



Living Architecture Performance Tool

Energy Conservation and Generation

White Paper

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1.0 INTRODUCTION AND BACKGROUND

1.1 THE GREEN INFRASTRUCTURE FOUNDATION (GIF)

The Green Infrastructure Foundation (GIF) is a tax-exempt, charitable organization affiliated with Green Roofs for Healthy Cities (GRHC). It is dedicated to promoting public awareness of the diverse benefits of green infrastructure like green roofs, green walls and urban forests as part of the built environment.

- GIF is a well-recognized source of information, technical assistance, case studies, evaluation tools and policy models for green infrastructure for both public sector and private sector decision-makers.
- GIF supports the efforts of other organizations that focus on related areas such as low-impact development, green buildings, eco-industrial development and other sustainable development initiatives.
- GIF's programs and activities are designed to promote the positive contributions green infrastructure can make in communities while addressing barriers to green infrastructure such as local, state and federal regulations, the lack of awareness among policymakers and their constituencies, and the lack of technical knowledge about green infrastructure among contractors and consultants.

1.2 LIVING ARCHITECTURE PERFORMANCE TOOL OBJECTIVES

Over the last two decades, thousands of building owners and professionals have been incorporating an increasing number of vegetative technologies on building envelopes and within the interiors of new and existing structures. Voluntary standards such as LEED and Sustainable Sites, combined with a variety of local government public policies, have supported the growth of these living architecture technologies. The United States Environmental Protection Agency (EPA) has been increasingly involved in supporting local and regional efforts to develop effective policies and implementation strategies.

Living architecture is defined by the integration of inorganic, non-living structures with organic, living systems to achieve superior ecological, social and economic performance. Living architecture currently includes well-known technologies such as green roofs, green facades and living walls.

While these technologies can simultaneously address many critical needs in our buildings and communities, it is difficult to describe the interacting costs and benefits of these technologies in standardized way. A siloed, one-size-fits-all approach to the design and operation of these systems ignores or undervalues the range and scope of benefits that living architecture provides. An example of this is an analysis that concludes that white roofs are the best way to reduce the urban heat island effect, only because all of the benefits associated with green roofs and walls – i.e. the

ability to reduce the urban heat island, support biodiversity, cleanse the air, generate employment, etc. – are discounted from the valuation. This complexity is both a challenge and an opportunity.

The main factors that contribute to the complexity of living architecture are as follows:

- **Diversity of benefits.** In comparison to other green building technologies, living architecture provides a wide range of benefits, which are often quantified independently and according to different metrics.
- **Variety of spatial scales on which benefits are accrued.** The many benefits of living architecture are also realized at different spatial scales, from individual buildings, to neighbourhoods and districts, and even across entire watersheds. Some benefits, such as urban heat island mitigation, or preventing a combined sewer overflow event, will only be realized when a certain threshold of implementation is reached.
- **Compound benefits.** When combined, multiple living architecture technologies can provide greater overall benefit than when used in isolation.
- **Climate and microclimate.** Living architecture performance benefits are often dependent on the weather and climate environment of the region they are situated in. For example, in some regions, rainfall patterns are often sufficient to maintain vegetation whereas this is not possible in arid and semi-arid regions, which must provide irrigation support during certain periods of the year. Performance benefits may also be impacted by micro-climatic effects, such as the amount of available shade or sun.
- **Diversity of technologies.** The benefits of living architecture vary considerably from one technology type to another. For example, an interior living wall that is integrated with the mechanical system and acts as a bio-filter serves to remove pollutants from indoor air whereas an ordinary interior living wall or an exterior living wall may not.
- **Diversity of design, product and maintenance practices.** Through design, product and maintenance practice variation, there are often dramatic differences in the performance of different technologies in the same category. For example, a green roof can retain 100% of the annual stormwater runoff, or as little as 10%, depending on its components such as the growing media composition, types of plants, and drainage layer type. Improper maintenance may also result in inconsistent performance.
- **Private vs. public benefits.** Some of the benefits accrue to the building or property owner who makes the investment in living architecture, while other benefits accrue to the general public or the surrounding area. Quantifying these benefits and identifying their beneficiaries adds to the complexity of living architecture.
- **Second-tier impacts.** Many benefits are related to second tier impacts. For example, green walls can reduce the urban heat island effect, which in turn reduces energy consumption for air conditioning for buildings experiencing reduced ambient temperatures. This can act as a feedback loop, providing further benefits.
- **Trade-offs.** Costs in some areas can create benefits in other areas. For example, while irrigation of green roofs consumes water, it may also reduce water consumption elsewhere in a building. Less water may be required in the cooling tower due to the reduced cooling requirements from the contributions of the green roof.

These complexities have resulted in a number of barriers to the full standardization and realization of the performance benefits of living architecture. There are a number of related challenges that the Living Architecture Performance Tool aims to address. These include:

- ***Inconsistent policy.*** Policymakers are often keen to create regulatory and financial incentives for living architectural system implementation due to their many public benefits. However, they do not have a performance-based system that can be used as a reference, which they can then support with policy measures. In the absence of a performance standard framework, the adoption of multiple design, construction and maintenance standards by different local jurisdictions over time will not serve the industry well. One of the initial driving forces behind the USGBC's LEED program was the fact that governments adopted the voluntary standard and tied it to procurement policies and incentives for new buildings. A similar system needs to be in place for living architecture systems – to guard against the manufacture, design, installation and maintenance of systems that may underperform, and to highlight best practices to help ensure maximum performance benefits for public and private building owners.
- ***Insufficient product testing.*** The influx of new products, particularly in the field of living walls, is a welcome trend, but in the absence of clear performance standards can leave many consumers without the necessary means of selecting a system and/or design that will meet their needs. For manufacturers, a third party certification of product performance will give them an advantage in the marketplace against firms that are unwilling to test their products for performance benefits.
- ***Lack of benchmark for quantifying the performance of projects.*** Increasingly, water and energy utilities, with support and encouragement from the EPA, are beginning to embrace green infrastructure as a means to reduce energy consumption and the urban heat island, manage stormwater runoff to prevent combined sewer overflows and improve water quality, as a complement to traditional grey infrastructure approaches. Yet without clear performance measures, many projects fail to meet their intended design objectives or have difficulty quantifying their long-term financial benefits.
- ***Representation of living architecture in voluntary standards for green buildings and sites.*** Voluntary performance standards, such as the USGBC's LEED and Sustainable Sites could benefit from a more clearly articulated reference standard for living architecture technologies. This would help to address credits that are seen by the industry as dysfunctional in some environments, like removal of irrigation systems, and strengthen the application of existing credits.

The lack of a comprehensive framework of clear performance benefit metrics for living architecture systems threatens their long-term application to green buildings and sustainable sites, thereby jeopardizing the many benefits they provide building owners and the broader community.

1.3 THE LIVING ARCHITECTURE PERFORMANCE TOOL

Part of the success of the USGBC's LEED rating system is that it made the complexity of green building understandable and therefore actionable. Over past two years, Green Roofs for Healthy Cities and the Green Infrastructure Foundation have been working with a variety of stakeholders to develop a performance framework called the Living Architecture Performance Tool (LAPT) in order to begin the important work of addressing the challenges described above. It is an ambitious effort, which will require ongoing development over five years or more, but like LEED, it has the potential to be transformative.

