

*ISAP Annual Meeting of Technical Committee on Asphalt Pavements and Environment*  
January 13<sup>th</sup>, 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.



*End of life strategies of asphalt pavements*

## Life Cycle Assessment of Reclaimed Asphalt

Matt Wayman et al.

**Deliverable 3.4**  
**Life cycle assessment of reclaimed asphalt**



The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement n° 218747.

Report: [http://re-road.fehrl.org/index.php?m=48&mode=download&id\\_file=14729](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  Quantity:  Ton

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

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# 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](#)
-  [Equipment Estimator](#)
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## BUILD MATERIALS LIST

Materials Table:

902  Quantity:  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  Number Used:  Hours:

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

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# Savings

- Total emissions: 37.57 t of CO<sub>2</sub> 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

Evaluation of Cool Pavement Strategies for  
Heat Island Mitigation

December 2012

Hui Li

# Potential Benefits

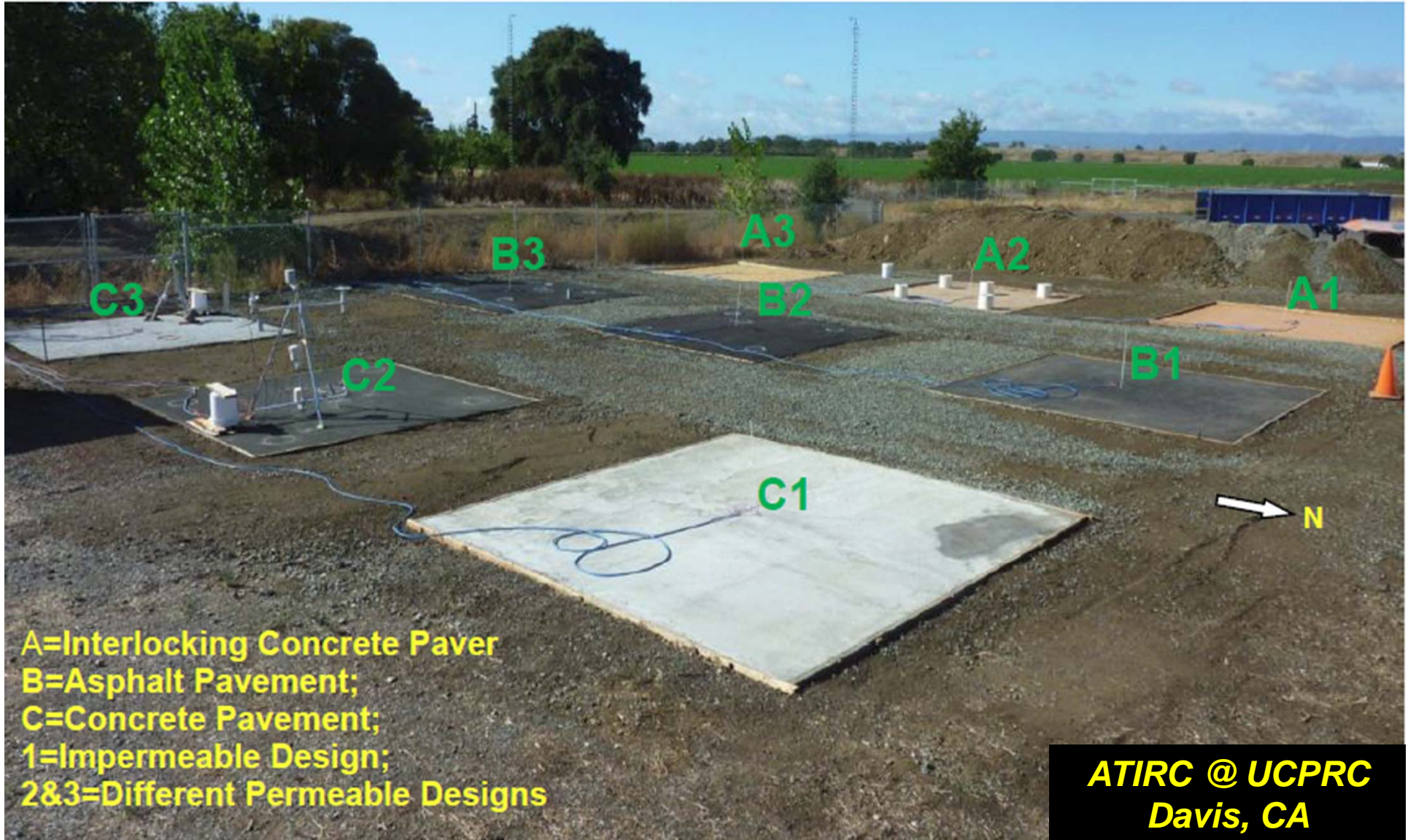
## from Cool (& Permeable) Pavement

- 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



**A=Interlocking Concrete Paver**  
**B=Asphalt Pavement;**  
**C=Concrete Pavement;**  
**1=Impermeable Design;**  
**2&3=Different Permeable Designs**

**ATIRC @ UCPRC**  
**Davis, CA**

# Field Measurements

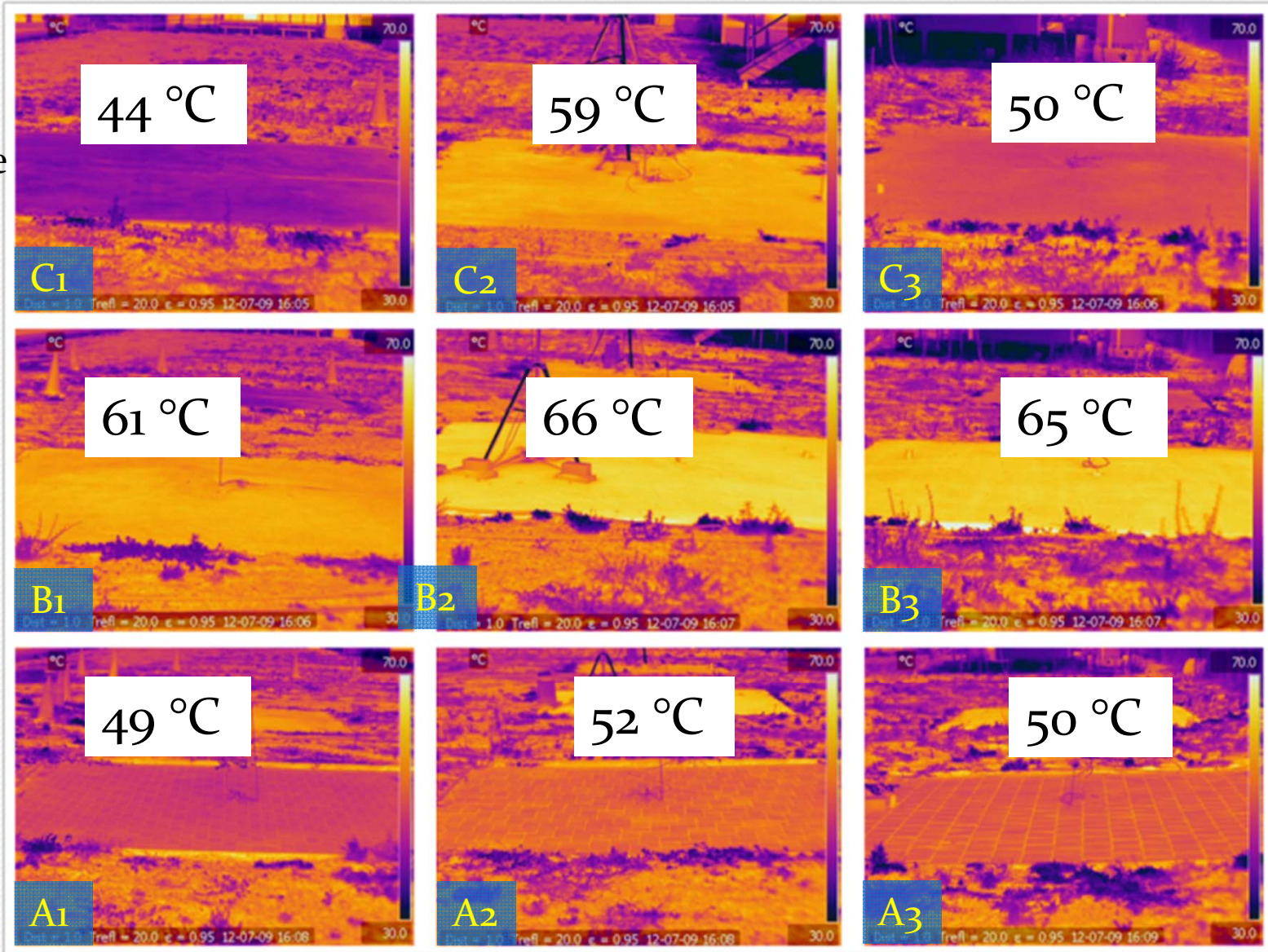
1. Permeability, Thermal conductivity & Heat Capacity, Evaporation Rate
2. Albedo (surface reflectivity) & effect on pavement thermal performance
3. Thermal behavior of different pavement types under different conditions on test sections
  - 1) asphalt, concrete vs. paver
  - 2) permeable vs. impermeable
  - 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

