UPDATE: THE GREEN-ROOF INTEGRATED PV CANOPY STUDY AT BRONX DESIGN AND CONSTRUCTION ACADEMY

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ABSTRACT

In the urban environment, space is a premium. In terms of real estate, no space can go unused and rooftops are fair game particularly in the realm of energy efficiency.

Both PV and green roofs are widely employed strategies for effectively using a building's roof space to reduce energy loads, but they have largely been studied independently of each other. Few examples of research exist that study the synergistic effects of combining these two technologies.

In collaboration with Columbia University, Energy-Environment Research Club (E2RC) students and teachers at Bronx Design & Construction Academy build a model Green Roof Integrated Photovoltaic Canopy in an effort to test this claim.

Bronx Design & Construction Academy is a Career & Technical Education High School situated in The South Bronx, one of the poorest congressional districts in the United States. Our Energy-Environment Research Club (E2RC) provides students with unparalleled hand-on instruction in renewable energy and sustainable home design.

Last year E2RC students presented at the American Solar Energy Society (ASES) World Renewable Energy Forum. This year they took 2nd place for all of the Americas in the Zayed Future Energy Prize where they presented at the annual World Future Energy Summit (ADSW) during the Abu Dhabi Sustainability Week.

This update evaluates over one year of experimental data collected from four test apparatuses; representing a standard built-up roof (control), a green roof, a standard fixed-tilt photovoltaic system on a built-up roof, and a Green Roof-Integrated PV- canopy (GRiPV-c) system. We use temperature, relative humidity and solar insolation data to quantitatively model the positive impact of a combined green roof and photovoltaic canopy system on the PV system's efficiencies, and the insulative value of the roof surface. We find the strongest increases versus our control roof in the combined GRIPV-c system.

1. INTRODUCTION

Many advantages exist to the widespread diffusion of green roofs throughout an urban environment such as New York City. An increase in permeable surfaces will decrease rainwater runoff during precipitation events, while plant growth and subsequent evpotranspiration help sequester CO_2 and decrease the urban heat island effect. Rainwater runoff mitigation is one of the primary reasons why NYC mayor Michael Bloomberg's PlaNYC initiative has thrown its support behind green-roofs. PlaNYC hopes to make 90% of the city's waterways suitable for recreation by 2030 and a major part of this challenge is dealing with sewer overflow during precipitation events. In this plan, 40% of the rainwater runoff is to be eliminated through an increase in the city's green surfaces—many of these, green roofs. (1)

Solar PV installations, by contrast, do not deal with rainwater runoff or urban heat-island issues, but *do* strongly decrease environmental pollution and stress on the grid from offsetting dirty electricity during peak demand times.(2) PlaNYC, the City University of New York (CUNY) and the Department of Energy all support the rapid growth of PV deployment on the city's rooftops via the New York Solar America Cities Initiative. (3) By streamlining the permitting and approval process and strengthening the local incentive structure, NY Solar America Cities initiative projects an increase to 45-75 MW of PV capacity in the five boroughs by 2016.

In this paper, we conduct an empirical study to examine the synergistic benefits gained by combining these two environmentally friendly roof treatments: increased PV electrical production from lower cell temperatures and increased thermal resistivity of the roof. By showing that the technologies are not mutually exclusive, we make the case that forward-thinking municipal organizations like PlaNYC should consider promoting the installation of combination GRiPV-c systems in addition to their promotion of each as stand-alone.

Of no less importance, we discuss the effort made to make this study an experiential learning experience for students at Bronx Design & Construction Academy (BDCA). High school science club students at BDCA were involved in every aspect of the project, from design of the experimental setup, to metrology, to analysis of data from the data acquisition system and dissemination of the results. A second primary aim of this paper is our discussion of how we involved the students, and ways in which this research can be expanded to provide further opportunities for students at BDCA and other schools.

2. BACKGROUND

Few studies have examined the synergies between green roofs and Photovoltaic (PV) arrays and there remains a great need for further testing. Several notable examples provide a foundation and justified the need for this continued research.

