Scientific Overview of Pavements and Heat Islands

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Slide 1: Title Slide

Kamil Kaloush: Thank you, Neelam. It's my pleasure to be part of this webcast, and I'm really glad to share with the participants and everyone here today some of our work and knowledge related to the urban heat island and pavements. So thank you for that long introduction. I'm glad Ohio State finally won in the Rose Bowl this year. Let's see, I'm trying to – I'm trying to move forward with my slides, and I'm not able to do it.

Neelam Patel: Kamil, go on and click on your screen with your mouse.

Slide 2: Do Pavements Contribute to UHI?

Kamil Kaloush: OK. Thank you for doing that. This slide right here is not really the agenda for this presentation. You know, the question, "Do pavements really contribute to the urban heat island or not? If so, how much and where within the urban environment that we have?" I will overview some of the evaluation techniques, what are some of those driving factors (Neelam has introduced some of them already) and talk about the different types of pavement materials, their properties, their design characteristics and how they interact and influence the urban heat island in a way. And I'll talk a little bit about some of the mitigation strategies out there and some of these opportunities that are already existing for both pavement industries out there. And a couple of slides at the end just to introduce some of the tools and the models that we have been using to – in order to assess the urban heat island and the contribution of pavements within that.

Slide 3: ASTER Satellite Imagery

Kamil Kaloush: This is - what you will see here is actually a – an ASTER satellite imagery, this is really one of my favorite satellite imagery that actually got me interested into this subject area. And, what you see here is a surface temperature for the Phoenix area and the surrounding urban locations and hold a quite few mountain ranges here around the Phoenix. This was taken back in 2003 at 11 o'clock at night in October. October was pretty warm. We had warm temperatures. And what you see here is actually a scale of temperatures. The bright yellow is actually the highest surface temperature that has been recorded for that moment. If we take the urban location and take the top twenty percent of the surface temperature from this image being analyzed, you will see that in the red markers over here. You know, one thing that you can really

– came out of this is that the highway system is very well-highlighted within this urban environment. And, we estimate these paved surfaces, not only highways and parking lots and the shopping center and everything else, about forty percent of the urbanized land cover in Phoenix. And the conclusion from this is really evidence that really pavements do contribute to the urban heat island effect.

Slide 4: How Much and Where?

Kamil Kaloush: On the next slide here, I will show you just a – one of several evaluations in terms of the air temperatures Neelam have mentioned. We have a range anywhere between 9 to 27 degrees. What you are looking at here is air temperature versus the hour of the day. It's a 24-hour cycle for an urbanized location within the Sky Harbor Airport here in the city of Phoenix, and Encanto Park which is a green space within the city, and a rural site which is the City of Maricopa. And, you also see the solar flux that has been recorded for that – in July 2005 for that day. So if you look at the peak temperatures, which are typical in the late afternoon here in the area, you will see that just about all of these sites have similar peak temperatures during the afternoon. But if you look at the late afternoon hours and the early morning hours, you see this is where we have the biggest or largest difference in temperatures between the sites. And basically, here what you are seeing is the urbanized location that you'll have, you know, in this particular case up to 10 degrees Fahrenheit. And again, we have seen anywhere between 12 to 15 degrees Fahrenheit difference there. And these are, again, representing the – an urban location versus a city of Maricopa which is an outside rural area.

Slide 5: UHI Evaluation Techniques

Kamil Kaloush: Evaluation techniques for the urban heat island, we've been successful, though I just showed you the ASTER thermal imagery and the effect of – or the results that you can get from the surface temperatures. We've been using the infrared thermal imagery cameras as they do a good job in looking at the, you know, city blocks to evaluate the different infrastructure. There are also some mobile transects that actually they are – these are equipment mounted on a vehicle. It has the infrared camera, the GPS. It has a humidity and air temperature sensors inside a solar shield, and what it does, it travel through the town or the city and can get a profile – line profile of the temperatures across a certain location. They've been, you know, very good to assess the temperature profile. We can use them with the thermocouple in pavements near the surface, you know, throughout the pavement itself or utilize a - also a weather station with that. Again, trying to understand the heating mechanism, the heat absorption and transfers and re-emittance into the atmosphere. Also, we can capture some of these properties in the lab, we can – we can run some thermal conductivity tests, so specific heat capacity on the different types of materials, really try to understand the - some of those fundamental properties as part of the process.

