Green Roofs for a Greener Future: An In-Depth Look at Increasing Building Efficiency at UMass Amherst

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Figure 1: Rendered view of green roof on top of Hampden Art Gallery
Source:
https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1025&context=larp_ms_projects

1. Executive Summary

The University of Massachusetts Amherst has made a goal to meet a carbon net zero goal by 2030. In order to reach this goal, the university will need to look for and address sources of energy inefficiency on campus. This energy inefficiency is especially important to investigate in its biggest consumer of energy, heating and cooling buildings, which makes up about 34% of each building's energy use. The UMass campus's older buildings did not need to meet the same energy standards they do now because of out of date energy efficiency standards, so they are largely inefficient, losing about 20% of their heat and cooled air through the roofs. Building energy inefficiency wastes a considerable amount of energy, and necessitates that the university produce and use more energy, thereby CO_2.

Green roofs take advantage of a living roof's natural capacity to heat and cool through improved insulation and evapotranspiration, which in turn provides increased performance in solar panels to further improve emission reductions in older buildings. Older buildings provide an opportunity to utilize valuable space and improve efficiency while avoiding the waste associated with tearing down old buildings to be replaced with new structures built to higher standards.

We have many buildings on campus that could be retrofitted with green roofs, as they thrive on buildings with lower heights and more surface area. In a model using the Hampden Art Gallery, we found that a green roof would pay itself off in ~11.4 years and had a net present value of over $3 million if left in place for 50 years, even accounting for maintenance. In total, we have estimated that retrofitting our campus with green roofs has the potential to prevent the equivalent of 7467.8 Mt CO_2 emissions per year.

Green roofs offer both energy reduction and environmental benefits, and retrofitting the roofs we have now is the most cost-effective and practical use of our time and funds to meet our carbon mitigation goal.

2. Introduction

Global climate change is one of the most pressing issues that we as a society need to worry about. Right now, the level of carbon dioxide in the Earth's atmosphere is higher than it has been in 800,000 years, at about 404.7 ppm in 2018 [**1**]. This leads to what is known as the greenhouse effect, which traps heat in our atmosphere and causes our planet to slowly heat up. This can have disastrous effects, like global sea level rise, and more frequent and extreme weather events. We can see this happening already on the coast from Florida to North Carolina, which saw its median annual number of flood days more than double from 2005 to 2015 [**2**]. In order to slow the progression of climate change, UMass is taking the lead by setting a goal to become carbon net zero by 2030. To reduce its carbon emissions to that extent, though, it is important to focus on practical and cost-effective technology. UMass uses an extraordinary amount of energy to power its over 200 buildings. The university has made steps to employ renewable energy sources, such as photovoltaic solar panels, but currently these are only providing 4% of the total energy required to run the campus [**3**]. The generation of this electricity to power buildings, either purchased from the grid or produced by the central heating plant, is the source of 85% of the university's carbon dioxide emissions [**3**]. In order to address this, we need to find where UMass's building energy use can be reduced.

Carbon neutrality is inherently an interdisciplinary issue: it requires knowledge in many fields to adequately address it. For this reason, our team took an interdisciplinary approach including research in building efficiency, reducing energy demand, and heating and cooling efficiency to find how existing buildings can efficiently be improved to mitigate our carbon emissions. This included research in structural engineering, plant biology, sustainability, and many other fields to investigate the best possible way to decrease our CO_2 emissions.

3. Problem Statement

Building Inefficiency at UMass and its Causes

In order for UMass to reach its goal of carbon neutrality by 2030, the university will need to look for and address sources of energy inefficiency on campus. The production of electricity is the largest source of carbon dioxide production, so in order to reduce our CO_2 emissions, we need to decrease our energy usage as a university. The single largest source of energy use is heating and cooling our buildings, so it is crucial that that process is as energy efficient as possible. A large percentage of energy use on campus comes from the inefficient heating and cooling of buildings, especially buildings built in the 20th century and before. This happens because older buildings did not have to meet the same standard newer buildings do for building envelopes and several weak points, such as windows and roofing, in older buildings which can allow heated and/or cooled air to seep out.