The focus of the LAPT is to develop consensus-based performance criteria and metrics for all major types of living architecture, beginning initially with green roofs, green facades and living walls, and then in later phases incorporating other technologies that integrate living and non-living building systems. The objectives in developing the LAPT are as follows:

- To further the integration of living systems in buildings and to articulate the ecosystem services they provide.
- To improve the public and professional understanding of the value and multiple benefits of fully incorporating living architecture into the built environment.
- To encourage continuous improvement among living architecture professionals through a widely recognized standard of practice and feedback mechanisms from implemented projects.
- To build upon, inform and align with the on-going development of other high-performance rating systems, including Leadership in Energy and Environmental Design (LEED), Sustainable Sites Initiative (SITES), Roofpoint, and the Living Building Challenge.
- To help set the agenda for ongoing research activities and encourage greater collaboration among research groups.
- To establish performance metrics, benchmarks and design parameters that can be used by utility managers and government leaders to develop supportive policies and programs.
- To facilitate more uniform testing and evaluation of new products and implementation approaches against the performance metrics wherever possible.
- To help guide funding and investment decisions that accurately reflect the performance characteristics of living architecture systems and applications.

1.4 WHAT TYPES OF LIVING ARCHITECTURE EXIST?

There are many different living architecture systems, and new technologies are being developed every year. The major technological categories of living architecture currently include:

Green Roofs (Vegetative Roofs, Eco-Roofs, Garden Roofs)

A contained green space on top of a human made structure below, above, or at-grade. Green roofs typically utilize high quality waterproofing, a root barrier, drainage layer, filter fabric, engineered growing media and plants. Green roofs encompass a wide variety of project types and approaches.

Extensive green roof systems utilize less than 6" (15 cm) of growing medium and have more limited plant species and minimal maintenance requirements.

Intensive green roof systems use more than 6" (15 cm) of growing medium and can sometimes support small trees and shrubs and typically require more ongoing maintenance than extensive systems.

Roof systems can often accommodate both approaches based on the building's loading capacity or the budget for the roof system. Such *semi-intensive* systems are defined as those with at least 25 per cent of the planted area as either extensive or intensive.

Green Walls (vertical gardens, living walls, bio-walls)

Green walls are a class of living architecture that provides for vegetation on the vertical plane and are typically attached directly to the building envelope on both interior and exterior surfaces.

There are four different types of green walls: living walls, green facades, interior green walls (biowalls) and living retaining walls.

Living walls include vertical hydroponic membranes and inorganic fabric systems. Many living wall technologies are modular in design, with various types of compartments, and pre-grown units of growing medium and plants that are connected to a racking system, which is then attached directly to the building envelope. Modules can be made of plastic, polystyrene, synthetic fabric, clay, or concrete, and generally support a diverse range of plant life. Regardless of the system used, living wall systems are visually striking and have a major biophilic impact.

Green facades are systems in which vines and climbing plants or cascading ground covers grow up or down on supportive structures attached to walls. Plants growing on green facades are generally rooted in soil beds at the base, or in elevated planters at intermediate levels or even on rooftops. Green facades can be attached to existing walls or built as freestanding structures that support the ability of plants to grow and climb. Two primary sub-types of these systems are modular trellis panels, and wire, rope or cable net materials. Modular trellis panels typically use preformed lattices made of stainless steel that fix to the building envelop and lock into each other, and the ground. Rope or cable net systems use flexible stainless steel to create a mesh that plants are able to climb.

Interior green walls (biowalls) incorporate plants on walls within buildings. Interior green walls can be designed to pull indoor air through their leaves and root systems to improve indoor air quality by removing contaminants, or they may simply enhance aesthetic values within indoor spaces.

Living retaining wall systems are specially designed to stabilize a slope while also supporting vegetation. They provide structural strength that resists lateral forces and protects slopes from erosion. They are often modular in construction, with interlocking units that may be comprised of metal, plastic, mats, or woven willow plants. The intent of living retaining wall systems is to become fully covered with plants so the underlying support structures disappear from view.

Other forms of living architecture

A growing number of living architecture systems and strategies fit within these definitions. While the Living Architecture Performance Tool was initially conceived to address green roofs and walls, it quickly became evident that similar metrics should be used to describe the performance of any form of living architecture, and would have greater value in doing so.

For example, various living systems are developed and operated to manage, clean or re-use stormwater and/or wastewater. These include various designs (constructed wetland, living machine, biotopes, natural pools and spas), that clean water for human contact or improve indoor living conditions (air quality, humidity, temperature). The term “living architecture” implies integration with a built form, and all of these elements may be developed on or within built structures, or immediately adjacent to built structures.

A **Biofiltration system or Biotope** is a landscape element designed and engineered to receive and improve the quality of a particular water flow, such as surface water runoff, building process water, or from some other source. Such systems are generally low-input, relying on gravity rather than pumps, and include a cross-section of mineral material (gravel, sand), engineered soil/organic material, and plants. The combination of materials soils and plants filters and cools the water as it flows through. Rain gardens and bioswales also use this approach to receive, retain, and filter rainwater.

A **living machine (Eco-Machine, ecological engine, etc.)** is an intensive bioremediation system typically used to treat wastewater. Specific aquatic and wetland plants, bacteria, algae, protozoa, plankton, snails and other organisms are used in the system to provide specific cleansing or trophic functions. It can also produce beneficial by-products, such as reuse-quality water, and habitat for ornamental plants and the production of plant biomass. These plant by-products, in turn, can be used in building materials, animal feed or to produce energy from biomass combustion or anaerobic digestion.

A **constructed wetland** is an artificial wetland, marsh or swamp created as new or restored habitat for native and migratory wildlife. Wetlands can also receive anthropogenic discharge such as wastewater, stormwater runoff, or sewage treatment, or be used for land reclamation after mining, refineries, or other ecological disturbances. In many jurisdictions, constructed wetlands are required as mitigation for natural wetlands lost to land development.

These general classes of living architecture will be used as the basis for development of the Living Architecture Performance Tool. Some of the performance metrics developed in the LAPT will not apply to all of these types of living architecture, and will continue to evolve over time based on ongoing research and application of the performance tool.

1.5 APPROACH TO DEVELOPING THE LIVING ARCHITECTURE PERFORMANCE TOOL

An important early step in the development of the LAPT is the commissioning of white papers in major subject areas related to living architecture. With funds raised from various sources, the goal of the white papers is to define the state of performance metrics and their application to various types of living architecture. White paper development can be conducted by GRHC/GIF staff or research groups, and guided by technical committees subject to extensive peer review. An executive committee will then work to bring the white paper findings together into a comprehensive framework.

Multi-stakeholder committee discussions have already taken place in the context of different Technical Committees, which will be expanded to include more stakeholders. Technical committees will report to the Executive Committee who responsibilities include coordinating all of the work of the Technical Committees into a coherent and cohesive framework. Technical committees will oversee the development of the White Papers in their respective subject areas and conduct outreach to additional stakeholders.

