Study of Storms on the Javits Center Green Roof

A. Cho, H. Sanyal, J. Cataldo

***Abstract*—**A quantitative analysis of the different variables on both the South and North green roofs of the Jacob K. Javits Convention Center was taken to find mathematical relationships between net radiation and evapotranspiration (ET), average outside temperature, and the lysimeter weight. Groups of datasets were analyzed, and the relationships were plotted on linear and semi-log graphs to find consistent relationships. Antecedent conditions for each rainstorm were also recorded and plotted against the volumetric water difference within the lysimeter. The first relation was the inverse parabolic relationship between the lysimeter weight and the net radiation and ET. The peaks and valleys of the lysimeter weight corresponded to valleys and peaks in the net radiation and ET respectively, with the 8/22/15 and 1/22/16 datasets showing this trend. The U-shaped and inverse U-shaped plots of the two variables coincided, indicating an inverse relationship between the two variables. Cross variable relationships were examined through graphs with lysimeter weight as the dependent variable on the y-axis. 10 out of 16 of the plots of lysimeter weight vs. outside temperature plots had R^2 values > 0.9. Antecedent conditions were also recorded for rainstorms, categorized by the amount of precipitation accumulating during the storm. Plotted against the change in the volumetric water weight difference within the lysimeter, a logarithmic regression was found with large R^2 values. The datasets were compared using the Mann Whitney U-test to see if the datasets were statistically different, using a significance level of 5%; all datasets compared showed a U test statistic value, proving the null hypothesis of the datasets being different from being true.

***Keywords*—**Green roof, green infrastructure, Javits Center, evapotranspiration, net radiation, lysimeter.

I. INTRODUCTION

GREEN roofs were first established decades ago, and over the course of recent decades, they have become a staple of environmental consciousness in urban locations. They provide a host of benefits, such as improved stormwater management, insulation to regulate building temperatures, reversal of the urban heat island effect, and extensions of ecological corridors [1], [2].

One of the most significant urban green roofs is The Jacob K. Javits Convention Center Green Roof. The JJCGR is located in New York City, and is the second largest green roof in the United States, with a surface area of 27,316 m^2 [3]. Sensors on the roof have been collecting 6 years of data, recording quantitative long-term rainfall-runoff response. The drainage system was custom built to irrigate the green roof and the three tributary areas, each of which corresponds with a Parshall Flume, as shown in Fig. 1. Each tributary area has three weighing lysimeters, which are made up of square pieces of green roof matrix encased within a 0.372 m^2 metal box. The entire lysimeter system extends 0.089 m above the top of the green roof, and is surrounded by four sloped sections of green roof to reduce thermal effects [3].