For example, Brownson, Iulo and Witmer of Penn State presented results at ASES 2010 outlining the gains in performance (both of the green roof substrate and of a PV system atop it) based on analysis of Penn State's 2009 "Natural Fusion" home they designed for the 2009 Solar Decathlon. The Natural Fusion home employed deep sedum trays on the roof with low-lying mixed vegetation and a canopy several inches above holding Solyndra™ CIGS (Cadmium-Indium-Gallium di-Selenide) PV cylinders. Although the Natural Fusion GRIPV system described in the papers by Brownson et al. provides a summary description of this interesting application of a novel PV technology, a 2002 paper by Kohler et al., presented at Rio '02, examines and identifies the key synergies unique to GRIPV systems in much more thorough detail. (4-6)

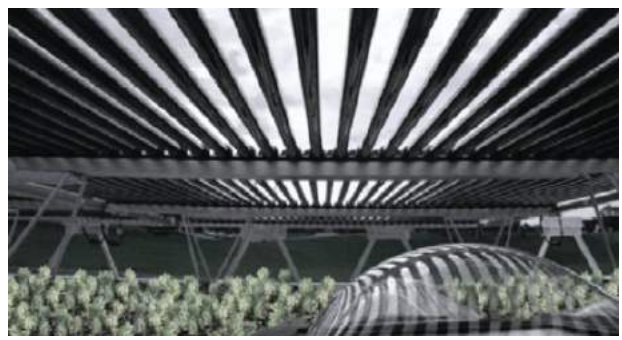

Fig. 1: Solyndra/ Green-roof canopy atop the Natural Fusion home.

Furthermore, Kohler et al. examine somewhat un-conventional GRIPV designs in that their green roof incorporates plants growing up to a height of 40 cm and required periodic (annual trimming) to maintain height. Fig. 2 displays one of these GRIPV-tested systems which features 1-axis tracking and multi-crystalline PV modules.(6)

The two positive interactions measured and identified in the study were:

- Green roofs reduce operation temperature of the PV system, thus increasing efficiency and energy yield
- The PV array offers shading for the green roof,

thus improving growth of plants and increasing species variety.

We also seek to measure this reduction in back-of- module temperature, given the temperature drop in the local microclimate from the green roof's evapotranspiration in our study and thereby simulate performance gains vis-à-vis a more traditional PV system.

Fig. 2: The GRIPV system with intensive green roof and monocrystalline PV in Kholer et al., 2002.

Both the GRIPV systems referenced above share the common shortcoming of not allowing for synergistic use of space on the roof. On buildings were point-loading considerations are not an issue and green roofs provide the potential for a recreational park-setting for the occupants, the PV array would be better situated at an elevation above head-height.

Our experimental study explores and quantifies the benefits outlined by Kohler et al. under a new design paradigm: the GRIPV-canopy. In addition to these benefits, we will be simulating the reduced burden on HVAC loads given reduction in surface temperatures and addition of photovoltaic generating capacity.

3. STUDY SITE: ABOUT THE BDCA

Bronx Design & Construction Academy1 is located in The South Bronx, one of the poorest congressional districts in the United States. BDCA's certified Career and Technical Educational (CTE) programs allows economically disadvantaged students to get unparalleled hand-on instruction in the trades, thereby provide a way out of the poverty cycle. A majority of BDCA graduates will find jobs upon graduation. BDCA high school offers endorsed diplomas in the Building Trades including plumbing, carpentry, electrical practice and installation, architectural drafting, and Heating, Ventilating, and Air Conditioning. These diplomas enable graduates to obtain Master Licenses from the NYC Department of Buildings. Once licensed, graduates can open their own contracting firms.

Additionally, BDCA (formally Alfred E. Smith CTE HS) partners with Edward J. Molloy for Initiative for Construction Skills that provides students the unique opportunity to enter NYC Unions upon graduation. Since 2001 Alfred E. Smith has repeatedly helped place over 20 percent of each graduating class in high-level union jobs; including the MTA, Metro North, Long Island Railroad, Smalls Electrical Construction Inc., and New York City School Construction Authority to name a few. Many others find professional jobs in Plumbing, Electrical, Carpentry, Auto Mechanics, HVAC as well as Pre Engineering. AES is associated with New York Electrical Contracting Association, New York Building Congress, New York Building and Construction Trades Council of Greater New York, Building Trades Employers Association, Architectural Construction and Engineering (ACE) Mentoring program.

Alfred E. Smith CTE HS also offers the training to put technical education to the test in regional and National competitions. Year after year Smith students practice what they've learned, compete, and consistently take home trophies from Skills USA and the National Automotive Technology Competition.

Fig. 3: Bronx Design & Construction Academy students presenting GRiPV-c study results to a local middle school during Sustainability Week in Abu Dhabi.