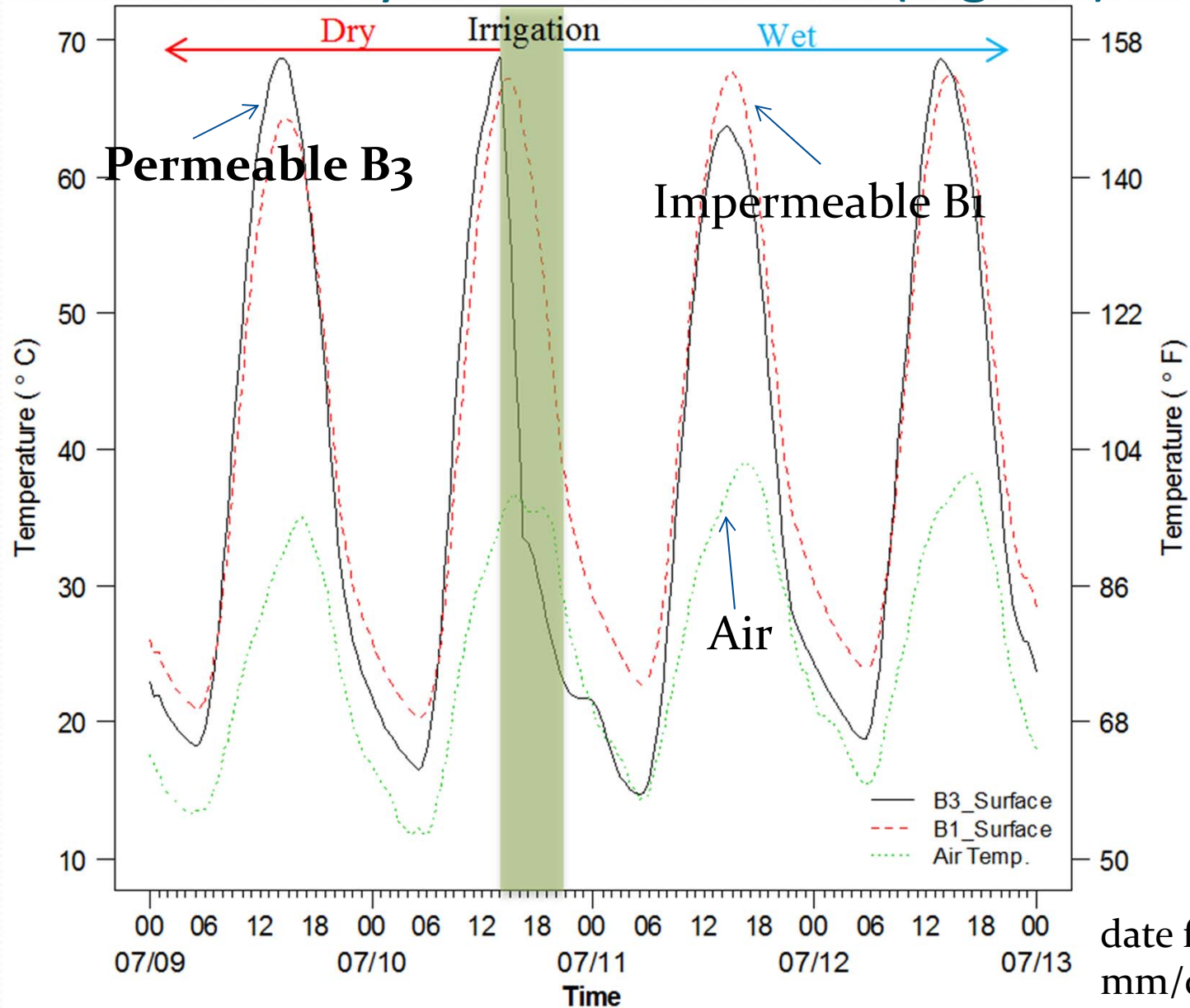


B: Asphalt

A: Paver

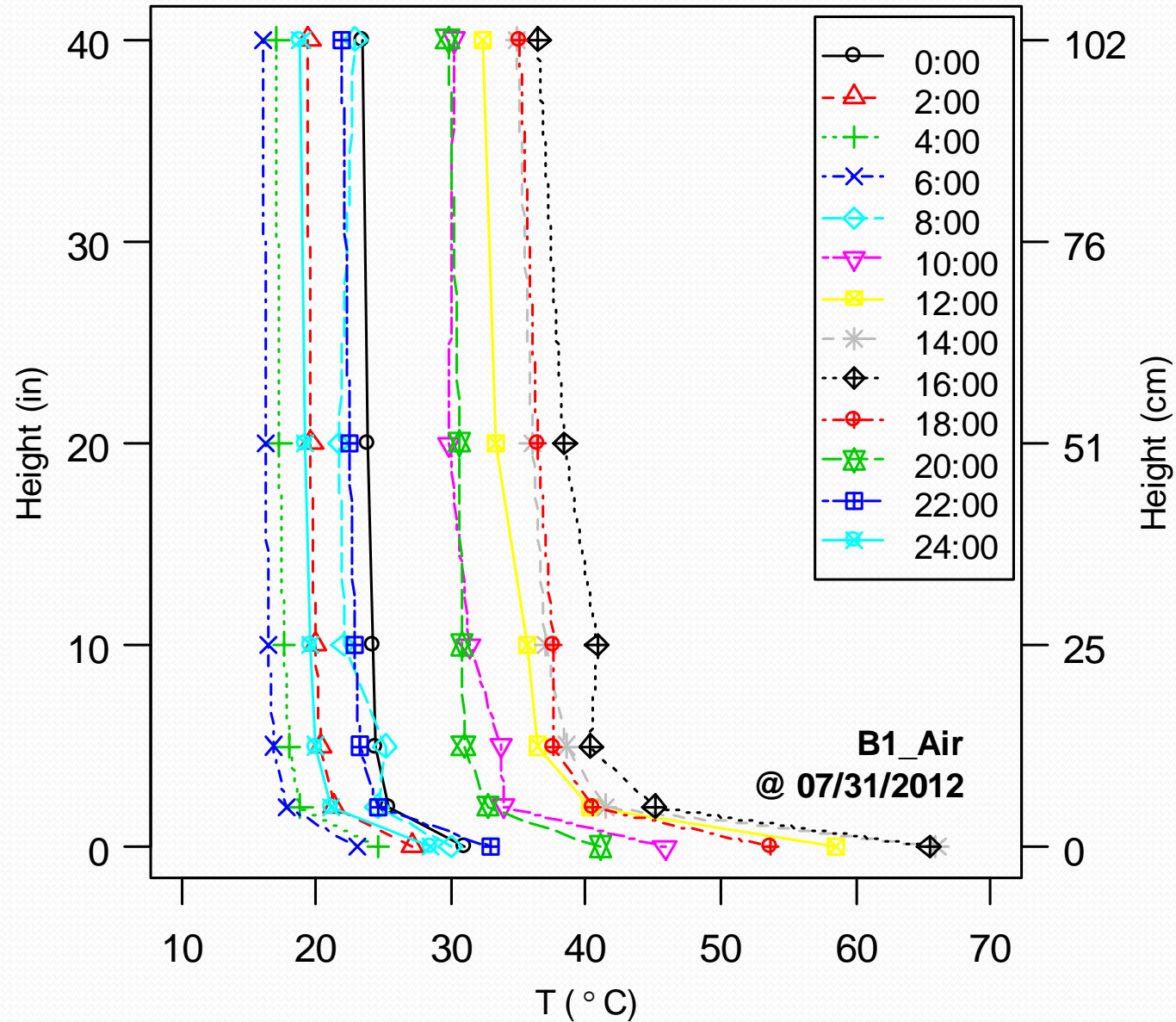
**Lighter is hotter: legend range of 30 to 70 °C**