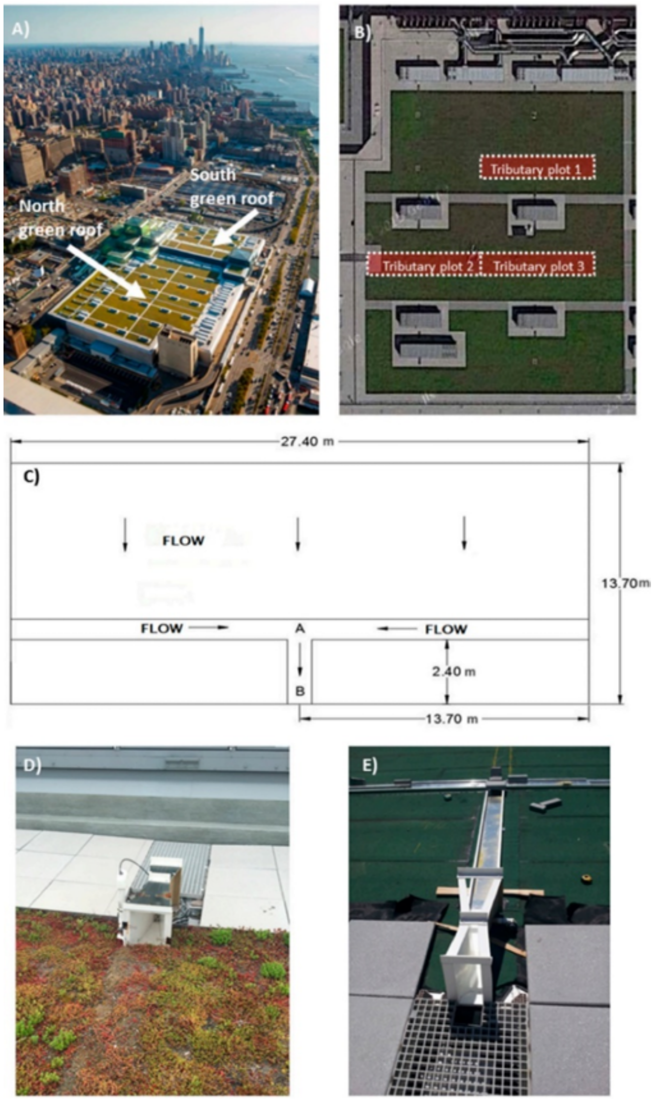

Fig. 1 (a) Bird's eye view of Javits Center green roof; (b) The three tributary areas of the JJCGR where runoff is collected; (c) flow paths across tributary areas; (d) end of tributary area (point B in (c)), where flow enters the Parshall flume; (e) construction of Parshall flume and flow channels in Jacob Javits Center Green Roof

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TABLE I
DATA COLLECTED AND MEASURED DURING STUDY OF JACOB JAVITS CENTER GREEN ROOF

Date	Values Compared (X vs. Y)	X-Axis	Y-Axis	Antecedent Period (min)	Type	Equation	R^2
8/22/2015	Lys. Weight vs Time (pre 2PM)	Time (hrs)	Lys. Weight (lbs)	24385	Linear	-14.236x + 85.196	0.9945
8/22/2015	Lys. Weight vs Time (post 2PM)	Time (hrs)	Lys. Weight (lbs)	24385	Linear	10.527x + 70.957	0.8205
8/22/2015	Lys. Weight vs Time (pre 1PM)	Time (hrs)	Net Rad. & ET (W/m^2)	24385	Linear	.0415x - 0.0096	0.9215
8/22/2015	Lys. Weight vs Time (post 1PM)	Time (hrs)	Net Rad. & ET (W/m^2)	24385	Linear	-.0485x + 0.039	0.9048
8/22/2015	Lys. Weight vs Net Rad. & ET	Net Rad. & ET (W/m^{2}2)	Lys. Weight (lbs)	24385	Linear	-356.41x + 81.882	0.9329
8/22/2015	Lys. Weight vs Net Rad. & ET	Net Rad. & ET (W/m^2)	Lys. Weight (lbs)	24385	Semi-log	$81.899e^{-4.479x}$	0.9301
8/22/2015	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	38880	Linear	-.48986 + 91.589	0.8016
8/22/2015	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	38880	Semi-log	$92.557e^{-.006x}$	0.7999
1/1/2021	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	38880	Linear	11.936x +905.85	0.9818
1/1/2021	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	38880	Semi-log	$906.13e^{.0128x}$	0.9821
1/1/2021	Net Rad & ET vs Outside Temp	Net Rad. & ET (W/m^2)	Outside Temp (C)	38880	Semi-log	$2.0696e^{.0059x}$	0.9816
2/1/2021	Lys. Weight vs Time	Time (hrs)	Lys. Weight (lbs)	38881	Semi-log	$y = 78.07e^{0.82x}$	0.971
2/1/2021	Lys. Weight vs Time	Time (hrs)	Lys. Weight (lbs)	38881	Linear	72.39x + 78.06	0.97
2/1/2021	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	24385	Linear	8.2644x + 92.453	0.7923
2/1/2021	Lys. Weight vs Outside Temp	Outside Temp (C)	Lys. Weight (lbs)	38881	Semi-log	$92.49e^{.0865x}$	0.7951
	8/22/15 vs 1/1/21 Data Comparison	Outside Temp (C)	Lys. Weight (lbs)	N/A	Linear	N/A	N/A
	8/22/15 vs 1/1/21 Data Comparison	Outside Temp (C)	Lys. Weight (lbs)	N/A	Semi-log	N/A	N/A
	1/1/21 vs 2/1/21 Data Comparison	Outside Temp (C)	Lys. Weight (lbs)	N/A	Linear	N/A	N/A
	8/22/15 Time Trends	Time (hrs)	Lys. Weight (lbs), Outside Temp (C)	N/A	Linear	N/A	N/A
	1/1/21 Time Trends	Time (hrs)	Lys. Weight (lbs), Outside Temp (C)	N/A	Linear	N/A	N/A
	2/1/21 Time Trends	Time (hrs)	Lys. Weight (lbs), Outside Temp (C)	N/A	Linear	N/A	N/A
	Lys. Mass vs Antecedent Dry Period	Antecedent Dry Period (hrs)	Lys. Weight (lbs)	N/A	Linear	N/A	N/A

