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Energy Flow through the Onondaga County Convention Center Green Roof in Syracuse, NY

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ABSTRACT

Buildings in the Northeast U.S. with large interior open spaces and high ceilings require substantial amounts of energy to heat and cool the spaces. The objectives of this experiment are to model the heat flux across different layers of a green roof and to estimate the thermal resistance of the layers. The project will examine conditions in winter and summer, considering air temperature and snow cover on the roof. The scope of this study includes measurements of the transfer of energy through the green roof on the Onondaga County Convention Center in Syracuse, NY. The methods include collection of data from Campbell Scientific temperature probes at six heights through the roof layers, ranging from the Convention Center ceiling to the ambient air above the roof. The temperature data are stored in CR-1000 data loggers. Under certain conditions, the green roof is expected to be an effective barrier to energy flow across the roof. The implications of this work are a better understanding of how green roofs function as a barrier to energy loss from the building in winter and a barrier to energy gain from direct sunlight in the summer. This, in turn, can assist designers of green roofs in a variety of climates.

KEYWORDS

Green Roof, Energy Flow, Heating and Cooling, R-values

INTRODUCTION

Green roofs are sometimes used to reduce the amount of flooding and combined sewer overflow in a city caused by lack of surface area where rainwater can infiltrate into the soil. However, they can also have other benefits, such as reducing the heat loss during winter and reducing heat gain in summer, leading to reductions in energy used for heating and cooling.

For example, Jaffal et al. (2012) report a 6% reduction in annual energy demand in a simulation study with a single-family house when a green roof is added. Another simulation study by Zhang et al. (2017) shows the potential temperature reduction of the external surface of a building and subsequent energy savings with a green roof. Dahanayake and Chow (2018) have determined that green roofs and green walls reduce the surface temperature of buildings, therefore controlling the cooling load to maintain indoor temperatures.

The overall goal of this study is to determine the heat flux through the Onondaga County Convention Center green roof in different seasons, and to calculate the thermal resistance of the roof layers. Previous work on heat flux through this roof was based on a smaller dataset and produced preliminary findings for 2014-15 (Squier and Davidson, 2016).

This study looks at temperatures in different layers of the Onondaga County Convention Center green roof from December 2016 through February 2018. Heat flux was calculated for December 2016 until June 2017. Times in winter were chosen when there was sufficient snowpack to insulate the surface from variable air temperature, creating quasi steady state conditions in which the thermal resistance (R-values) were calculated.

METHODS

During construction of the roof, Campbell Scientific T109 temperature probes were placed in 4 roof layers (A, B, C, G); this was accomplished at 5 widely separated stations on the roof. Three more probes were affixed to the ceiling below at Y (**Figure 1**).

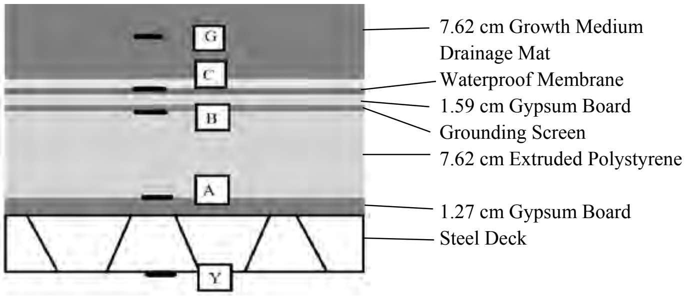

Figure 1: Layers of the roof and locations of the temperature sensors.

Because of possible malfunctioning probes, duplicate temperature sensors were placed in a number of roof layers. When analyzing the temperature data, some values from probes at stations 3 and 4 were flagged due to inconsistent temperatures for short time periods; the problematic data represent only a small fraction of the data from these sensors. Nevertheless, it was decided to exclude values from stations 3 and 4 in calculating average temperatures and R-values. Thus, data from only stations 1, 2, and 5 were used in the current study.

R-values were calculated over a period of high snow depth, 400-600 mm, which occurred over March 15-19, 2017 (**Figure 2**).