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

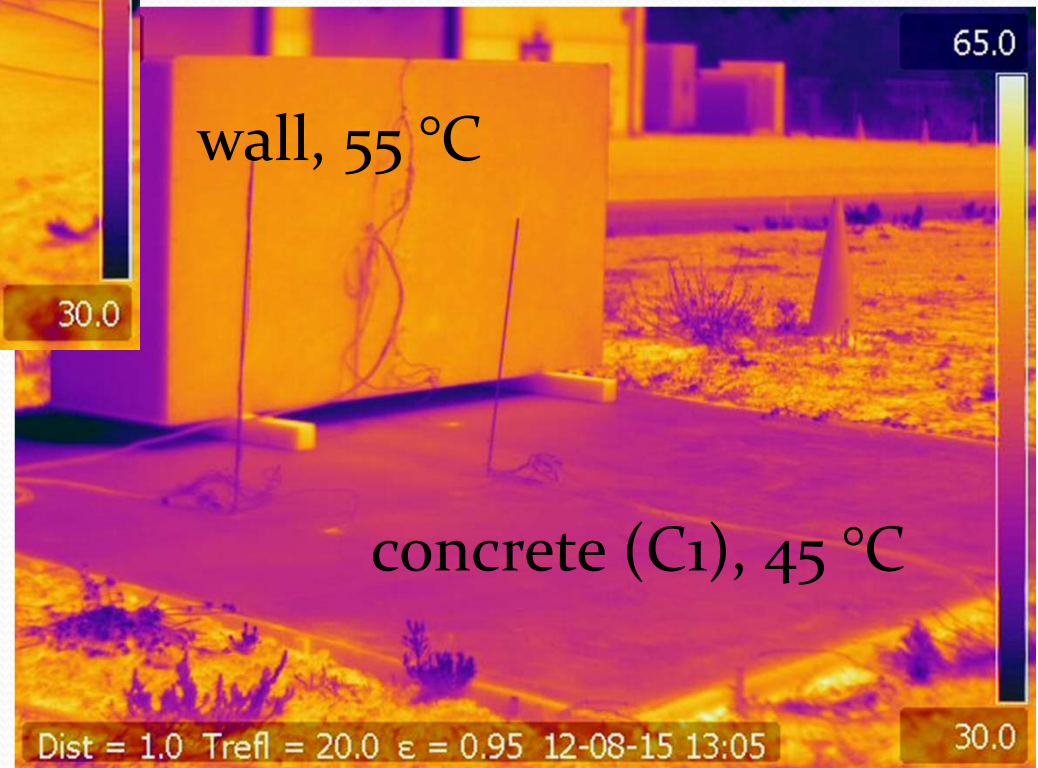
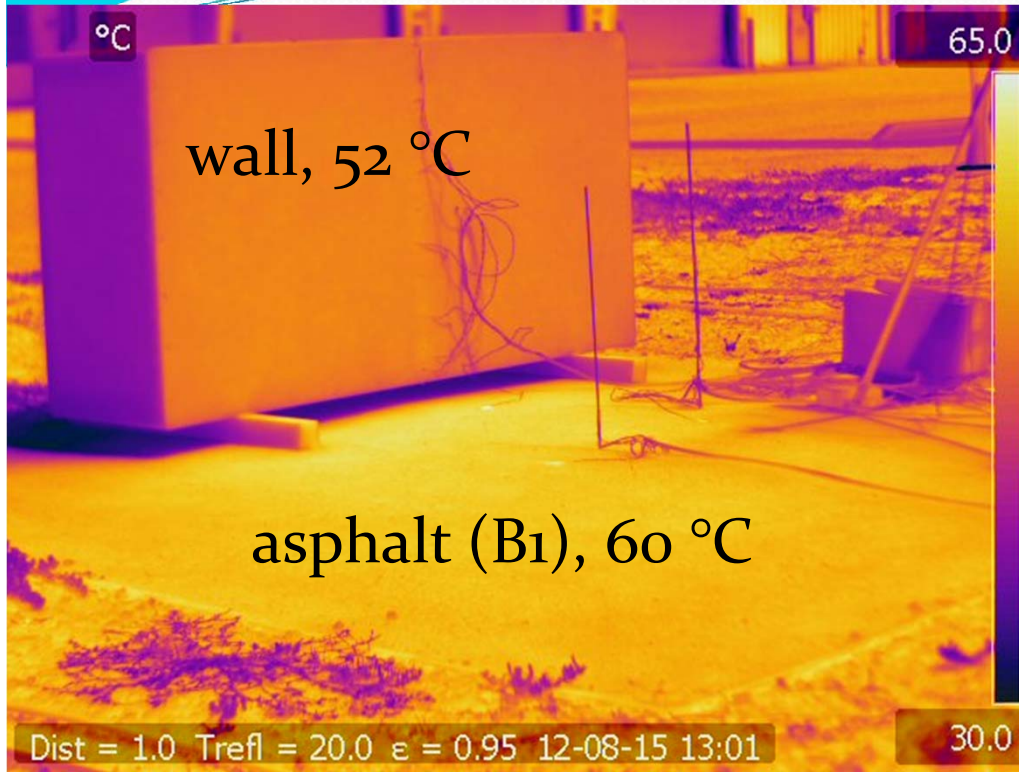


date format:  
mm/dd)