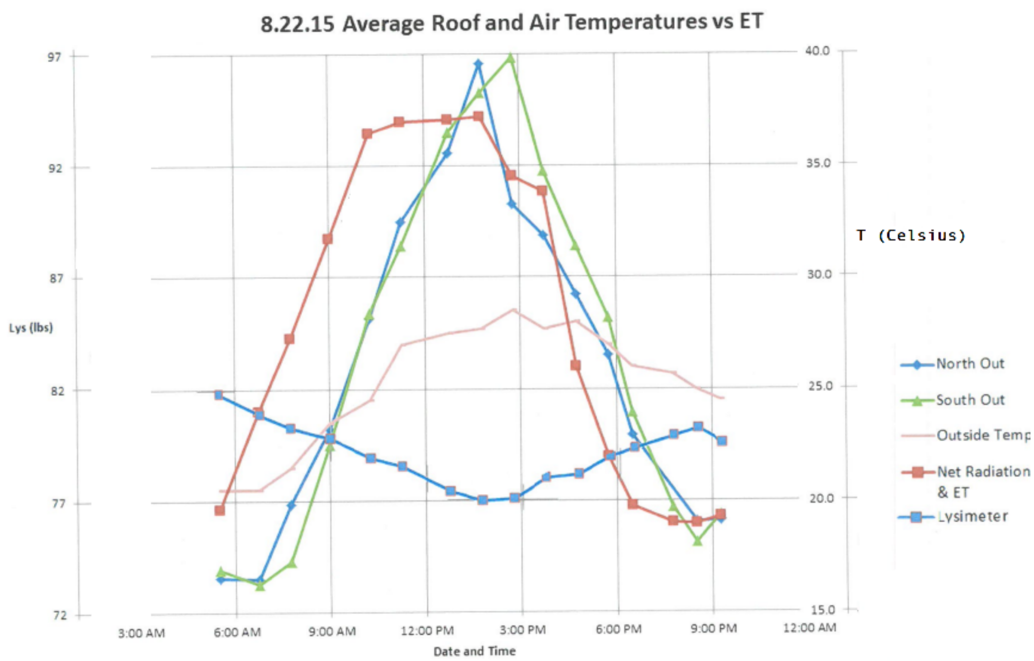

Fig. 2 Net radiation and ET, lysimeter weight, and outside temperature compared over time on 8/22/15

The green roof itself is built with the following components: a pre-vegetated sedum mat, a growing medium ranging in depth of 1.5 cm, a fleece layer for additional retention, a 2 mm drainage layer, and a root barrier. The materials were obtained from Xeroflor, New York. The roof finished construction in the spring of 2014, and is separated into a north and south section [3], [4]. These sections are also shown in Fig. 1.

One of the most significant processes which occurs on a green roof is ET. In fact, studies have shown that ET is the most important process for reduction of heat flux, and can be responsible for up to 30% of building cooling [1], [5]. Over the course of this study, the radiation and ET from the JJCGR are measured, using crop data as the metric, as well as the readings from the lysimeters located in each of the green roof tributary areas. These data are compared graphically to determine a relationship between the variables.

