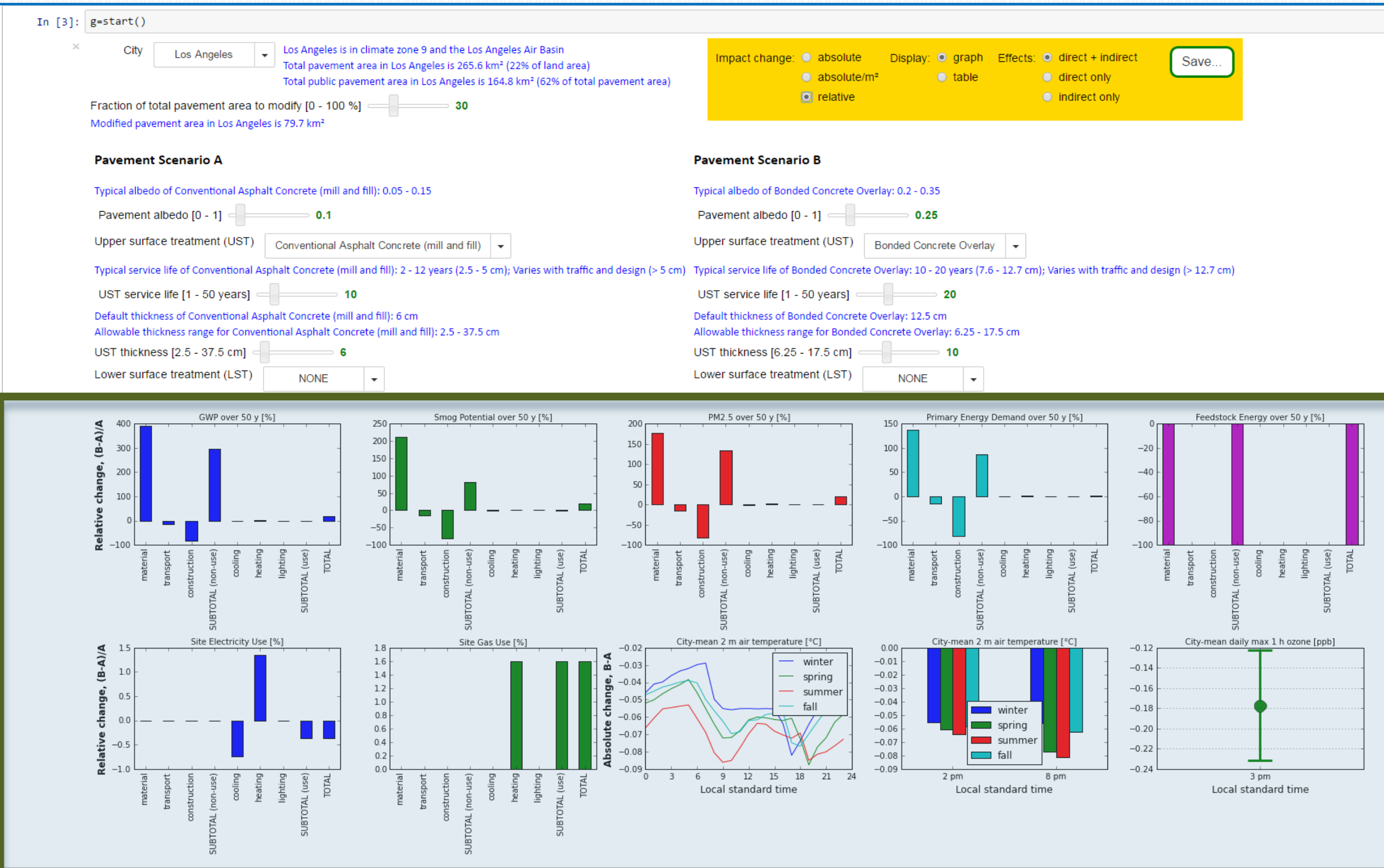
20% treatment/year, 100% replacement



Summary LCI and LCIA of treatments (ex.) non-use stages
(based on 2012 electricity grid mix, functional unit of 1 ln-km)