Possible White Paper topics are as follows:

Water Committee

- Stormwater Quantity Management
- Stormwater Quality Management
- Water Capture, Reuse and Irrigation

Energy Committee

- Energy Efficiency and Conservation

Life Sciences Committee

- Biodiversity
- Growing Media Sciences
- Plant Sciences and Food Production
- Ecosystem Integration and Life Cycle Impacts

Health and Well-Being Committee

- Biophilic Design Potential
- Air Quality
- Noise Reduction

Materials/Components

Planning/Implementation Process Committee

Integrated Design Process

Management, Operations, and Stewardship

Research and Education

The White Papers will constitute the basic elements that allow for the development of the LAPT. Some will be relatively straightforward to produce while others will likely require a greater level of effort. Each of the proposed White Papers will follow a standardized format that will facilitate future synthesis into a cohesive framework. This paper is the third white paper to be developed, on the subject of Energy Conservation and Generation.

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2.0 BUILDINGS AND ENERGY

The buildings sector is the single largest global user of energy, accounting for around 40% of energy use in developed countries (US Department of Energy, 2012; European Commission, 2012). The homogenization of building design means that buildings are often designed without regard to local context, climate, or available local water, energy and material resources. Rather, the drivers of new building design continue to be minimal initial cost and the ability to be rapidly constructed. Poor building design is compensated for by using increasingly energy-intensive heating, ventilation and cooling (HVAC) systems. These HVAC systems allow us to maintain a uniform indoor environment, regardless of the location of the building. Despite the dramatic differences in climate between Phoenix and Boston, for example, the average new building in each city is remarkably similar.

While energy conservation or generation is a concern in new construction, the situation is even more troubling in older buildings. The average age of commercial buildings in the US is over 40 years, and 80% of its housing stock is over 15 years old (Institute for Market Transformation, 2012). Similarly, 35% of all buildings in the European Union are over 50 years old (European Commission, 2015). Many of these older buildings were constructed in eras of extremely permissive building codes. It may not be feasible or desirable to replace many of these poorly designed buildings for several years, even though energy and maintenance costs build up. This presents an opportunity for retrofits that can significantly improve energy performance.

2.1 LIVING ARCHITECTURE AND ENERGY

Only a few generations ago, humans relied on renewable natural resources for all their needs – agriculture, forestry and fishing provided the major inputs to run our economies. Since the advent of industrial civilization, we have shifted from biological solar income to fossil fuels as our main source of energy, expanding production and population. However, now that we have become a global civilization with an ever-increasing demand for raw materials and finished goods, we find ourselves confronted by declining availability of fossil fuels, and the dire consequences of climate change and environmental degradation associated with fossil fuel extraction and combustion (Allen, 2013).

Our challenge is to support our needs using only renewable energy in the next few decades, while mitigating and reversing climate change and environmental destruction. Our growing understanding of the services already provided by our ecosystems can help us achieve this goal. Redesigning our built environments to conform to ecosystem attributes holds the key to a sustainable future (Allen, 2013). We live in an era where more and more jurisdictions are pricing the use of carbon, and where we are transitioning from centralized to distributed power generation.

Living architecture has been used for hundreds or even thousands of years for its many benefits. While the hanging gardens of Babylon – one of the original Seven Wonders of the World - were mostly prized for their aesthetic appeal, sod roofs have been used in Scandinavia since the middle

ages for their insulative properties. Similarly, vines have been planted in urban areas throughout history, not only as a source of food, but also for their shade.

Living architecture has come a long way since those early designs, and today is a complex and delicate field that requires knowledge of architecture, biology, landscape architecture, building science, and mechanical and electrical engineering. Using an integrated design process is essential to designing living architecture for performance and optimal benefit. Living architecture has many potential energy benefits that largely fall into three categories: moderation of heat transfer through the building envelope, improving building heating, ventilation and cooling (HVAC) systems through integration, and improving the opportunity for and efficiency of renewable energy technologies. Other energy benefits include the reduction of the urban heat island effect and the potential to sequester carbon.

2.2 MODERATION OF HEAT TRANSFER THROUGH OF THE BUILDING ENVELOPE

The energy balance of a green roof or wall is similar to that of a traditional roof or wall: it is dominated by incoming solar radiation, and balanced by sensible (convective) and latent (evaporative) heat flux from soil and plant surfaces, along with conduction of heat into plants and the growing media.

Thermal moderation of a building envelope is one of the most important benefits of living architecture. Engineers, architects, investors and building owners tend to ask a simple question when considering a green roof or living wall to conserve energy: “What is the R-Value?” The thermal performance of living architecture is far more complicated than merely a layer of insulation, and living architecture uses the following methods of heat transfer and dispersal to moderate a building envelope:

- Evapotranspiration (latent heat loss) – transpiration occurs when water is moved from the growing medium through a plant and then released as vapour through stomata in its leaves. Water also evaporates directly from the growing medium. The phase change, or evaporation, from liquid to vapour causes latent heat to be released, lowering the surrounding temperature. Our bodies use essentially the same method of cooling when we sweat.
- Convection (sensible heat loss) – the transfer of heat from one element to another by the movement of a fluid. In this case, foliage transfers heat to the surrounding atmosphere by the movement of wind, due to its larger surface area compared to a conventional building surface. Many plants wilt or go dormant during the winter, reducing their surface area and by extension, convective heat losses.
- Reflectivity (albedo) – green roofs tend to have a higher albedo (or reflectivity) than conventional roofs, making them absorb less solar radiation. Some plants, like sedums, become more reflective under heat stress. Many plants also shrivel in the winter, reducing

their surface area and decreasing albedo. This allows for more heat to be absorbed when desirable.

- *Thermal mass* – all the layers of a green roof or wall system contribute to increased thermal mass compared to a traditional roof or wall. The increased mass allows for the absorbance of heat during the day and the slow release of heat at night. Increased water content contributes significantly to thermal mass, and many succulent plants like sedums store water, increasing this effect.
- *Solar shading* - foliage in living architecture shades building surfaces from direct exposure to solar radiation, reducing heat gain. As foliage absorbs the heat, it uses mechanisms described above to dissipate heat much more effectively than a building surface.

(Wark, 2011; EnergyPlus, 2014)

Every component of a green roof plays an important role in its thermal behaviour: the canopy shades the surface of the soil from solar radiation. The level of shading depends heavily on the vegetation type and foliage density (expressed in leaf area index, or LAI, a dimensionless quantity defined as the one-sided leaf area per ground surface area). While this shading can be achieved by shading devices like screens or pergolas, the shading devices would absorb or reflect solar energy, deflecting energy to the surrounding environment or increasing thermal transmittance due to its increased temperature. Conversely, plants absorb most solar radiation but use it for their biological functions (evapotranspiration, photosynthesis, etc.). Biologically motivated, forced evaporation from the foliage decreases leaf surface temperature and cools the air in contact with the foliage. As long as there is enough moisture in the growing medium, the intensity of evapotranspiration is directly proportional to the heat stress. This means that this biological cooling mechanism is adapted to ambient heat stress and is maximized during times of high solar intensity, when the need for cooling in buildings is also highest (Wark, 2011).

The layer of air between the canopy and soil is significantly cooler than the ambient air temperature on a sunny day due to the shading and evapotranspirative effects of the foliage. This air also forms an insulating layer and acts as a convective buffer, minimizing heat gain. The layer of growing medium has a high thermal mass and acts as a heat sink, especially when moisture levels are high. It absorbs heat during the day, holds it and releases it slowly at night, minimizing transfer to the building below (Wark, 2011).