II. Results

The lysimeters were used to record the volume of water retained within the soil layer, and recorded the weight with a sensitivity of about 1-2 grams [4].

The net radiation and ET were recorded on the roof using the Penman-Monteith method, which effectively estimates the ET data with respect to a reference crop and its consistent performance within both acrid and humid climates. These data, the lysimeter weight in grams, and the outside temperature were the three variables which were examined within the graphical analysis for trends and mathematical relationships, as seen in Table I [6].

As seen in Fig. 2, the trend between lysimeter weight compared to the net radiation & ET shows inverse relationships throughout the day between the two variables. For the 8/22/15 dataset, lysimeter weights peak around 6:00 AM at 82 pounds, from a low of 77 pounds, whereas during this time the net rad. and ET increases from its initial value. Net rad. and ET peaks to a maximum value around 10PM, while the lysimeter weight steadily decreases from its peak. The net rad. and ET make a negatively concave U shape with the lysimeter weight from about 12PM to 7:12 PM, with the vertex of both U-shaped curves located around 2:24 PM.

Similar trends are seen on 1/22/16, with an inverse relationship between lysimeter weight and net radiation & ET. On this date, lysimeter weight makes a U shape, peaking at 93 pounds at about 7 AM, before dropping to 91.7 pounds at 10 AM, and increasing thereafter. In contrast, net radiation & ET peaked at about 11 AM, decreasing thereafter, in a complete inverse of the lysimeter weight trend.

There is a trend between outside temperature and the lysimeter weight. All three datasets had an increase in lysimeter weight when the outside temperature increased, as can be seen in Fig. 3. All three datasets showed strong linear and exponential regressions on linear and semi-log plots respectively, as shown in Table I. All R^2 values and plots can be seen in Table I and Figs. 2-4.

The major trends which were seen throughout the datasets were the lysimeter weight positively correlated with temperature, and the inverse relationship between lysimeter weight and net radiation throughout the day. The first common trend appeared contradictory, as warmer outside temperatures would indicate more ET, as the warmer temperatures would encourage evaporation. The second trend of lysimeter weight inversely peaked and declined with the net radiation and ET. One consideration was the change in the water saturation of the soil based on temperature, a consequence of the lysimeter set up on the rooftop of the Javits Center, where it is more sensitive to humidity changes throughout the year [7].

A typical trend linear graph is shown in Fig. 4, which shows the lysimeter weight against time for the measurements on 2/1/21. There is an R^2 value of 0.97. Table I lists 22 linear and semilogarithmic plots which follow similar trends.