To reduce the amount of energy used at UMass, we need to find out what that energy is being used for. In the United States, an average of 9% of the energy used in commercial buildings is used to cool buildings, and 25% of the energy is used to heat buildings [**4**]. One of the main reasons for this is heat leaking. Heat energy leaks out of buildings by doorways, windows, roofs, chimneys and many other ways. The better a building can prevent heat loss, the more efficient it will be [**5**]. Thus, it is critical to identify buildings at UMass that are primarily contributing to heat loss. A study done at MIT in 2011 used infrared imaging to detect heat loss in buildings in the greater Boston and Cambridge area. This meant that the buildings investigated were older, with one building being 100 years old. Their results showed that 20% of the buildings they looked at were losing a significant amount of heat through their roofs [**6**]. Because this research was conducted on buildings similar in purpose, age, and climate, it is likely highly comparable to many of the sources of inefficiency for buildings at UMass. The heat loss and energy inefficiency of buildings at UMass is a severe issue that we must address.

Older buildings are often notorious for having low energy efficiency in terms of insulation due to weaker building standards at the time of construction. To illustrate this, we can compare two buildings with similar functions on campus. Both South College and Whitmore need to be heated in the winter and cooled in the summer, but in 2019 South College used about 7.2 Watts/Ft^2, whereas Whitmore used 11.0 Watts/Ft^2 [**3**]. The difference between these two buildings is that Whitmore was completed in 1967, and South College was completed in 2017, 50 years later [**7**]. The regulations in place when these buildings were planned and built changed a lot over those 50 years, including differences in the standards that a building's insulation had to meet.

Building insulation standards are based on the acceptable amount of energy that can be transferred by a building per unit surface area per degree difference in temperature, and can be measured in u-values. For example, a building with a window u-value of 1.0 W/m^2K will lose 1.0 Watt per square meter when the temperature outside the building is 1 degree Kelvin lower than the temperature inside the building. In this case, it is desirable to have a lower u-value, so that the heated and cooled air does not leak out into its surroundings and waste the energy used to regulate its temperature. We created a model to see the effects of updating different building elements from the 1980 standards to modern standards. We found that improving roof insulation from pre-1980s (u = 0.6 W/m^2K) to modern standards (u = 0.25 W/m^2K) nearly halved the u-value of the entire building envelope excluding the floor from 0.52 W/m^2K to 0.31 W/m^2K. In contrast, improving windows (pre-1980s u = 0.9 W/m^2K, modern u = 0.465 W/m^2K) reduced envelope u-value by only 0.05 (0.52 W/m^2K to 0.47 W/m^2K) (**Tables 1, 2**). In general, targeting building efficiency improvements to specific building components can have drastic improvements upon an older building's energy efficiency in terms of insulation.

Reaching our carbon net zero goal at UMass will be difficult, but it can be reached if we address problems that already exist on campus. Because our building standards have changed to benefit energy efficiency, it is important to update our older buildings in the most cost effective way to address the areas where we are lacking, like heat loss through our roofs. If we can decrease the amount of energy needed to heat and cool buildings, we can reduce the largest contributor to building energy use.

4. Solution Technology Explainer

How Green Roofs Can Save Energy in Heating and Cooling as Well as Increase Solar Panel Efficiency

Significant efforts are being put into ensuring that newer buildings can reach increasingly strict efficiency standards to mitigate carbon emissions. However, focusing efforts in this area ignores the potential improvements for efficiency in existing infrastructure. The vast majority of buildings that will be present by 2025 already exist, and a significant portion are more than half a century old and fail to meet modern building standards [**8**]. Green infrastructure, particularly green roofs, are capable of resolving this in older buildings, and can become more effective in improving energy efficiency the older a building is. Older buildings are generally built with weaker insulation due to lower standards at the time of construction, making the relative benefit of green roofs greater. Green roofs are a type of roof covered in vegetation separated from the original building structure by a waterproof membrane. Retrofitted green roofs are capable of generating significant energy and emissions benefits for older buildings by improving insulation to reduce heating costs, blocking solar radiation and utilizing evapotranspiration to improve cooling performance, and by working synergistically to improve the performance of other retrofitted green features such as solar panels.

