Energy Performance of Green Roofs: the role of the roof in affecting building energy and the urban atmospheric environment

Slide 1: Title Slide

David Sailor: OK. I'm here, is my first slide of my presentation being projected?

Neelam Patel: Yes, it is, David.

David Sailor: OK, I'm ready to go then. Hi, so thank you for inviting me to speak today at the webinar on Green Roofs, it's a pleasure to be able to talk a little bit about some of the work that I've done as well as highlight some of the work that others have done in this field.

Slide 2: Why Green roofs?

David Sailor: So, Neelam did a really good job of giving the overview of some of the benefits of Green Roof and so the focus of my presentation is just on one aspect which is the energy balance on the rooftop of a Green Roof and how it impacts both the energy consumption of the building but also the urban Heat Islands. So I'll start by talking about the impact of Green Roof on the building and its energies.

Slide 3: The Building Sector

David Sailor: To provide some context, the building sector is responsible for something like 40 percent of all energy consumption in the U.S. and a similar fraction of a nation's CO_2 emissions. Of this energy use, on the order of about one third is for heating and cooling demand in buildings. So, this leads us to seek ways in which we can reduce HVAC energy used in buildings. In the context of this presentation, the natural question then is what role can Green Roofs play in reducing building energy usage?

Slide 4: Causes of Heating/Cooling Loads in Buildings

David Sailor: To answer this, we need to first consider the various factors that contributed – that contribute energy use in buildings; these include things such as in-door energy use, energy used to condition air that infiltrates the building, solar heat gained through the windows and significantly in back buildings, HVAC load as windows tend to transmit on the order of 50 to perhaps 80 percent of the instant solar energy, conduction of heat through the walls and then finally, conduction of heat through the rooftop. So as this inventory suggests, the Green Roof can play a role but by themselves, Green Roofs are unlikely to make a huge dent in the building's overall energy bill.

Slide 5: Heat Transfer on a Green Roof

David Sailor: So, to understand better the role of the Roof in the conduction of heat to the building, I'll give a brief overview of the energy balance on a Green Roof. To start with, the energy provided by the sun is the major input of energy to the system. The plants then intercept and reflect some of this radiation. The radiation that makes it to the surface of the growing media is partially reflected. Some of the absorbed energy at the surface is convected away as sensible heat and some is omitted as long wave radiation.

Some of the converted – some of the energy is then also converted to latent heat or evaporative cooling through both evaporation from the soil surface but also from transpiration from the plant surfaces. And finally, to balance this energy that is not taken away from that surface is conducted into the growing media and then partially absorbed by the growing media and stored in the soil and finally some of that actually makes its way into the building.

Slide 6: Conventional Roof

David Sailor: So how does this play out in terms of impacting the roof top surface temperature and heat flux into the building? To start with, let's consider this as a simple conventional roof top with perhaps a darker membrane, so a darker membrane during, let's say, a hot summer day will typically absorb quite a bit of the solar energy instant upon, it heating up to say, 120, to perhaps 150 degrees Fahrenheit. At night time, however, since the membrane has relatively little thermal mass typically above an insulation layer, it will actually emit long wave radiation readily and cool off fairly rapidly at night.

Slide 7: “Cool” White Roof

David Sailor: In contrast, a white roof, or what they refer to as a cool roof, will not heat up as much during the day because it reflects so much larger a fraction of the solar energy but it will also have the same sort of effect at night, where it will emit its heat out to the environment fairly readily and cool off substantially at night.

Slide 8: Green Roof

David Sailor: So a Green Roof, in contrast to both the other roofs, measurements in modeling show that the surface of a Green Roof actually does typically remain fairly cool, like the white roof, on a hot summer day and so this means less convective heat flux into urban environment which of course, impact the urban Heat Island. Of course, the Green Roof has stored a great deal of that energy during the day and as a result, will stay warmer at night and possibly conduct some of the stored heat into the building and certainly convect more heat into the urban environment at night.

Slide 9: Studies/Measurements Introduction Slide

David Sailor: So, to illustrate these conceptual descriptions of how the Green Roof impacts the surface energy balance, we can look at various measurement studies. I've compiled a few here.

Slide 10: Study 1

David Sailor: The first one is an example from some suite of test roofs that were conducted at Penn State University and if you look at the trace of measurements of surface temperatures, these are all for the month of July back in 2003 – summer time temperatures – and what you see clearly is that during the daytime, the roof surface is cooled substantially, say 30 to 40 degrees cooler than a traditional roof during the same time. At night, however, as the – as the area highlighted over here, the Green Roof remains warmer because as I've said, it stores more heat.

Slide 11: Study 2

David Sailor: And a similar sort of study at the University of Central Florida, researchers from Florida Solar Energy Center found similar results. They also measured heat fluxes in addition to temperatures and we're able to show that the Green Roof significantly reduces conduction into the building during the day but does result in unwanted flux of heat into the building at night. Due – and again this is due to the stored heat in the growing media and that's shown here in this red box down below.