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

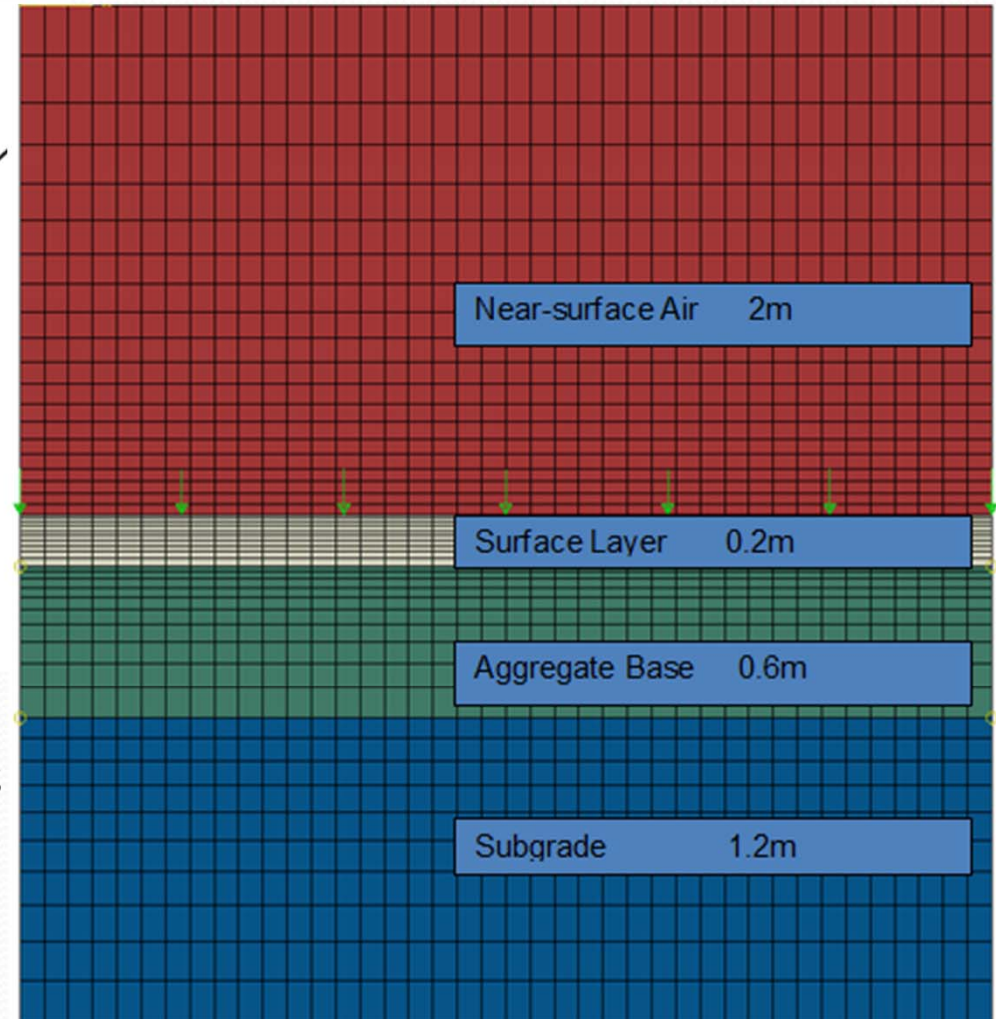
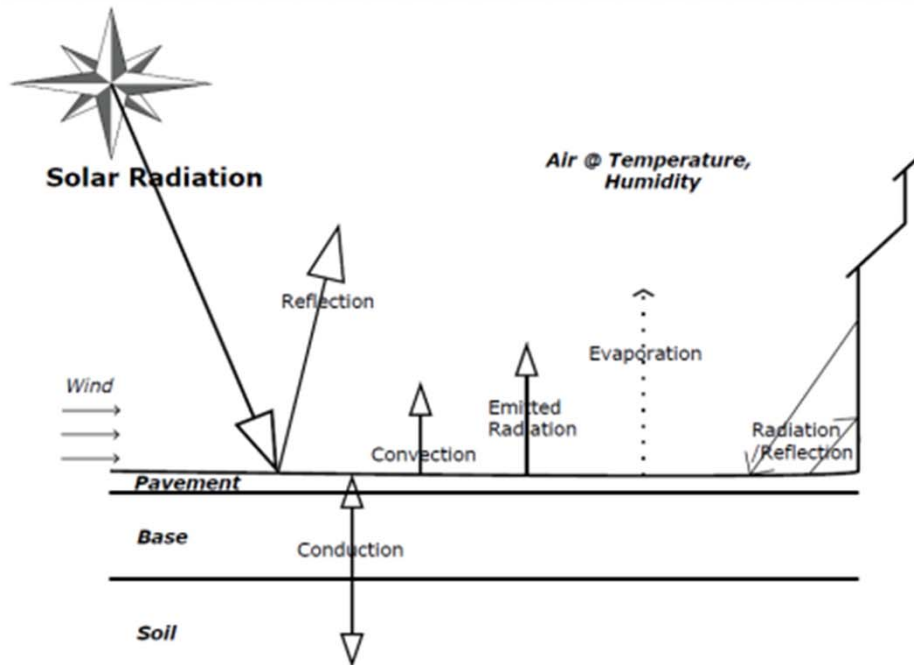