Green roofs reduce the energy demand required to heat older buildings by reducing the amount of energy released to the atmosphere per unit surface area. Because green roofs are made of several layers of vegetative substrate, each layer is affected by the cold separately. A study in Finland was performed on the thermal properties of green roofs in a Nordic climate and found that the thermal conductivity of these layers decreased when penetrated by frost. This gave the green roofs a higher thermal resistance, meaning a greater capacity to resist heat flow. In other words, instead of the heat from inside of the building leaking out through the roof, the tested buildings were able to retain their heat more than a conventional roof would. [**9**]. Given that green roofs are better insulated than regular roofs, it is no surprise that the U.S. General Services Administration also found that in winter, a green roof can reduce energy usage by 13% to 33%. This range in energy usage is because the energy savings depend on climate, wind, and snow cover. For example, snow cover can increase green roofs' insulative properties, and evapotranspiration is more effective in a dry climate [**10**]. As shown by their ability to insulate the roofs of buildings even in a cold Nordic climate, green roofs are very capable of reducing a building's energy bill and increasing its energy efficiency.

Similar to how green roofs can lower the heating requirements of a building, they can also reduce the energy demands to cool buildings during the summer. Green roofs protect buildings by providing shade, and they also release excess heat through evapotranspiration, which is the total amount of water lost through both evaporation and transpiration. Evapotranspiration is an endothermic reaction, meaning it absorbs heat from the environment. In a simulation, the passive heat loss increased by a factor of three during the summer [**11**]. This means that every day in the summer, the green roof allowed heat to escape three times as fast as a normal roof would without using any electricity, and this decreased the summer air temperature inside the building by 2℃. This resulted in an annual energy demand reduction of 6%. One of the primary reasons for this decrease in temperature is that the green roof allows evapotranspiration to happen. By decreasing the need for air conditioning in summer, green roofs have the ability to lower a building's energy usage.

Often when people or organizations consider green roofs, they consider them as competition for roof space with solar panels. This is not the case. Green roofs have the potential to have significant impacts on the energy efficiency of buildings on their own, but when you take into consideration the ways that green roofs can work together with solar panels, they have the potential to both save and help produce energy. Solar panels are most effective at a temperature of 25℃ [**12**], which is a difficult temperature to achieve during summer. By combining a green roof with a solar roof, the vegetation can help to increase the efficiency of the solar panels by 16% by keeping the temperature lower [**13**]. Furthermore, a solar and green combined roof requires less maintenance and therefore lowers the cost of implementing solar panels because the green roof helps to keep foreign particles from disturbing the solar panels, which leads to losses in panel productivity [**14**]. These two technologies are, therefore, not in competition with each other for roof space, but actually can compound each other's impacts.

Green roofs take advantage of a living roof's natural capacity to heat and cool through improved insulation and evapotranspiration, which in turn provides increased performance in solar panels to further improve emission reductions in older buildings. Older buildings provide an opportunity to utilize valuable space and improve efficiency while avoiding the waste associated with tearing down old buildings to be replaced with new structures built to higher standards.

5. Implementation Plan

Green Roof Implementation Considerations - Weight, Materials, and Cost

Green roofs can significantly increase a building's efficiency by improving insulation. UMass can employ the benefits of this technology to support existing buildings on campus in being more energy efficient. Several variables must be considered when installing a green roof depending on its location and purpose. Some green roofs are intended to be places for people to gather whereas our purpose for retrofitting buildings with green roofs is to improve insulation and increase building efficiency. Implementing green roofs at UMass will require a thorough understanding of which buildings can support the weight of a green roof, the appropriate materials to use, and the financial foresight to cover the initial cost of green roofs and reap the long-term benefits.

In order to implement green roofs at UMass, the university needs to first look at which buildings are the most energy inefficient and which can benefit most from green roofs. Older buildings that are wide and short tend to be the best for green roofs because they are energy inefficient and they have a greater roof to surface area ratio. Older buildings are less energy efficient because building standards and insulation quality were less advanced when they were built. The next consideration is a building's weight-bearing capacity in order to ensure that roofs do not cave in upon building a green roof. For example, a senior engineering student estimated that Hampden Gallery is able to hold an additional 15-20 lbs/ft^2 of dead load [**15**]. Dead load is a term used to define weight on a roof that is not fluctuation, but rather is constantly there. A green roof on Hampden would need to be less than 20 lbs/ft^2 in total, which means the roof could have three inches of planting material [**16**]. This is enough to support hardy plant species capable of surviving on roofs such as *Sedum* [**17**].

