Analysis of Green Roofs Ability to Mitigate Hail Damage on Roofs

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DOI: 10.29322/IJSRP.11.04.2021.p11248
http://dx.doi.org/10.29322/IJSRP.11.04.2021.p11248

Abstract- Green roofs can significantly reduce, and in most cases eliminate, the damage and cost of roof repairs caused by hailstorms. Green roofs act as a buffering layer of substrate and plants, absorbing the destructive impact of hail hitting the surface during a hailstorm. Anticipating severe weather and implementing cost-effective protection strategies, such as green roofs, can result in significant savings for property owners and insurance companies. This study demonstrates and quantifies the advantages associated with the use of green roofs to prevent hail damage and associated cost benefits. Testing and data collection in this study were based on the current recommended testing method, UL 2218 Standard for Impact Resistance of Prepared Roof Covering Materials, testing impact resistance by dropping steel balls onto the roof surfaces from various heights.

Index Terms- Green Roof, Hailstorm Mitigation, Green Infrastructure, Insurance Assessor, Insurance Premium Discount, Roof Protection

I. INTRODUCTION

Understanding the frequency and consequence of severe weather events, such as hailstorms, can help develop strategies and recommendations for preparedness and protection of private and public property (Rauhala 2009). Property damage and financial impact due to hailstorms have been on the increase over the past decade (NIBC 2019) with population growth in the region. The area with the most frequent and most severe hail events in the United States, also often referred to as 'Hail Alley', includes the states of Colorado, Nebraska, and Wyoming (Butler 2018, ISO 2020). as well as the states of Texas and Kansas, making the majority of the Great Plains area a prime target for hailstorm destruction (Tang 2019). Additionally, the frequency of hailstorm events is on the rise for the eastern states (Tang 2019).

Green roofs have a great potential to mitigate or prevent damage caused by hailstorms based on their substrate and plant layers ability to buffer impact from hailstones. This study demonstrates green roofs' ability to protect roofs from damages caused by the type of hailstorms and size of hail typically generating the highest number of claims and costliest damage in infrastructure in the Hail Alley and Great Plains region. Given the harsh ultraviolet light conditions in Colorado, green roof systems should be designed and installed with redundancy to perform for a minimum of 50 years (Cupit 2020).

About Hail

A thunderstorm producing hail is known as a hailstorm. Hail is formed from droplets of water carried upward by the updraft of thunderstorms. When the droplets reach colder atmospheres, the water freezes into ice. The ice droplets fall and accumulate moisture on their surface which also freezes. The frozen droplets can be carried back into the upper regions of the storm if the updraft is strong enough. As this cycle continues, hailstones increase in size until their weight is too great for the updraft to support, allowing the hail to fall to the ground. Severe hail is defined by the National Weather Service as hailstones measuring at least one inch in diameter, however, under some circumstances, hailstones can reach or exceed a diameter of 15 cm (6 in). The national record (set in 2010 in South Dakota) was 20 cm (8 in) in diameter (almost the size of a volleyball) and weighed almost 907 grams (2 pounds). According to the National Weather Service (NWS) the largest recorded hail in Colorado was 12.27 cm (4.83 in) in diameter (almost the size of a softball) and weighed just over 225 grams (a half-pound) (Rice 2019, NOAA 2019). Various ranges and level of rarity of hail sizes are described in Figure 1.

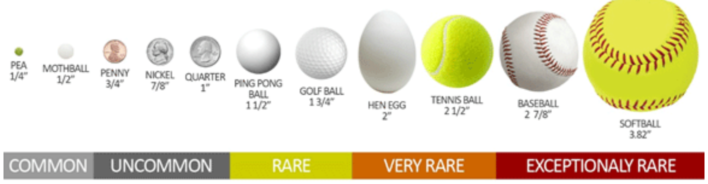

Figure 1: The range and level of rarity of various hail sizes. Based on chart by Michael S. Lewis, NOAA.

The high elevation of the Great Plains area receives the most frequent and most severe hailstorms because the freezing point of water is lower and closer to the ground (NOAA 2019). Due to this condition, hailstones have less time during their fall to melt, and as a result, hit the ground and roof surfaces with more force and higher velocity than in states on the east coast (NOAA 2019).