The roof to envelope ratio is an important factor when considering the effectiveness of a green roof at moderating a building envelope. A green roof will have a significantly larger effect on a large, low-rise building than it will on a high rise with a small floor plate. Conversely, living walls and green facades will have less of an effect on a low-rise building with a large floor plate.

Living walls and green facades can also thermally moderate a building envelope in a way similar to green roofs. While there are many different types of green wall technologies that work differently, green walls and facades can generally use the same methods of heat transfer and dispersal as green roofs and can be effective energy conservation tools. The effects of living walls and green facades are explored further in section 2.6.2.

2.3 LIVING ARCHITECTURE INTEGRATION INTO BUILDING ENERGY SYSTEMS

An emerging, but promising benefit of living architecture comes through the potential to integrate living architecture into building heating, ventilation and cooling (HVAC) systems, and to design living architecture to optimize their performance. The shading of outdoor HVAC units by vegetation can lower their operating temperature and make them operate more efficiently. Denser and more productive vegetation can be located closer to HVAC air intakes to lower the ambient temperature. Since cooler air requires less energy to condition it for indoor use, this reduces the energy required for air conditioning (Mankiewicz and Simon, 2007).

Advances in indoor green wall technology have made it possible to integrate green walls into HVAC systems to improve indoor air quality; these are sometimes called *biowalls*. Indoor air is contaminated by processes within buildings (respiration by people, exhaust from equipment, and volatile organic compounds from building materials) and must be periodically exchanged for ‘fresh’ outdoor air. Biofiltration can be utilized to help remove some of these contaminants – large wetted surfaces are used that allow biofilms to form. These biofilms accumulate contaminants, which are then broken down by bacteria. These biological processes can be supported by plants and integrated into indoor living walls, where roots support microbial communities and leaves help remove contaminants. When these indoor living walls are integrated into building HVAC systems, there is the potential to reduce the frequency of air changes, reducing heating and air conditioning costs (Allen, 2013).

A speculative but potentially promising approach would entail drawing air from the drainage system under a green roof. Air would travel through the plants and growing medium in this scenario. This would allow the green roof to act as an evaporative cooler, reducing intake temperatures. Biofilms could also be integrated, allowing the green roof to act as a biofilter. This approach could lower the demand for cooling and conventional air exchange (Allen, 2013).

Indoor living walls can also provide evaporative cooling, humidification or dehumidification. In winter, they can supply humidification as irrigated plants evapotranspire. In dry summer climates, they can provide evaporative cooling as plants transpire. In humid summer climates, they can dehumidify indoor spaces if irrigated with cold water. This is because water below the dew point of the surrounding air will absorb water vapour (Allen, 2013).

2.4 LIVING ARCHITECTURE AND RENEWABLE ENERGY

Using green roofs in combination with solar PV arrays brings the benefits of green roofs (energy savings, stormwater management, biodiversity improvement) together with the benefits of solar PV panels (in-situ energy generation, reduction of grid-sourced energy use) and synergies between both systems. These synergies have the potential to be wide ranging, and include:

- Increased efficiency of PV panels due to reduced ambient temperature

- Increased incident sunlight reflected to PV panels due to increased roof albedo
- In-situ generation of renewable energy, which can also be used to power irrigation equipment for the green roof
- Better use of space that captures the benefits of both technologies
- Increased revenue/savings (from generated energy) can offset the additional costs of a green roof
- PV panels protect the plants and growing media from direct exposure to sunlight and wind, reducing drying and excessive evapotranspiration while enhancing plant growth and species variety
- The thermal capacity of plants helps protect PV panels from winter cold
- Racking and support systems for solar panels can be designed so that the green roof layers act as ballast, thereby saving the need for roof penetrations or concrete pavers
- Increased membrane life due to the protection of green roofs mean PV panels must be moved for reroofing less often

(Lamnlatou and Chemisana, 2015; Peck and van der Linde, 2010)

While research is still in its infancy, the potential benefits of integrating other living architecture with other forms of renewable energy are promising.

Wind turbines have the potential to be integrated with living architecture. Building height and form often contribute to increased, but unpredictable and turbulent wind (Allen, 2013). While conventional wind turbines cannot harness this wind, innovations in vertical axis wind turbines allow them to harness turbulent wind without regard to orientation (Eriksson, 2008). Placing turbines on the edges of green roofs could take advantage of the windiest locations, while also buffering winds, allowing for a more moderate microclimate.



Figure 1: The BIQ House (Arup, 2013)

There are also possibilities to grow plants for biomass on or within building envelopes. The BIQ House in Hamburg (Figure 1) uses an innovative bioreactor façade: Microalgae (plants that are barely bigger than bacteria) grow within this facade. Nutrients are supplied, and the algae uses sunlight to photosynthesize and grow. The algae is harvested and turned into biogas, which generates electricity. Similarly, the residual biomass of green roof or wall plants can be harvested to generate energy. If biomass production is a goal, plants that produce more biomass than typical green roof plants can be selected if resources are available (Allen, 2013).

A Dutch company has recently even found a way to harness the waste protons and electrons generated by bacteria in green roof growing media into energy. While the technology is still in its infancy, the company claims that 100m² will eventually be able to power the average Dutch

household. In the longer term, a variation of the technology could even be scaled up and turn large wetland areas into living power plants (Ingham, 2014).

2.5 URBAN HEAT ISLAND REDUCTION

Urbanization has replaced large areas of natural landscape with artificial structures and surfaces, altering near-surface climate and causing air temperatures to rise. This phenomenon, referred to as the urban heat island (UHI) effect, occurs because building materials commonly used in urban areas, such as concrete and asphalt, have significantly different thermal and surface radiative properties than natural landscapes. Materials such as waterproofing, asphalt, and concrete absorb energy from the sun and convert it to sensible heat (Peck and Richie, 2009; Wong, 2005). Reduced evapotranspiration because of less vegetation, combined with waste heat from buildings, cars, and industrial activities, can contribute to the urban heat island effect. On some days, the temperatures in dense urban areas can be as much as 12 °C (22 °F) higher than in surrounding rural areas (Oke, 1987).

There are several negative effects caused by the urban heat island effect, including:

- **Increased energy consumption** – a 1 °C increase in summer air temperature increase has been correlated with a 3.8% increase in peak demand load for air conditioning. Air conditioner use also creates waste heat that further increases urban air temperatures. Additionally, increased summer peak loads cause problems for energy generators and distributors (Liu, 2006).
- **Increased air pollution** – Elevated temperatures caused by the UHI effect promote chemical reactions where volatile organic compounds, nitrous oxides and other industrial pollutants mix to form ground level ozone. These conditions dramatically degrade air quality, as well as damaging vegetation (Peck and Richie, 2009).
- **Health impacts** - Air pollution has a host of negative health impacts, including respiratory problems like asthma, as well as cardiac irritability. Greater instances of extreme heat also mean increased levels of heat stress and other heat-related illnesses. In the United States, more than 1000 people die on average every year due to extreme heat (Changnon et al., 1996).
- **Ecosystem impacts** – Increased heat and air pollution can damage vegetation by affecting photosynthesis and fruit/seed production. Extreme heat can also stress plants and animals and reduce their ability to survive and thrive in the urban environment (Peck and Richie, 2009).
- **Economic impacts** - In addition to increased costs of energy, healthcare, water and transportation, more extreme heat negatively affects tourism and related activities as many residents leave urban areas to avoid excessive heat (Peck and Richie, 2009).
- **Increased water use** – More water is needed to support stressed vegetation. Increased energy generation due to increased demand also requires more water (Peck and Richie, 2009).