Beyond weight capacity and building suitability considerations, implementing a successful green roof requires the components to be able to withstand rooftop conditions and avoid stormwater leakage. When implementing a vegetation layer, it is worth noting that while flat roofs will have even water distribution, a sloped roof will cause water to flow downwards, making the growing medium at the eaves significantly wetter than at the ridge [**18**]. For the vegetation layer to survive, selected plants must be able to accommodate the water load at any given point on the roof. *Sedum* is a drought tolerant plant genus and can be an effective choice for ridge planting where soil is dry, while herbaceous plants generally have higher water usage and can therefore tolerate and utilize stormwater when planted on the eaves of a roof [**19**]. The growth medium itself should be light and capable of holding sufficient water and nutrients to support the vegetation while being porous enough to drain excess water from the soil [**20**]. Waterproof membranes are also critical to prevent roof damage through stormwater leakage, and can be installed as a solid or a liquid [**20**]. Solid membranes are strong candidates for roofs with gentle slope, while liquid membranes can be more effective on roofs with steeper slopes or for roofs with multiple fixtures [**20**]. In all cases, a membrane should be resistant to root penetration to avoid long-term damage.

Performing a cost-benefit analysis on implementing these green roofs on UMass's own buildings reveals that despite the initial costs, the green roofs eventually pay themselves off in the long term financially and in terms of carbon savings. From an emissions standpoint, green roofs have the potential to prevent the equivalent of approximately 7467.8 Mt CO_2 emissions per year by reducing building energy usage by 6%. Building energy usage causes 85% of carbon emissions from campus every year so green roofs reducing that 85% by 6% would be a total carbon emissions reduction of 5%. While we cannot find the value of the total roof square footage of UMass's buildings, with this information we would be able to quickly find the dollar value of reducing carbon emissions per metric ton. While newer buildings with higher building energy standards can be helpful to UMass in reducing carbon emission, they also have added carbon emissions due to construction. In addition to reducing carbon emissions, green roofs do not have the added carbon cost required to construct a new energy-efficient building on campus because the buildings are being retrofitted rather than demolished and rebuilt.

To determine the financial cost [**21**], we used an online tool and found the surface area on top of several UMass buildings: Hampden Art Gallery, Prince and Melville Halls), Franklin, Hampshire, and Berkshire Dining Commons, and Hasbrouck Laboratory. These buildings were all selected because they have a comparatively lower building height, and therefore a green roof can have a greater effect on lowering the buildings' energy costs. Using data from a study published by the EPA, we calculated an average cost of installation and maintenance per square foot of roof, taking into consideration the required 2 year necessary period of maintenance [**22**]. This period of time is known as the "establishment period" and includes weeding, distributing plant growth, and general inspection. We found that the average cost of retrofitting a traditional roof with root-repelling membrane, installing a green roof system, purchasing the plants, labor, and maintaining the green roof for the first two years was about $\$31/ft^2$ (**Table 3**). This means that for a building like the Hampden Art Gallery, the initial cost would be about $900,944 (**Table 4**). However, the General Services Administration found that green roofs have a net present value of $2.70 per square foot per year [**23**]. This value represents the possible profitability of an investment, and takes the future expected costs and benefits into account, with inflation also accounted for. Using this data, we found that a green roof on top of these buildings would pay itself off in about 11.4 years (**Table 5**). In addition, green roofs can last up to 3 times as long as conventional roofs, or about 30 to 50 years [**24**]. Considering the longevity of green roofs, we found that if a green roof were to stay on top of our example building, Hampden Art Gallery, for 50 years, the University would save over $3 million in heating and cooling costs, as is shown in Table 5, as well as a reduction in stormwater runoff and CO_2 emissions on that building alone (**Table 5**). All of this data leads us to believe that installing green roofs on as many buildings on campus as possible would not only be beneficial to our environment, but save the university a considerable amount of money in the process.

