Increasing Energy Efficiency
Northeast US

This document is a collection of abstracts with citations compiled by Drexel University highlighting research around green roofs' ability to increase energy efficiency in the Northeast United States. This is not a comprehensive literature review but is intended to be a first stop for a green roof researcher. These abstracts were compiled by Tenaya Hubbell-Wood and Korin Tangtrakul, under direction of Dr. Franco Montalto of Drexel University. Contact Korin for more information: krt73@drexel.edu

This document will be updated periodically to include the latest research. It was last updated in February 2020.

Exploring the building energy impacts of green roof design decisions - a modeling study of buildings in four distinct climates

Sailor, David J. & Elley, Timothy B. & Gibson, Max (2011). Exploring the building energy impacts of green roof design decisions - a modeling study of buildings in four distinct climates. Journal of Building Physics, Vol 35, P 372-391 DOI: 10.1177/1744259111420076

This study explores the complex and interacting physical mechanisms that lead to building energy use implications of green roof design decisions. The EnergyPlus building energy simulation program, complete with an integrated green roof simulation module, was used to analyze the effects of roof surface design on building energy consumption. Simulations were conducted for both black and white membrane control roofs and nine variations of green roofs. The investigation included a total of eight buildings - new office and new multi-family lodging buildings, each in four cities representing diverse climatic conditions: Houston, Texas; New York City, New York; Phoenix, Arizona; and Portland, Oregon. Building energy performance of green roofs was generally found to improve with increasing soil depth and vegetative density. Heating (natural gas) energy savings were greatest for the lodging buildings in the colder climates. Cooling energy (electricity) savings varied for the different building types and cities. In all cases, a baseline green roof resulted in a heating energy cost savings compared to the conventional black membrane roof. In six of the eight buildings, the white roof resulted in lower annual energy cost than the baseline green roof. However, a high vegetative cover green roof was found to outperform the white roof in six of the eight buildings.

Heat flux and seasonal thermal performance of an extensive green roof

Squier, Mallory & Davidson, Cliff I. (2016) Heat flux and seasonal thermal performance of an extensive green roof, Building and Environment, ISSN: 0360-1323, Vol: 107, Page: 235-244. DOI: 10.1016/j.buildenv.2016.07.025

Green roofs influence the overall energy balance of buildings. In this study, the thermal properties of a green roof are determined using field data gathered from an extensive 0.56 ha green roof in Syracuse, NY. Sensors installed at five stations across the roof measure temperature at four depths within the roof layers. Data have been gathered from September 2013 to September 2015. Heat fluxes range from -5.76 W m(-2) to 9.46 W m(-2). Negative (downward) heat flux is found during summer and early fall, and positive (upward) heat flux dominates during the heating season. Solar radiation can heat the upper layers of the roof significantly above ambient air temperatures during the summer. Accumulated snow acts as an insulator during the winter months. Thermal resistance, R, is determined during a two-week period with significant snow accumulation, during which time heat flow through the roof reached a quasi-steady state. Thermal resistance for the overall roof is found to average 3.1 m(2) K W-1. The largest individual thermal resistance is from the extruded polystyrene insulation layer (R = 2.6 m(2) K W-1). Overall, the green roof dampens the extreme responses often observed on urban roofs. Vegetation and substrate layers may be used in addition to insulation, but are not recommended in lieu of insulation for a Central New York climate.

Green roof for zero energy buildings: a pilot project

Asdrubali , Francesco & Evangelisti, Luca & Guattari, Claudia (2019) Green roof for zero energy buildings: a pilot project. Materials Science and Engineering. Vol 609. DOI: 10.1088/1757-899X/609/7/072011.

