ISAP Annual Meeting of Technical Committee on Asphalt Pavements and Environment
January 13th, 2013, Washington DC.

Report on WG Activities -- Pavement LCA

John Harvey, UC Davis
Amlan Mukherjee, Michigan Tech
Hui Li, UC Davis

Outline

- LCA and Construction 2012, Nantes, France July 10-12
- Pavement LCA Work at University of Nottingham
- Pavement LCA Work at VTI/Europe
- Project Emissions Estimator (PE-2) at Michigan Tech
- Cool Pavement Research at UC Davis
- Pavement-Vehicle Interaction Work at MIT
- Pavement LCA Work at UC Davis

LCA and Construction 2012

Nantes, France July 10-12

- International Symposium on Life Cycle Assessment and Construction for civil engineering and buildings
- Organized by IFSTTAR and CSTB
- RILEM Proceedings PRO 86, edited by Anne Venura and Chantal de la Roche
- Several papers specifically on pavement LCA and implementation
- Other papers and discussions without papers covering topics generically, including End Of Life and Recycling Allocations, Feedstock Energy

Summary of LCA and Construction 2012

Notes by T. Parry, J. Harvey

- There is no such thing as a 'right' LCA result. Decisions about allocation, functional unit, etc., are therefore, 'political' decisions and should be made by decision makers, who may decide to 'promote' recycling by reducing the allocated impact to recycled materials, etc. Decision makers don't understand this. We need to suggest the way forward, with justification.
- We need to decide what needs to be reported about methodology along with results of LCA studies. This might be based on EN15804 but requires interpretation for our sector.
- This means we need to get our heads around EPDs (perhaps as defined in ENs). There are EPDs with sector rules for some construction products in some EU countries and we probably need to take a look at them and understand how they work, before developing them for our sector.

- Heavy emphasis on greenhouse gases and energy in pavement LCA, need to not forget other pollutants (air, water) and depletion of finite resources. Original application of LCA was to look at ozone depletion.
- Feedstock energy is a difficult concept. It takes depletion of a finite resource (oil usually) and converts it into energy units, often then mixed up with consumed energy. Suggestion by Santero and Ventura to keep energy separate, consider feedstock in terms of resource depletion, for asphalt often inaccessible once mixed with rock.

Pavement LCA Work
at University of Nottingham

Tony Parry et al.
University of Nottingham

Huang, Spray and Parry, Sensitivity analysis of methodological choices in road pavement LCA, Int J Life Cycle Assess (2013) 18:93–101.

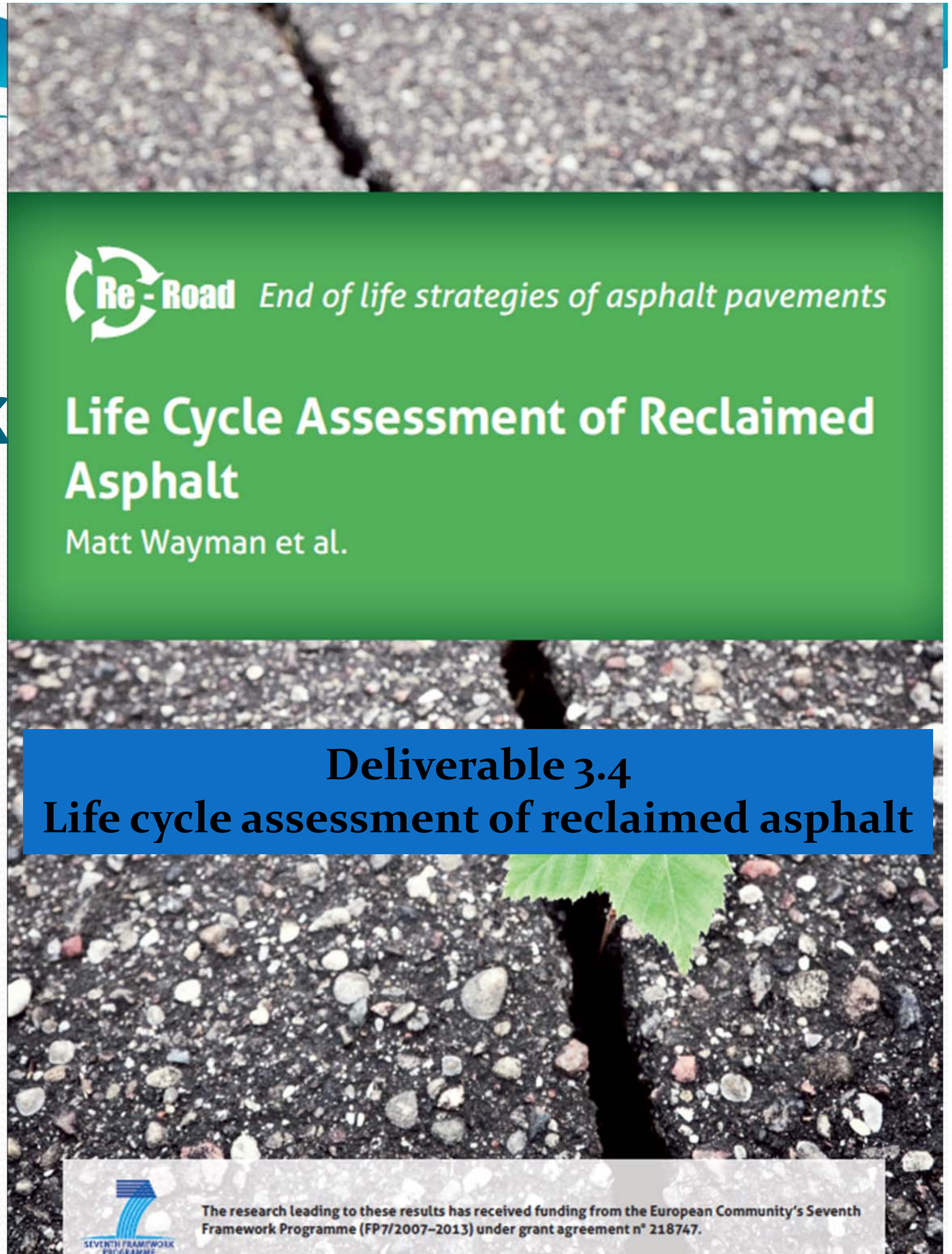
- The Nottingham group investigated
  - Methodological choices (e.g. concerning allocation at EOL recycling and to by/co-products). Can make a significant difference to the results, so need to be standardised in order to have comparable and transparent results.
  - Case studies using different allocation (economic/mass) for blast furnace slag and bitumen. Construction products are generally cheap (e.g. compared to metals and petrochemicals) so economic allocation reduces the allocated impacts compared to mass, but there is a case for zero allocation to 'wastes' to encourage use.
  - A method to credit some EOL recycling benefits to original production may encourage recycling and recyclability but the degree of benefit is probably an arbitrary decision due to uncertainty in future recycling rates and regional variations in future supply and demand.
  - These considerations (along with many others, such as future traffic flow assumptions etc.) may drive allocation decisions in different directions for different circumstances, and so compromise comparability.

Other update from the T. Parry (UK)

The UK Institute of Civil Engineers (ICE) has set up a Low-C Panel, which amongst other things, is going to try to write a 'methodology for methodologies' that might be a first step to resolving problems of comparability.

Pavement LCA Work at VTI/Europe

Matt Wayman et al.
VTI, et al.



Report: http://re-road.fehrl.org/index.php?m=48&mode=download&id_file=14729

Questions on reclaimed asphalt

- What is the additional benefit of recycling surface course back into new surface course?
- How does the toxicity of reclaimed asphalt compare to that of virgin aggregates and bitumen?
- How do the benefits of recycling compare to those of warm mix asphalt?
- By how much does moisture in RA diminish the benefits of recycling?
- How significant is durability in relation to recycled mixtures?

- Used abundant data that had been generated by past research and some of the new data that would be generated in the course of the Re-Road project. The first task in the process was to assimilate all available data into the framework. The data available proved to be quite comprehensive and of high quality, from published, peer reviewed articles and previous FP7 projects. It is therefore hoped that the study will be a useful "one stop shop" for life cycle data going forward.

- The results of the LCA prove that, above all, recycling to a bound course was significantly more environmentally advantageous than recycling to an unbound course. Appreciable extra benefit can be realised if high specification aggregates are preserved in their original application by surface-to-surface course recycling, due to the quarries that produce these specialised aggregates being widely spaced (hence requiring large transport distances for the aggregates). The moisture content that is sometimes present in reclaimed asphalt only mildly counteracts the recycling benefits.

- The results also indicate that low level recycling (just 15% to bound courses) is significantly more environmentally beneficial than warm mixing, particularly if the additives used to facilitate warm mixing are included in the analysis.
- The research also revealed that LCA is perhaps not the best technique to analyse the significance of the toxic effects of organic compounds that experiments have shown to be present in the leachates and vapours arising from the use of reclaimed asphalt materials. The risk assessment that has also been conducted as part of Re-Road (Deliverable 3.3) is likely to be the best source of information regarding these potential toxic or harmful compounds.
- The study has produced a useful framework of reliable results; however, in terms of future enhancement, more information regarding the durability of different types of asphalt mixtures, including those incorporating reclaimed asphalt, would be extremely useful. As is the case with many life cycle based studies of construction products, any further certainty with regards to the likely lifespans of materials would be extremely useful, since the rate of replacement of materials can be very significant in environmental terms.