Slide 12: Whole Building Energy Use

David Sailor: So several measurements of roof temperatures and fluxes do not give a complete picture of how a Green Roof will actually impact the energy of this building. So that's – as this slide suggest, the roof top heat flux interacts with things like the internal loads of the building, thermostat and occupancy schedule, infiltration and ventilation, and seasonal weather conditions.

Slide 13: Green Roof Model

David Sailor: So, to investigate these sorts of interactions, we found it necessary to actually develop a comprehensive model that represents the physics of what's happening on a Green Roof and then integrate that with a building energy simulation model. So this Green Roof model that we developed includes the way in which vegetation shades the roof from solar radiation and also interacts with the long wave radiation leaving the surface of the rooftop and it also includes the evaporative cooling effects of the green roof and the way in which vegetation affects the near surface wind speed and hence the convection of heat; of sensible heat into the environment. The model also captures the role of heat storage and transport in the soil that depend significantly on the level of moisture on the soil.

Slide 14: Green Roof Energy Model Summary

David Sailor: So we developed that model and implemented it in a building energy stimulation software package called EnergyPlus. So as of April 2007, our model was standard in the standard release of EnergyPlus from the U.S. Department of Energy and the inputs for the model are the standard source of parameters that you would use in any building energy simulation software package in terms of things like building details and schedules.

You need to have a weather file but you also need the additional inputs that describe the Green Roof itself, the various design parameters, the leaf area index, the types of vegetation, the height of vegetation, the density and also precipitation data and whether you're irrigating the roof. The model output then presents hourly building electricity and natural gas use and so, by integrating a physically based model and then validating it with the observed data that we found from various projects around the country; we are now able to quantitatively estimate the impact of any Green Roof on any building in any climate.

Slide 15: Example Simulation

David Sailor: So just as a very quick example, we've done simulations for a large number of different types of buildings; this one happens to be just a simple residential two-story building in London. If you look at the impact in the graph in terms of the cooling electricity saving of the Green Roof relative to a convectional roof, of course, you see what you'd expect which is a significant cooling energy savings in the summer. However, there's a portion of the year in the other months in particular where they store heat in the building actually contribute to increased electricity for air conditioning.

And if you look more specifically, just at the hourly consumptions over the course of a single day in, say, in June as shown here – even though the net effect of the Green Roof is clearly a reduction in electricity for cooling, it's interesting to note that the thermal map of the roof actually leads to a small cooling penalty in the early morning hours. This is more than compensated for by the savings in the afternoon and evening hours but it's important to recognize that you have these tradeoffs going on both diurnally across a single day but also across the seasons.

Now what's particularly interesting in this example is that if you look then at the predictive annual heating energy savings of the Green Roof relative to conventional roof, you actually see a fairly substantial gas saving – again it's associated with the fact that the roof – a Green Roof adds insulation in the winter so it has benefits both in summer and in winter, in contrast to something say like, a cool roof that would have a large benefit in summer and a small penalty in winter.

Slide 16: A Green Roof Energy Calculator

David Sailor: So that tool is great for us but one thing that we recognized was that in order to use that kind of tool you really need to have building energy modeling expertise. And we wanted to create a tool that was more accessible to those who were not energy modeling experts and so we are in the process, with funding from the U.S. Green Building Council, of creating a simplified Green Roof energy calculator.

And so what we do is we used the detailed energy model that we've developed for EnergyPlus, that's a model – a large number of proto-typical building, we've – so far we've isolated 100 North American cities that we're looking at and for each prototype building, we stimulate a large variety of Green Roof implementations and also conventional and cool roof control cases to compare the performance again. And so we used the model output then to populate the database and – sorry about that – and we used that database then to drive this – what will be a web-enabled resource so that the user can fairly, simply, essentially interpolate within that database to represent the type of roof that they're interested in exploring.

Slide: The Urban Heat Island

David Sailor: So switching gears now, to talk a little bit about the Urban Heat Island effect, of course all of this – this whole discussion that I'm engaging in here is focused on the energy balance of the roof top and so obviously, the way in which a Green Roof impacts the building is going to impact the building energy use but also the heat then convected into the urban environment and so there's clearly a Heat Island impact potential.

And so if you look at this – this figure here just gives you the general sense of what the various contributors to the Heat Island are, and Neelam already went over this. So in particular, a Green Roof has the potential to provide both evaporative cooling on the building rooftops surfaces, and to modify the sensible heat exchange as I suggested having benefits in terms of reducing sensible heat during the day but perhaps a penalty in increased sensible heat at night.

Another thing to note is that a lot of Heat Island mitigation strategies focused at the near surface, whether it's paving or street trees, both cool roofs and green roofs focused at roof top level which, in a city, can be hundreds of feet above the ground level. And so its impact on the near surface thermal environment is not as significant.

Slide 18: Green Roofs and the UHI – Portland Oregon

David Sailor: So, I wanted to highlight a few Heat Island studies that have happened in the past decade. The first one is a study that we were involved with, where we were looking at how green roofs might impact the Urban Heat Island of the city of Portland. Specifically, the city asked us the question what impact might there be if the entire Central East side industrial district were redeveloped to include 100 percent green roofs over the next, say, 50 years?