# Impact on Vertical Surface (13:00 8/15/2012)



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

# Modeling for Thermal Behavior



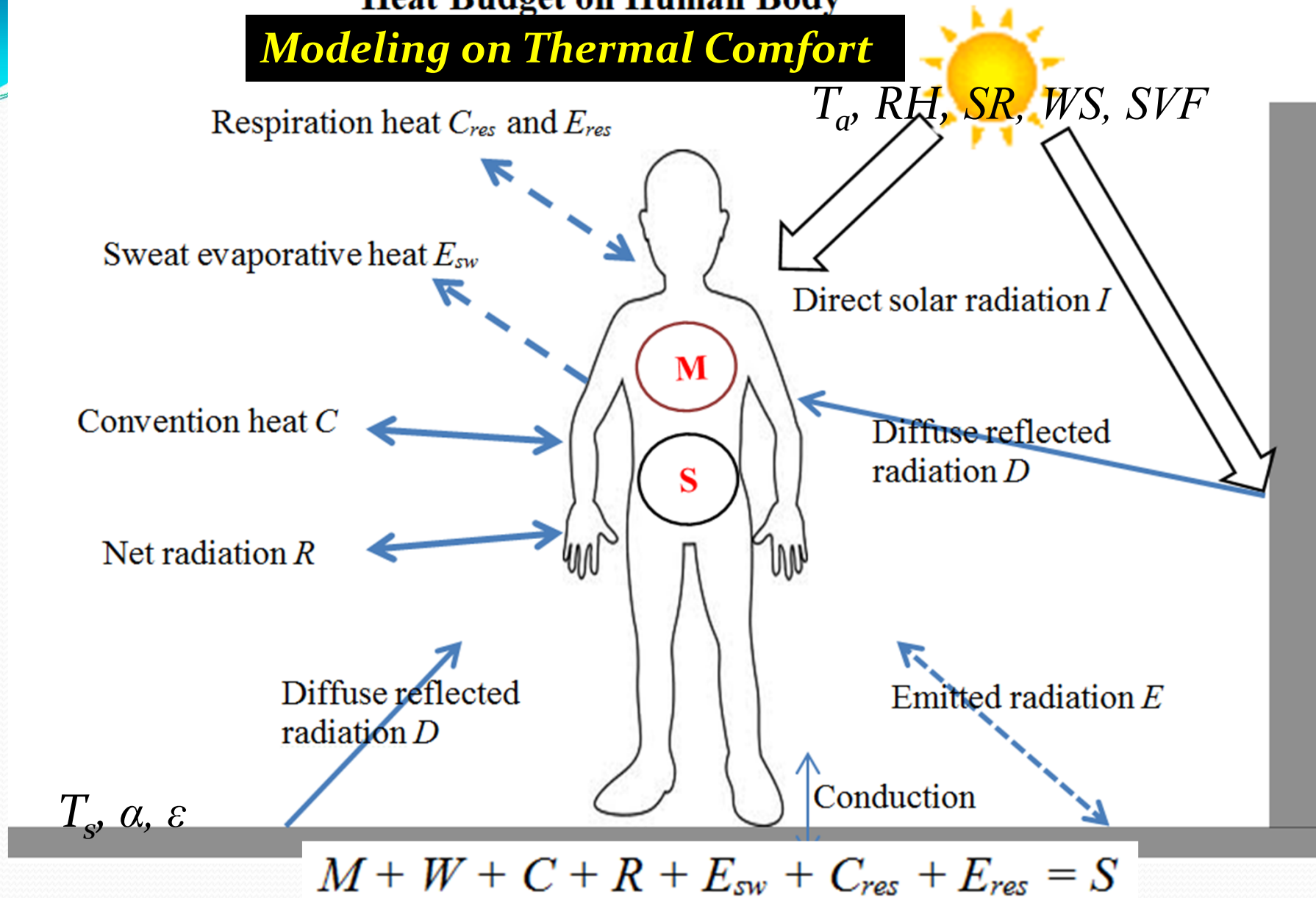
The model considers :

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



# Heat Budget on Human Body

## Modeling on Thermal Comfort



$M$  is the metabolic rate ( $W/m^2$ ).  $W$  is the rate of mechanical work ( $W/m^2$ ).  $S$  ( $W/m^2$ ) is the total storage heat flow in the body.

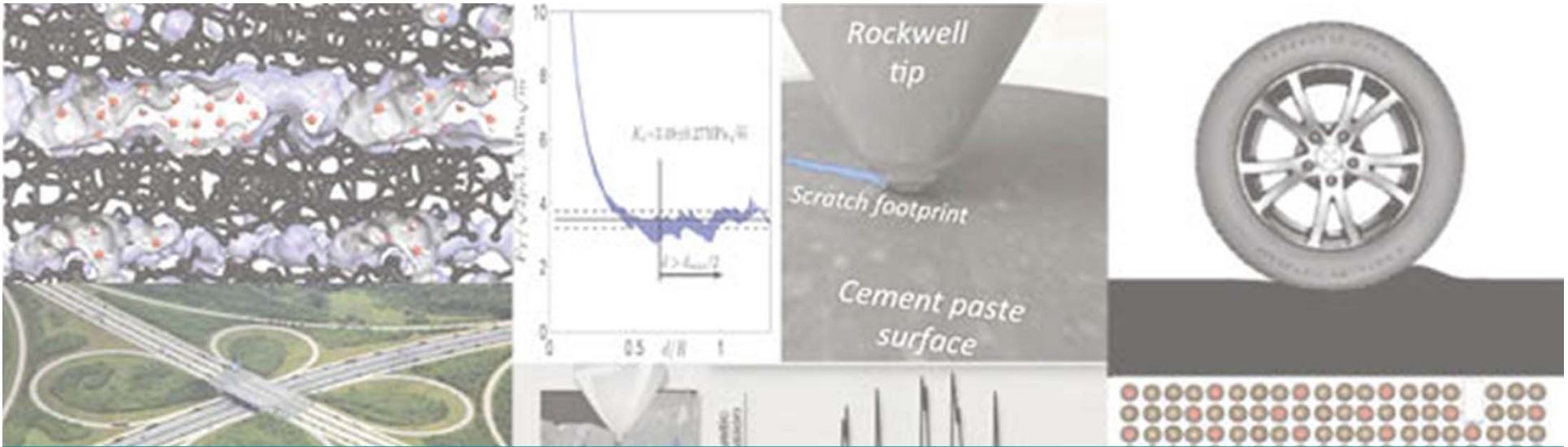
# Next Steps for Cool Pavement Research

- 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:**

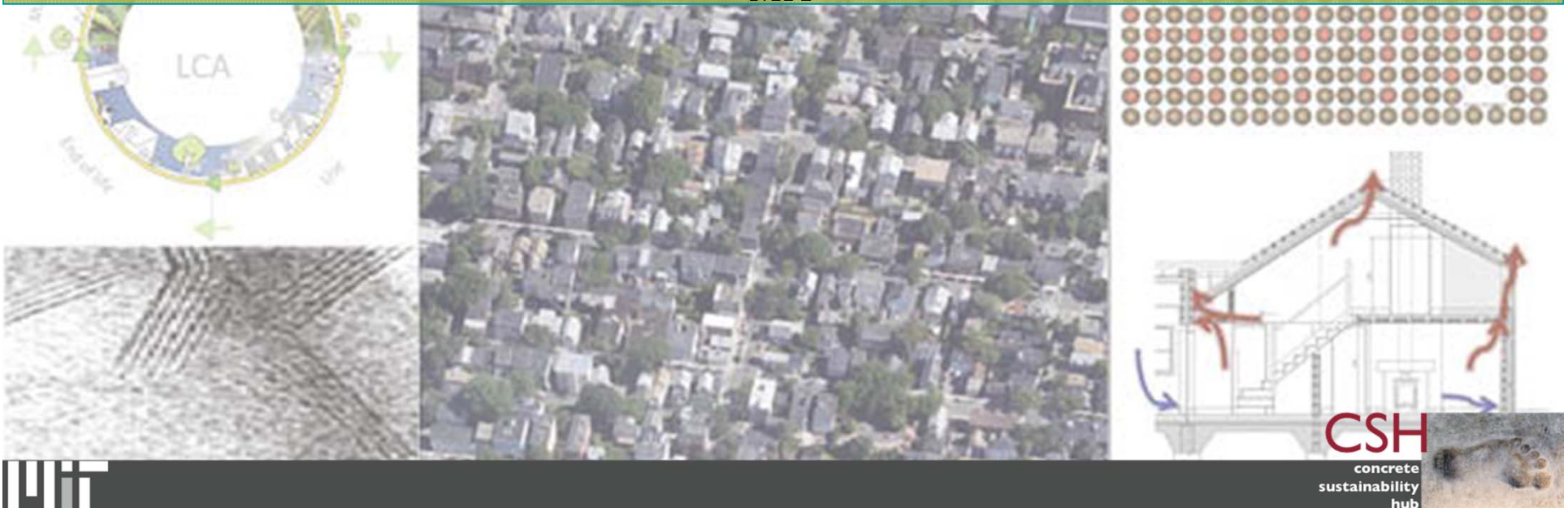
Li, Hui (2012) Evaluation of Cool Pavement Strategies for Heat Island Mitigation. ITS-UC Davis, Research Report UCD-ITS-RR-12-33,