PE-2 to Estimate Emissions Savings

-Application for Michigan Ave. Reconstruction

Amlan Mukherjee

Michigan Tech

Project Emissions Estimator (PE-2)

- Web Based Construction Project Inventory
  - Based on 14 highway construction, maintenance & rehab projects that were closely monitored
  - Resources: All materials & equipment used on site
  - Site Information: Layout, operation design
  - Travel Distances: On site and to site travel distances
- Provides: Project emissions calculated using a Life Cycle Assessment method:
  - Footprint in carbon emission equivalents "to gate"
  - Example: The Michigan Ave. Reconstruction Project

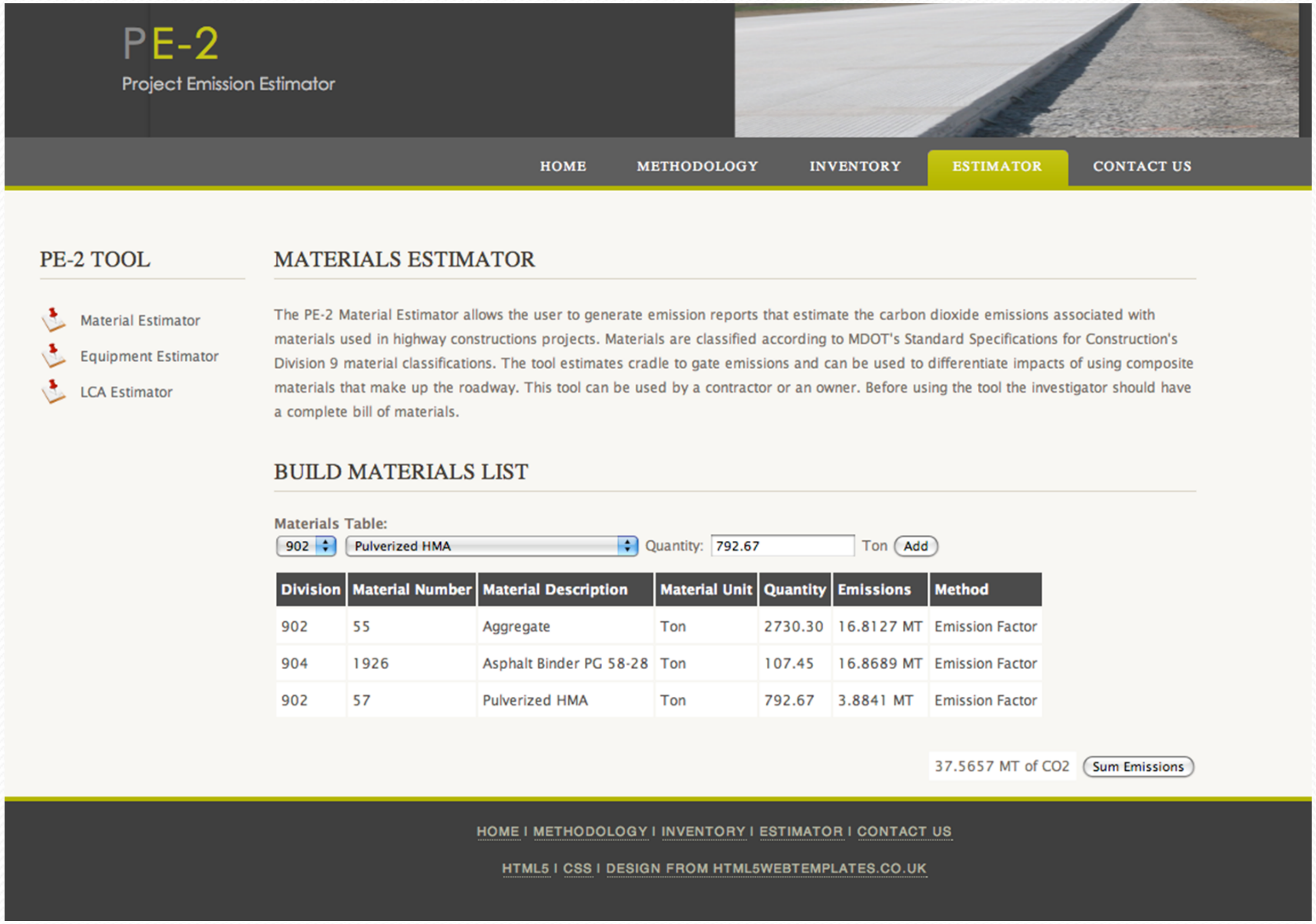
PE-2 Estimator Tool

- An online tool to estimate highway project emissions:
  - Empirical estimates based on project inventory
  - Use phase included: MOVES emission estimator used
- Properties:
  - Users can load:
    - Material & equipment use estimates using online estimate tool
    - Expected pavement maintenance schedule
  - Returns annualized emissions over the expected pavement life
  - Can be used as a project level & network level emission estimator

Michigan Ave. Profile

- Aggregate profile
  - Total weight used: 3522.97 t (Virgin = 2730.30 t)
  - Recycled aggregate: RAP (15%) + RAS (7.5%) = 792.67 t
- Asphalt binder profile
  - Total weight used: 176.15 t (Virgin = 107.45 t)
  - Recycled aggregate: RAP (~4%) & RAS (~18%) = 68.70 t

Estimator at work



PE-2
Project Emission Estimator

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PE-2 TOOL

- Material Estimator
- Equipment Estimator
- LCA Estimator

MATERIALS ESTIMATOR

The PE-2 Material Estimator allows the user to generate emission reports that estimate the carbon dioxide emissions associated with materials used in highway constructions projects. Materials are classified according to MDOT's Standard Specifications for Construction's Division 9 material classifications. The tool estimates cradle to gate emissions and can be used to differentiate impacts of using composite materials that make up the roadway. This tool can be used by a contractor or an owner. Before using the tool the investigator should have a complete bill of materials.

BUILD MATERIALS LIST

Materials Table:
902 | Pulverized HMA | Quantity: 792.67 Ton | Add

Division	Material Number	Material Description	Material Unit	Quantity	Emissions	Method
902	55	Aggregate	Ton	2730.30	16.8127 MT	Emission Factor
904	1926	Asphalt Binder PG 58-28	Ton	107.45	16.8689 MT	Emission Factor
902	57	Pulverized HMA	Ton	792.67	3.8841 MT	Emission Factor

37.5657 MT of CO2 | Sum Emissions

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HTML5 I CSS I DESIGN FROM HTML5WEBTEMPLATES.CO.UK

Materials: Example Input

- 1000 CY of concrete:
  - Cement: 179 t (395 lb/cy)
  - Class C Fly Ash (30% by wt): 76 t (170 lb/cy)
  - Coarse Aggregate: 823 t
  - Fine Aggregate: 569 t

Materials Estimator

PE-2
Project Emission Estimator

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PE-2 TOOL

- Material Estimator
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BUILD MATERIALS LIST

Materials Table:
902 | Granular Material (Ton) | Quantity: 569 Ton | Add

Division	Material Number	Material Description	Material Unit	Quantity	Emissions	Method
901	4525	Portland Cement Type I	Ton	179	150.539 MT	Emission Factor
901	1727	Fly Ash	Ton	76	1.3513 MT	Emission Factor
902	55	Aggregate 21A	Ton	823	5.0679 MT	Emission Factor
902	1726	Granular Material (Ton)	Ton	569	0.0380 MT	Emission Factor

156.9962 MT of CO2 | Sum Emissions

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Example Input

- Roadtec Pavers: 40.5 hrs
- Roadtec MTV: 33.5 hrs
- Hypac Compactor: 39.5 hrs
- Dynapac Steel drum roller: 76.5 hrs

Equipment Estimator

PE-2
Project Emission Estimator

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PE-2 TOOL

- Material Estimator
- Equipment Estimator
- LCA Estimator

BUILD EQUIPMENT LIST

The PE-2 Equipment Emission Estimator allows the user to generate emission reports based on the amount and durations of equipment being used on site. Emission metrics are derived from fuel consumption. On-Site equipment is classified into 33 generalized equipment categories. The generated reports outline emissions and fuel used per working day of the contract per equipment category.

32 – Rollers | Steel Drum Roller | Number Used: 1 | Hours: 76.5 | Add

Division	Fuel Rate	Equipment Description	Number Used	Hours	Emissions	Gallons Used
27	2.0706	8' Paver	1	40.5	0.8593 MT	83.8605
26	3.7516	Roadtec Mat'l X-fer Machine	1	33.5	1.2878 MT	125.6796
29	0.1146	Compactor	1	39.5	0.0464 MT	4.5275
32	1.7801	Steel Drum Roller	1	76.5	1.3954 MT	136.1746

3.5889 MT of CO2 Sum Emissions

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Savings

- Total emissions: 37.57 t of CO_2 Equivalents
- Savings
  - 24% Savings in emissions due to use of RAP & RAS:
    - 5% savings due to use of recycled aggregate
    - 39% savings due to recycled binder
  - Total tonnage of material saved from landfill: 792.67 tons

Cool Pavement Research

John Harvey & Hui Li
UC Davis

UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH
Davis • Berkeley | CENTER