Slide 6: Infrared Lapse near Millennium Park

Kamil Kaloush: This is some of the use of the infrared camera that we have actually used back in 2007 for the city of Chicago with the time lapsed infrared view, and again, our interest here is to look at pavements and the sidewalks and the paved surfaces and as you go from the early morning hours, 5:00 a.m., and again, the bright colors here that you see on this is actually, will indicate the higher surface temperature. If you go to the 8 a.m., you can start seeing that actually the roadways and the paved surfaces here are start showing the higher surface temperature, and you go to 11:00 a.m., and again, they are the brightest, and move on to 1:00 p.m. and they are the actually the last, you know, surfaces that actually will cool down into the evening hours. So again, that's - it's a – it's a – it's a good shot just showing how we can assess the different surface temperature using the infrared camera.

Slide 7: What are the driving factors?

Kamil Kaloush: What are some of those driving factors? I have a list here. They are not inclusive of everything, but, canyon geometry within the – within the city, the buildings, they will form some type of canyons that would tend to trap the thermal energy near the bottom surface and this is exactly the same thing for roadways and when you have a depressed highway section versus a highway section that's actually constructed at grade. The thermal properties are important. Dense materials will absorb and retain more thermal energy than the natural surface cover or even a porous material. Anthropogenic heat, these are heat released from combustion of fuels, electrical energy, including the vehicles driving on the highways and they can result in elevation of the temperatures within dense urban areas. And the urban greenhouse effect – the warmer air and air pollution within the city will act as a micro-greenhouse effect, if you wish, preventing the heat from radiating from the warm surfaces. And of course, we have the effect of reflectivity, albedo, again, the total reflectivity of a city is reduced, you know, due to trapping effect of shortwave radiation of the building canyons that I just mentioned.

Reduction of evaporating surfaces as the city expand and we change, you know, from the natural vegetation to a more of a paved infrastructure. There is a loss in the moisture that can actually adversely affect the temperature within the city itself and that will also contribute and be one the driving factors as well. And then finally, in some areas of the city, the wind patterns can actually be blocked, you know, causing pockets with little wind flow, and again, the – this reduced mixing of air greatly reduce the heat released from the streets, you know, or the highways within that urban environment.

Slide 8: Example

Kamil Kaloush: This is just an example. I mentioned about the, you know, canyon geometry and the depressed section versus at grade section. This is a – just a blowup of Interstate 101 here on the east side of the Phoenix area. This is exactly the same pavement. This is warmer comparing to what you see here, it's much cooler. You don't see the - as much red marks. If you look at the actual highway, this location right here has the advantage of being at grade. It has the – there is landscape along side and agricultural on the other side, and so, it kind of cools down faster at nighttime comparing to the same pavement structure that you see here, but this one is within residential area. We have sound walls and it's a depressed section because of the location. So that will have tendency to trap heat in this case.

Slide 9: Fundamental Properties

Kamil Kaloush: What we see here is some – you know, for pavements, we really – we need to understand some of those, you know, fundamental properties that actually we can control and understand better the mechanism of the urban heat island and the heating mechanism. Albedo is on top of the list here, which is really the measure of the surface reflectivity. It's an important factor of - but again, it's not really the only one. We have several others. Emissivity which controls the far infrared re-radiation from the surface back to the sky is also an important aspect. And then, there are several really fundamental properties in terms of thermal conductivity, the specific heat capacity, and the density of the material.