Slide 19: Results: Heat Island Reduction

David Sailor: And so what we did was we applied a regional or mesoscale atmospheric model and the modified region in our domain is shown here with the red dash line. We ran this model for both the control case but then also for a case in which every roof top in the region was modified to be a green roof and – if my video works here – you can look at the temperature perturbation associated with the green roof over the course of the day. So those contours were just 2/10ths of decreased contours, and what you find out is that in the peak of a summer day, massive greening of the roof tops in that region could reduce peak air temperatures by about one and a half degrees Fahrenheit.

Slide 20: Green Roofs and the UHI – New York City

David Sailor: Moving on to a study that was conducted by some researchers at Columbia University – well, what they did was they used remotely sensitive thermal images of the surface of New York City. They combined that with land use data to estimate the potential for green roofs to reduce surface temperatures, and what they found was that green roofs could reduce average surface temperatures by nearly one degree Celsius. And while this result is important, we tend to be more interested in the air temperature Heat Islands and their approach was not able to estimate that. So that's the one question mark in terms of their modeling.

Slide 21: Toronto Canada – Control Simulation

David Sailor: In a third study, again this is a study somewhat similar to the one that I presented as the work that we had done in Portland. Brad Bass and colleagues at the University of Toronto and Environment Canada also used a regional-scale atmosphere model. What they did, first of all, was they represented the current positions in Toronto – as sort of a baseline.

Slide 22: Temperature change with green roofs and urban vegetation

David Sailor: Then they modified the model to include a combination of green roofs and urban vegetation. So this was not exclusively a green roof study but rather a combination of green roofs and urban vegetation at the street level. And this figure shows the – I'm sorry – a contour plot of the temperature differences between the green case and the control. And their results suggest that the combination of both green roofs and urban vegetations could reduce urban temperatures – urban air temperatures by one to two degree Celsius, but that – what part of that was due to the green roofs is not entirely clear because they didn't isolate the green roofs in the study.

Slide 23: PV and Green Roof Integration

David Sailor: And finally, I want to sort of segue into a little discussion of some ongoing research that we have going on here at Portland state. This is an NSF-funded project that confronts the notion that the rooftop design decision is sort of an either or issue where you have to decide, "Do I want a green roof?" Or, "I want a white roof," or, "I want to put photovoltaic panels on my roof."

So in this study, we're specifically looking at potential synergistic interactions between photovoltaic panels and green roofing located underneath the panel. And the basic premise is that the panel efficiency will improve as the green roof lowers the effective operating temperatures of the panel. At the same time, the shading of the panel may benefit both vegetation health and diversity in what is otherwise a rather harsh environment on the building rooftop.

Slide 24: Energy Balance Graphic

David Sailor: And so this graphic simply suggests the energy balance we're looking at.

Slide 25: Roof design affects sensible heating of the urban environment

David Sailor: Some of our early model results in looking at what the rooftop design decision does to the sensible heat release in the urban environment show that, of course, a traditional roof dumps a lot of heat into the environment during the daytime on a hot summer day. Both the white roof and the green roof, they'll dump less heat, perhaps about 50 percent less during the day. However, green roof will actually store heat and release it at night so it releases more heat at night than either traditional or white roof.

Slide 26-27: Pictures

David Sailor: And so here are a couple of pictures of our initial study site. We have four of these trays each with four panels, and we've recently seeded them. We've got sedum now, or several species of sedum growing. And we're still early into the project, but it should have some interesting results by the end of this summer.

Slide 28: Some final thoughts…

David Sailor: And so just to wrap up, just some summarizing comments, final thoughts here. The energy performance of green roofs depends upon many factors; growing media, plant coverage, plant type, building characteristics, weather conditions which include, of course, geographical location. Also the green roofs not only impact air conditioning, but in many applications, have even more important impacts on wintertime heating loads.

I'd also like to draw attention to the fact that the energy performance depends very much on what you choose for your control or your baseline that you compare them against, whether you're comparing against a traditional roof, a dark roof or a cool roof matters. And finally, green roofs can contribute to the heat island mitigation but this is complicated by thermal storage issues which result in more nocturnal heating in the urban environment than other roofing alternatives. And so – I'm sorry.

Slide 29: Questions?

David Sailor: So with that, I'll conclude and I do welcome questions, of course, at the end of the session, but also feel free to contact me by my e-mail if you have any lingering questions. That concludes my presentation.

Neelam Patel: Thank you, Dave. That was an excellent presentation that presented a balanced view of using green roofs for both energy conservation as well as heat island mitigation.

And as I mentioned in my presentation, it is important to think about heat island mitigation especially – and including green roof from the multiple benefits prospective. And we focus in on two multiple benefits up to this point, but our next presenter, Jason Berner, will talk about the stormwater mitigation benefits of green roofs. And before we get into that, I just want to reiterate to please send in your questions with the presenter that you would like to answer, address it to the presenter that you would like to answer the question.