Zero Energy Buildings (ZEBs) and nearly Zero Energy Buildings (nZEBs) can be designed from scratch or they can be obtained after deep refurbishments of existing constructions. Both passive and active strategies are fundamental to achieve the ZEB or nZEB target. According to this, among passive systems, green roofs can be a viable solution because they allow to achieve energy savings, also reducing the urban heat island phenomenon. In this research, an innovative roof-lawn system was preliminary analyzed by installing several measurement instruments for obtaining information about thermal heat exchanges. Heat-flow meters, surface temperature and air temperature probes were installed, comparing the performance of the roof-lawn system with a nearby simple old roof, in order to quantify the two different behaviors from a thermal point of view.

The roof-lawn system revealed its advantages, showing a higher thermal inertia with no overheating and a lower thermal transmittance, as well as better indoor conditions for the occupants of the building. The study is the first step of a path which aims to design a more complex and complete system, also considering the structural part of the roof.

Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate

Susca, Tiziana. (2019) Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate. Building and Environment. Vol. 162. DOI: 10.1016/j.buildenv.2019.106273.

In the next decades, the increase in global population will lead to further urbanization determining, on the one hand, an increase in building energy use and, on the other hand, a surge in urban temperature, which, in turn, affects building energy demand. Since the building sector greatly contributes to the use of energy globally, the amelioration of this sector is an urgent issue to contribute to climate stabilization.

Published literature shows that green roofs affect both directly and indirectly building energy use, delivering the message that green roofs are fit-all solutions. However, the efficacy of the deployment of green roofs varies depending on climate and their specific design.

The present study provides a geographically explicit review of the potential building energy benefits deriving from the installation of green roofs depending on their specific design aiming at answering the following research questions:

-Are green roofs fit-all solutions for decreasing building energy use in diverse climates?
-How should insulation, growing media, and plant selection of green roofs be calibrated in different climates to maximize their effect on building energy use?
-How can green roofs contribute to urban heat island-mitigation in different climates?

Answering these research-questions, this study provides urban decision-makers and planning agencies useful insights, not only to prioritize strategies, but also to efficiently design by-laws and local regulations to maximize the potential positive effect of urban-wide green roof deployment on building energy use.

Thermal behaviour of a green roof containing insulation cork board. An experimental characterization using a bioclimatic chamber

Almeida, Ricardo & Simones, Nuno & Tadeu, Antonio & Palha, Paulo & Almeida, Joao (2019) Thermal behaviour of a green roof containing insulation cork board. An experimental characterization using a bioclimatic chamber. Building and Environment. Vol. 160. DOI: 10.1016/j.buildenv.2019.106179.

Green roof technology is increasingly being used to improve the energy and environmental performance of buildings. However, the description of the thermal behaviour of green roofs is very complex since it depends on several variables and relies on intricate phenomena.

In this work the authors characterize a green roof system that replaces the conventional drainage and water storage polyethylene membranes with insulation cork boards (ICB). To enable the experimental characterization of this system, a double walk-in bioclimatic chamber was designed and built to recreate indoor and outdoor environmental conditions. Winter and summer environments with steady and unsteady conditions in both dry and wet states were simulated. Thermocouples and heat flux sensors were used to collect data over time from the different layers of the green roof prototypes.

Measurements were first performed on a concrete slab insulated with ICB to assess the contribution of the latter to the thermal performance of the system. The effect on the heat transfer was further evaluated for systems of increasing complexity, containing first a substrate layer and then vegetation. It was noted that the substrate and vegetation layers improved the thermal insulation, and reduced heat fluxes and the thermal amplitude within the system. The vegetation layer was found to be of key importance to the overall performance of the green roof. It was also found that ICB and the substrate layers lose part of their insulation capacity when the system was wetted, although it was fully restored in the ICB layer within a few hours.

Variations in photovoltaic performance due to climate and low-slope roof choice

Nagengast, Amy & Hendrickson, Chris & Matthews, Scott. (2013) Variations in photovoltaic performance due to climate and low-slope roof choice. Energy and Buildings, ISSN 0378-7788, Vol. 64, Pages 493-502. DOI: 10.1016/j.enbuild.2013.05.009.