Given the example of the Hampden Art Gallery, we can see a clear vision of what implementation of green roofs at UMass would look like. From here, we can use the same concepts to apply these takeaways to other buildings that have similar properties to Hampden.

6. Project Pros/Cons

The Good, the Bad, and the Green: Other Implications of Green Roofs at UMass

There are many possible solutions to lower the amount of CO_2 emitted at UMass. Each solution comes with its own unique set of pros and cons relating to energy, the environment, social equity, and to economics. Retrofitting UMass buildings would decrease the amount of energy needed to heat and cool buildings, and the green roofs would assist in stormwater management and support Amherst's biodiversity. Even with the upfront costs and the miniscule amounts of toxins released, the pros of green roofs far outweigh the cons.

One of the largest advantages of implementing green roofs on campus is their potential for energy savings through thermal insulation and evapotranspiration. By saving energy, the campus will lower its CO_2 emissions. An important idea to keep in mind is "a joule of energy saved is better than a joule of energy made" (Scott Auerbach, 2020). However, there is variability in the exact potential for energy savings. Experiments using models of roofs have shown that green roofs can save between 13% and 33% in the winter and can reduce heat flux (the transfer of heat into or out of a building through the roof) by up to 72% in the summer, but the numbers vary depending on building specifics **[25]**. However, we can estimate our energy savings based on similar climates. In a 2005 study in Toronto, they found that over the course of a year, an average buildings' energy demand decreased by 20% in the winter and by 80% in the summer [**26**]. By comparing the energy savings for UMass to other buildings in a similar climate, green roofs lead to a clear decrease in energy demand.

Retrofitted green roofs have dynamically robust environmental advantages due to their capacity to reduce CO_2 emissions with minimal construction while also improving stormwater management and supporting biodiversity. By sequestering carbon into plant structures and soil through photosynthesis, green roofs are able to mitigate building CO_2 production and absorb a small proportion of emissions that continue to be emitted by buildings. By lowering energy demand, less CO_2 is necessary to meet UMass's heating and cooling needs. Green roofs also improve stormwater management. Stormwater threatens environmental health by generating runoff, which is excess rainwater that travels across hard surfaces and accumulates pollutants. Runoff eventually reaches and contaminates water sources [**27**]. Green roofs prevent this by providing a permeable surface to absorb stormwater to be used by plants, and by providing a soil microbiome capable of breaking down pollutants before they can cause damage in aquatic ecosystems. In total, green roofs reduce runoff by an average of 80% compared to 24% in conventional roofs [**28**]. In terms of biodiversity, green roofs provide an opportunity for a variety of native plants to grow, with sloped roofs providing differences in soil moisture and additional fixtures such as solar panels providing shade, giving all varieties of water and shade tolerant plants a chance to thrive [**29**].

While green roofs are overwhelmingly beneficial when it comes to their impact on energy and the environment, there are drawbacks pertaining to social equity and the economics. However, the benefits of these facets still outweigh the con. First of all, the waterproof membrane required to install a green roof has been shown to release some toxins into the environment. [**30**]. However, non-green roofs also need a waterproof membrane. In a green roof, the membrane is protected by the vegetation, so the waterproof membrane will actually leak less toxins than normal roofs in the same period of time [**31**]. Other than this issue, green roofs generally have positive impacts on social welfare including increasing mental health and physical health [**32**]. Furthermore, another negative impact is the upfront cost of implementing green roofs. The upfront costs of retrofitting a green roof onto an old roof varies but is, on average, $31 per square foot (**Table 3**). However there is little to no maintenance costs and the financial benefits of it pay it back in about 11.4 years. (**Table 5**). All in all, although there are negative impacts in the areas of finance and implications on the community, the positive impacts outweigh them.

Green roofs' environmental, economic, equitable, and economic pros far outweigh their cons. Even taking into account their less attractive effects, green roofs are still extremely beneficial for UMass, especially when taking their environmental and economic impacts into account.