Hailstorms and Property Damage

A significant additional cost to insurance companies, building owners and occupants, beyond the actual cost of roof repair, can be associated with loss of revenue due to business closure during extended periods of time for repairs to complete after hailstorm damage. An example of this is the Colorado Mills Mall, a 1.1 million-square-foot shopping center located near Interstate 70 West and Sixth Avenue in the City of Lakewood, Colorado. On May 8, 2017, a severe thunderstorm formed over the western suburbs of Denver around 2:30 PM Mountain Time. The Colorado Mills Mall was closed for more than six months due to repairs. One year after the hailstorm hit, only 130 of the initial 200 stores were back being open (Brady 2018). In May of 2018, the Rocky Mountain Insurance Information Association (RMIIA) announced that this hailstorm caused around $2.3 billion in damages – $ 900 million more than first estimated. The National Weather Service (NWS), a division of NOAA and part of the United States Department of Commerce, ranks this event as the second-costliest hailstorm in U.S. history. The 2019 City of Lakewood, Colorado Annual Budget Report identified a loss of $4 million in tax generated revenue from the Colorado Mills Mall for the City of Lakewood for the previous fiscal year (RMIIA 2015; NOAA 2020).

II. STUDY DESIGN

This study was modeled after the Underwriters Laboratories 2218 (UL 2218) Standard for Impact Resistance of Prepared Roof Covering Materials testing method, to provide impact resistance data for evaluation of prepared roof covering materials. USAA defines an impact-resistant roof as “a roof made with materials that are wind and hail resistant and less susceptible to damage.” All testing in this study was done on low slope roofs modules, as most commercial large-scale roofs in this area of the United States are low slope. According to the National Roofing Contractor Association 2015-2016 Market Survey, 74% of commercial large-scale roofs were revealed to be low slopes of 2:12 or less (NRCA 2016). Based on an anecdotal review for the Green Roof Ordinance, the Metro Denver alone has approximately 5,000 acres of low slope roof surfaces.

To test our first hypothesis that extensive 10.16 cm and 15.24 cm (4 in and 6 in) deep (modular and loose laid) green roofs systems have the ability to pass the UL 2218 class 4 requirements, a testing site for dropping steel balls onto low slope roofing test modules was built. A series of steel balls, with corresponding sizes typical of hailstones we experience in the Great Plains region, were dropped from corresponding heights onto the test roof surfaces. The masses of the steel balls combined with the drop heights are said to represent hail’s kinetic energy (Graham 24). The UL 2218 testing standard calls for visual examination for fractures to determine damage from impact testing (Crenshaw and Koontz 2001). The roof testing modules for this study, reflecting regional roof materials and profiles, were constructed with the ability to separate all layers after impact for a more comprehensive understanding of potential damage. Individual roofing test modules were constructed replicating 10.16 cm and 15.24 cm (4 in and 6 in) deep modular and loose laid green roofs systems along with control modules replicating six of the most common roof profiles in Colorado for comparison.

III. METHODOLOGY

The UL 2218 Impact Resistance Testing for Roofing Materials involves dropping steel balls of differing diameters from varying heights onto the roofing material being tested. The material’s exposed surface, back surface, and under layers must be free of any cracking, splitting, tearing, rupture, or fracturing to gain an impact-resistant classification (Graham 24). UL 2218 has four levels of impact resistance classifications, with Class 1 being the lowest classified level and Class 4 being the highest (Graham 2008; Laurie 1960). Qualifying roof assemblies are assigned Class 1-4 ratings depending upon the successful performance of the assembly. Heights from which varying sizes of steel balls are dropped can be seen below in Table 1, and have been determined to achieve the same kinetic energy as hailstones of the same size would achieve during an actual storm (Insurance Institute for Business & Home Safety 3, year).

Table I: UL 2218 rating class criteria (Crenshaw and Koontz 2001; Table II).

Rating Class	Criteria
1	Roofing material can withstand impact from a 3.18 cm (1-1/4 in) diameter steel ball dropped from a height of 3.66 m (12 ft)
2	Roofing material can withstand impact from a 3.81 cm (1-1/2 in) diameter steel ball dropped from a height of 4.27 m (14 ft)
3	Roofing material can withstand impact from a 4.45 cm (1-3/4 in) diameter steel ball dropped from a height of 5.18 m (17 ft)
4	Roofing material can withstand impact from a 5.08 cm (2 in) diameter steel ball dropped from a height of 6.096 m (20 ft)

The determination of heights the steel balls are dropped from comes from calculations of actual hailstone impact energy measured in Joules by J.A.P. Laurie in 1960 (Crenshaw and Koontz 2001; Table II).