With urban space at a premium, roofs are being targeted as an opportunity to deploy sustainable energy technologies for buildings. This research evaluates the combination of green roofs and solar photovoltaics specifically through their temperature and electricity production relationship. Measurements over a one year study period from July 1, 2011 to June 30, 2012 from a large field project in Pittsburgh, Pennsylvania were used to determine the differences in power output from green and black roofs as well as to derive two regression functions for back-surface panel temperature and photovoltaic (PV) output. These estimation functions were applied to three different cities (San Diego, CA; Huntsville, AL; and Phoenix, AZ) chosen to represent a wide range of irradiance and temperature values. Based on the specific test-bed configuration, the green or black roof choice under the PV panels had little impact on the PV performance. The difference in magnitude of power generation for green roof-PV compared with black roof-PV assemblies was small (0.5%) corresponding to an annual loss of $9160 panels in Pittsburgh and a benefit of approximately $8/60 panels per year in Phoenix. Results also suggest that sites consistently above 25 C (77 F) will most likely see a small, positive impact from a green roof-PV combination. Building managers and designers should consider this temperature and power output interaction a minor economic factor in roof decisions.

Designing and Installing a Retrofit Heated Green Roof Using Either Co-Gen Waste Hot Water or Municipal Waste Steam Heat as Energy Source

Dell, Robert & Wei, Stan & Parikh, Raj & Unthorsson, Runar & Foley, William. (2014). IMECE2014-39066 Designing and Installing a Retrofit Heated Green Roof Using Either Co-gen Waste or Municpal Waste Steam Heat as Energy Source. 10.1115/IMECE2014-39066.

Municipal District Heating Services and Combined Heat and Power (CHP) systems can produce waste heat in the form of steam condensate and hot water. The authors have developed a system to use this thermal pollution to heat the soil and growth medium of green roofs and outdoor gardens. The system enables plant life to survive colder climates and increases growth often in excess of 20% (Power2013-98172). In New York City test heated green roofs, the system can save vast amounts of normally required cooling water that is tapped from the overburdened municipal supply (IMECE2013-65200). Existing small scale green roofs in New York City and larger scale heated green roof retrofit in New York City is presented to indicate additional construction details, thermal considerations, and potential code compliance considerations.

Hydrometeorological determinants of green roof performance via a vertically-resolved model for heat and water transport

Sun, Ting & Bou-Zeid, Elie & Wang, Zhi-Hua & Zerba, Eileen & Ni, Guangheng. (2013). Hydrometeorological determinants of green roof performance via a vertically-resolved model for heat and water transport. Building and Environment. 60. 211-224. 10.1016/j.buildenv.2012.10.018.

In this study, the Princeton Roof Model (PROM) is developed, validated and used to simulate the hygrothermal dynamics of green roof systems. PROM is embedded within the framework of the Princeton Urban Canopy Model, with a multi-layer spatially-analytical heat transfer scheme and an improved hydrological module. The model is validated by comparing simulated surface temperature and soil moisture to the measurements at two experimental sites, one in Beijing, China and the other in New Jersey, USA. The results demonstrate that PROM is able to capture the diurnal cycle of roof temperatures and the soil moisture dynamics of green roofs with high accuracy. Driven by a 30-day summertime meteorological forcing from July 2001, PROM is used to investigate the green roof thermal improvement to the urban indoor and outdoor environments, compared to conventional roofs. The impact of green roofs is significant in reducing surface temperatures, and outdoor and indoor heat fluxes during this summer period. To quantify this thermal improvement, three indices related to surface temperature, outdoor heat flux and indoor heat flux, are introduced; and the dependence of these indices on hydrological and meteorological conditions is investigated. The results indicate that incoming solar radiation and medium layer moisture are the main determinants of the green roof performance.