ITS UCDAVIS
INSTITUTE OF TRANSPORTATION STUDIES

Research Report – UCD-ITS-RR-12-33

Evaluation of Cool Pavement Strategies for Heat Island Mitigation

December 2012

Hui Li

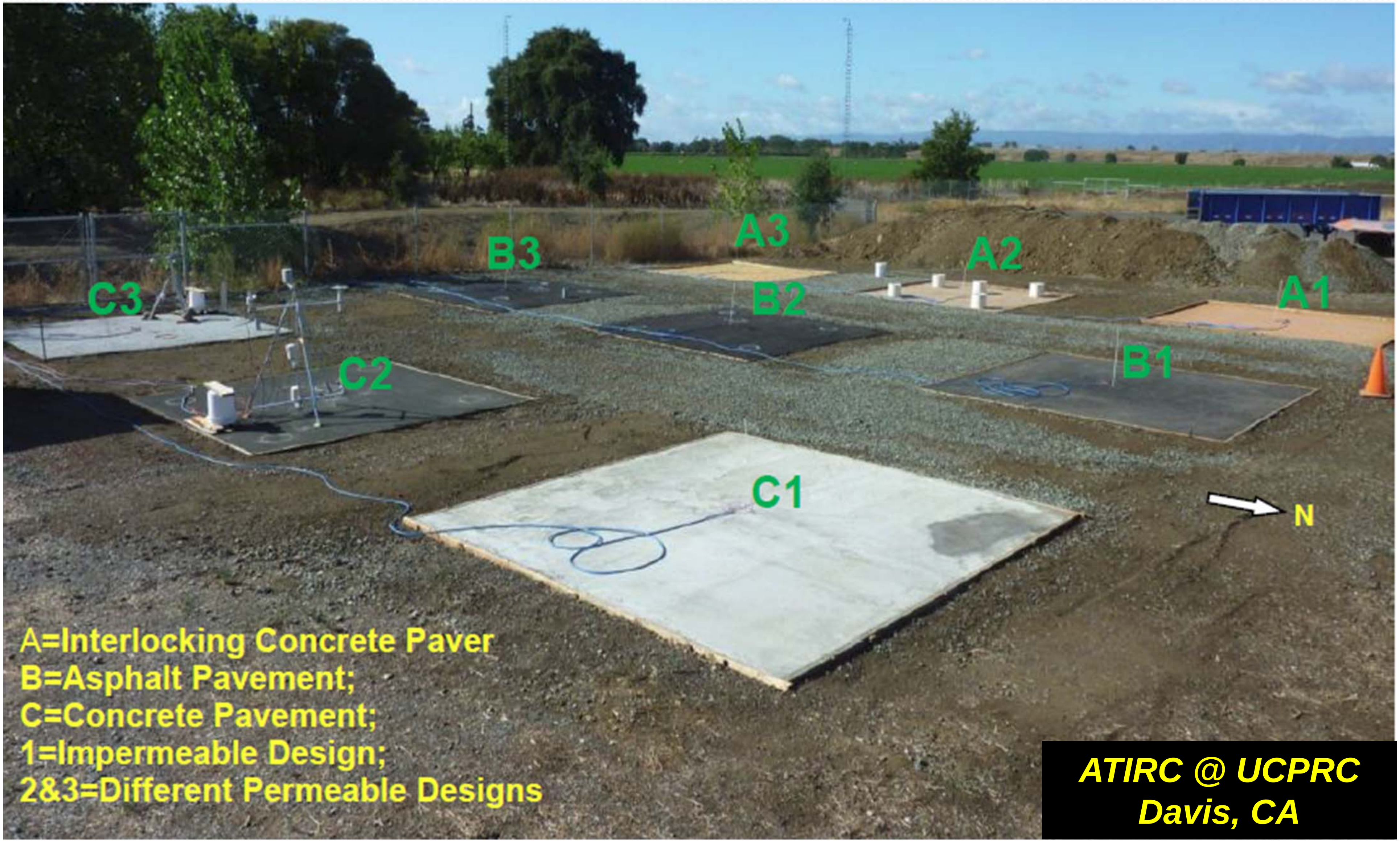
Institute of Transportation Studies • University of California, Davis
One Shields Avenue • Davis, California 95616
PHONE (530) 752-6548 • FAX (530) 752-6572
www.its.ucdavis.edu

Potential Benefits from Cool (& Permeable) Pavement

- Help create a livable and walkable community in hot summer (*mitigated local heat stress*)*
- Reduce energy use for building and vehicle cooling*
- Improve air quality (ground-level ozone)
- Reduce stormwater runoff
- Improve water quality
- Recharge groundwater

Dependent on location and application!

Test Sections for Cool Pavement Research



Field Measurements

1. Permeability, Thermal conductivity & Heat Capacity, Evaporation Rate
2. Albedo (surface reflectivity) & effect on pavement thermal performance
3. Thermal behavior of different pavement types under different conditions on test sections
   1) asphalt, concrete vs. paver
   2) permeable vs. impermeable
   3) dry vs. wet (irrigation)
4. Thermal impact of pavement on near-surface air
5. Thermal interaction between pavement and other surface

Modeling & Simulation

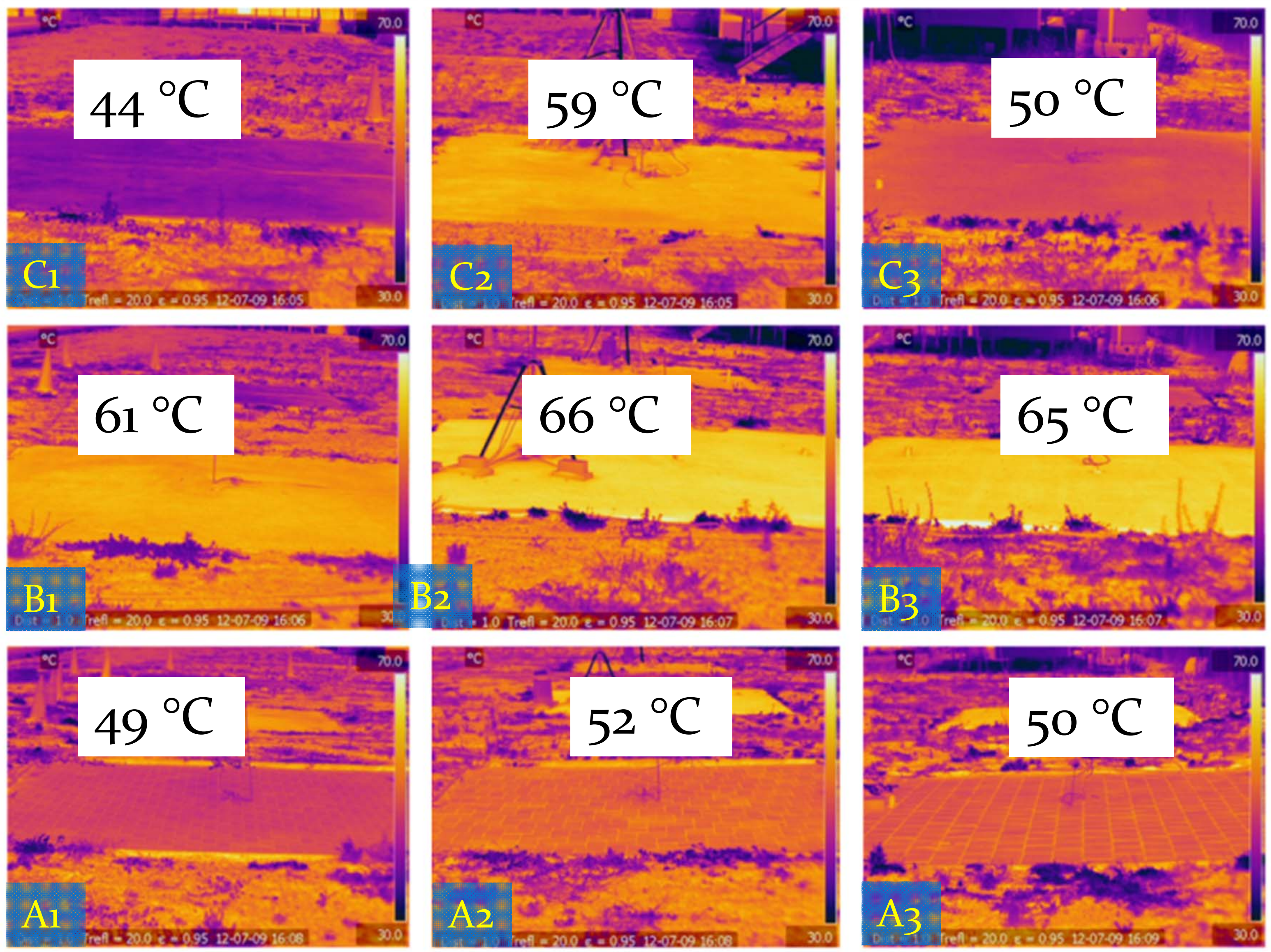
- Thermal behavior of pavement and near-surface air
  - Different cool pavement strategies
  - Different seasons
  - Different climates
- Effect on human thermal comfort
  - Integrate pavement, wall, sky-view and human body
  - Advanced thermal comfort index
    - Physiological Equivalent Temperature (PET)
    - Characterize both temperature and radiation
- Effect on building energy use (preliminary)
  - Thermal load