Item	Life Cycle Phase	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED Total* [MJ]	PED (non-ren)** [MJ]	Feedstock Energy [MJ]
Cape Seal	Material	5.03E+03	8.24E+02	4.03E+00	1.05E+05	1.00E+05	3.75E+05
	Transport	6.53E+02	1.04E+02	2.09E-01	9.35E+03	9.35E+03	0.00E+00
	Construction	1.49E+03	6.56E+02	1.17E+00	2.05E+04	2.05E+04	0.00E+00
	Total	7.17E+03	1.58E+03	5.40E+00	1.35E+05	1.30E+05	3.75E+05
Chip Seal	Material	3.64E+03	5.97E+02	2.91E+00	7.60E+04	7.23E+04	2.69E+05
	Transport	4.80E+02	7.65E+01	1.53E-01	6.87E+03	6.87E+03	0.00E+00
	Construction	8.12E+02	3.59E+02	6.37E-01	1.12E+04	1.12E+04	0.00E+00
	Total	4.93E+03	1.03E+03	3.70E+00	9.41E+04	9.04E+04	2.69E+05
Fog Seal	Material	1.06E+03	1.72E+02	8.73E-01	2.24E+04	2.14E+04	8.42E+04
	Transport	1.31E+01	2.08E+00	4.17E-03	1.87E+02	1.87E+02	0.00E+00
	Construction	2.14E+02	9.46E+01	1.68E-01	2.95E+03	2.95E+03	0.00E+00
	Total	1.29E+03	2.69E+02	1.05E+00	2.56E+04	2.46E+04	8.42E+04
Reflective Coating – BPA	Material	1.04E+04	4.46E+02	2.75E+00	2.52E+05	2.46E+05	n/a
	Transport	1.38E+02	2.21E+01	4.43E-02	1.98E+03	1.98E+03	n/a
	Construction	2.01E+02	8.88E+01	1.58E-01	2.77E+03	2.77E+03	n/a
	Total	1.07E+04	5.57E+02	2.95E+00	2.57E+05	2.51E+05	n/a
Reflective Coating - Polyester Styrene	Material	1.22E+04	5.77E+02	1.42E+01	2.55E+05	2.43E+05	n/a
	Transport	1.38E+02	2.21E+01	4.43E-02	1.98E+03	1.98E+03	n/a
	Construction	2.01E+02	8.88E+01	1.58E-01	2.77E+03	2.77E+03	n/a
	Total	1.25E+04	6.88E+02	1.44E+01	2.59E+05	2.47E+05	n/a

Pavement life cycle assessment (pLCA) tool



Provides comparison between treatments

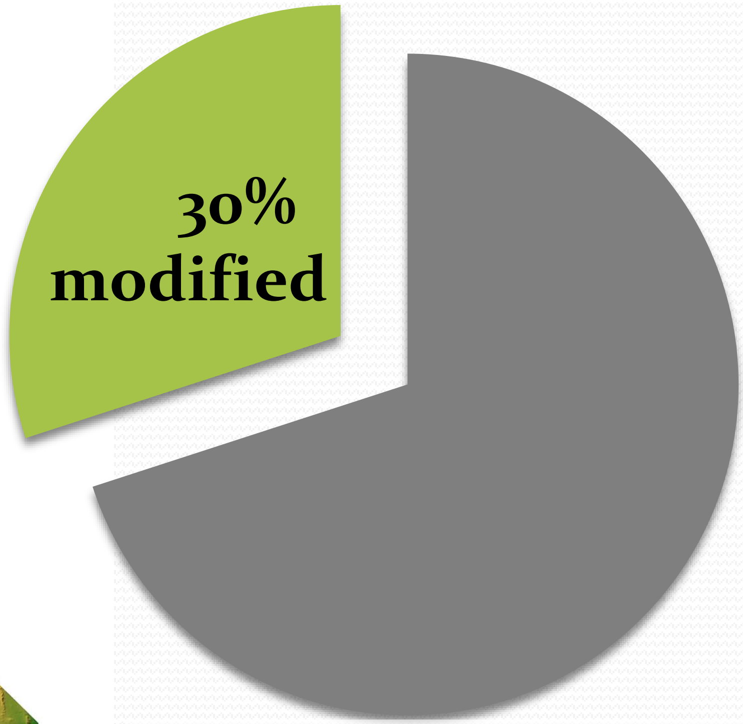
User inputs:

- City
- Percent of city repaved
- Treatment lives, thicknesses, albedos

Main Assumptions

- Pavements change albedo instantly
- Pavements maintain albedo through lifecycle
- Same pavement replacement at end of life
- The tool does not track the spatial distribution of environmental effects
- The climate modeling methodology focused on city-wide air temperature changes
- The building prototypes used for the building energy simulations followed California's 2008 Title 24 building energy efficiency standards
- The environmental impacts of electrical energy use are based on the California 2020 renewable energy portfolio
- Time-adjusted warming potentials are not considered

The case studies evaluate cool pavement campaigns in two California cities



Total city paved area

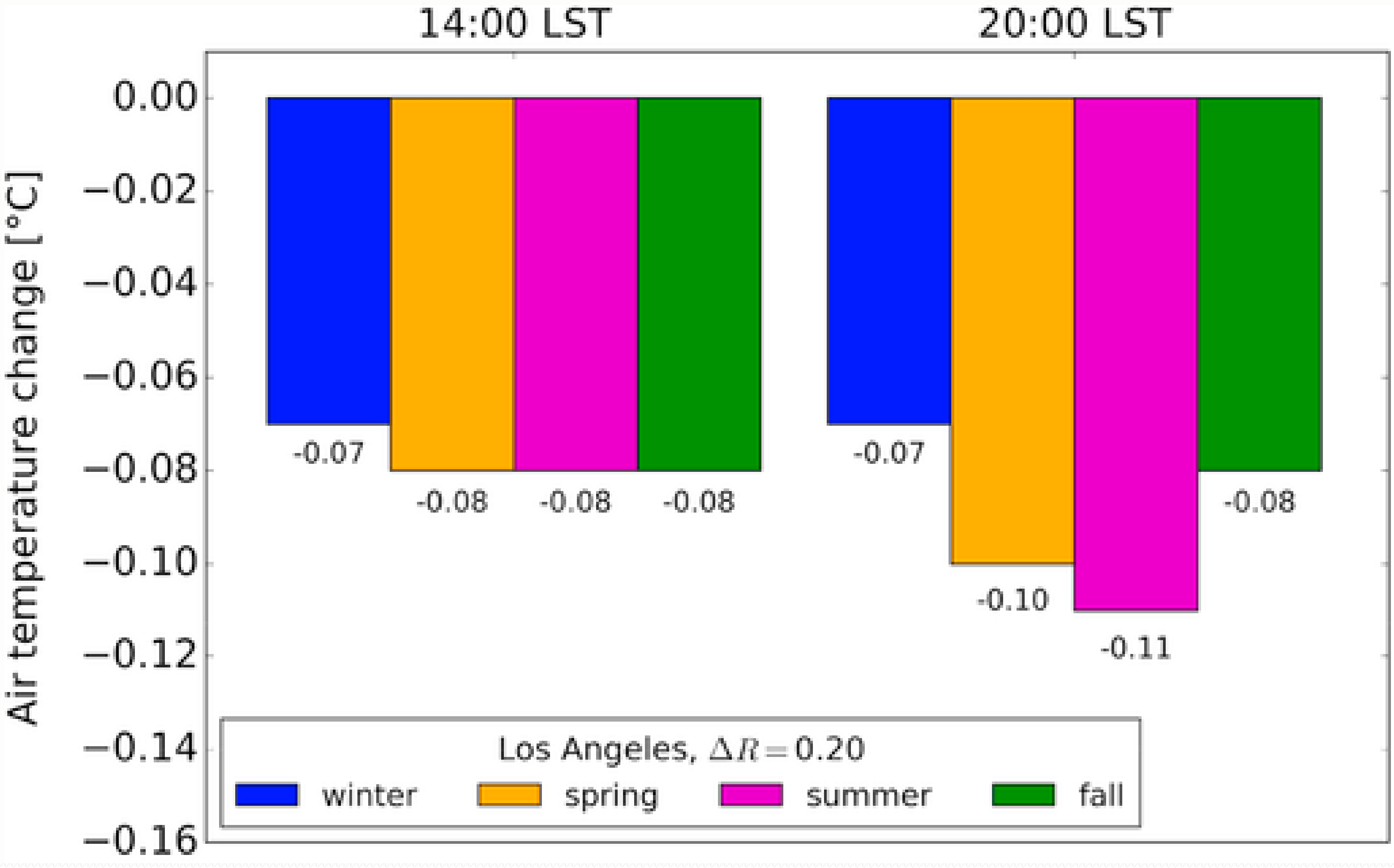
Specifications of the three pavement case studies