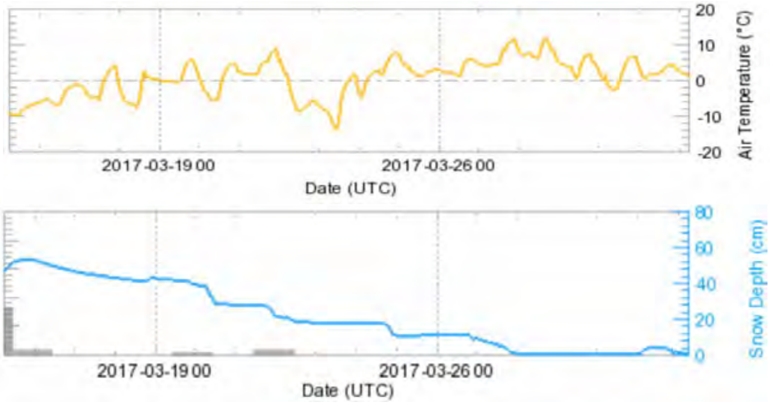

Figure 2: Air Temperature and Snow Depth as reported by the National Weather Service. The y-axis on the left side of both graphs corresponds to March 15, 2017.

The snow depth on the roof was assumed to be the same as the data collected by the National Weather Service station in Dewitt, NY, 4.1 km from the test site. This snow depth is consistent with the height of snow used by Squier and Davidson (2016) to calculate the R-values.

Fourier's equation was used for the steady state calculation of flux and resistance:

$$q = \frac{1}{R}\Delta T \tag{1}$$

where q is heat flux through the layers (W m^{-2}), R is the thermal resistance of the layers between the sensors (m^2 K W^{-1}), and ΔT is the difference in temperatures (degrees K) between the layers of the roof, calculated using the data from the temperature sensors. The R-values reported by the manufacturer are in **Table 1**. Additionally, the values calculated by Squier and Davidson (2016) based on limited data are in **Table 2.**

Table 1: Layers of the roof and their respective thickness and thermal resistance values as reported by the manufacturer.

Layer	**Thickness (cm)**	**Material R-Values (m^2 K W^{-1})**
Growth Medium	3.81	0.211
Drainage Mat	0.63	n/a
Waterproof Membrane	0.12	0.028
Gypsum Board 2	1.59	0.118
Grounding Screen	0.102	0
Extruded Polystyrene Insulation	7.62	2.64
Gypsum Board 1	1.27	0.079

Table 2: R-values calculated by Squier and Davidson (2016) at stations 1, 3, 4, and 5 from February 1-14, 2015.

	5	**1**	**4**	**3**
B-C (Gypsum Board 2)	0.245	0.170	0.180	0.268
C-G (Waterproof Membrane and Growth Medium)	0.216	0.306	0.218	0.241
Overall, A-G	3.100	3.116	3.038	3.149

RESULTS AND DISCUSSION

Using Fourier's equation, the R-values across the roof layers for March 15-19, 2017 are given in **Table 3**. Based on the difference in temperature between layers B and C in both **Table 2** and **Table 3,** the R-values at station 5 are higher than the R-values at station 1. Conversely, over C-G, values at station 5 are less than the values at station 1. Values for stations 3 and 4 as presented by Squier and Davidson (2016) could not be compared for March 2017 due to malfunctioning sensors. It should be noted that station 2 reported average values in between the values of stations 1 and 5 in **Table 3**.

Table 3: R-values calculated at stations 1, 2, and 5 from March 15-19, 2017.

	5	**1**	**2**
B-C	0.246	0.139	0.174
C-G	0.214	0.327	0.278
Overall, A-G	3.100	3.106	3.092

The relationships between R-values shown in **Tables 2 and 3** are consistent. The values across different stations may be explained by the placement of sensors within the layers at each station. It is possible that some sensors rest slightly higher or lower than others at different stations, which would account for these deviations.

Figure 3 shows the temperature data for the G layer at the three stations used in this experiment from December 1, 2016 until March 31, 2017. The effect of the mid-March snowpack was to insulate the soil so that the temperature of the G layer hovered around 0º C throughout the period, despite wide variations in air temperature as shown in **Figure 2**.