[http://www.its.ucdavis.edu/?page\\_id=10063&pub\\_id=1803](http://www.its.ucdavis.edu/?page_id=10063&pub_id=1803)

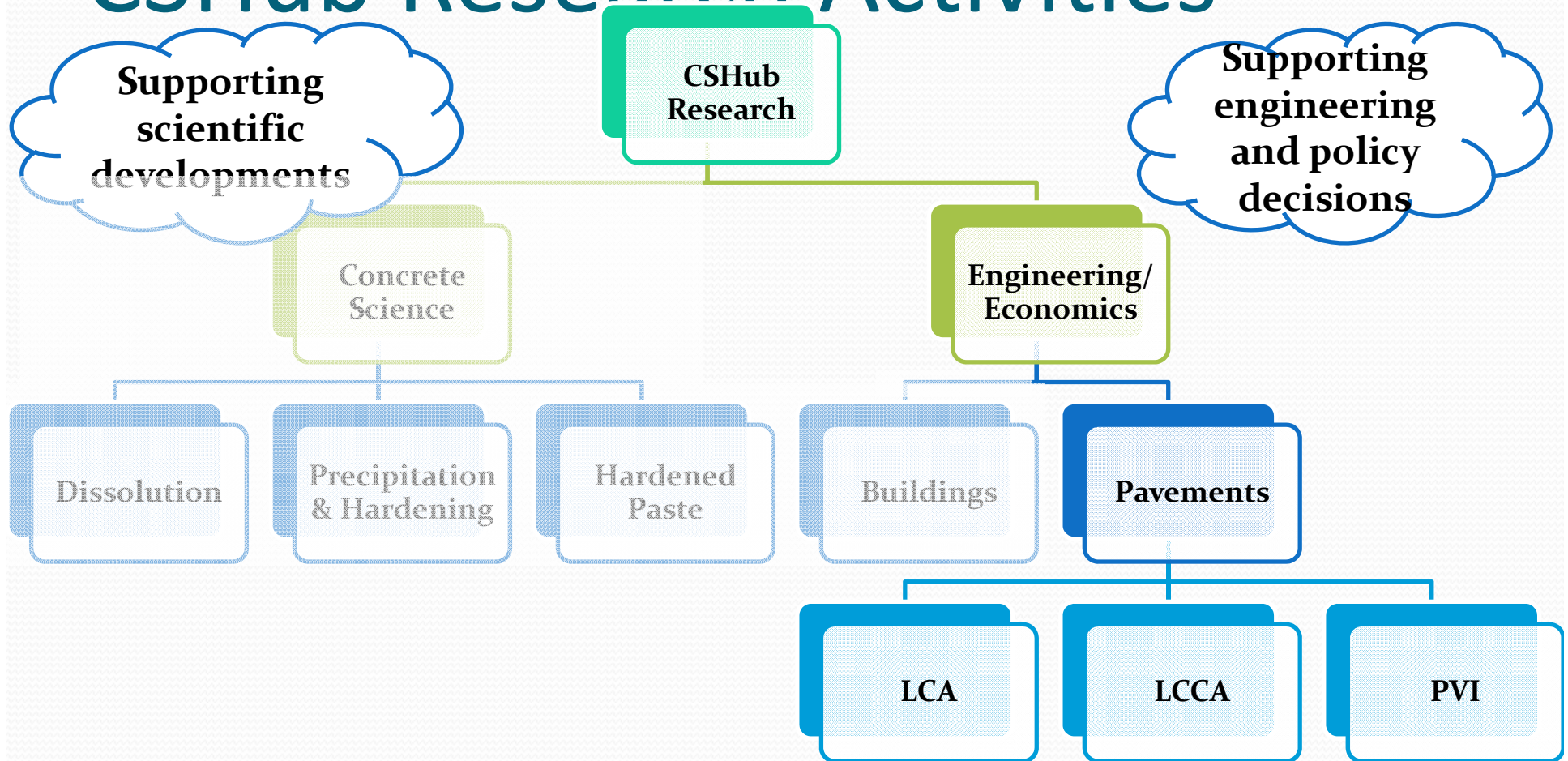


# Pavement-Vehicle Interaction

Mehdi Akbarian, Arghavan Louhghalam, Franz-Josef Ulm  
MIT

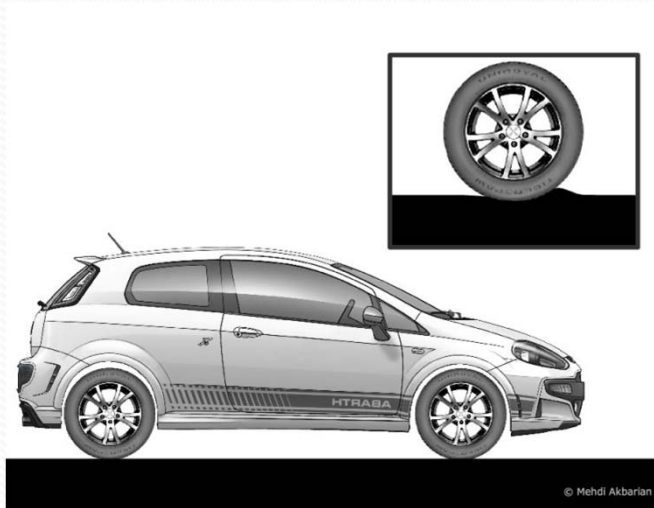


# CSHub Research Activities



*Presentation Focus* →

# Model-Based Assessment of Pavement Vehicle Interaction (PVI)



Pavement Deflection

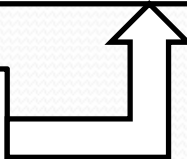
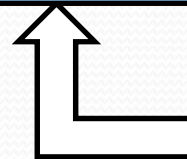
MIT-Model