This is something that, you know, we have been producing different types of materials and we can – we thought - we think that we can actually control some of these properties within a material design. So the lower the thermal conductivity, the less specific heat capacity. And sometimes, if you have lower density that would really help to reduce the amount of heat being retained into that material. So they provide an opportunity to better understand the heat retention and improve – you know, upon our future design. Some of the mitigation strategies for pavements, increased albedo comes to mind. It's definitely a good thing if you use pigment, light-colored aggregates, resin binders. There are also opportunities for surface coatings with nanoparticles. This is not for the whole mix, just for the surface that actually can provide an increased reflectivity in that fashion.

Slide 10: UHI Pavement Mitigation Strategies

Kamil Kaloush: Porous pavements, both in the HMA, the hot mix asphalt, and the Portland cement concrete, the pervious concrete, they really help provide a good control of the thermal conductivity, the density of the material, and the thermal diffusivity. And, therefore, they provide that added benefit of retaining less heat. And, again, we are more concerned of the nighttime phenomenon urban heat island. Whitetopping strategies for the Portland cement concrete. They have the advantage or the albedo benefit. They also have the advantage of having a lower thermal mass, lower thickness as a pavement thickness, so you have less heat retention. So we have seen actually nice cool surfaces from this technology. Then, we move on to reflective asphalt pavement techniques. If you are a TRB or we have actually paper has been published in our subcommittee about two years ago that talks about different techniques. In fact, I do have a slide here later on, but again, this is a technique that can better control the albedo and especially for newly constructed pavements.

The use of thermal resistant materials, the specific aggregates types are better in heat conduction or retention comparing to others, admixtures. And here in Arizona, we use a lot of a crumb rubber – asphalt rubber in the valley. We see some benefits on less heat retention and absorption in this process too. And while the last couple of items here is not always economical or practical, but, you know, provides some kind of cover - trees in urban streets is very helpful, the use of solar panels especially for parking garages, they are - actually will provide a good mitigation option as well too.

My favorite line at the bottom, "To pave or not to pave." It's – and don't take me wrong here because I do earn my living basically from working with pavements. But there are also a lot of residential areas here in the Phoenix area that - they don't elect to pave their driveways. They go with the natural landscape. They do some kind of stabilization process to kind of blend in with the design there. And that's still an option that, actually, we don't have to pave all the time.

Slide 11: Pavement Design Characteristics

Kamil Kaloush: Quick screens here of the pavement design characteristics. This is a thin – ultra-thin whitetopping pavements. It's about 2 inches of Portland cement concrete, have a good characteristics of having a lower surface temperature especially during the day. So again, this is the high albedo, lower thickness that will provide a good option for urban heat island.

Slide 12: Pavement Design Characteristics

Kamil Kaloush: Reflective asphalt pavements, surface chip seals, lighter color aggregates to being utilized, again, will increase the reflectivity. There's a - a couple of years ago, like I mentioned, some experiments dealing with the gritting and shot blasting and basically upgrading the surface binder. So it's almost like an accelerated process to lighten up the asphalt pavement at the beginning of its life, in a way, so it has been also showed to be a good pavement design characteristic for UHI.

This is a shot of the asphalt rubber that we have here in the valley. And, again, the thin layers that you see here, porous layer, that will have tendency to shed that heat much quicker at nighttime comparing to a thicker pavement. And you'll see here from a thermal image that's actually providing a thermal or a cool surface at nighttime. When you don't have traffic, traffic is an important factor, really add to the complexity of things. You can see that, actually, you do have a warmer surface. This is an HOV lane that has not been used at that time and you can see it stays much warmer at nighttime.

Slide 13: Pervious/Porous Parking Lots

Kamil Kaloush: So pervious and porous parking lots, they are actually – we have done some documentation where we provide good benefits for UHI; low thermal conductivity, specific capacity and density, in addition, of course, to the storm water management and recharging, of course, the groundwater aquifers, so it becomes a good option there as well.

Slide 14: Other?