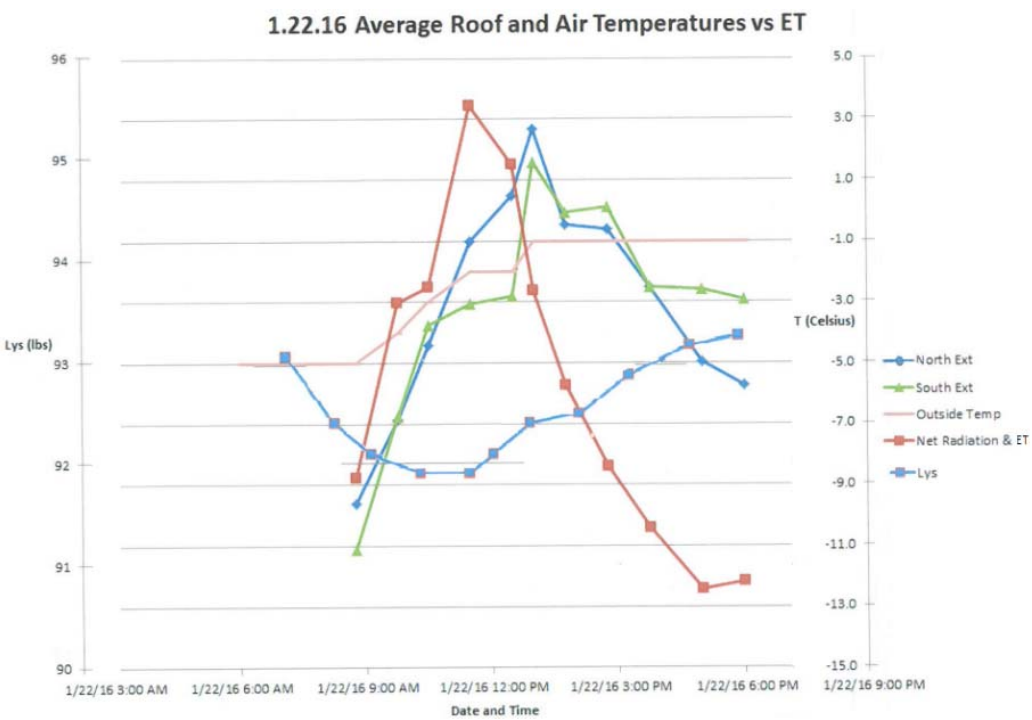

Fig. 3 Net radiation and ET, lysimeter weight, and outside temperature compared over time on 1/22/16