Case study	Typical treatment	Less-typical treatment	Aged albedo	Albedo increase	Service life (y)	Thickness per installation (cm)	Thickness installed over 50 y (cm)
1. Routine maintenance	Slurry seal	-	0.10	-	7	-	-
	-	1A: Styrene acrylate reflective coating	0.30	0.20	5	-	-
	-	1B: Chip seal	0.23	0.13	7	-	-
2. Rehabilitation	Mill-and-fill AC	-	0.10	-	10	6	30
	-	2A: BCOA (no SCM)	0.25	0.15	20	10	25
	-	2B: BCOA (low SCM)	0.25	0.15	20	10	25
	-	2C: BCOA (high SCM)	0.25	0.15	20	10	25
3. Long-life rehabilitation	Mill-and-fill AC	-	0.10	-	20	15	37.5
	-	3A: BCOA (no SCM)	0.25	0.15	30	15	25
	-	3B: BCOA (low SCM)	0.25	0.15	30	15	25
	-	3C: BCOA (high SCM)	0.25	0.15	30	15	25

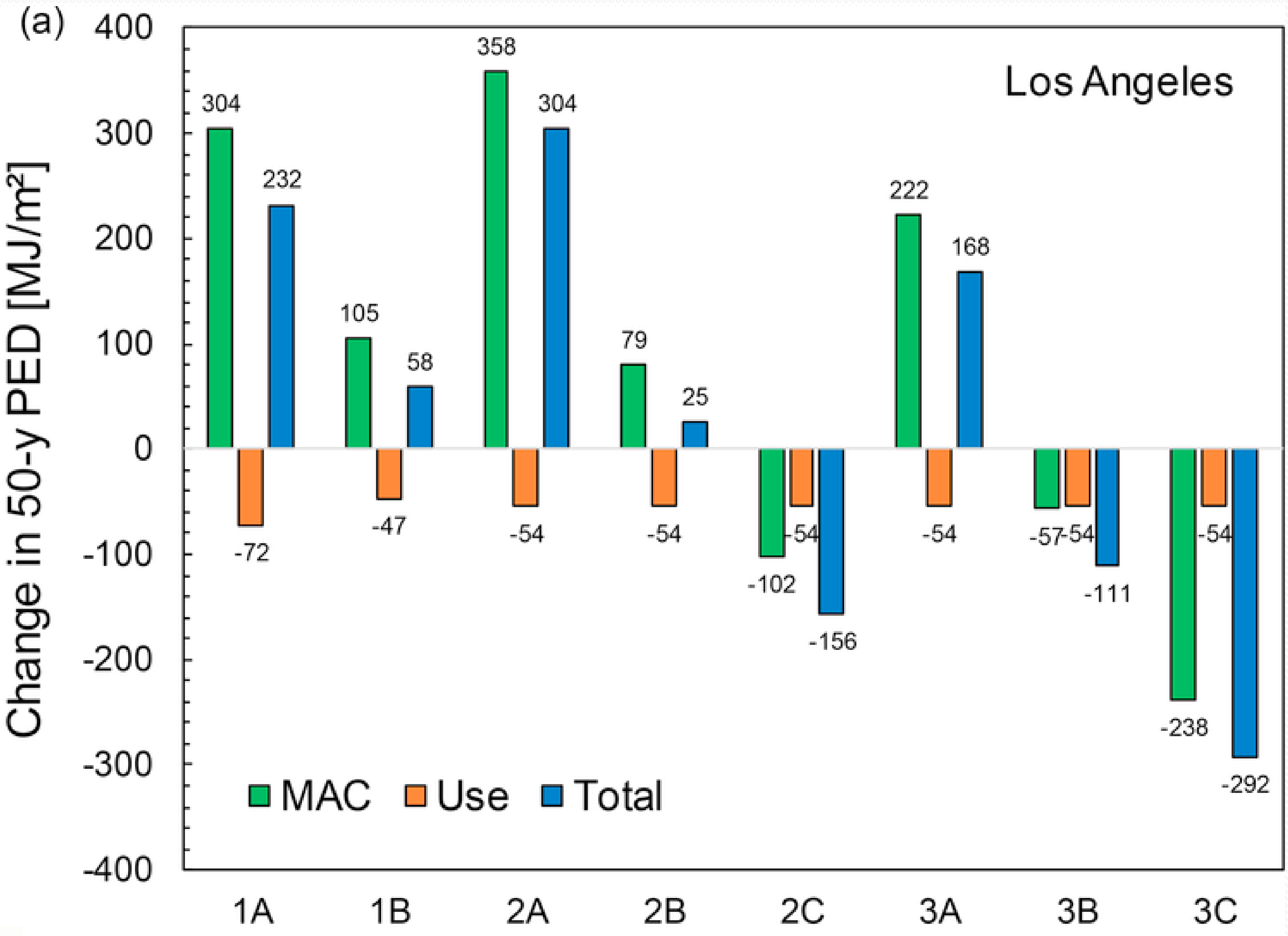
Composition of each pavement treatment considered in this study