Kamil Kaloush: Other non-pavement items that we have actually worked with. This is a U-haul parking lot here in the Phoenix area and they went with an option where they actually – I believe it's called gravel pave. So it's actually a plastic grid and membrane that they place on top of a subbase - on top of the subgrade and they can put any types of gravel size and color on top of it. So the plastic grid and membrane will provide that confinement and stability for the pavements to kind of actually, you know, help with the traffic load and so forth.

Slide 15: Hybrid Designs

Kamil Kaloush: So this is – actually shows it's – again it's another type of porous pavement that will have a benefit of less heat retention. These are some of the solar panels. Again, they are – provide a good shading for the asphalt here in this case. Reduced lower temperature in addition to, you know, getting energy for lighting and so forth from the solar panels. We can do hybrid designs, composite designs. This is, again, merging a pervious or combining pervious for parking stalls and conventional pavement for the actual passages of traffic depending on how much structure you need. That's a good combination in this process as well.

Slide 16: Modifying Radiative Properties

Kamil Kaloush: This is just a slide to show you the modifying – the radiative properties. And, again, this is something that's not really that new. There's a lot of paint technologies out there. You can paint your house dark brown, if you wish. And there are some additives that added to the paint that will help to reflect more of the solar energy being emitted. So that's something definitely - it can also be applied for pavements. We have done a couple of test sections here with the local companies here in the Phoenix area and it's under experimentation. But again, the idea is to reflect more of that solar radiation by controlling the additives into a surface sealant, if you wish, that you can – it can be placed on top of the pavement.

Slide 17: Laboratory Evaluation

Kamil Kaloush: This is just to show you some of the laboratory evaluation. There is an ESEM Standard that we do for thermal conductivity to measure the thermal property or thermal conductivity of asphalt or concrete materials. We have done a – or came up with a modified version where, instead of using plates, we use a cylindrical specimens and – to measure the, you know, basic thermal conductivity of that material. It will be a bit more practical for pavements since everything we do is basically looking into using cylinders for other testing. So again these are measurements – some of the specific, you know, fundamental properties to help us better understand and model our pavements.

Slide 18: Tools- Models

Kamil Kaloush: Some of the tools that we have, you know, we can take all this information and put into a simple model analysis looking into the environmental condition, you know, our pavement structure thicknesses, you know, the thermal properties now from laboratory measurements. We can actually model the heat conduction retention and re-emittance into the atmosphere from such – from such work. Or we can take the same formulation in a simple form, and we can apply the same thing for a large city, metropolitan area in this case. So – and again, understanding the landscape, how much of the pavement is really - is part of this landscape, how many of the roofs and vegetation and so forth.

Slide 19: City – Wide Analysis

Kamil Kaloush: We can control the different variables and try to understand if we implement a certain policy where we're using the more reflective roofs or more reflective pavements, what's really the impact on the overall temperature and of course manner, in a way. So we have actually have done some of this work as well, too.

Slide 20: Concluding Remarks

Kamil Kaloush: So finally, I just want to conclude some of these remarks and I'm sure some of you will have some questions at the end. But pavements, really, definitely play an important role in the urban heat island effect. And I think some of those preceding slides actually kind of showed you that.

There is no one solution that actually fits all. Cooler pavement designs will likely need to be addressed with existing techniques and materials that we have. And I hope you appreciate the complexity of this - all these different various designs that we have and materials and, of course, the optimization process that we need to work on to meet other requirements, in a way. So more work still needs to be done; more research, testing, modeling and documentation of field experiments that, really, is taking place, will really help us to advance our knowledge in this area.

Slide 21: Thank you!

Kamil Kaloush: So with that, I think, I will conclude my presentation for now, and perhaps, we'll talk later on. Thank you very much.

Neelam Patel: Thank you, Kamil. That was a great overview. I'd just like to point out some of the topics – the characteristics of pavements that help reduce heat island effect that Kamil mentioned are in the heat island compendium chapter on cool pavements, and also the different types of cool pavements are also outlined in the cool pavement compendium chapter, if you're interested in more information. If you do have questions for Kamil at this time, I encourage you to send them in using the go to meeting question function and include his name, so we can get to those in the question and answer session.