In 1998, the Urban Heat Island Pilot Project conducted by the EPA used flyovers to measure surface temperatures and identify hotspots in five cities. They found that rooftops were the hottest spots, with temperatures of up to 71 °C (160 °F). Conversely, the coolest areas were water bodies or vegetated areas, with temperatures of 24-35 °C (75-95 °F). Because most roofs are dark (i.e. have a low albedo), they reflect very little solar energy, and therefore heat rapidly. Cool roofs (also known as white or reflective roofs) help to reduce the urban heat island effect because they have a higher albedo, absorbing significantly less of the sun's energy (Peck and Richie, 2009).

While green roofs generally have a higher albedo than conventional dark roofs (but not cool roofs), they also use other methods of heat transfer and dispersal to mitigate UHI that cool roofs do not.

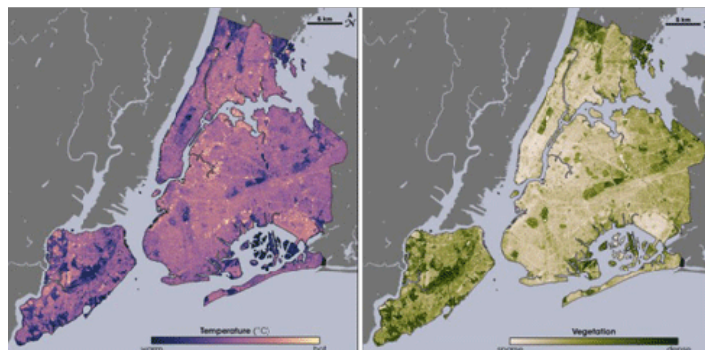


Figure 2: Surface Temperature (Left) and Vegetation (Right) in New York City. Source: NASA

Evapotranspiration is a very important cooling function of green roofs and walls: plants use solar energy to move water from the growing medium and release it as vapour through stomata in their leaves. Water also evaporates directly from the growing medium. The phase change, or evaporation, from liquid water to water vapour causes latent heat to be released, lowering the surrounding temperature (Wark, 2011; Bass et al, 2003; Scherba et al, 2011).

Georgescu et al. (2014) recently created an atmospheric model, analyzing urban climates in six US regions. They found that by the year 2100, without adaptations to our urban environments, metropolitan expansion is expected to raise surface temperatures by 1-2 °C (1.8-3.6 °F) across large areas of the US. These temperature rises are independent of greenhouse-gas induced climate change, and are not at the scale of individual cities, but rather, across large regional swaths of the country. The researchers found that using cool roofs, green roofs, or a mix of both would entirely offset urban-induced warming. They found that cool roofs provided the greatest cooling benefit, though this impact varied, and was more pronounced in drier regions. However, cool roofs reduce winter solar gain, which could raise heating costs. The researchers also found that large-scale cool-roof implementation could have adverse hydrological impacts, reducing precipitation in a belt from Florida to the Northeast, as well as in the Southwest. Green roof implementation, in contrast, was associated with greater precipitation in the Mid-Atlantic and Chicago/Detroit regions. The authors argue that there is no one-sized fits all approach; solutions must be tailored to region's specific geographic and climate needs (Georgescu et al., 2014).

Green roofs, along with other living architecture, are clearly an important tool in an overall strategy to reduce UHI. A 2006 report prepared for the New York State Energy Research and Development Authority by the Columbia Center for Climate Systems Research explored opportunities to reduce New York City's urban heat island. The study utilized a regional climate model in combination with

observed meteorological satellite and GIS data to determine the impact of urban forestry, green roof, and light-coloured surfaces on UHI. During the summer months, the daily minimum surface and near-surface air temperature in the city was 4 °C (7 °F) warmer than that in the surrounding rural and suburban areas.

The results indicated that vegetation rather than surface albedo alone or other features of the urban physical geography, such as road density, was crucial in determining the urban heat potential. The report concluded that a combined strategy of implementing green roofs and maximizing the amount of vegetation in New York by planting trees along streets and in open areas offers more potential cooling than any one strategy (Rosenzweig et al., 2006).

Similarly, a study by Bass et al. (2003) used a regional simulation model using 50% green roof coverage distributed evenly throughout Toronto. The authors found that the impact was significant – reducing temperatures by as much as 2 °C (3.6 °F) in some areas. Scherba et al (2011), modeled roofs in six US cities; they compared black, white and green roofs with and without solar photovoltaic panels. They found that white roofs performed slightly better at reducing heat flux into the urban environment, and both white and green roofs vastly outperformed black roofs. However, the authors only studied sensible heat flux, and did not take latent heat flux (evaporation), which is an important mechanism for green roof cooling, into account. In fact, Sailor (1994) concluded that low latent heat flux due to lack of vegetation in urban areas is the single most significant contributing factor to the UHI phenomenon.

Cities like New York, Toronto, Chicago and Tokyo have made urban greening, including the use of green roofs, a central part of aggressive efforts to combat UHI. New York has approved a tax abatement of up to \$100,000 per project to support green roof installation; Toronto has a green roof requirement on all new large commercial, institutional or residential buildings as well as an incentive program for existing buildings; Chicago uses density bonuses and an expedited building permit system; Tokyo uses property tax reductions, bonus plot ratios, and a mandatory 20% greening ratio for larger sites.

Stuttgart, Germany has taken a slightly different, forward thinking approach. The city is located in a valley characterized by low wind speeds and weak air circulation, leading to significant urban microclimatic effects, including UHI. Besides encouraging green roofs and walls, the city created linear green spaces as ventilation passages and induction corridors to support air exchange. These corridors are selected based on detailed study of urban climatology and help promote the transport of cool, fresh air from the hillsides surrounding the city (Hebbert and Webb, 2011). While it may be unfeasible to create natural corridors in already developed cities, there are lessons to be learned from Stuttgart. Cities could designate green corridors along prevailing winds, where encouraging and incentivizing the use of living architecture could have impacts on the urban climate and microclimate. Creating a series of connected living architecture projects can have the added benefit of encouraging urban biodiversity and creating habitat corridors (Rosenzweig, 2003).

It is difficult to separate the influence of living architecture on the Urban Heat Island effect from its influence on building energy conservation, because they are strongly linked. Additionally, living

architecture uses the same mechanisms of heat transfer and dispersal to reduce both UHI and energy use. However, studies have attempted to examine the connection. A modeling study by Alexandri and Jones (2008) found that using green roofs and green facades to green ‘urban canyons’ in dense urban areas lowers ambient air temperatures, reduces UHI and reduces the energy required for air conditioning in the summer.