Table II: Parameters for each UL 2218 rating class based on data by J.A.P. Laurie 1960 Crenshaw and Koontz 2001; Table I).

Rating Class	**1**	**2**	**3**	**4**
Hailstone Diameter (Centimeters)	3.18	3.81	4.45	5.08
Hailstone Diameter (Inches)	1-1/4	1-1/2	1-3/4	2
Approximate Hailstone Impact Energy Transmitted (Joules)	5.42	10.85	18.96	29.80
Steel Ball Diameter (Centimeters)	3.18	3.81	4.45	5.08
Steel Ball Diameter (Inches)	1-1/4	1-1/2	1-3/4	2

Steel Ball Weight (Ounces)	4.69	7.93	12.59	18.94
Drop Height (Meters)	3.66	4.27	5.18	6.096
Drop Height (Feet)	12	14	17	20
Terminal Velocity (m/s)	8.47	9.15	10.08	10.93
Terminal Velocity (mph)	18.94	20.47	22.55	24.45
Approximate Steel Ball Impact Energy Transmitted (Joules)	5	10	18	31

All test modules were built to be 1 ft wide x 2 ft deep and had various depths depending on the layers of the roof system. All five roof profiles; A, B, C, and D were tested for UL 2218 class 1, 2, 3, and 4, and were constructed with the following six (also common to Colorado) types of roof waterproof membranes listed in Table III below:

Table III: Selected waterproof membranes for all profiles (A, B, C, D, and E) in this study.

60 mil Adhered EPDM (Ethylene propylene diene terpolymer)
Silicone Coated 60 mil Adhered EPDM (Ethylene propylene diene terpolymer)
60 mil Adhered PVC (Polyvinyl chloride)
60 mil Adhered TPO (Thermoplastic polyolefin)
Cold Process Asphalt Gravel-Surface Built-Up System Roof, 4-Ply of Felt, Gravel-Surfaced
MBS - Modified Bitumen Gravel-Surface Built-Up System

Note: while EPDM was previously more popular, PVC and TPO currently make up 72% of the current market in Colorado (Cupit 2020).

All five different types of roof test modules (profile A, B, C, D, and E) were built with the ability to separate all layers after impact for inspection of damage/no damage (or fail/pass), using a two-peg pressure system in opposite corners to ensure assembly integrity during testing.

Common Roof Profiles

The three common roof profiles (A, B, and C) were tested with the six different water proof membranes (Table III) resulting in a total of 18 common roof test modules, and were constructed to represent roof materials and profiles common to Colorado and the Great Plains region:

- **Roof Profile A**: Insulation Based Roof with a Concrete Layer
- **Roof Profile B**: Concrete Based Roof with Insulation Layer (Inverted profile)
- **Roof Profile C**: Concrete Based Roof with no Gypsum Board or Insulation

Profile A – test module layers:
- Variable (as listed in Table 3) Waterproof Membrane
- Henry 203 Cold Applied Roof Adhesive
- 1.27 cm (0.5 in) Primed Gypsum Cover Board
- 5.08 cm (2.0 in) Polyisocyanurate Insulation
- 5.08 cm (2.0 in) Concrete Base

Profile B – test module layers:
- Variable (as listed in Table 3) Waterproof Membrane
- Henry 203 Cold Applied Roof Adhesive
- 1.27 cm (0.5 in) Primed Gypsum Cover Board
- 5.08 cm (2.0 in) Polyisocyanurate Insulation
- 5.08 cm (2.0 in) Concrete Base

Profile C – test module layers:
- Variable (as listed in Table 3) Waterproof Membrane
- Henry 203 Cold Applied Roof Adhesive
- 5.08 cm (2.0 in) Concrete Base

Green Roof Profiles

Two types of green roof test modules (D: modular, and E: lose laid – each with 4 in and 6 in depth) were constructed, based on the most common types of extensive green roof systems in the US (US GSA 2011; Table IV).

