ENVIRONMENTAL MONITORING IN PREPARATION FOR THE INSTALLATION OF A GREEN ROOF

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ABSTRACT

Green roofs are becoming an increasingly popular way to improve the environmental, economic, and aesthetic performance of both new and existing buildings. Along with the green roofs themselves, it is also common to install sensors to measure various environmental parameters that are affected by or important to the operation of the roof such as precipitation, temperature, and runoff. However, for most of these systems, the sensors are installed at the same time or even after the green roof. Therefore, no before-and-after comparisons can be made for those roofs. To account for this missing data, monitoring equipment was installed on a Purdue University campus building to measure existing conditions for the year prior to the expected construction of a green roof. This equipment currently includes a weather station, along with runoff, heat flux, and temperature sensors, and there are plans to monitor air quality as well. Preliminary findings from values recorded thus far appear to validate the expected behavior of the roof. Stormwater runoff directly correlates to rainfall, and roof temperature is dependent on ambient air temperature and solar radiation. Data from the heat flux sensors, however, is not yet fully explained. This ongoing experiment should see significant changes in the data once the green roof is installed, but until that time, it will continue to serve its role as the control setup for measuring the performance of a standard roof.

1. INTRODUCTION

In 2009, Boiler Green Initiative, a student organization at Purdue installed the University's first green roof on Schleman Hall. This project included a sensor network to determine the fate of stormwater on the roof as well as to monitor surface temperature fluctuations. In 2012, the School of Civil Engineering installed its own green roof, and there were plans to measure the flow of heat through the roof, but that equipment has not yet been deployed. This pattern of installing monitoring equipment along with or after the green roof itself is the norm, and although data gathered from such a setup is often very useful and has been used in many research projects both at Purdue and around the world, there is still more that can be done in terms of simply gathering data prior to the installation of a green roof in order to have it available for a direct before-and-after comparison. This way, the environmental benefits of a particular green roof can easily be quantified and studied. So, this is what Boiler Green Initiative, in its current Knoy Hall green roof project, has been doing.

2. PROJECT LOCATION

2.1 Justification

Knoy Hall was chosen by Boiler Green Initiative for their current project for a variety of reasons. It has an upcoming scheduled roof replacement, which will lower the cost of installing a green roof. It has three roof levels above the main entrance which are visible from inside the building, and which also might be able to be made accessible to the public. The building is surprisingly strong and can hold the extra weight of a green roof. Knoy Hall is located in the main academic area of campus and receives a considerable about of traffic. Finally, the building is also located in an area serviced by a combined sewer system. In a combined sewer, both sewage and stormwater flow into the same pipe for delivery to a wastewater treatment plant. However, during large rain events, flow in the combined sewer exceeds the capacity of the treatment plant, and some of this mixture is diverted to a nearby waterway such as the Wabash River. Such events, of which there were 43 in West Lafayette in 2012, are a major source of water pollution. Therefore, reducing and delaying the amount of stormwater entering a combined sewer by using green roofs and other best management practices can help to mitigate this problem. This is why being able to accurately assess this impact on stormwater runoff is one of the key monitoring objectives for this project.

Figure 1: Knoy Hall as it currently is and what it may look like

2.2 Current Plan

The final scope of the Knoy Hall green roof project is contingent on the amount of funding secured. At a minimum, the lowest roof tier will receive a new waterproofing membrane and be covered with trays which contain the growing medium and plant material. The next goal in terms of fundraising would be to remove an interior office and open a second entrance onto the roof to make it publicly accessible with handrail, pavers, and benches. This accessibility is vital to securing the support of building occupants for the project. Although making the roof accessible would reduce the area covered by plants and the roof's net environmental benefit, its aesthetic value would increase and it would become a desirable and usable space. This would also allow for signage and tours, thus increasing the roof's educational value. Next on the priorities list is the installation of green roof trays on the second and third roof tiers. These roofs are larger than the lowest tier, but they are more difficult to make accessible. An additional option is to include vertical elements, such as potted trees or a green wall system to make the roofs visible from ground level. The aesthetic benefits of doing so would greatly outweigh the environmental ones. One final option for the project would be to also install green roof trays on the main roof. This roof has the largest area, but it would not be visible or accessible to building occupants.