Thermal Images (Dry): 4pm 7/9/2012

C: Concrete

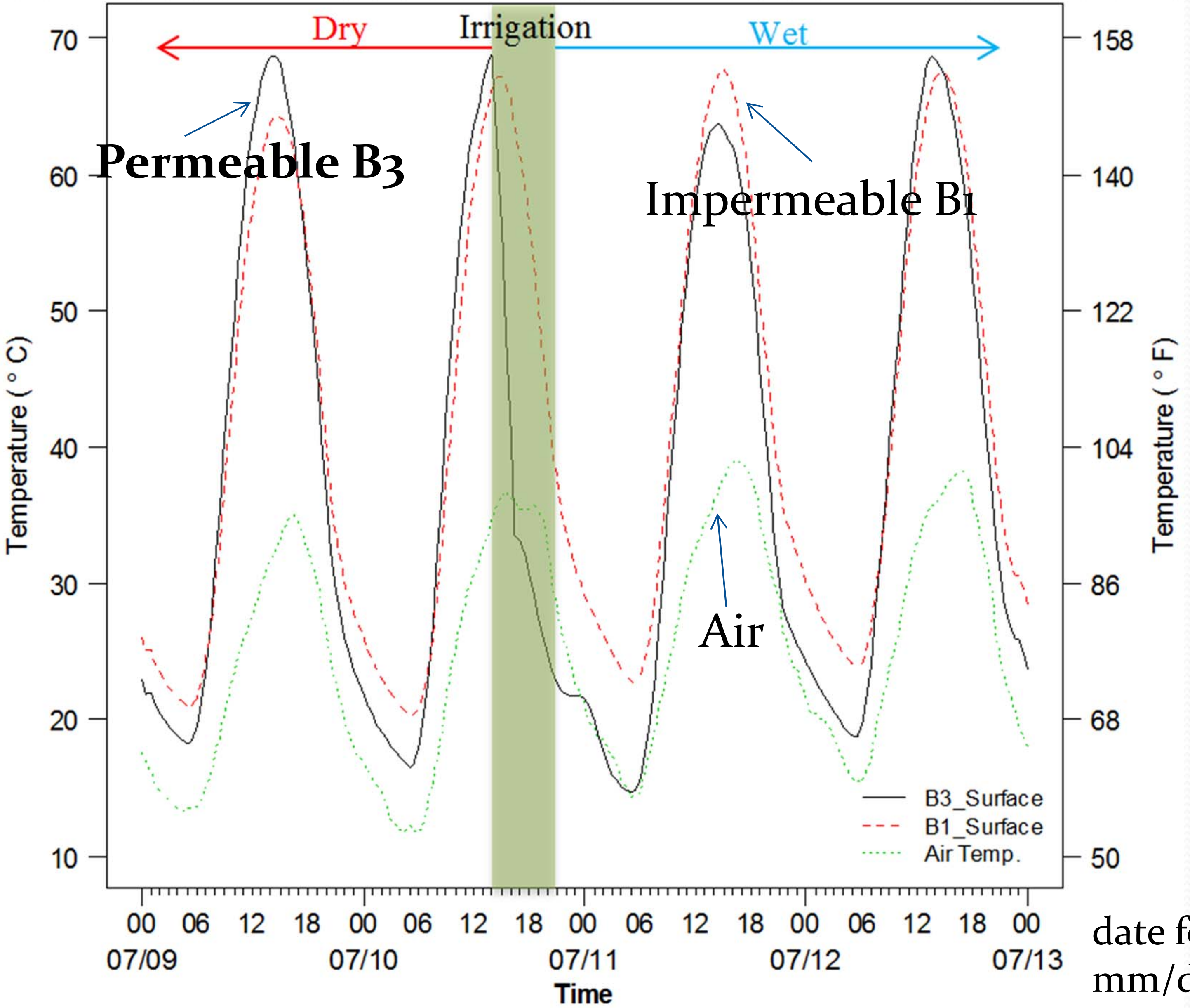
B: Asphalt

A: Paver



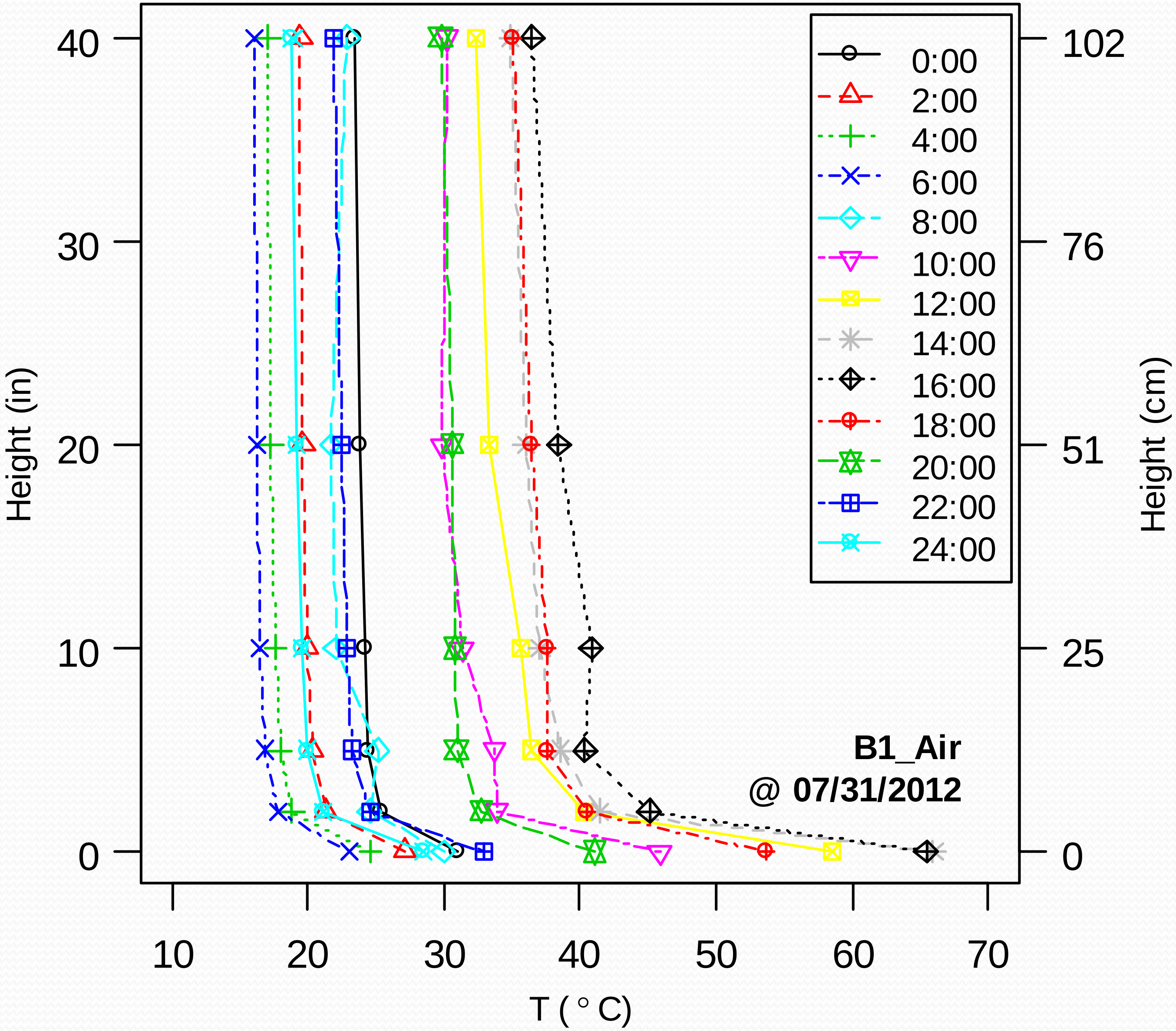
Lighter is hotter: legend range of 30 to 70 °C

Thermal performance of permeable pavement under dry & wet conditions (e.g. B3).