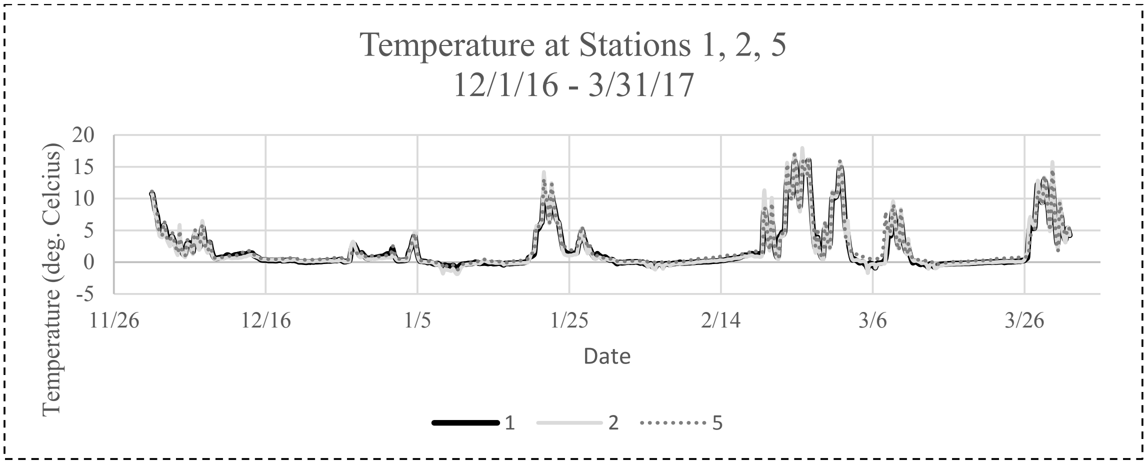

Figure 3: G-layer temperatures from three stations during Dec. 1, 2016 - March 31, 2017.

Figure 4 shows the temperatures in the different layers of the roof during 20 days of typical weather in the summer. Values shown are the averages at stations 1, 2, and 5. The temperatures at sensors G, C, and B follow the curve of the air temperature and frequently exceed the air temperature due to direct sunlight reaching the roof. The peaks at G, C, and B occur slightly later each day than the peak in air temperature, due to the time for heat conduction through the roof. Temperatures at A and Y are much lower than the air temperature and the other sensors in the roof because the Center is air conditioned. The greatest difference in temperature between adjacent sensors occurs between A and B.

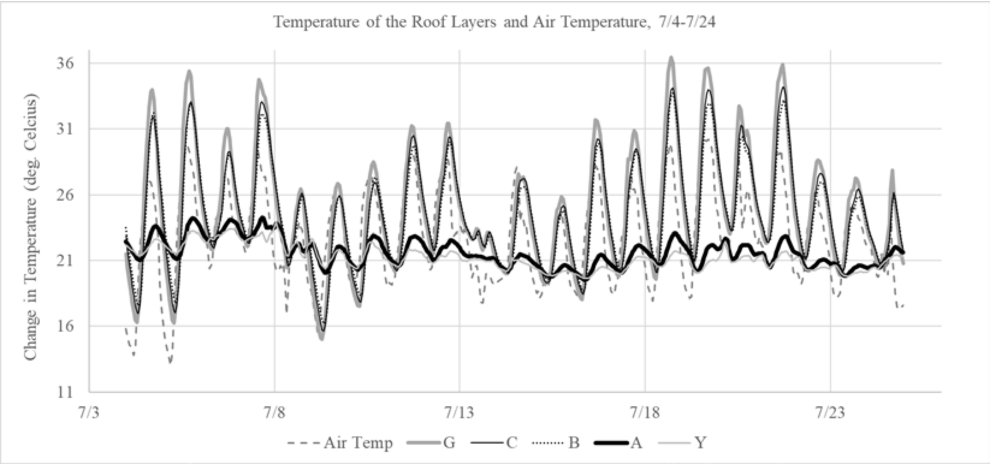

Figure 4: Temperature of each layer of the roof during July 4-24, 2017

Figure 5 shows the temperatures in the different layers of the roof during a 20-day period with typical winter weather. According to the National Weather Service there was no snow until January 24. There was significant snowpack (~100 mm) from January 24-27. From January 28-29, there is no snow on the roof, which corresponds to the small increase in temperature in the roof layers on January 28. Finally, there is significant snowpack again from January 31-February 9. The temperatures at Y and A reflect the heated interior of the building. The greatest difference in temperature between adjacent sensors again occurs over the insulation layer from sensor A to sensor B. Sensor G is closest to the air, followed by sensors C and B. The temperature at B is higher than at C, which is higher than at G, consistent with distance from the heated interior. Around January 23, there is an increase in air temperature, and the temperatures at sensors G, C, and B increase and are nearly the same over this period.