Accumulated snow layer influence on the heat transfer process through green roof assemblies

Zhao, Mingjie & Srebric, Jelena & Berghage, Robert D. & Dressler, Kevin A. (2015) Accumulated snow layer influence on the heat transfer process through green roof assemblies. Building and Environment, ISSN: 0360-1323, Vol: 87, Page: 82-91. DOI: 10.1016/j.buildenv.2014.12.018

A green roof can reduce the peak thermal cooling loads and reduce the building energy consumption during the summer. It is also necessary to understand the thermal performance of these green roof assemblies during the winter when affected by an accumulation of snow on the rooftops. This study presents an experimental investigation and discusses the snow influence on the heat transfer processes through green roof assemblies. The on-site experiments were conducted in the outdoor test facility in Pennsylvania, U.S.A. during the winter of 2010/2011.

The experiments were conducted on green roof buildings and on reference buildings for comparison. The collected data included the local meteorology, building operation data, and manually measured snow properties. The measured heat fluxes show that the heat flow though the green roof assemblies compared to the typical roof assemblies were reduced by approximately 23% when there was not an accumulated snow layer. However, this difference in the heat flux was only 5% when the roof structure had an accumulated snow layer. To quantify the snow effects on the heat transfer through green roof assemblies, the Johansen method was then used for snow conductivity calculations on rooftops. These equations should be a part of the total energy balance for the snow covered green roof assemblies because the snow layer significantly altered the heat transfer through these roof assemblies.

Comparative environmental life cycle assessment of green roofs

Kosareo, Lisa & Ries, Robert. (2007). Comparative environmental life cycle assessment of green roofs. Building and Environment, ISSN: 0360-1323, Vol: 42, Issue: 7, Page: 2606-2613. DOI: 10.1016/j.buildenv.2006.06.019

This paper describes the life cycle environmental cost characteristics of intensive and extensive green roofs versus conventional roofs. A life cycle inventory and environmental impact assessment is used to document and analyze the similarities and differences in the environmental impacts of the fabrication, transportation, installation, operation, maintenance, and disposal of all three roof systems. This is important because there are additional resources committed to green roofs from which environmentally relevant benefits, such as reduced electrical energy use for building cooling, are derived. The extensive green roof design for the case study presented here is from an actual 1115 m(2) (12,000 ft(2)) green roof project on a retail store in Pittsburgh, PA, USA. The case study includes a conventional ballasted roof, an extensive, or shallow growing medium green roof, and an intensive, or deep growing medium green roof. For the life cycle inventory and the material use, both the types of material used and the transportation distances to the site are with respect to this project.
The study found that, for the Pittsburgh, PA climate, the energy use reduction that is realized because of the lower thermal conductivity of the roof due to the green roof growing medium is the critical factor in determining the relative magnitude of the environmental impact of the alternatives compared here. Although the energy use reduction is not very large in relation to the overall building energy use, it is significant for environmental impact over the life cycle of the building.

Repurposing Waste Steam and Hot Water to Accelerate Plant Growth in Heated Green Roofs

Dell, Robert, Unnthorsson, Runar, Wei, C. S., and Foley, William. "Repurposing Waste Steam and Hot Water to Accelerate Plant Growth in Heated Green Roofs." Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition. Volume 6B: Energy. San Diego, California, USA. November 15–21, 2013. V06BT07A036. ASME. DOI: 10.1115/IMECE2013-65200

Municipal steam district heating services such as New York City's Consolidated Edison's have no recirculation system. The waste heat, usually in the form of steam condensate and hot water, is mixed with and cooled by municipal potable water. Since 2006, The Center for Innovation and Applied Technology and The Laboratory for Energy Reclamation and Innovation at the Cooper Union have been developing a system to use this thermal pollution to heat the growth medium of green roofs. The authors have also constructed three geothermal heated gardens systems in Iceland. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) specifications for heated sidewalks were referenced in all locations. The heated green roofs have the potential to save more than 2,000,000 cubic meters of potable water if applied to 40% of Consolidated Edison's steam customers. Plant growth is often accelerated by 20% or more in all locations.