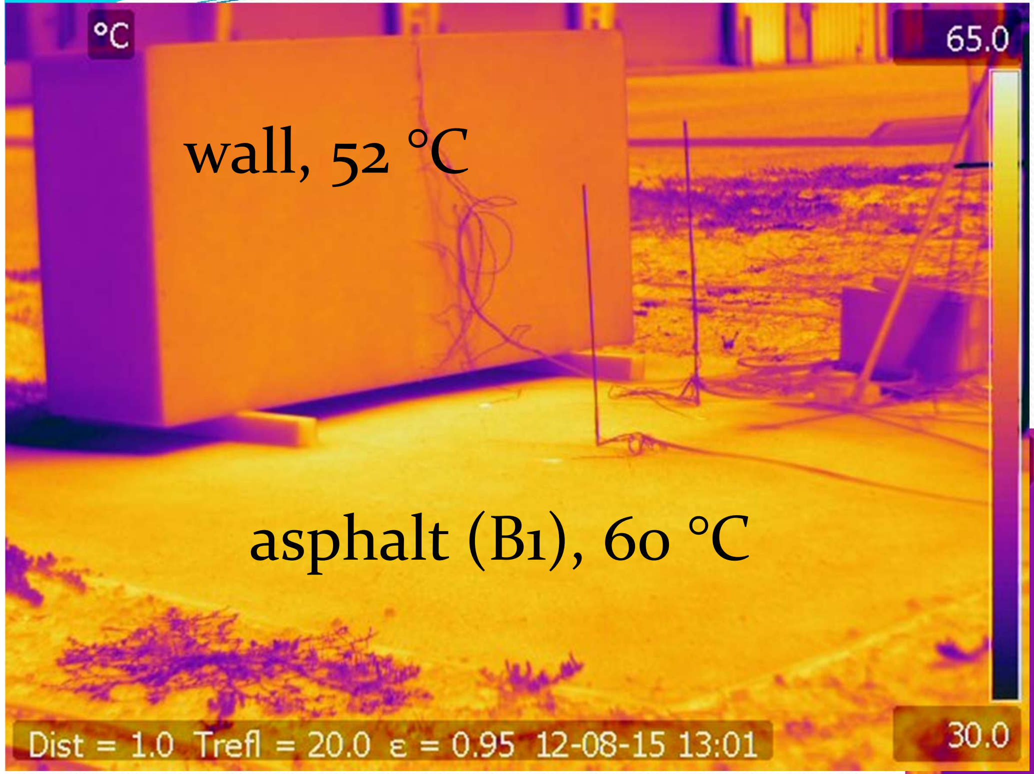


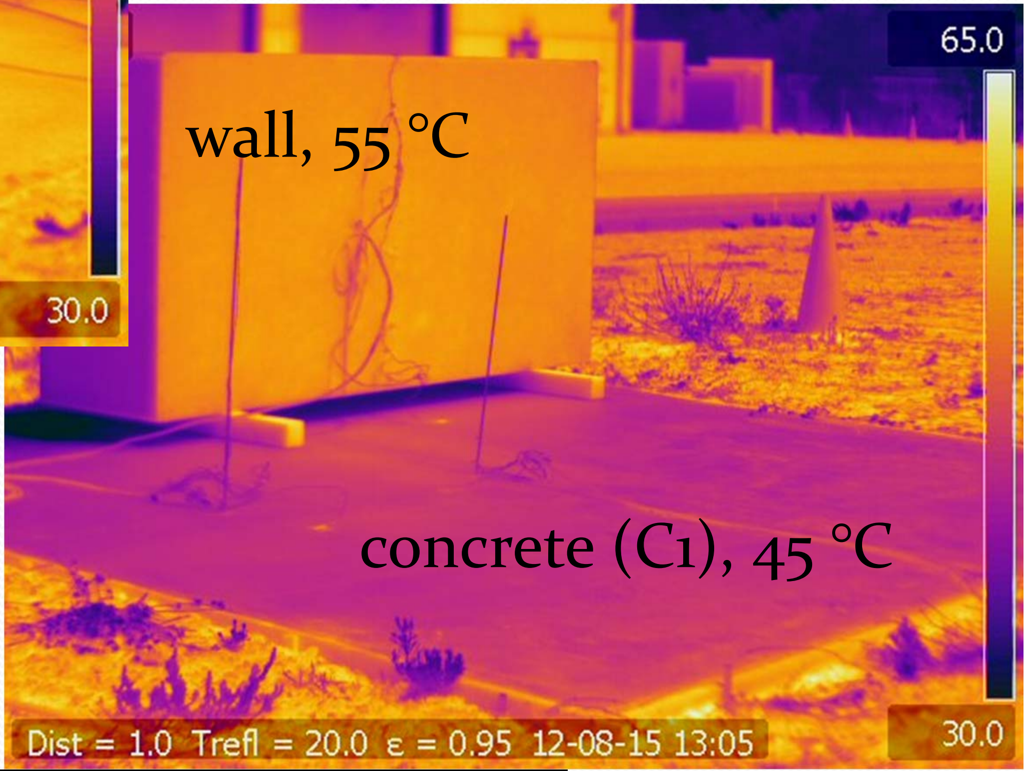
date format: mm/dd)

Impact on near-surface air temperature (example: B1 on Jul/31/12)



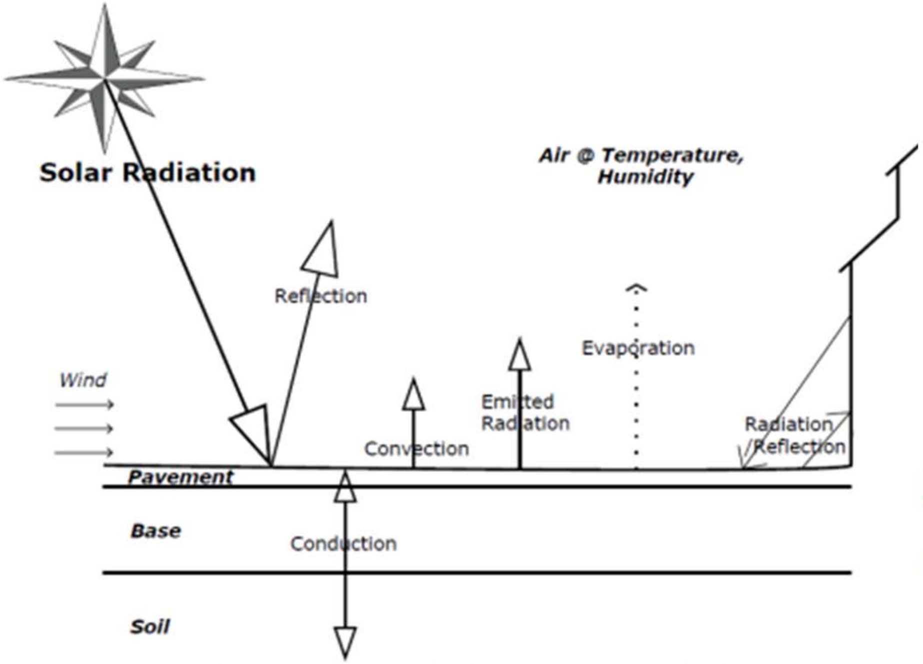
Impact on Vertical Surface (13:00 8/15/2012)