3. DATA COLLECTION

3.1 Sensor Network

To collect data on various conditions being experienced on the current roof, a monitoring equipment system has been set up on the lowest tier of Knoy Hall. This particular tier was chosen since it is the one that is most likely to receive a green roof as part of this project. The equipment consists of various sensors connected to two separate dataloggers which then independently send tabulated data to a server via radio and the Internet. The system is solar-powered, which allows it to operate without running wires from the inside building. Additionally, the system is mounted, for the most part, to a tripod which is attached to concrete-filled tubs. The reasoning for this is to allow it to easily be moved to another project site after enough data has been collected on Knoy Hall. Two dataloggers are required since one came as part of preassembled weather station and had no room for additional sensors. This weather station includes a rain gauge, wind vane and anemometer, temperature and humidity sensor, and a pyranometer. Equipment for the second datalogger includes a barometric pressure sensor, two heat flux sensors, two temperature probes, and four pressure transducers. The heat flux sensors and temperature probes are located in two separate spots on the roof to account for spatial variation. They are buried underneath the rock ballast but sit on top of the insulation. The pressure transducers are fitted on hydraulic control structures which are located in the roof drains in order to measure runoff.

Figure 2: Equipment on Knoy

3.2 Hydraulic Control Structures

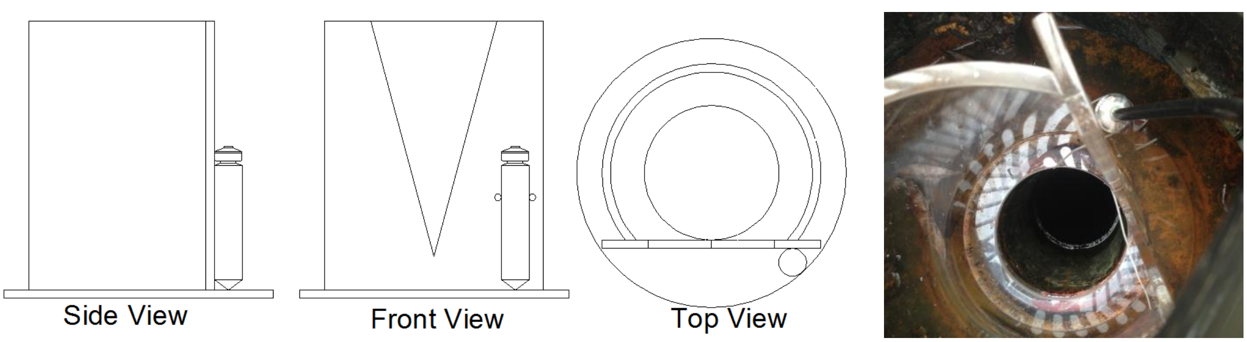

Figure 3: Hydraulic control structures as designed and installed

The ability to accurately collect runoff data from the roof is critical to the monitoring effort and the desire to be able to quantify the runoff reduction that takes place once the green roof is installed. However, due to constraints with the existing building, it was impossible to install an inline flow meter, tipping bucket gauge, or other sensor downstream of the drains to measure the amount of water coming off the roof. Therefore, runoff monitoring was limited to the drains themselves, immediately before water leaves the roof. It was determined that a weir system was most suitable to this application, since the height of the water behind the weir directly correlates to the amount of flow going through it, and the height of the water is easily measured with pressure transducers. In the design used for Knoy Hall, which consists of a V-notch weir plate glued to a longitudinally-cut cylindrical shell and a baseplate, water pools in the drains outside the structure until its level is high enough that it flows through the weir and down the orifice in the middle of the base. To prevent water from flowing underneath the hydraulic control structure, it is secured to the drain with a silicon sealant. The datalogger converts the pressure transducer readings to flow values with equations that were derived when the weirs were calibrated in a hydraulics lab. Due to variances in construction, each structure had to be calibrated separately. This involved measuring the height of the water for a variety of known flow rates and fitting curves to the resulting data points.

4. RESULTS AND DISCUSSION

4.1 Water

Since the installation of the monitoring equipment, there have been too few rain events to be able to create a representative aggregation of rainfall versus runoff results on Knoy Hall. However, preliminary results show that the roof currently does a terrible job of either delaying or retaining rainfall. Figure 4 shows the results of an early morning thunderstorm, in which both rainfall and runoff peaked during the same 15-minute period and their relative intensities paralleled each other for the rest of the event. Runoff then continued to trickle off the roof for about two and a half hours after the last rain fell. Once the green roof is installed, there should be a noticeable delay between the peaks of rainfall and flow, meaning that the water is being significantly delayed by the green roof media, something which a conventional roof cannot do. Integration of the total rainfall and runoff for the lowest roof tier returned a result of about 1400 liters of water for both, within about a four percent error. This indicates that virtually all of the water that fell on the roof also flowed down the drains. With the green roof, there will be an obvious reduction in runoff compared to rainfall, but the total percentage reduction will be dependent on factors specific to each rain event such as rain intensity and the soil moisture, as well as properties of the green roof including soil depth and total area.