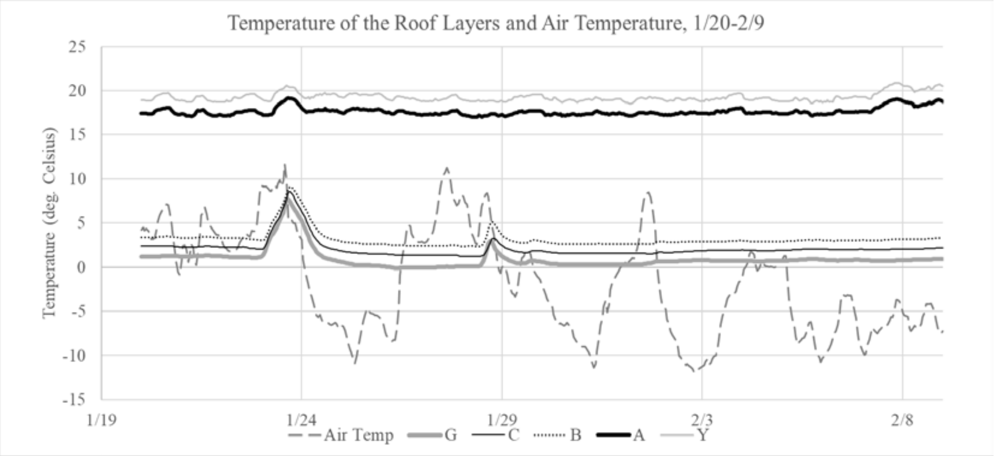

Figure 5: Temperature of each layer of the roof during January 20 - February 9, 2018.

The heat flux from A to B shows the transfer of energy across the insulation layer. **Figure 6** shows this heat flux over six months. During the winter months, there is generally a positive flux of heat escaping the building through the roof. During the summer months, the flux is negative, indicating heat entering the building. The heat flux from March 15-19 (shown by dashed lines) is positive as expected, and this time period corresponds to the period of high snowpack on the roof, as shown in Figure 2.

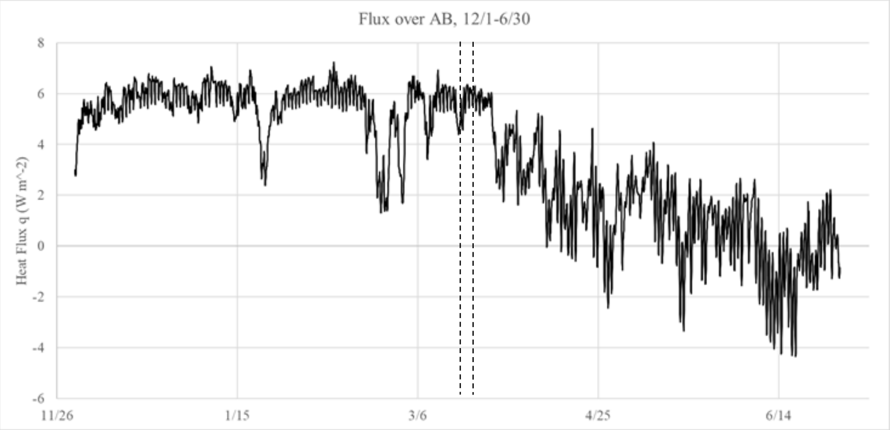

Figure 6: The heat flux through the insulation layer during Dec. 1, 2016 - June 30, 2017.

CONCLUSION

Temperatures have been measured from December 2016 to February 2018 in layers of a green roof on the Onondaga County Convention Center. The inside temperature at the ceiling, and temperatures in the lowest roof layers below the insulation, remain around 20° C in both winter and summer. The greatest difference in temperature between adjacent sensors occurs across the insulation layer (A to B). The temperatures at the top of the insulation (B), at the upper gypsum board (C), and in the growth medium (G) are closer to the air temperature. During the winter, and when there is significant snowpack on the roof, the temperature in these upper layers remains at 0-5° C despite much colder air temperatures. The insulation layer provides the main barrier to heat escaping the building during cold conditions. During the summer, the temperatures in the top layers of the roof tend to be higher than the air temperature, due to the impact of direct sunlight impinging on the roof surface.

The calculated R-values of the green roof are consistent with previously calculated R-values based on limited data. The values from stations 1, 2, and 5 show distinct differences that may be due to the precise placement of the sensors within the various roof layers. For example, the R-values overall from A to G are nearly identical at all three stations, but the R-values between sensors B and C at stations 1 and 2 are much smaller than at station 5. This indicates that sensors B and C are probably closer together at stations 1 and 2 than originally thought, providing more information on the build of the roof. Additional data collection and analysis is underway, both at the green roof and at a traditional roof nearby.

ACKNOWLEDGMENT

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