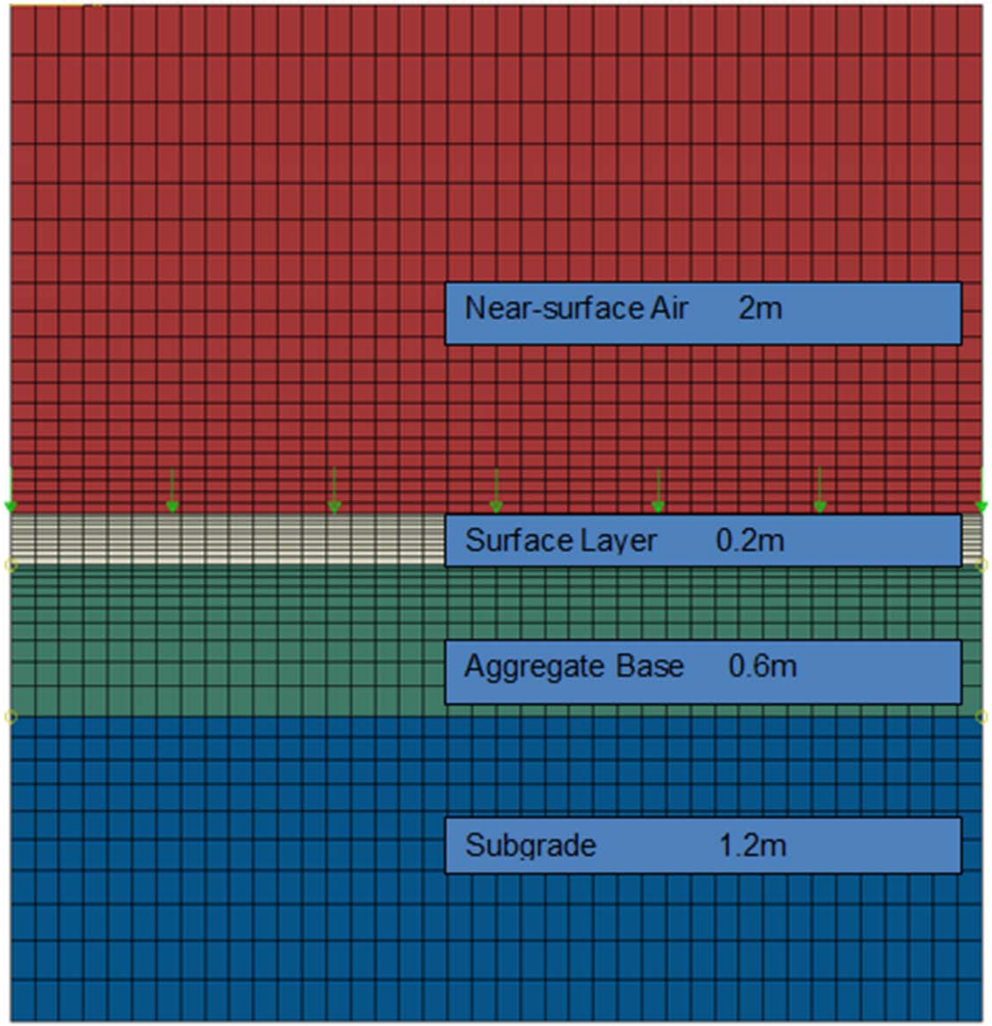




Lighter is hotter: legend range of 30 to 65 °C

Modeling for Thermal Behavior



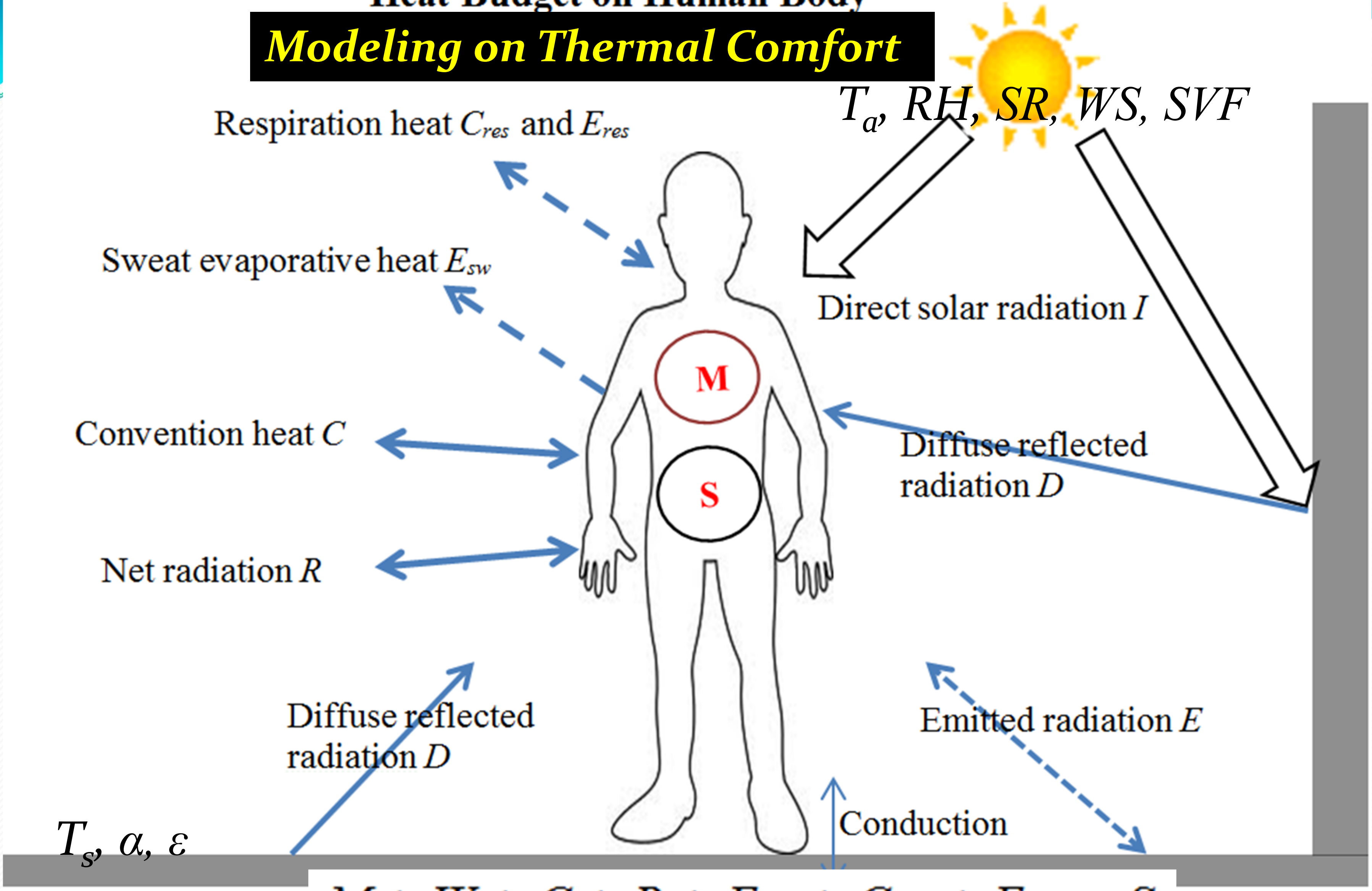


The model considers :

- Energy balance on the pavement surface;
- Coupled processes of radiation, conduction, convection, shading and evaporation;.

Heat Budget on Human Body

Modeling on Thermal Comfort



$$M + W + C + R + E_{sw} + C_{res} + E_{res} = S$$

M is the metabolic rate (W/m²). *W* is the rate of mechanical work (W/m²). *S* (W/m²) is the total storage heat flow in the body.

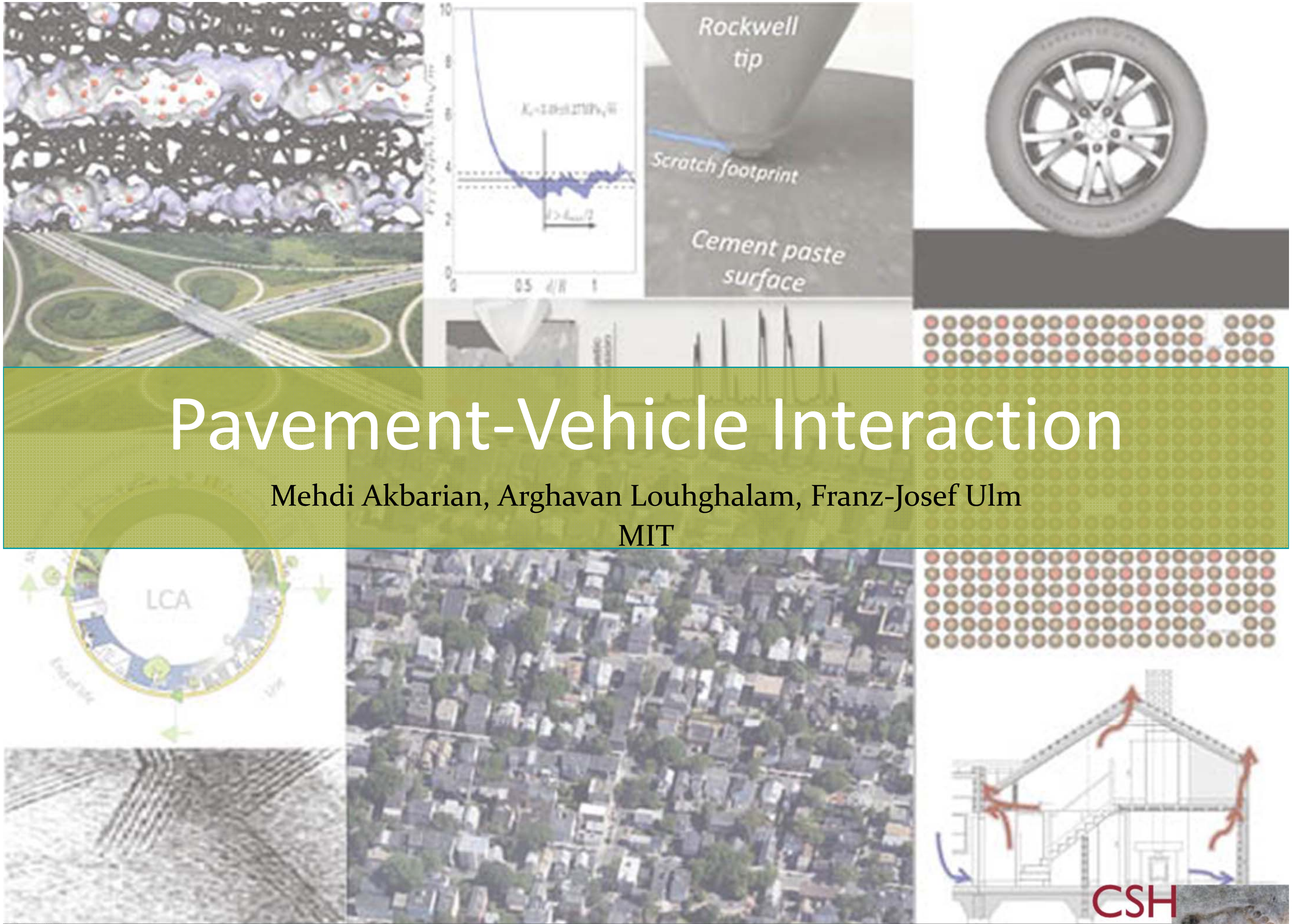
Next Steps for Cool Pavement Research

- California Air Resources Board study (LBNL, UCPRC) to evaluate urban area heat island for matrix of California cities/regions
  - Starts April 2013, two year project
  - Focus on greenhouse gas. Includes LCA to consider materials production and construction impacts as well as savings from air conditioner use.
- Other ideas for improving and validating models
  - No funding yet!

Report/Dissertation:
Li, Hui (2012) Evaluation of Cool Pavement Strategies for Heat Island Mitigation. ITS-UC Davis, Research Report UCD-ITS-RR-12-33, http://www.its.ucdavis.edu/?page_id=10063&pub_id=1803