Bronx Design & Construction Academy students helped design and construct the model homes used in our study. Each home sports a different rooftop coverage type: Control with gravel bed, Green roof only, Mock solar PV coverage only, and Green roof with mock solar PV coverage. In addition to helping design and build the homes, the students helped set up the data acquisition system, helped analyze the data and made a presentation on study design and initial findings to an audience of Columbia University Graduate students.

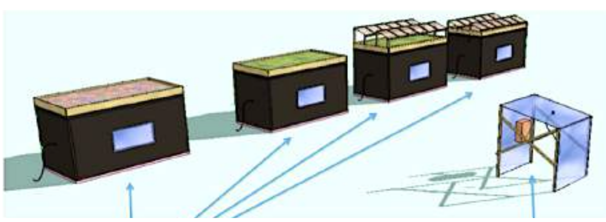

Fig. 4: The four test houses as originally designed and the data acquisition hub. From left to right; gravel roof, green roof, GRiPV-c, gravel + PV.

It is experiences like these that are formative in helping to not only break the poverty cycle through knowledge-sharing and experiential learning, but to train the next generation of knowledge leaders that will magnify the voice of renewable energy in the public arena.

4. METHODOLOGY

4.1 Experimental Setup

To assure that the data collected is consistent and comparable, specially designed monitoring enclosures were constructed and co-located adjacent to each other. Four enclosures were designed to collect the data used to calculate the performance and efficiency improvements of the GRIPV-c system. Additionally, a stand to hold a pyranometer and ambient temperature and relative humidity monitor was constructed and co-located with the monitoring enclosures.

The enclosures are designed to withstand the loading of the maximum roofing weights and to be sealed with silicone and EPDM to prevent thermal leakage. Each 'house' was constructed by the students with a structural skeleton built from pine 2x2 (5 cm x 5 cm) studs, ¼" (6.4 mm) plywood, and wrapped in " (25 mm) rigid foam insulation. Each house was then painted a matte black to absorb the maximum amount of solar radiation so that temperature swings recorded by the data acquisition equipment would be most readily visible.

Fig. **4** shows all four roofs as initially designed. On the gravel-roofed house, we monitor internal temperature, and near surface roof temperature. On the standard green roof house, we also monitored internal temperature, and near surface green roof temperature. Varietal sedum trays were used for the green roof materials. The tray depths are approximately 4". The gravel + PV roof is meant to synthesize a standard solar roof installation upon a built-up-roof. Monitoring parameters for this enclosure include internal temperature, near surface roof temperature and back-of-module (BOM) temperature. PV arrays were synthesized from black-painted Plexiglas rectangles at 45° tilt (from horizontal). Monitoring parameters for the GRiPV-c roof include internal temperature, near surface roof temperature and back-of-module temperature.

In addition to the sensors on the houses, we also measured ambient relative humidity and temperature and plane of array (POA) irradiance using thermistors and a Licor pyranometer. All parameters were originally intended to be sampled at 15-minute intervals throughout the study period.

4.2 Data Collection and Analysis

Due to instrumental error, only the instrumentation monitoring the GRiPV-c and PV + gravel roof houses were sampled at the proper interval and thus several months of data were lost. For this report, as a result, we only analyze the performance deviations between the GRiPV-c house and the PV + gravel house.

Fig. 5: Bronx Design & Construction Academy students calibrating and labeling the environmental sensors through the Data Acquisition System.

All sensors connect to two HOBO Data Acquisition System hubs from OnSet Computers. Data collection started in May 2011 and has been ongoing in 15-minute intervals 8 months as of this writing for the two roofs with PV arrays.

Silicon-based Photovoltaics are adversely affected (in terms of solar/electric conversion efficiency) by elevated temperatures and to a lesser extent by decreased solar radiation. To synthesize the performance divergences between our PV systems from collected data, we created a model using the Shockley diode equation an parameters from the *JAMS(L) 72-180* monocrystalline silicon JA Solar module.[1]
We end up with a model of the form:

$$P_{CAP} \cdot E \cdot \Delta \left(T_{BOM} \left[E\left(\alpha_{\varphi}\eta + \alpha_{\vartheta} \right) + \beta_{\varphi}\eta + \beta_{\vartheta} \right] + E\left(\gamma_{\varphi}\eta + \gamma_{\vartheta} \right) + \delta_{\varphi}\eta + \delta_{\vartheta} \right) \cdot 10^{-4}$$