Treatment	Composition
Slurry seal	6.5 kg crushed fine aggregate and 0.68 kg residual asphalt per m^2 pavement
Styrene acrylate reflective coating	60% unsaturated polyester resin, 24% styrene, 8% titanium dioxide, 4% silicon dioxide, 1% iron oxide, 0.5% polysiloxane, 0.5% ethylene bis(steramide), and 2% cobalt napthenate by mass, applied at 1 kg per m^2 pavement
Chip seal	1.8 L bitumen emulsion and 19 kg aggregate per m^2 pavement
Mill-and-fill AC	38% coarse aggregate, 57% fine aggregate, 5% dust, 4% asphalt binder, and 15% reclaimed asphalt pavement by mass
BCOA (no SCM)	1071 kg coarse aggregate, 598 kg fine aggregate, 448 kg cement, 1.8 kg polypropylene fibers, 1.9 kg water reducer (Daracern 65 at 390 mL per 100 kg of cement), 1.6 kg retarder (Daratard 17 at 325 mL per 100 kg of cement), 0.6 kg air entraining admixture (Daravair 1400 at 120 mL per 100 kg of cement), and 161 kg water per m^3 wet concrete
BCOA (low SCM)	1085 kg coarse aggregate, 764 kg fine aggregate, 267 kg cement, 71 kg fly ash, 1.8 kg polypropylene fibers, and 145 kg water per m^3 wet concrete
BCOA (high SCM)	1038 kg coarse aggregate, 817 kg fine aggregate, 139 kg cement, 56 kg slag, 84 kg of fly ash, and 173 kg water per m^3 wet concrete