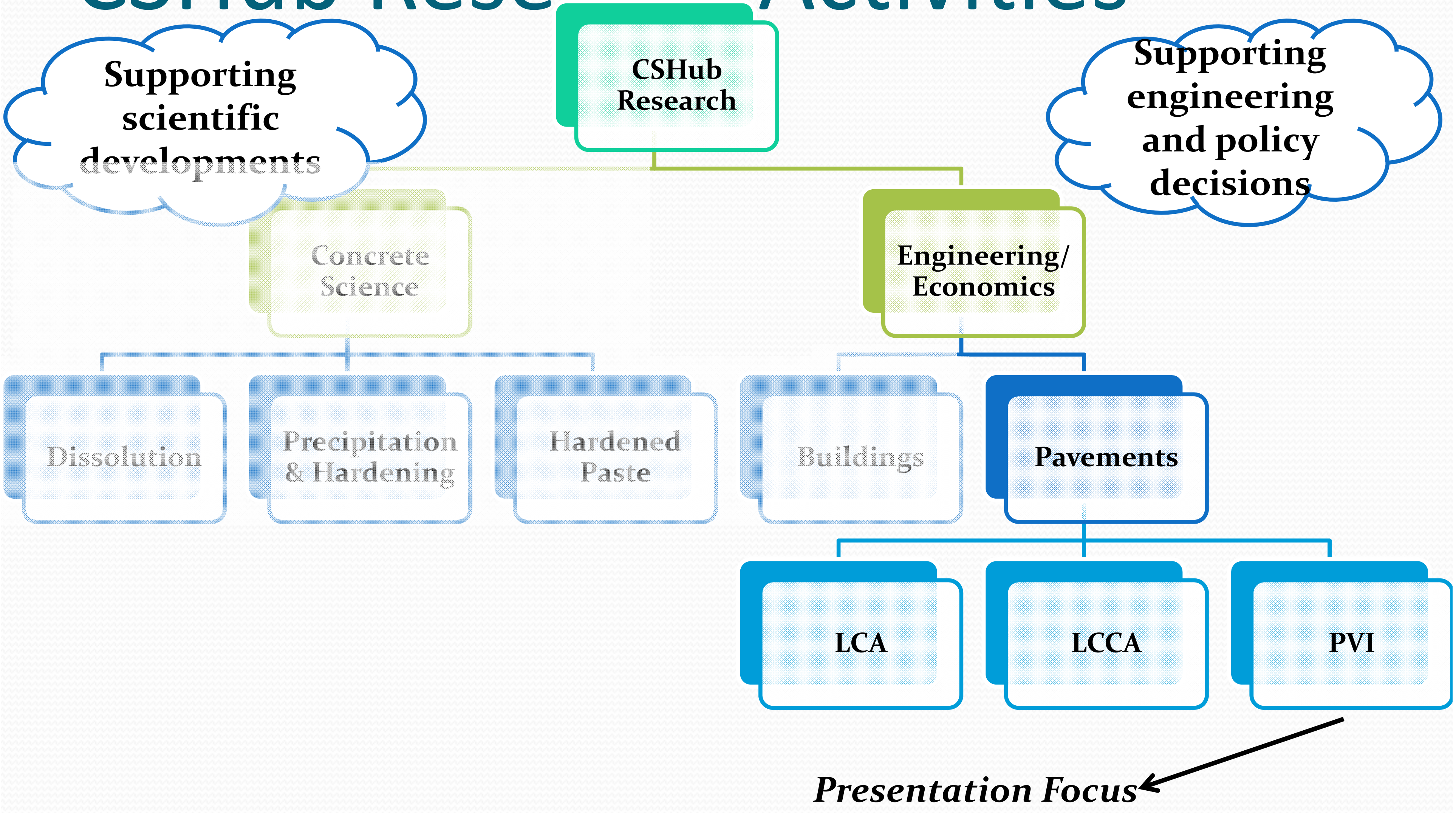
Pavement-Vehicle Interaction

Mehdi Akbarian, Arghavan Louhghalam, Franz-Josef Ulm
MIT

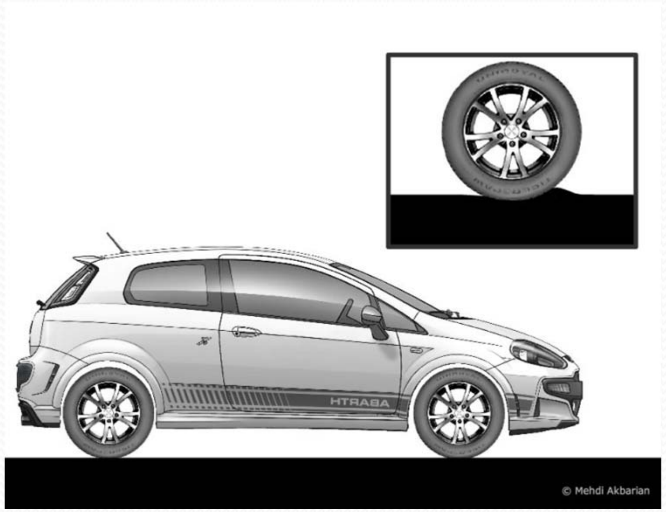


CSH concrete sustainability hub

CSHub Research Activities



Model-Based Assessment of Pavement Vehicle Interaction (PVI)



Pavement Deflection

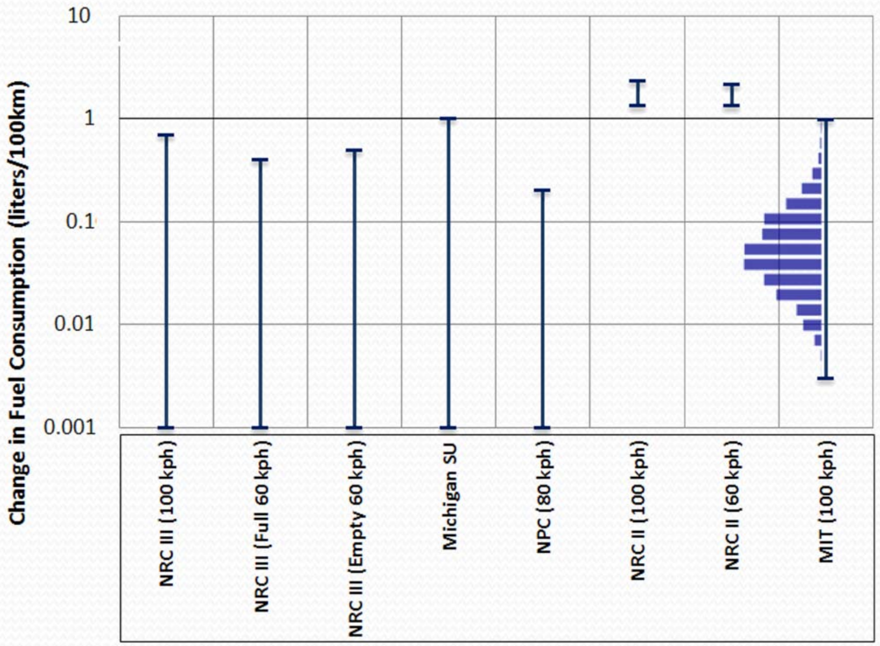
Pavement Roughness

US Network Deflection Induced Fuel Consumption

Sample output:

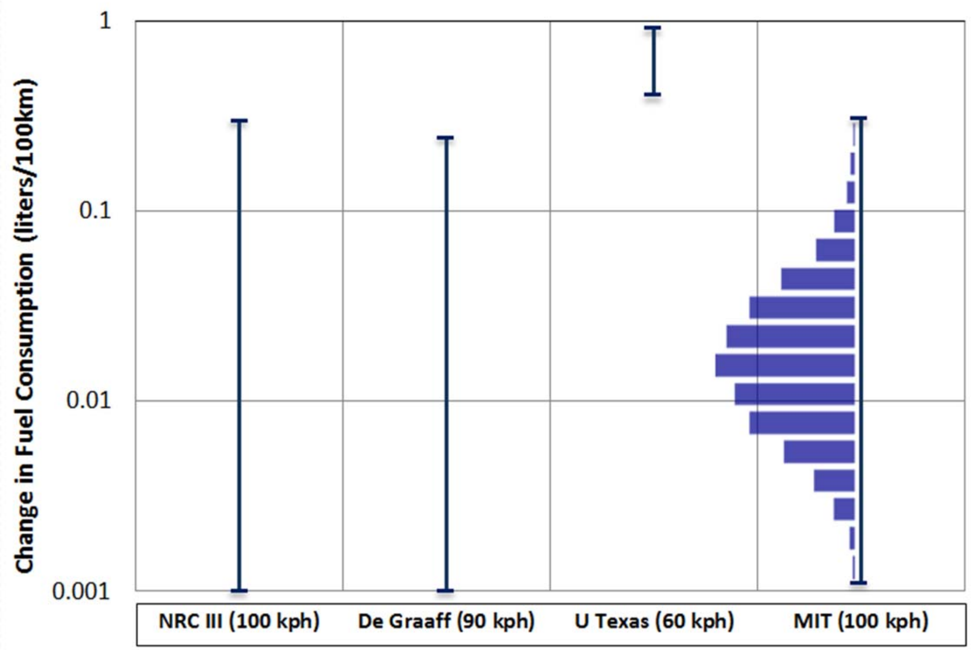
Comparison of modeled fuel consumption on asphalt vs. concrete pavements to prior empirical studies.

Trucks:



Logarithmic

Cars:

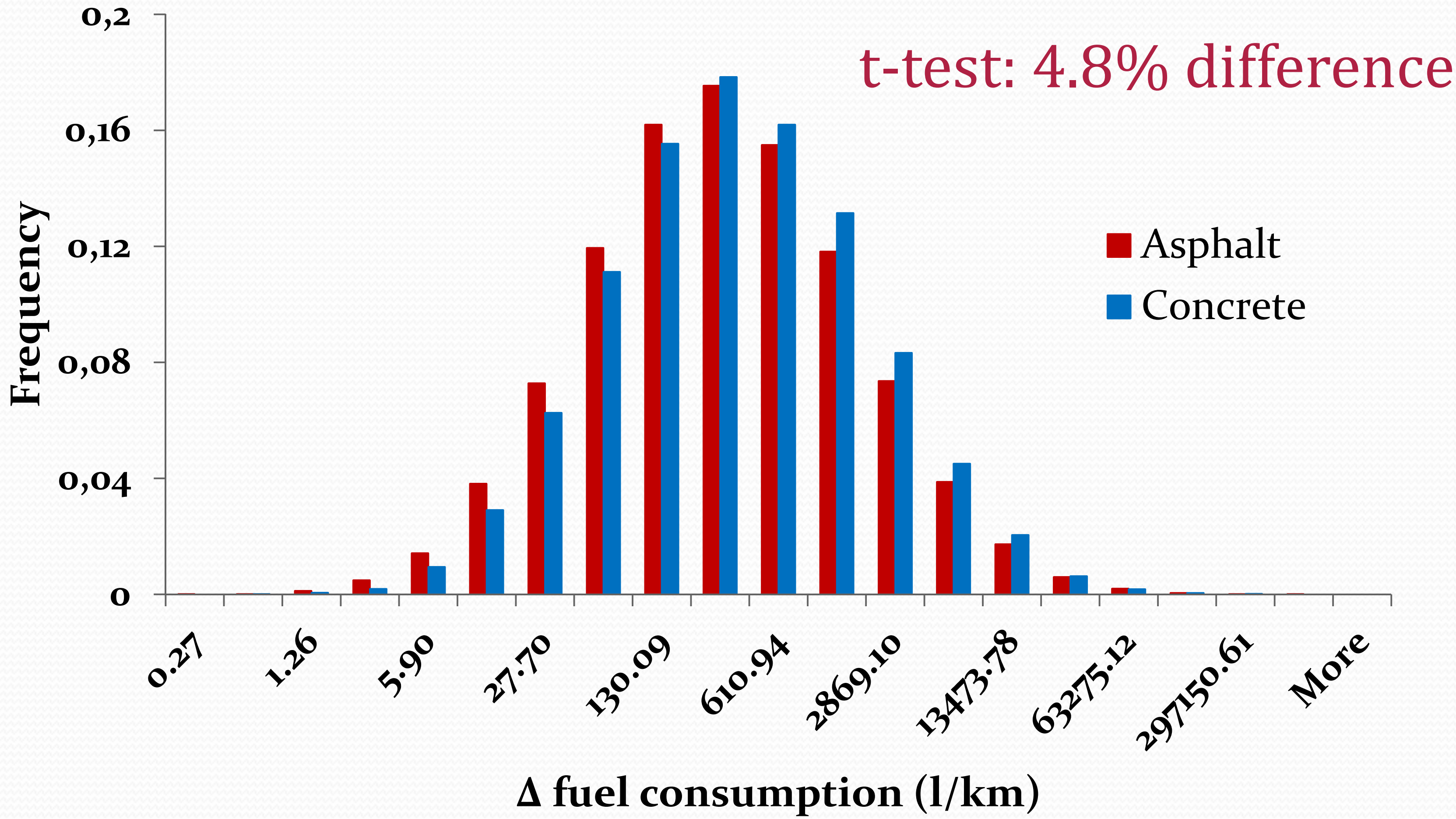


Logarithmic

Report:

*Akbarian M., Ulm J-F. 2012. Model Based Pavement-Vehicle Interaction Simulation for Life Cycle Assessment of Pavements. Concrete Sustainability Hub. MIT

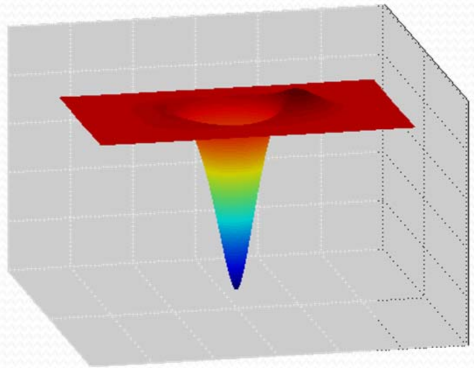
US Network Roughness Induced Fuel Consumption



The difference is statistically insignificant

In Progress:

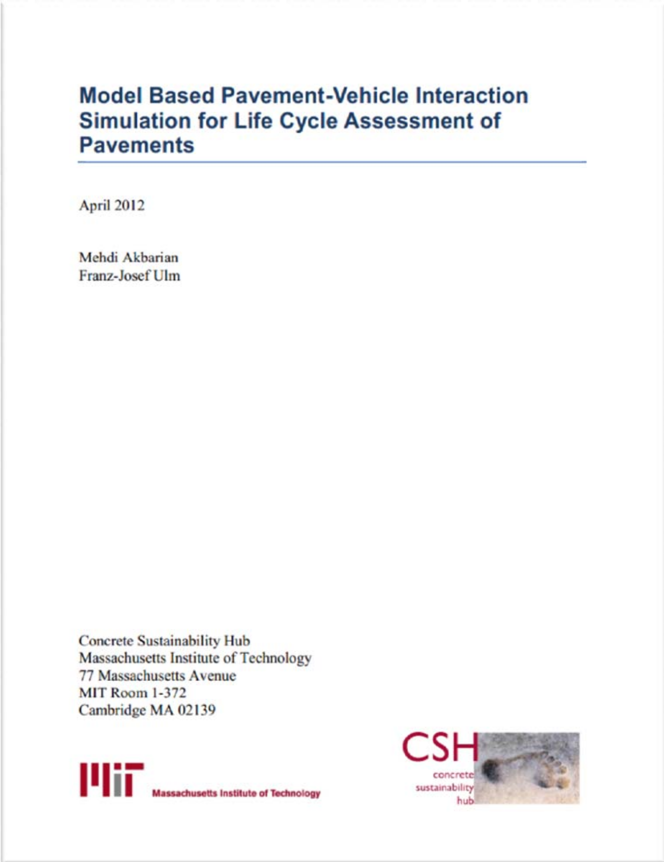
1. Plate on Viscoelastic Foundation
   - Calibrate, Validate
   - Scale gradient forces to F.C.
   - LTPP/State data



2. Viscoelasticity
   - Velocity and temp dependent
   - Impact on deflection
   - Viscous energy dissipation

3. Multilayer pavement
   - Composite pavement response for **bound** and **unbound** layers

More: web.mit.edu/cshub


Model Based Pavement-Vehicle Interaction Simulation for Life Cycle Assessment of Pavements

April 2012

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Franz-Josef Ulm

Concrete Sustainability Hub
Massachusetts Institute of Technology
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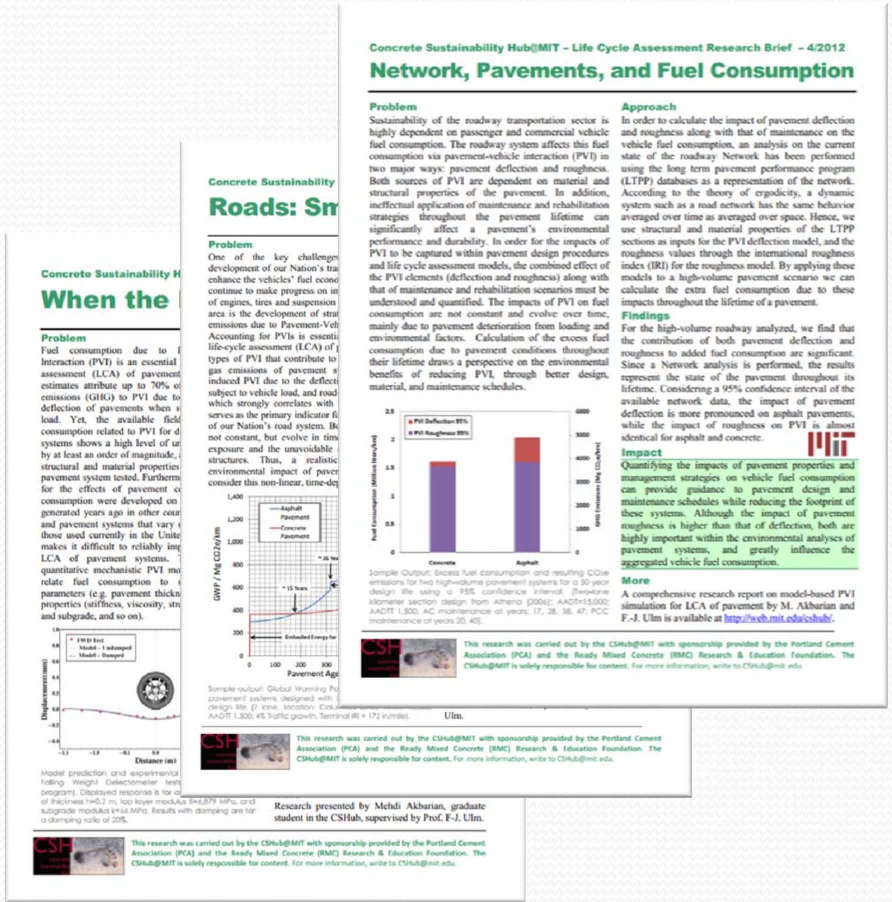
Massachusetts Institute of Technology

CSH concrete sustainability hub

Report



Briefs

Pavement LCA work at UCPRC

J. Harvey, A. Kendall, T. Wang, I.S. Lee, E. Coleri
UC Davis

UCPRC
UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH
Davis • Berkeley | CENTER

Updating and implementing LCA model

- Updates to model in progress (done by summer 2013)
  - Expand list of maintenance and rehabilitation treatments
  - Consideration of construction work zone traffic delay
  - Implement model for energy dissipation due to viscoelastic asphaltic layers
  - Investigation of effects of smoother pavement on vehicle operating speeds (California freeways)
- Implementation
  - Initial GHG calculator considering materials production, construction and use phase due to IRI implemented in new Caltrans PMS
  - Calculating $/ton CO_2e from M&R treatments for network, sensitivity to IRI treatment level

GHG and energy consumption due to deflection

- Three sources of energy consumption in Use Phase:
  - Roughness (IRI) through suspension
  - Macrotexture through tires (minor compared to roughness)
  - Deflection
- Approaches to energy consumption due to deflection
  - MIT: viscoelastic effects in subgrade (surface modeled as elastic) result in wheel running up hill at small angles. Energy consumption due to angle, no dissipated energy in pavement.
  - UCPRC: implementing di Benedetto's viscoelastic asphalt model to estimate energy dissipation in asphaltic materials under different loads, speeds and temperatures; different asphalt materials (rubberized, polymer, conventional); different structures (flexible, semi-rigid, composite).