In this equation, P_{CAP} is the system capacity (kW_{DC}), E is the instantaneous radiative flux measured by the pyranometer (in suns), Δ is the de-rate factor (chosen as ~79% of peak capacity for the analysis in this paper), T_{BOM} is the instantaneous BOM module temperature measured on the synthetic array, η is the module efficiency at STC, and $(\alpha,\beta,\gamma,\delta)_{(\phi,\theta)}$ are parameters derived from linear regression as outlined below:

	ϕ	ϑ
α	-3.6878216	0.00241131
β	-38.392567	0.00230441
γ	1572.74065	0.02807582
δ	9503.72045	0.02809402

Measuring true thermal performance of the roof types was beyond the scope of what our experimental setup would allow. Thus, we calculated the difference between the roofs by measuring the divergence in mean temperature over given time periods and the difference in the standard deviation of temperatures within each house and at the surface of each house. The latter gives an impression of the variability of the temperature parameters. A lower variability (and thus standard deviation) of the internal temperatures would indicate better thermal insulative properties while lower variability of the surface temperatures would indicate less extreme surface temperature swings throughout the day.

5. RESULTS

Using the models described above, we analyze measured temperature data and find that the GRiPV-c house has lower variability and lower mean temperatures for every parameter.

Over the time period 5/30/11 through 1/25/12, the variability (σ) of temperatures inside the gravel-roofed house was 5.83% higher (10.0 °C vs. 9.45 °C) than the variability of temperatures inside the GRiPV-c roof house. Similarly, mean temperatures inside the gravel-roofed house were 4.61% higher than those in the GRiPV-c house (18.4 °C vs. 17.6 °C)

Mean *surface* temperatures were 2.24% higher on the gravel roof (19.3 °C) than on the GRiPV-c roof (18.9 °C). The variability of surface temperatures (σ) was 1.98% higher on the surface of the gravel roof (10.2 °C) than on the GRiPV-c roof (9.9° C).

Perhaps most importantly, we see a 2.42% increase in the performance of a PV system (in terms of the quantity of electricity generated) with thermal-sensitivity parameters of

[1] The JAMS(L) 72-180 solar module was chosen as the physical basis for our modeling because JA Solar was as of Q1 2011 the dominant player in solar module sales worldwide. It was thought that by using specifications from the best selling solar module as such, our results would best allow themselves to be generalized.

the JAMS(L) 72-180 module. A 500 kW GRiPV-c system at latitude tilt in New York State that produces 60,900 kWh/year, a 2.42% increase in performance means an extra $88,500 in revenue over its 30-year lifetime (assuming it is locked in at a $0.20/kWh PPA-rate.) If just 10% of the 70 MW projected by the PlaNYC team and NY Solar America Cities Initiative is GRiPV-c, this constitutes $1.2 million in increased revenues over a 30-year system lifetime period.

6. DISCUSSION

We are still collecting and analyzing data from this last year. Until we have included all of this data, projections of variability and mean temperature are biased since the data doesn't represent a full calendar year. However, it valuable to examine the change in parameters for a single summer month, as energy costs on day-ahead and real-time markets can increase drastically at peak summer hours.

Variability of temperatures inside the gravel-roofed house were 16.5% higher than in the GRiPV-c house in June. Similarly, variability of surface temperatures on the gravel house were 10.69% higher on the gravel-roofed house than the GRiPV-c house during the same month. Mean internal and surface temperatures were 5.1% and 1.73% higher on the gravel roof than the GRiPV-c roof, respectively and PV performance saw a 2.56% increase in June.

5. CONCLUSIONS

These results show a clear performance gain on a GRiPV-c roof versus a standard ballasted PV system on a built-up-roof. Not only was PV performance shown to be superior, but from lower average roof-surface temperatures, lower average internal temperatures and lower variability of these temperatures, one can assess that the thermal resistivity of the GRiPV-c roof system is superior to the gravel + PV more "traditional" roof system.

This work constituted an in-depth experiential learning opportunity for Bronx Design & Construction Academy students involved in the project. For this reason, and for the aforementioned performance benefits of such systems, we are currently seeking partners to help construct an actual GRiPV-c array on the roof of BDCA in the Bronx.

6. ACKNOWLEDGEMENTS

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Bronx Design & Construction Academy provided unparalleled support by hosting the site of this pilot study, and creatively embedding the GRiPVc study into their science and Career & Technical Education Curriculum.

Bronx Design & Construction Academy students have been vital in building and maintain the system.

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