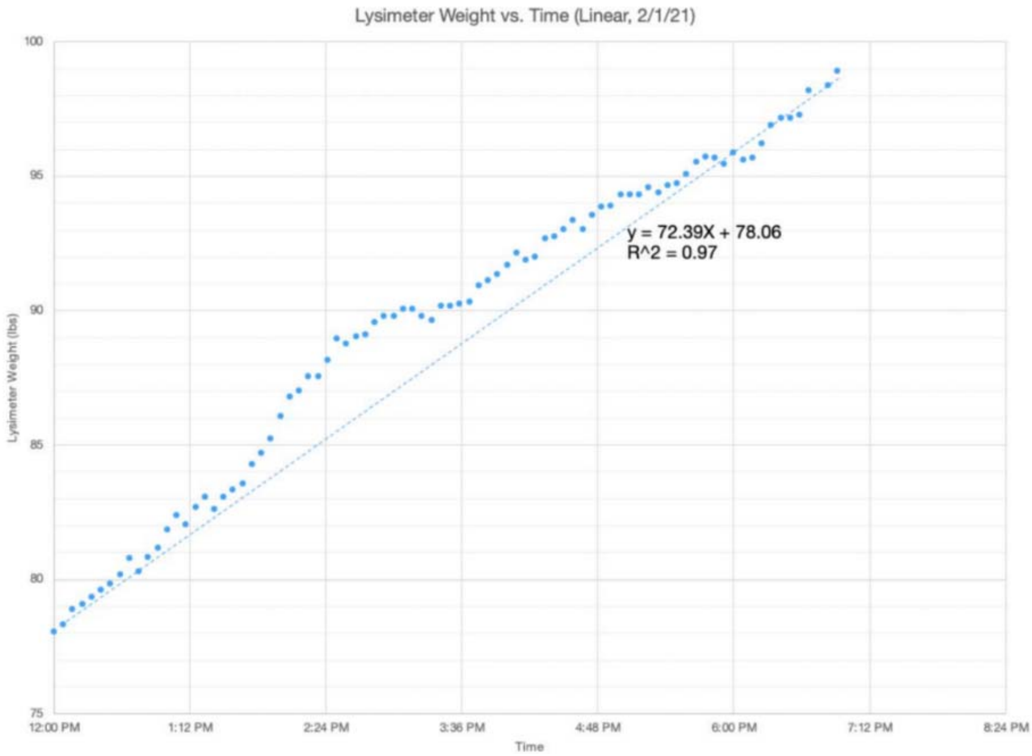

Fig. 4 Linear trend graph for lysimeter weight vs. time on 2/1/21

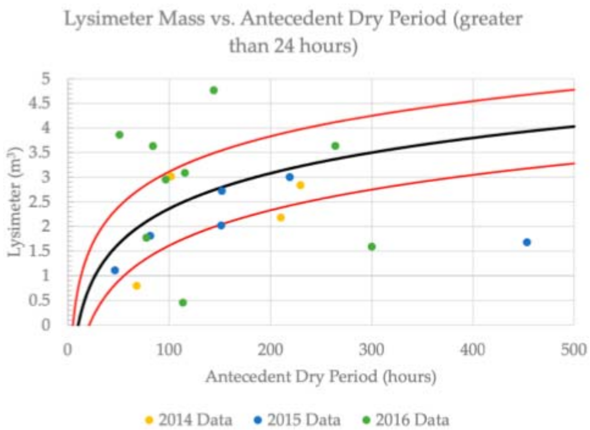

Fig. 5 Antecedent conditions for lysimeter recorded from 2014 to 2016, with red lines signifying standard deviation

When measuring the antecedent conditions, the change in water weight of the lysimeter was calculated. The change in the lysimeter weight was taken since the last storm, and was converted to the water weight collected, accounting for the porosity of the soil by finding the change in volume of the lysimeter before and after the storm to find the volumetric water outflow. This was plotted with the antecedent conditions of the storms to find a relationship between the change in volume the water weight of the lysimeter to the antecedent.

The antecedent conditions were recorded for datapoints within the Javits Centers to plot the antecedent dry period (Fig. 5) in relation to the volumetric water difference within the lysimeter between the period. This was calculated by finding the change in lysimeter weight from the start to the end of the dry period, which was converted into the change in volume taking into account the dimensions of the lysimeter and the porosity of the soil layer, which was then treated as the volumetric change in water within the lysimeter. This was used for rainstorms which fit under the heavy rain criteria, which was defined as storms with precipitation of more than 16 inches. This relation between the antecedent dry period in hours and the volumetric water difference was plotted and fitted with a logarithmic regression.

A Mann-Whitney U test was completed on the different datasets to compare the lysimeter weight, average outside temperature, net radiation, and ET. The datasets were compared, with the corresponding variables ranked between one another, resulting in different Mann Whitney U tests being conducted between the unique datasets. The data were ranked, and the U value was found for each pairing. Choosing an alpha value of 0.05, the critical U value for each sample size was found and compared to the U value found for each dataset. All corresponding datasets between three different dates had a p value of 0.05 and therefore, were significant results, accepting the null hypothesis and finding no significant differences between the selected populations.

III. Conclusions

Relationships between the lysimeter weight, outside temperature, and net radiation and ET were plotted on linear and semi-logarithmic plots and fitted with linear and exponential regressions respectively. The antecedent conditions were examined, and the relationship between the volumetric water difference within the lysimeter and the antecedent time between heavy storms were plotted and fitted with a logarithmic curve.

The inverse U shapes of the net radiation and ET throughout the days were seen, as the peaks and valleys of both variables coincided with one another.

A negative correlation was found in the data, with the net radiation increasing as the lysimeter weight decreasing, with R^2 values greater than 0.9.

Relationships such as the net radiation and ET vs. outside temperature and lysimeter weight did not lead to any significant regressions, while outside temperature vs. lysimeter weight showed significant regressions and similar tendencies when compared to one another. All four datasets showed a linear and exponential regression on linear and semi-log plots.

The advantages of the green roof in heat mitigation and reducing the continuous temperature within the Javits Center show its success in controlling heat throughout the different seasons. The data recorded on the Javits Center Green Roof within the 6 years of collection displays identifiable trends in the datasets, and its environmental impact and efficiency in care and maintenance are considerable arguments for replacing traditional roofing methods with green roofs. The plants offer more runoff pathways due to the roof irrigation system, and the stored water from runoff is collected and reused for water filtering and natural cooling systems, using gravity to move throughout the building, neutralizing incoming radiation from the sun. The green roof can provide an environmental benefit through the installation of more plants and greenery onto an urban landscape such as New York City.

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