Pavement Roughness

MEPDG+HDM4

Structure and Material

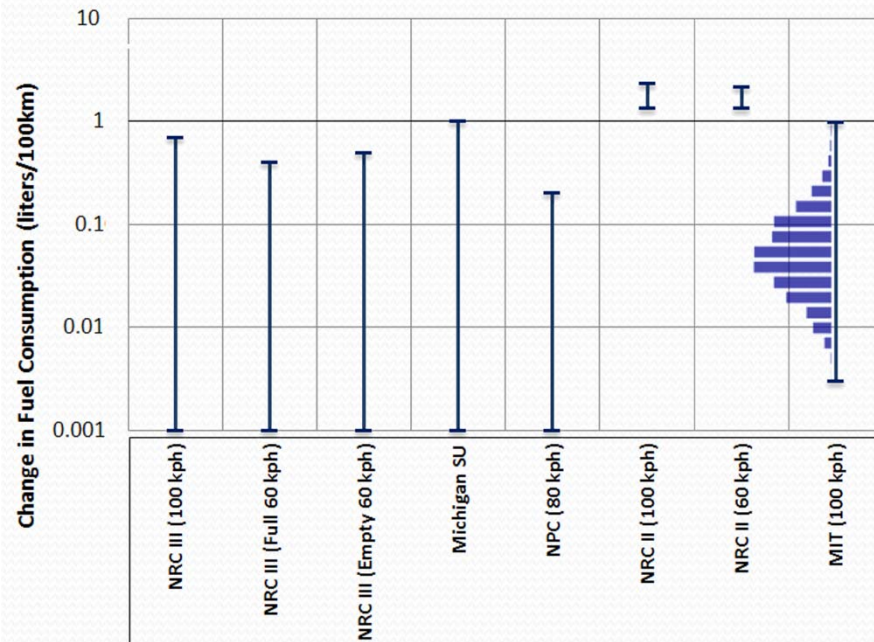


# US Network Deflection Induced Fuel Consumption

Sample output:

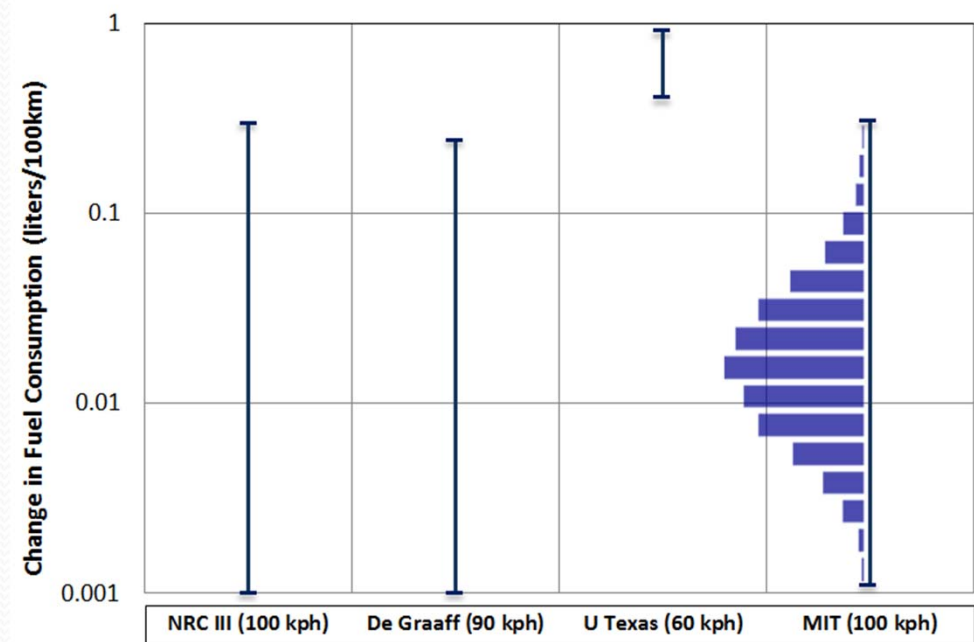
Comparison of modeled fuel consumption on asphalt vs. concrete pavements to prior empirical studies.

Trucks:



Logarithmic

Cars:

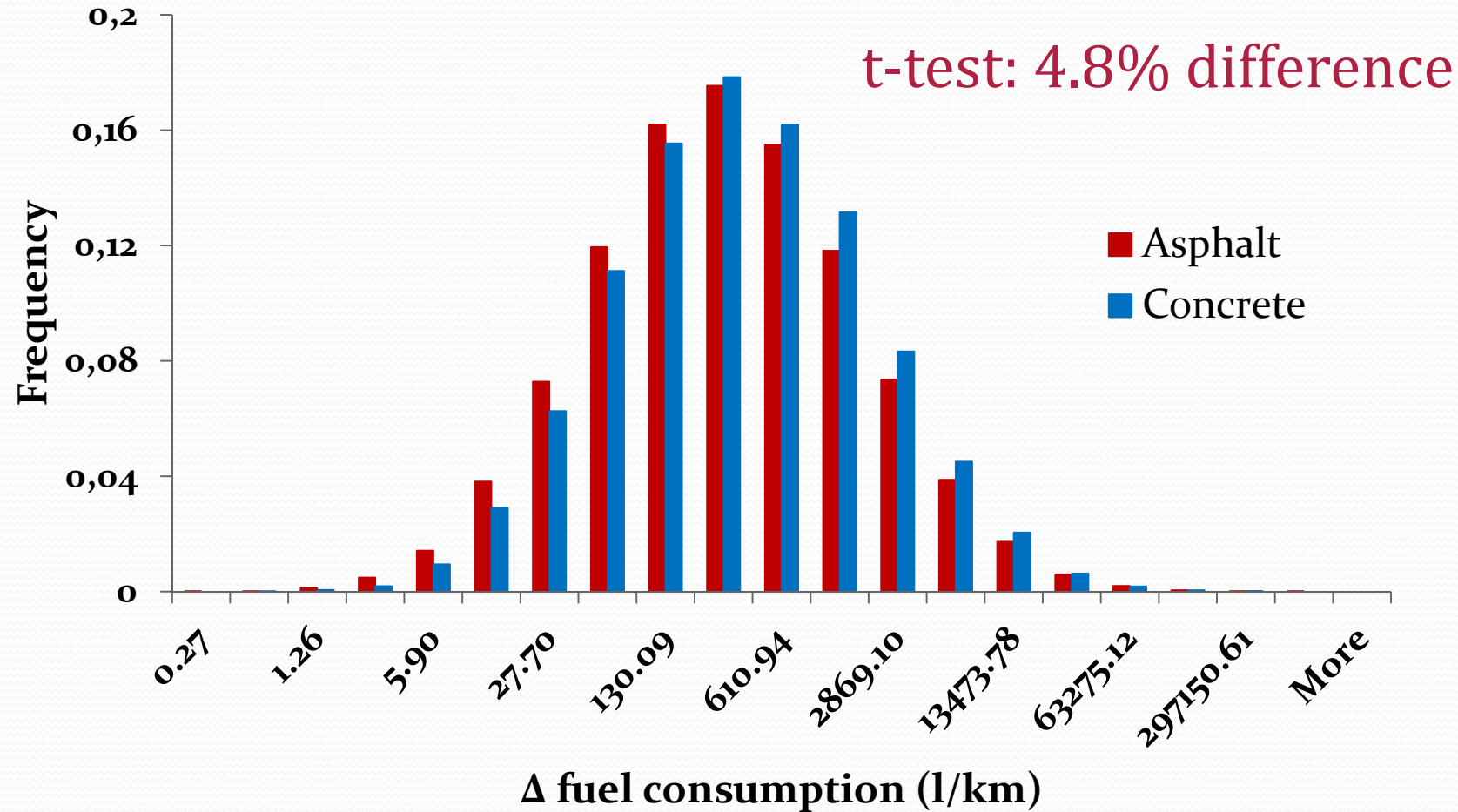


Logarithmic

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

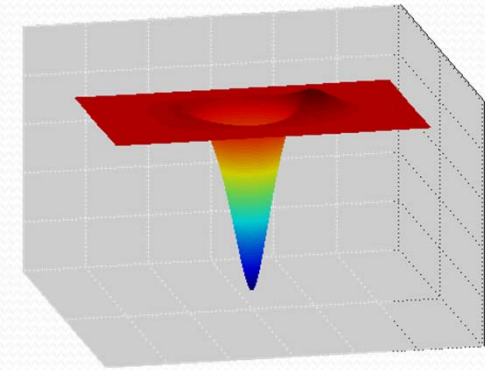
- Calibrate, Validate
- Scale gradient forces to F.C.
- LTPP/State data

### 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](http://web.mit.edu/cshub)

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

April 2012

Mehdi Akbarian  
Franz-Josef Ulm

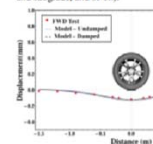
Concrete Sustainability Hub  
Massachusetts Institute of Technology  
77 Massachusetts Avenue  
MIT Room 1-372  
Cambridge MA 02139



# Report

## Concrete Sustainability When the

**Problem**  
Fuel consumption due to pavement-vehicle interaction (PVI) is an essential assessment (LCA) of pavement estimates attribute up to 70% of emissions (GHG) to PVI due to deflection of pavements when a load. Yet, the available field consumption related to PVI for systems shows a high level of uncertainty by at least an order of magnitude, structural and material properties pavement system tested. Furthermore for the effects of pavement consumption were developed on generated years ago in other countries and pavement systems that vary in those used currently in the United States makes it difficult to reliably use LCA of pavement systems. Quantitative mechanistic PVI models relate fuel consumption to parameters (e.g. pavement thickness, properties (stiffness, viscosity, strain and subgrade, and so on).

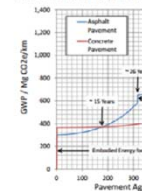


Model prediction and experimental falling Weight Deflectometer test program. Observed response is for a top layer modulus 84,877 MPa, and subgrade modulus 1,614 MPa. Results with damping are for a damping ratio of 20%.



## Concrete Sustainability Roads: S

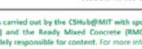
**Problem**  
One of the key challenges development of our Nation's infrastructure continue to make progress on in of engines, tires and suspension area is the development of strategies emissions due to Pavement-Veh Accounting for PVIs is essential life-cycle assessment (LCA) of types of PVI that contribute to gas emissions of pavement induced PVI due to the deflection subject to vehicle load, and road which strongly correlates with serves as the primary indicator of our Nation's road system. It is not constant, but evolve in time exposure and the unavoidable structures. Thus, a realistic environmental impact of pavement consider this non-linear, time-de



Sample Output: Excess fuel consumption and resulting CO2e emissions for two high-volume pavement systems for a 50 year design life using a 95% confidence interval. Two-lane urban section design from AASHTO AASHTO 1.500 AC maintenance at years 17, 38, 47; PCC maintenance at years 22, 43.



Sample output: Global Warming Potential (GWP) for pavement systems designed with design life (t) time, location: Columbus, Ohio, AASHTO 1.500 4% traffic growth, Terminal RH = 172 (mm).



Research presented by Mehdi Akbarian, graduate student in the CSHub, supervised by Prof. F.-J. Ulm.



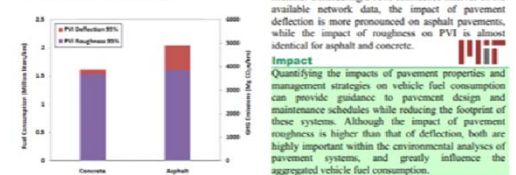
This research was carried out by the CSHub@MIT with sponsorship provided by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research & Education Foundation. The CSHub@MIT is solely responsible for content. For more information, write to CSHub@mit.edu.

## Concrete Sustainability Hub@MIT - Life Cycle Assessment Research Brief - 4/2012 Network, Pavements, and Fuel Consumption

**Problem**  
Sustainability of the roadway transportation sector is highly dependent on passenger and commercial vehicle fuel consumption. The roadway system affects this fuel consumption via pavement-vehicle interaction (PVI) in two major ways: pavement deflection and roughness. Both sources of PVI are dependent on material and structural properties of the pavement. In addition, ineffectual application of maintenance and rehabilitation strategies throughout the pavement lifetime can significantly affect a pavement's environmental performance and durability. In order for the impacts of PVI to be captured within pavement design procedures and life cycle assessment models, the combined effect of the PVI elements (deflection and roughness) along with that of maintenance and rehabilitation scenarios must be understood and quantified. The impacts of PVI on fuel consumption are not constant and evolve over time, mainly due to pavement deterioration from loading and environmental factors. Calculation of the excess fuel consumption due to pavement conditions throughout their lifetime draws a perspective on the environmental benefits of reducing PVI through better design, material, and maintenance schedules.

**Approach**  
In order to calculate the impact of pavement deflection and roughness along with that of maintenance on the vehicle fuel consumption, an analysis on the current state of the roadway Network has been performed using the long term pavement performance program (LTPP) databases as a representation of the network. According to the theory of elasticity, a dynamic system such as a road network has the same behavior averaged over time as averaged over space. Hence, we use structural and material properties of the LTPP sections as inputs for the PVI deflection model, and the roughness values through the international roughness index (IRI) for the roughness model. By applying these models to a high-volume pavement scenario we can calculate the extra fuel consumption due to these impacts throughout the lifetime of a pavement.

**Findings**  
For the high-volume roadway analyzed, we find that the contribution of both pavement deflection and roughness to added fuel consumption are significant. Since a Network analysis is performed, the results represent the state of the pavement throughout its lifetime. Considering a 95% confidence interval of the available network data, the impact of pavement deflection is more pronounced on asphalt pavements, while the impact of roughness on PVI is almost identical for asphalt and concrete.



Sample Output: Excess fuel consumption and resulting CO2e emissions for two high-volume pavement systems for a 50 year design life using a 95% confidence interval. Two-lane urban section design from AASHTO AASHTO 1.500 AC maintenance at years 17, 38, 47; PCC maintenance at years 22, 43.

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Ulm.

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Research presented by Mehdi Akbarian, graduate student in the CSHub, supervised by Prof. F.-J. Ulm.

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# Briefs

# Pavement LCA work at UCPRC

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UC Davis

# 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<sub>2</sub>e 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).