7. Conclusion

In order to bring older buildings to the efficiency standards of modern buildings and achieve net zero emissions by 2030, retrofitting with green roofs provides a viable solution requiring minimal construction. Green roofs provide year-round benefits through improved insulation and evaporative cooling, as well as synergistic benefits when installed with solar panels. Despite having a higher initial cost, these roofs have strong long-term benefits and are able to provide a return on their investment in 11.4 years through saved heating and cooling costs and improved roof durability. Numerically, implementation of green roofs has the potential to prevent the equivalent of approximately 7467.8 Mt CO_2 emissions per year by reducing strain on older buildings to provide adequate heating and cooling. This number can easily be converted to carbon savings per square foot as well as the dollar cost per unit CO_2 equivalent saved by dividing the net annual carbon savings by the total surface area of the roofs on campus and referring to the installation cost per square foot of green roof. Although our team did not have access to the total roof surface area of our campus, we believe it can be compiled from existing building records. While there is the potential for minimal environmental impacts due to the presence of a waterproof membrane, these negatives pale in comparison to the potential benefits of installing green roofs on older buildings. As a whole, our team has determined that UMass would benefit most from assessing older buildings with a high ratio of roof to surface area and weak insulation for consideration to install new green roofs.

8. Appendices

Table 1. Baseline and improved average u-values for simulated buildings (a lower u-value is preferable).

Building number	Building Aspect Ratio	% window coverage	Average u-value (baseline)	Avg u-value (green roof)	Avg u-value (better windows)
1	1:1	7%	0.4614	0.2427	0.4500
2	1:1	54%	0.5883	0.3696	0.5002
3	1:3	7%	0.4496	0.2420	0.4372
4	1:3	54%	0.5873	0.3797	0.4917

Table 2. Improvements in average u-value for simulated buildings with improved insulation (a lower u-value is preferable).

Building number	Green roof improvement from baseline	Better windows improvement from baseline	Average u-value difference (green roofs vs better windows)
1	-0.2188	-0.0114	-0.2073
2	-0.2188	-0.0881	-0.1307
3	-0.2076	-0.0124	-0.1952
4	-0.2076	-0.0956	-0.1120

Table 3. Calculation of cost per square foot to install all of the necessary green roof components.

Initial Cost (dollars per square foot)	Lowest price	Highest price	Average price
Re-roofing with root-repelling membrane	$10.00	$15.00	
Green Roof System (curbing, drainage layer, filter cloth, growing medium, decking and walkways)	$5.00	$10.00	
Plants	$1.00	$3.00	
Installation/Labor	$3.00	$8.00	

Maintenance (first two years)	$2.50	$4.00	
Total $/ft2	$22.00	$40.00	$31.00

Table 4. Initial costs of installing green roofs for several buildings on campus

Building	**Area (m^2)**	**Area (ft^2), Rounded**	**Initial Cost at Lowest Price**	**Initial Cost at Highest Price**	**Average Initial Cost**
Hampden	2722	29299	$629,929	$1,171,960.00	$900,944
Prince Hall	1695	18245	$392,268	$729,800.00	$561,034
Melville Hall	911	9806	$210,829	$392,240.00	$301,535
Frank DC	2663	28664	$616,276	$1,146,560.00	$881,418
Hasbrouck	2494	26845	$577,168	$1,073,800.00	$825,484
Hamp DC	2442	26285	$565,128	$1,051,400.00	$808,264
Berk DC	2519	27114	$582,951	$1,084,560.00	$833,756

Table 5. Total cost of buildings' green roofs over the course of 50 years.

Building	**Cost after 5 years**	**Cost after 10 years**	**Cost after 11.4 years**	**Cost after 15 years**	**Cost After 25 years**	**Cost After 50 years**
Hampden	$505,408	$109,871	-$879	-$285,665	-$1,076,738	-$3,054,421
Prince Hall	$314,726	$68,419	-$547	-$177,889	-$670,504	-$1,902,041
Melville Hall	$169,154	$36,773	-$294	-$95,609	-$360,371	-$1,022,276
Frank DC	$494,454	$107,490	-$860	-$279,474	-$1,053,402	-$2,988,222
Hasbrouck	$463,076	$100,669	-$805	-$261,739	-$986,554	-$2,798,591
Hamp DC	$453,416	$98,569	-$789	-$256,279	-$965,974	-$2,740,211
Berk DC	$467,717	$101,678	-$813	-$264,362	-$996,440	-$2,826,635

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