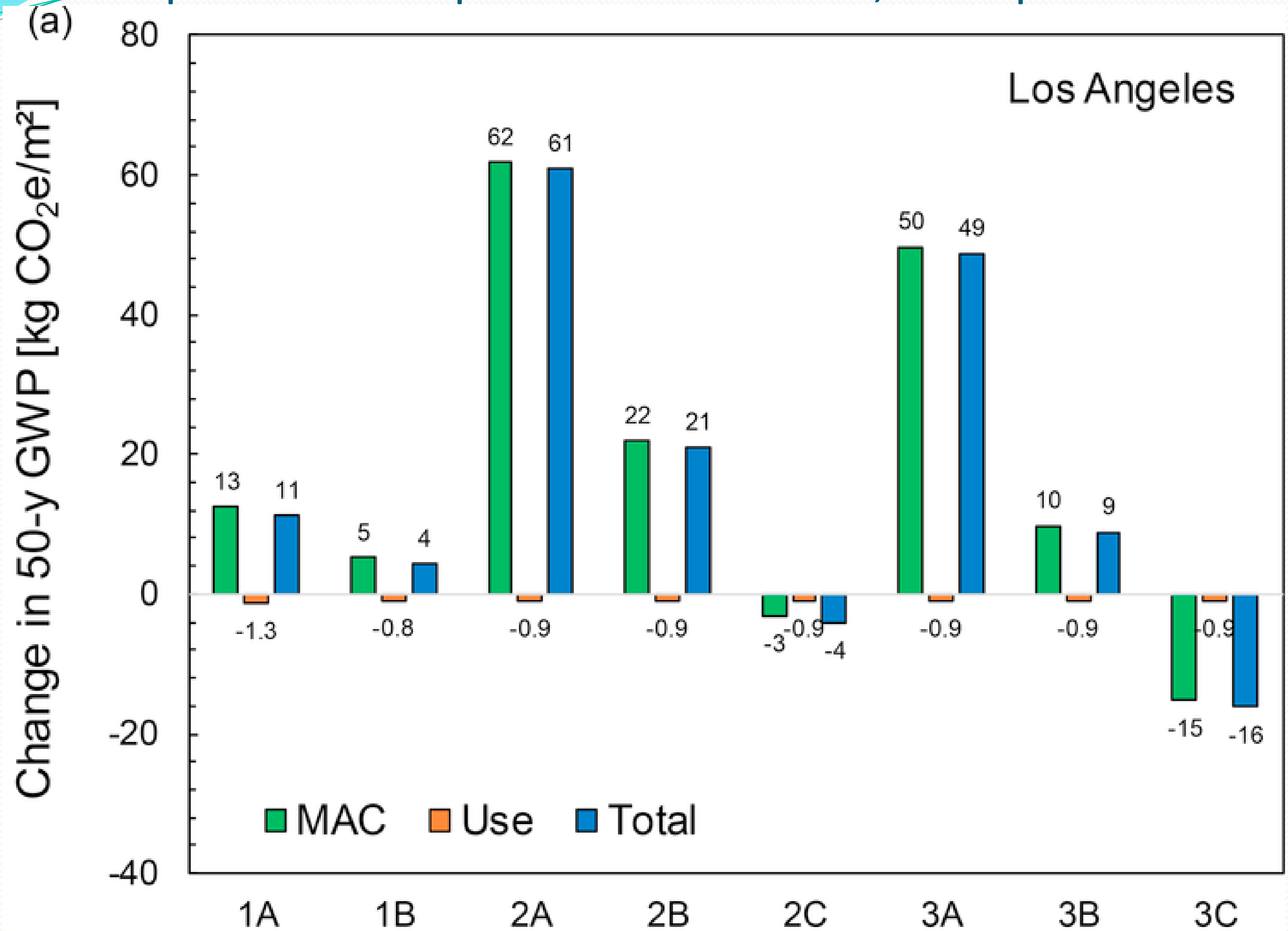
Seasonal average city-wide 2 m height air temperature changes upon raising by 0.20 the albedo of 30% of pavement in the city, example