A study by Akbari et al. (2001) found that implementing strategies to reverse the heat island effect in major US cities could reduce air-conditioning energy use by about 20 percent, with the resulting savings estimated to be \$10 billion per year¹. Similarly, an unpublished Environment Canada study focused on Toronto found that the energy demand associated with 1° C/1.8° F temperature increase in the summer is equivalent to 3.8% of total demand (Liu, 2006). Cooling the entire city is an energy demand-management strategy that has yet to be widely implemented, but holds significant promise.

Essentially, the urban heat island effect is caused by an alteration of land from natural to artificial surfaces; living architecture helps to reverse that phenomenon by returning natural surfaces to the urban environment, saving energy and water. Forward thinking planners envision cities in which stormwater and greywater are capture and retained to help reduce the urban heat island effect.

2.6 CARBON SEQUESTRATION

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide. The process of photosynthesis removes carbon dioxide from the atmosphere and stores it in plant biomass. Some of this carbon is transferred to the growing media via plant litter and exudates (Getter et al., 2009).

Living architecture can take advantage of photosynthesis to capture and sequester carbon from the atmosphere, in both plants and growing media. Getter et al. (2009) found that extensive green roofs have the potential to sequester a small, but still significant amount of carbon; the entire system of sedum-based roof studied (above and belowground plant biomass as well as growing medium organic matter) sequestered an average of 375 g C/m². Similarly, Whittinghill et al. (2014) found that while sedum and prairie green roofs have carbon sequestration ability, ground level ecosystems are more effective at sequestering carbon.

Luo et al. (2015), who studied test plots in Chengdu, China, explored an innovative approach. They found that a 1:1 mix of sewage sludge and natural soil sequestered significantly more carbon than natural soil alone. The researchers theorize that this may be due to the increased organic content and water retention provided by the mixed sewage sludge soil. This study suggests that using sewage sludge as a growing medium addition can improve carbon sequestration on green roofs, as well as reducing growing media costs, and providing an efficient way to utilize sewage sludge.

¹ UHI impacts on energy costs are likely to be significantly greater today

While it is possible to sequester carbon in living architecture, it is important to consider the life cycle impacts of living architecture components (growing media, membranes, support systems, etc.). The manufacture of these components incurs a 'carbon debt', and sequestration in plants and growing media may take several years to offset this debt (Getter et al., 2009).

Because green roof plants are generally selected for their hardiness and resource efficiency, selecting plants that produce larger amounts of biomass when resources are available can maximize carbon sequestration. Whittinghill et al. (2014) suggest using a deeper growing medium and more complex plant communities to maximize the carbon sequestration potential of green roofs.

Living architecture's potential for carbon sequestration is still a largely unexplored area of research, and further exploration should be conducted. The pyrolysis of living architecture biomass and subsequent incorporation of biochar is an especially promising field that deserves further attention.

2.7 SECONDARY AND TERTIARY ENERGY BENEFITS

In addition, there are several secondary and tertiary energy benefits associated with living architecture that are out of the scope of this paper, but should be noted:

- The treatment of stormwater and wastewater is an energy intensive process; using living architecture as part of low-impact approach to managing stormwater reduces this energy requirement (Mittal and Gaffigan, 2011). Similarly, using living architecture to help treat and reuse greywater reduces the energy used to treat wastewater off-site.
- Living architecture offers building materials additional protection from the elements (UV rays, wind, excessive moisture, thermal flux). Many of these building materials are hydrocarbon-based (tar, bitumen), or contain significant amounts of embodied energy (concrete, steel). Living architecture can replace these materials or increase their lifespan, reducing the life cycle energy costs associated with them (Wark, 2011).
- It can be argued that the highest value form of energy is food. There are significant opportunities to integrate urban agriculture with living architecture. Small rooftop gardens have been used for centuries; large scale rooftop urban agriculture has recently been implemented – these projects range from plants grown directly on a green roof (like Brooklyn Grange, in New York) to complex hydroponic systems in rooftop greenhouses (like Lufa Farms in Montreal). Food can also be grown in edible green walls or facades. In addition to the energy benefits of living architecture, integrating food production results in energy savings through reduced food transportation and spoilage and reduced inputs of fossil fuels and fertilizers (Allen, 2013). A recent report about Southern Ontario's food system found that a 10% reduction in imports for eight fruit and vegetable crops would result in an estimated 59% reduction in CO₂ emissions from the transportation of these commodities (Kubursi et al., 2015) – many of these fruits and vegetables could be grown in living architecture systems. Food production is the subject of a future LAPT white paper.

2.8 LITERATURE ON LIVING ARCHITECTURE AND ENERGY

2.8.1 GREEN ROOFS

Feng et al. (2010) presented an energy balance model of green roofs, and found that the vast majority of heat gain (99.1%) associated with a green roof was through solar radiation. When growing medium moisture levels are high, evapotranspiration plays a large role in heat dissipation (58.4%), while convection from the canopy to the atmosphere was also an important factor (30.9%). Only 0.6% of heat is transferred to the room below. The authors suggest that when soil moisture levels are lower, convection plays a more important role in the dissipation of heat, but more heat is transferred to the building. They argue that appropriate use of irrigation is an effective way to optimize green roof energy performance.

Feng and Hewage (2014) modeled the energy benefits of green roofs and walls for a LEED certified building in Kelowna, British Columbia. They found that covering the roof and walls of the building would reduce the 3.2% and 7.3% of the annual cooling energy required respectively, but had no impact on heating energy.

A study by Liu and Minor (2005) in Toronto tested two lightweight green roof systems, as well as a bare reference roof (steel deck with thermal insulation and modified bitumen waterproofing above). They found that the heat gain through the green roofs was reduced by 70-90% in the summer and the heat loss was reduced by 10-30% in the winter, compared to the reference roof. These numbers varied because of the different growing medium depths, and the different insulation used for each green roof. Additionally, peak temperatures were delayed by around 5 hours to past the peak cooling periods of the late afternoon, and only a small proportion of the roof heat was transferred to the room below.

Simmons et al. (2008) studied six different types of green roofs, in addition to reference black and white (reflective) roofs in the sub-tropical climate of Austin, TX. They found that compared to the reference roofs, all green roofs had significantly reduced temperatures on and below the surface. Additionally, peak temperature was delayed by 1-3 hours. The reduced temperature below roof membranes had an effect on internal temperatures, making them up to 18° C (32° F) cooler than spaces under the black roof, even with the presence of roof insulation. Although white roofs also reduced internal temperatures, the effect was much smaller (5° C/9° F).

Research has been conducted on the various different methods of heat transfer and dispersal that green roofs utilize:

- **Evapotranspiration**

- A model developed by for a single family home in La Rochelle, France, found that increases in leaf area index (LAI) decreased summer indoor air temperatures and cooling demand, but increased winter cooling demand, mainly due to transpiration and solar shading. However, increasing LAI offers diminishing returns, especially at

higher levels of LAI. It is also important to note that these findings are in the temperate climate of La Rochelle, France where winter temperatures rarely fall below freezing. These findings could be different in colder climates where transpiration is negligible in winter, and roofs may be snow-covered.