Table IV: Selected green roof systems for this study.

10.16 cm (4 in) Deep Green Roof – Modular Tray System
15.24 cm (6 in) Deep Green Roof – Modular Tray System
10.16 cm (4 in) Deep Green Roof – Loose Laid System
15.24 cm (6 in) Deep Green Roof – Loose Laid System

Each of the four different green roof profiles (Table 4) were tested with the six different water proof membranes resulting in a total of 20 green roof test modules. The plants used in the green roof test modules were common industry mix (LiveRoof) of *Sedums*, and the substrate was 90% expanded shale clay and 10% organic matter - a dry, rocky based substrate that reflects regional conditions and growing media material selection for Colorado. To hold the green roof profiles in place, a perimeter box was constructed for the loose laid green roof modules. Black PVC plastic trays (LiveRoof) was used for the modular green roof test modules.

Profile D – test module layers:
- 10.16 cm (4 in) modular and 15.24 cm (6 in) modular green roof
- Variable (as listed in Table 3) Waterproof Membrane
- Henry 203 Cold Applied Roof Adhesive
- 1.27 cm (0.5 in) Primed Gypsum Cover Board
- 5.08 cm (2.0 in) Polyisocyanurate Insulation
- 5.08 cm (2.0 in) Concrete Base

Profile E – test module layers:
- 10.16 cm (4 in) loose laid and 15.24 cm (6 in) loose laid green roof

- Variable (as listed in Table 3) Waterproof Membrane
- Henry 203 Cold Applied Roof Adhesive
- 1.27 cm (0.5 in) Primed Gypsum Cover Board
- 5.08 cm (2.0 in) Polyisocyanurate Insulation
- 5.08 cm (2.0 in) Concrete Base

IV. EXPERIMENTAL SETUP

As seen in Figure (2), a 6.096 m tall x 0.0508 m diameter vertical PVC tube (20 ft tall x 2 in) was constructed for precise impact delivery to evaluate the impact resistance of the test modules with various roof and green roof coverings. The PVC tube was hung precisely vertical to ensure no friction during each steel ball drop.

Holes were drilled into the PVC structure at 3.66 m, 4.27 m, 5.18 m, and 6.096 m (12 ft, 14 ft, 17 ft, and 20 ft) to allow for temporary plates made of metal to be inserted and function as ‘stoppers.’ Steel balls were released at the appropriate heights, 3.66 m, 4.27 m, 5.18 m, and 6.096 m (12 ft, 14 ft, 17 ft, and 20 ft) to simulate various sizes of hailstones and associated impact.

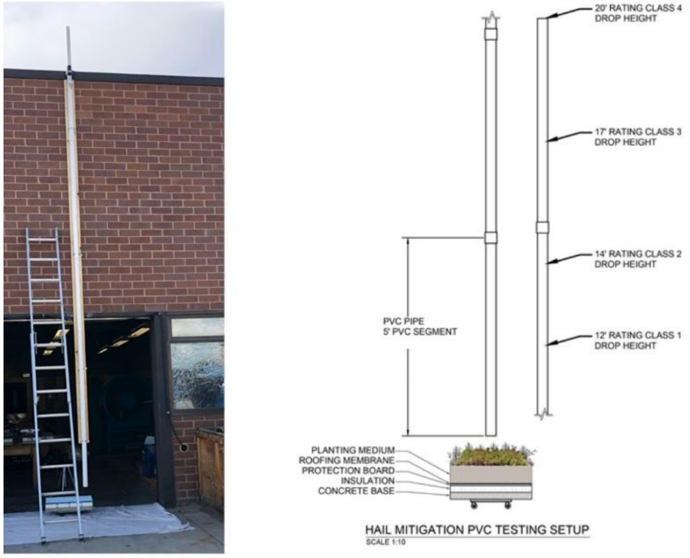

Figure 2: Experiment setup with vertical PVC pipe attached to building for delivery of 3.66 m, 4.27 m, 5.186 m, and 6.096 m (12 ft, 14 ft, 17 ft, and 20 ft) drops of steel balls to simulate impact of various sizes of hail.