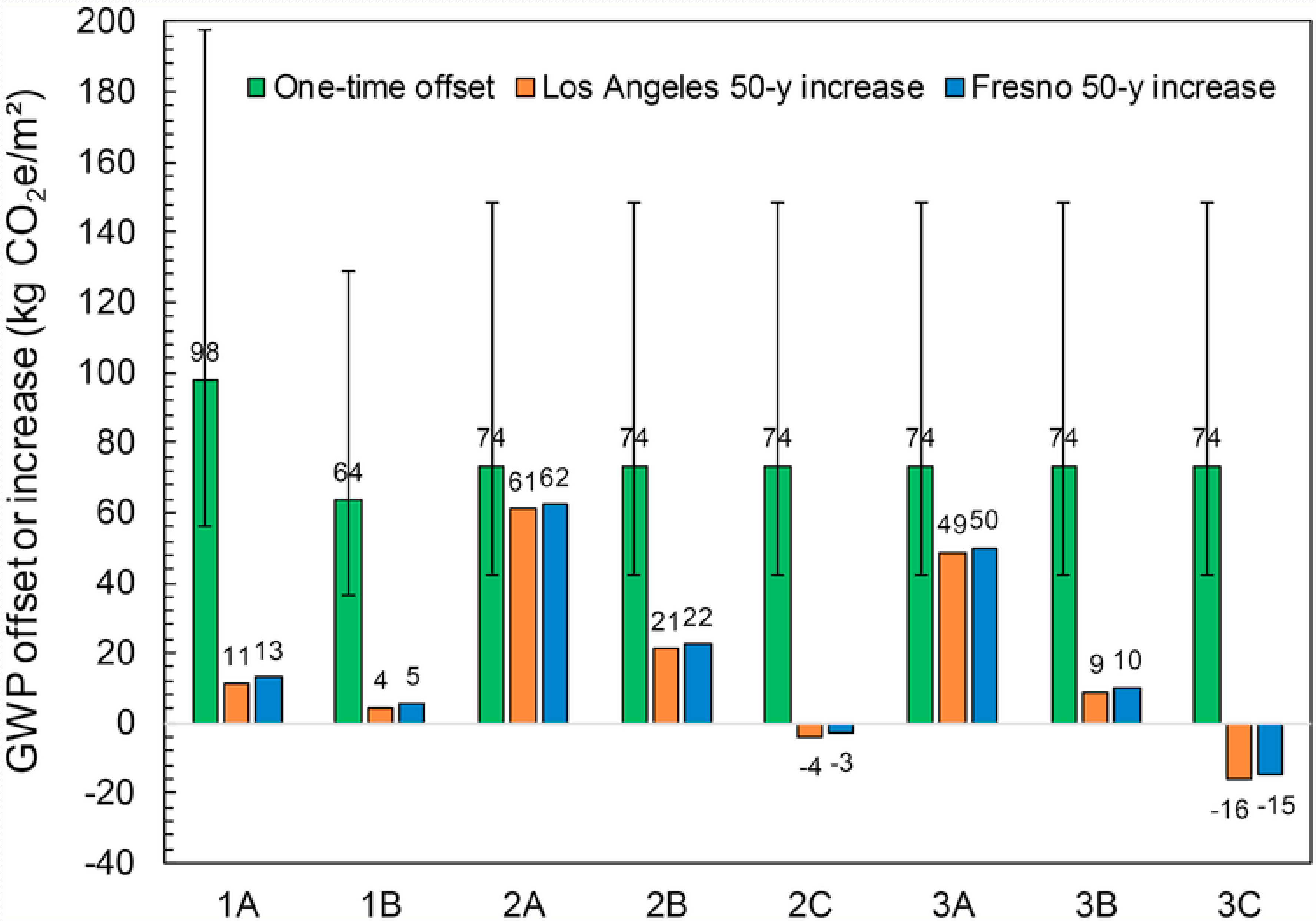
MAC-stage, use-stage, and total (MAC + use) changes in PED per unit area pavement modified, example



MAC-stage, use-stage, and total (MAC + use) changes in GWP per unit area pavement modified, example



Location-independent one-time GWP offset induced by global cooling compared to 50 y life cycle total GWP increases



Summary & Conclusions

- The pavement life cycle assessment method and decision support tool was developed, with which decision-makers can evaluate the life cycle impacts of various pavements from changing albedo, including both non-use phase and use-phase effects.
- Currently, most cities in California annually maintain a small portion of pavements with low-albedo, like slurry seals that traditionally have albedo values in the range of 0.07 to 0.10.
- Preliminary scenario analysis with the tool indicated that the energy and environmental effects of cool pavements from non-use phase (materials) are greater than those from use phase.
- Pavement technologies are needed that use less energy and are carbon intensive to produce, as well as cost-effective.

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Q&A

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