- Kumar and Kaushik (2005) developed a model that found canopy temperatures reduced approximately 70%, and heat flux reduced approximately 50% when leaf area index was increased from 0.5 to 3.5. They determined that this was largely due to the additional evapotranspiration and insulation provided by denser foliage.
- Lazzarin et al. (2005) modelled the role of evapotranspiration on a hospital green roof in North-Eastern Italy. They modelled wet and dry green roofs, and found that the dry roof was able to reduce the incoming heat flux by 60% compared to the bare reference roof. The wet roof was even more effective, losing twice as much heat through evapotranspiration than the dry roof. This suggests that wet green roofs can not only prevent heat flux through the building but also act as passive coolers, drawing heat from out of the building.
- While the literature on plant selection for optimized evapotranspiration is limited, Oberndorfer et al. (2007) make some inferences based on literature they studied. They argue that green roof energy models determine that most summer cooling benefits are associated with evapotranspiration, and in order to optimize this function, selecting plants with large surface areas or high leaf conductivity is a sound strategy. They go on to argue that performance is influenced by two main properties: the ability to recover from environmental fluctuation and disturbance and the optimal use of resources. They suggest using more resilient plants to increase the duration of plant functions, and designing for high plant diversity to optimize resource use and more constant plant coverage.

- **Convection**

- Ayata et al. (2011) developed a model to measure the convection or sensible heat flux of green roofs. They argue that because green roof surfaces have many parameters, they cannot be compared to regular surfaces used in existing energy models. The researchers argue that surface roughness, as measured by vegetation coverage and leaf area index, is an important factor in sensible heat flux. They go on to state that sensible heat flux is inversely proportional to soil moisture – as evapotranspiration decreases in dry periods, convective heat transfer becomes a more important part of the roof energy balance.
- Theodosiou (2003) found that convective heat loss is a factor in green roof performance, and is influenced by wind speed. He argues that higher wind speed not only increases convective heat loss, but also facilitates the removal of vapour near the green roof surface, encouraging higher rates of evapotranspiration.

- **Reflectivity (Albedo)**

- Gaffin et al. (2005) aimed to model the ‘equivalent albedo’ of a green roof – the albedo (or level of reflectivity) required by a non-green roof to reproduce the surface temperatures found on a green roof, taking into account both reflectivity and latent cooling potential. They found that the equivalent of a green roof is 0.7-0.85, comparable to the brightest possible white roofs and significantly more than the average black roof. Additionally, the albedo of white roofs declines by about 0.15 a year because of weathering and dirt accumulation.
 - Wark (2011) argues that succulent plants like sedums have a naturally adapted variable albedo. During hotter periods with lower water availability, they are waxy and more reflective, exhibiting a higher albedo. During the winter, their leaves become smaller and less shiny, and emit less heat due to their reduced surface area.
 - While white roofs may perform better when newly installed, the albedo of white roofs declines by about 0.15 a year because of weathering and dirt accumulation. Power washing of white roofs can remedy this, but is expensive, and many operators of buildings with large white roofs (like Walmart) do not power wash white roofs. Moseley et al. (2013) found that the maintenance costs of a white roof are more than twice that of an extensive, drought-tolerant green roof, even when power washing is not considered. This is largely because the green roof layers protect the membrane, reducing leaks and more than doubling membrane lifespan.
- **Thermal Mass**
 - Experiments by Liu and Minor (2005) on two green roofs in Toronto found that growing media depth improved thermal performance. Despite low vegetation coverage, the green roofs studied lowered heat flow in both the summer and winter. Greater growing medium depth was associated with better performance in summer. The roof with the shallower growing medium performed better in winter, but the researchers theorize that this is because of the extra insulation provided by different components in the construction of that green roof.
 - Del Barrio (1998) modelled the summer cooling potential of green roofs in Athens, finding that growing medium depth, density and moisture content were important factors in thermal performance. Greater depth and less dense media reduced heat flux. Less dense and coarser media is a poorer heat conductor, and additional air pockets in the soil contribute to its insulating properties. Conversely, higher moisture content was found to lead to increased heat flux.
 - **Shading**
 - Sailor et al (2011) compared energy performance in four US cities (New York, Phoenix, Houston, and Portland) and showed that the energy performance of green roofs was particularly improved by the increase in planting density in every city. Jaffal et al. (2011) reached the same conclusion, determining that vegetation coverage has a significant influence on the absorption of solar radiation by the foliage and thus on the solar shading effect.

- Fioretti et al. (2010) measured solar radiation on the surface of a green roof as well as below the foliage, finding that the shading effects of plants are apparent and the soil is exposed to significantly less radiation when shaded by plants. It can be assumed that the level of shading is influenced by plant factors like leaf area index, fractional vegetation coverage, and plant height. During periods where absorbing solar energy is desirable (the heating season), using plants that go dormant or shed foliage may be more appropriate.
- Clay et al. (2012) studied the effects of green roofs in the semi-arid Mediterranean climate of Adelaide, Australia. They discovered that the addition of a mesh walkway 150mm over the surface of a green roof bed reduced daily temperature variations 1.9 times compared to the equivalent uncovered green roof bed. They theorize that this is due to the effects of shading, while also allowing enough sunlight and air to allow for healthy plant growth.

There are non-green roof design factors that also affect energy performance:

- **Effect of Insulation**

- Roof insulation has a large impact on the thermal effects of green roofs. Jaffal et al. (2011) modeled a single family home in La Rochelle, France, and found that a green roof reduced the mean and maximum indoor air temperatures by 6.5° C (11.7° F) and 9.3° C (16.7° F) on an uninsulated roof in a temperate climate, but by less than 1° C (1.8° F) on a roof with 30 cm of insulation. This reduced building energy reduction by 50% for the uninsulated roof, but only 3% for the insulated roof.
- Similarly, Niachou et al. (2001) found that while a non-insulated building in a Mediterranean climate could reduce energy consumption by 37% with the addition of a green roof, a well-insulated building would see a reduction of less than 2%. These findings suggest that older, poorly insulated buildings are ideal candidates for green roof retrofits to reduce energy use. While adding additional insulation would undoubtedly be cheaper, green roofs act as passive coolers and would perform better than simple insulation, especially if irrigated.
- A variable insulation green roof model proposed by La Roche and Berardi (2014) (See Figure 2) could be the solution to optimizing green roof and insulation use in both summer and winter. The system uses a plenum between the green roof and the building below and a sensor-operated fan that couples (or decouples) the green roof from the room below. The plenum is ventilated only when the fan is operational, creating a variable insulation system that couples the roof with the building when its cooling potential is highest. Additionally an air change fan can be used to discharge green roof thermal mass when outdoor air is cooler. Both the plenum fan and the air change fan can be turned off when cooling is undesirable, so that the plenum is used as insulation.