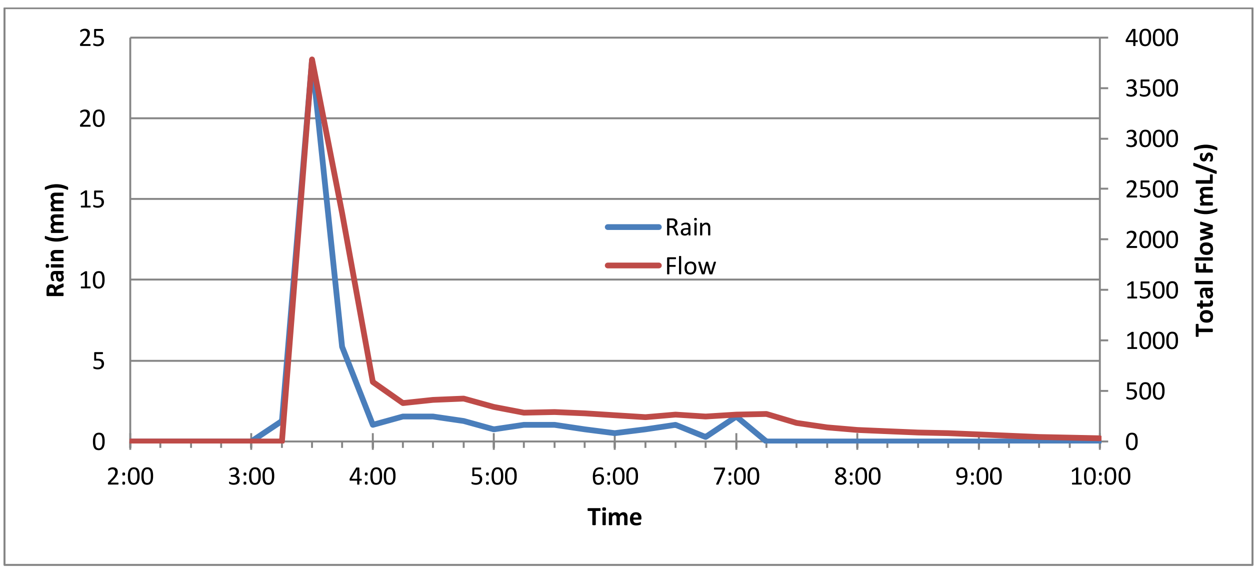

Figure 4: Rain event of 7/23/2013

4.2 Energy

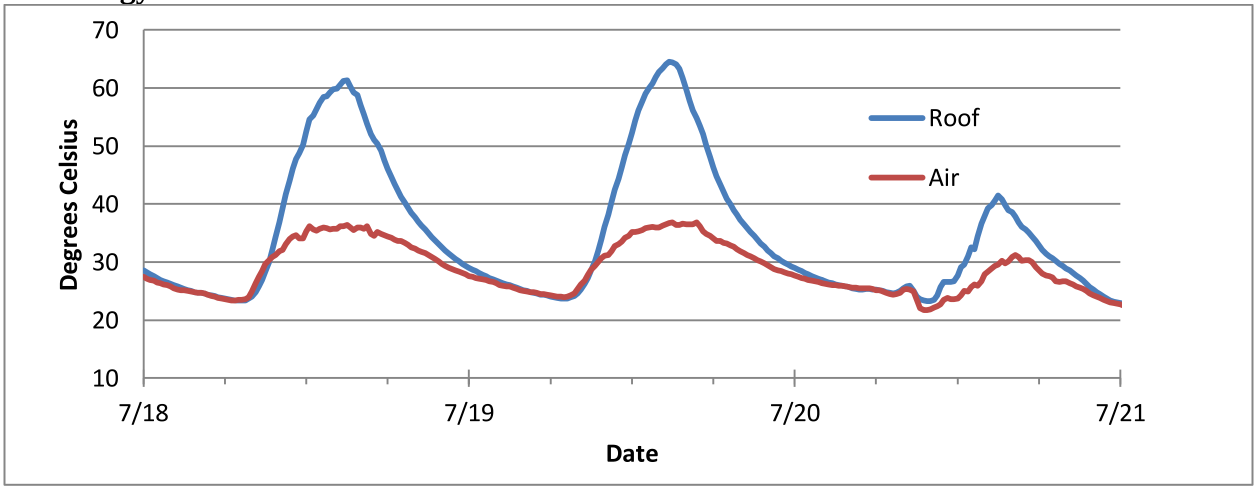

Figure 5: Roof and air temperature

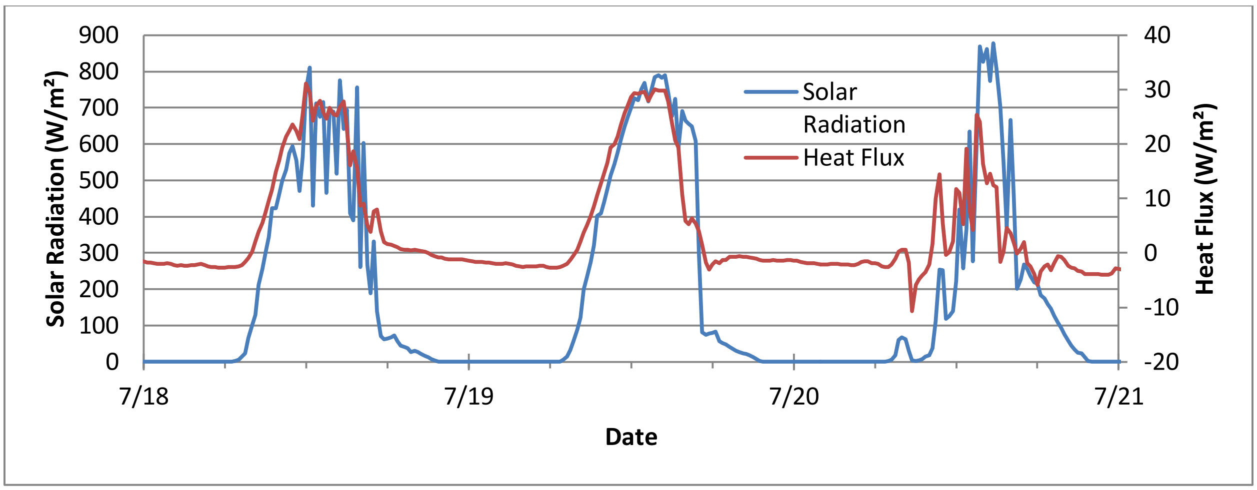

Figure 6: Solar radiation and heat flux

The biggest way that green roofs are economically beneficial to their owners is by decreasing building energy consumption through lower heating and cooling loads. To quantify this benefit is important if green roofs are to be further popularized. Figure 5 shows that the rock ballast on the roof rapidly heats up on sunny mornings and slowly loses its heat as it returns to the ambient air temperature in the evening and overnight. These large temperature swings will be greatly reduced once the green roof is installed, which should extend the life of the roof membrane. However, on Knoy Hall, the membrane is currently located underneath a layer of insulation, which already reduces some of these effects and may be a significant factor in how the current roof has been able to greatly outlive its expected lifespan. Figure 6 shows the relationship between solar radiation and heat flux. Heat flux is more strongly correlated to solar radiation than roof temperature, although both affect it. The general pattern is that heat flux rises along with roof temperature and solar radiation in the morning, varies along with cloud cover during the day, and in the evening, it drops along with the sun, despite the roof staying warm. Heat flux even goes negative at night. This most likely means that the roof deck below the sensors is acting as a thermal mass and releases its heat even more slowly than the ballast above the sensor. This heat is most likely going both to the atmosphere and into the building space. For July 19th, as an example of aggregated results, an average of 1.4kW and a maximum of about 7kW of heat entered the roof. These numbers should trend toward zero once the green roof is installed. Additionally, since no data has been collected in winter yet, no conclusions can be made about the roof's behavior and the amount of heat gained or lost through it during that season.

5. CONCLUSION AND FUTURE WORK

In addition to the sensors which are currently monitoring the roof, there are plans to install additional equipment in order to be able to gather a more complete picture of its environment and performance. This includes temperature and heat flux sensors underneath the roof deck in order to determine a more precise value for the amount of heat entering or escaping the building through the roof. Air quality, while not pertinent to the roof's water or energy characteristics, is a factor that will be affected by a green roof. Of course, soil moisture will be eventually monitored, as well. This ongoing experiment should see significant changes in the data once the green roof is installed, but until that time, it will continue to serve its role as the control setup for measuring the performance of a standard roof. The limitations of the current incarnation of Knoy Hall's roof are being quantified, which will let the benefits of the green roof be shown much more clearly.

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