A slow-motion Sony RX100V camera was set up at the point of impact to capture and record findings. Two of each common roof test modules and green roof test module was constructed for control. All test modules encountered two testing rounds dropping steel balls at respective heights for each impact class 1, 2, 3, and 4.

As seen in Figure 3, each test module had eight impact locations.

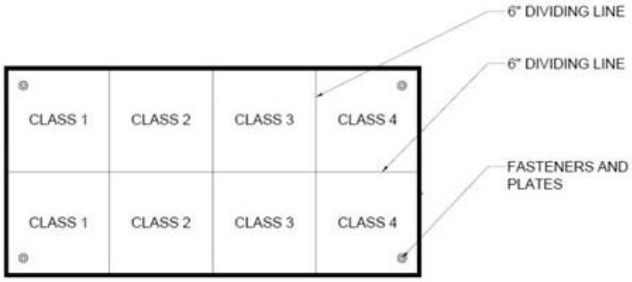

Figure 3: Diagram for impact locations on each roof test module.

Each roof test module was impacted with two rounds of Class 1, 2, 3, and 4 impacts to determine pass/fail rating for each subsequent layer in all profiles (A, B, C, D, and E). After impact, each layer within the testing module was carefully examined for evidence of damage per UL 2218 requirements. All indentations, tears, and other visible damage caused by impact was photographed and measured using a caliper to determine the depth and width of the impact site.

Final test result for green roof profiles in this study was confirmed by a certified testing lab, Haag Research & Testing in Flower Mound, Texas, who additionally ran UL 2218 tests and confirmed our results for green roof test modules Type D and E, with 10.16 cm and 15.24 cm (4 in and 6 in) modular and loose laid green roof profiles.

V. RESULTS

Test results for profiles A, B, C, D, and E for Class 1, 2, 3, and 4 are shown below.

Roof Profile A

All control roofing module layers up to and including the insulation layer (variable waterproof membrane, adhesive layer, gypsum board, and insulation) showed visible impact damage upon review, which led to “fail” scores in results tracking. Visible impact damage included indentations, splits, and tears in the materials. Variable waterproof membrane layers had less damage when gypsum boards and insulation layers beneath absorbed most of the impact.

Roof Profile B

Three superficial control roofing module layers (variable waterproof membrane, adhesive layer, and gypsum board) showed visible impact damage upon review, which led to “fail” scores in results tracking. Visible impact damage included indentations, splits, and tears in the materials. Variable waterproof membrane layers had less damage when gypsum board layers beneath absorbed most of the impact.

Roof Profile C

Variable waterproof membrane and concrete control roofing module layers showed visible impact damage upon review, which led to “fail” scores in results tracking. Visible impact damage included indentations, splits, and tears in the materials. Variable waterproof membrane layers had a greater amount of visible damage when no gypsum board layer was present and the concrete layer was above the insulation.

Roof Profile D

The testing of roofing modules with a green roof layer placed on top of the other roof profiles resulted in full protection of subsequent layers. No visible damage was noted on roofing layers tested under the green roof modules.

Roof Profile E

The testing of roofing modules with a green roof layer placed on top of the other roof profiles resulted in full protection of subsequent layers. No visible damage was noted on roofing layers tested under the green roof modules.

VI. KEY FINDINGS

Testing conducted with the green roof layer resulted in no damage to roofing membranes, gypsum boards, insulation, or concrete layers for all four class ratings. This proves that a 10.16 cm and 15.24 cm (4 in and 6 in) green roof layer meet the criteria for successful UL 2218 testing for classes 1, 2, 3, and 4.

The absence of an extensive green roof layer exposed the control testing modules to hail simulated damages, as evidenced in the testing data. Post testing physical observations and testing data of control samples illustrate visible impact damage on a minimum of two roof testing module layers.

VII. CONCLUSION

Study results demonstrate and quantify the advantages associated with the use of green roofs to prevent and mitigate hail damage and suggest adding mitigation of hail to the long list of green roof benefits broadly adopted by in cities across the planet. The results collected in this study were based on the current recommended testing method UL 2218 Standard for Impact Resistance of Prepared Roof Covering Materials and shows that green roofs meet a Class 4 rating. Study results demonstrate that extensive green roof systems commonly implemented on low slope roofs in the Great Plains region meet the UL 2218 class 4 requirements, and thereby could qualify for insurance premium discounts.

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