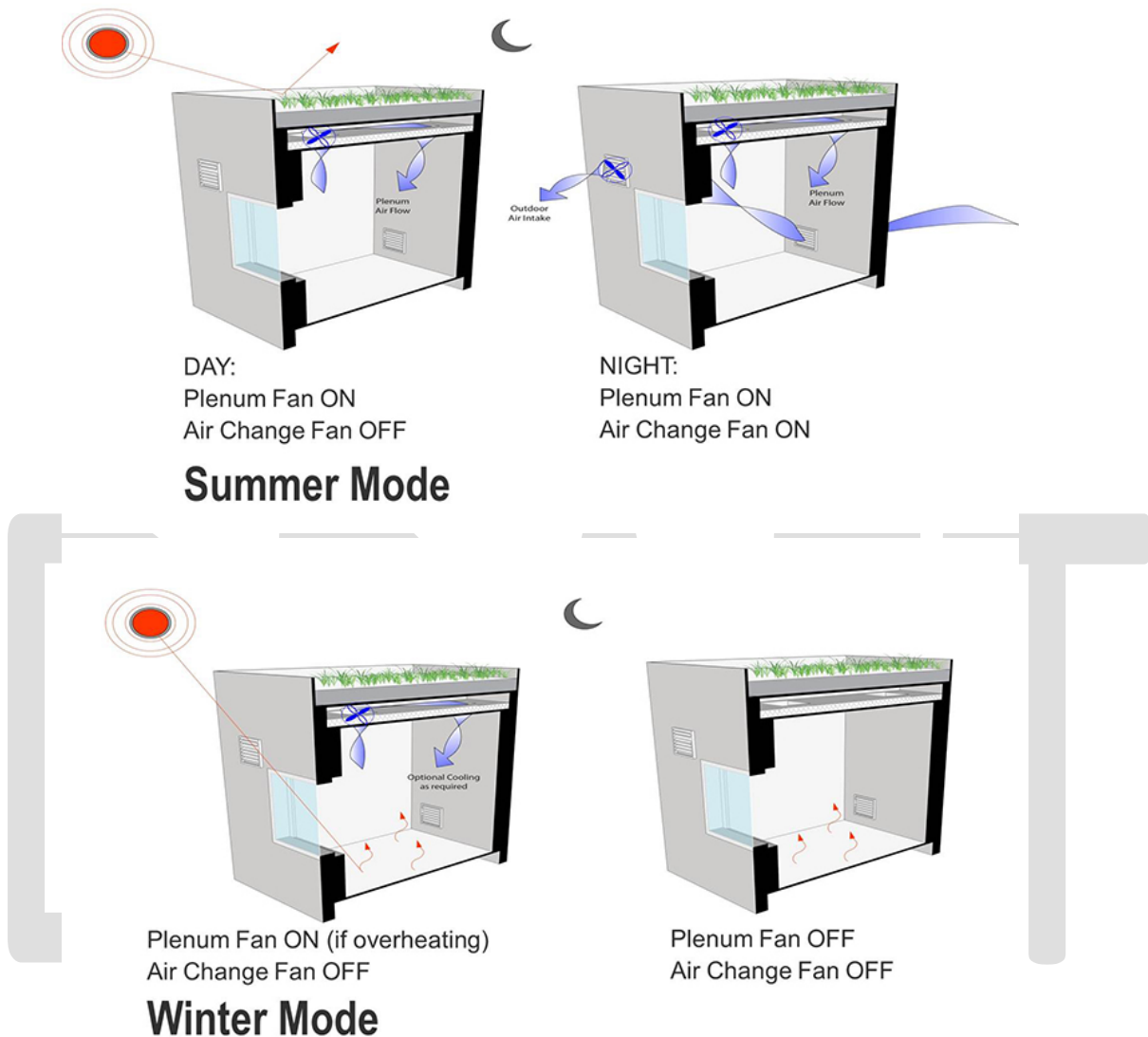


Figure 3: A variable insulation green roof (La Roche and Berardi, 2014)

- **Climate and Weather**

- Summer temperatures on concrete roof slabs have been found to be significantly reduced under a green roof versus under a conventional roof – up to 30°C or more. This holds true in the warm summer climate of La Rochelle, France (Jaffal et al. 2011), ; the hot and humid summer of Osaka, Japan (Onmura et al., 2001); the tropical summers of Taiwan (Lin et al., 2011) and Singapore (Wong et al., 2003); and the hot Mediterranean summer of Marche, Italy (Fioretti et al., 2010). Conversely, in the cold and snowy climate of Tartu, Estonia, the temperature under a green roof substrate was 30° C (54° C) warmer than that of a conventional steel sheet roof (Teemusk and Mander, 2010).

- Alexandri and Jones (2008) determined that green roofs and living walls have beneficial impacts in ‘urban canyons’ – the area between buildings in a dense urban environment. Based on a model developed by researchers, the microclimatic effects and reduced urban heat island of greening roofs and walls could lead to reductions in energy used for cooling buildings by 32-100%, depending on the climate.
- Theodosiou (2003) found that foliage height, foliage density (expressed in leaf area index), and growing medium thickness were all directly correlated to the ability of a green roof to cool a building. Interestingly, he argued that in the Mediterranean climate of Greece, using no insulation was the most effective design choice. This allows for a stronger thermal connection to the building and maximizes the cooling potential of green roofs during hot weather. He also found that green roofs are more effective at cooling when relative humidity is lower, and wind speeds are higher. This is because lower humidity and higher winds facilitate vapour removal from foliage and lead to higher evapotranspiration. Theodosiou did find that heating costs do increase marginally in the winter, but this is unlikely to be an issue in a colder climate where insulation is necessary and winter evapotranspiration levels are very low or non-existent.
- Song et al. (2013) outlined an innovative approach that could reduce energy costs while also dramatically improving stormwater management performance and increasing biodiversity: using constructed wetland ecosystems on green roofs. Their study of an experimental wetland green roof demonstrated that wetland plants have high evapotranspiration rates, working to cool the building in hot summer months. At the same time, the layer of water has a high thermal mass, which moderates temperature fluctuations. Wetland macrophytes are drought-resistant, flood-resistant, low-maintenance and accumulate high biomass, acting as a carbon sink. By planting for full coverage to reduce evapotranspiration off the water surface, the wetland ecosystem would actually require less irrigation than a terrestrial, grass-based green roof (Song et al., 2013). While would require more water than a green roof planted with sedums or other drought-tolerant plants, this approach may be worth exploring when structural capacity is available, when greywater reuse is planned, or in areas of high precipitation.
- Given the importance of weather and climate to the performance of living architecture, more research is needed regarding performance in different climates. Detailed design strategies to optimize energy performance in arid climates should be explored further, as well as the potential to integrate water management and energy performance by capturing and re-using water. The energy performance of green roofs in cold climates where plants are dormant and/or green roofs are covered by snow should also be explored further.

The following table describes possible strategies for green roofs to optimize energy performance by designing for desired benefits, based on common climate zones in North America. For example, a green roof in a cooling-season dominated climate would be designed for maximum cooling

potential, while one in a climate where both heating and cooling are prevalent would balance summer cooling with winter insulation.

Table A – Green roof energy design strategies for typical climates in North America

Type of Climate	Example	Heating	Cooling	Precipitation	Design Strategies
<i>Dfa</i> (Humid Continental); <i>Cfb</i> (Temperate Maritime)	Toronto; Vancouver	Moderate - High	Low - Moderate	Moderate, year round	Use moderate to high levels of insulation; use plants that go dormant or shed foliage to maximize winter solar gain; maximize summer evapotranspiration by using an optimum plant mix and a high leaf area index; maximize water availability by using deeper growing media, a water storage layer or providing irrigation, preferably using captured rainfall or grey water
<i>Csb</i> (Mediterranean); <i>Bwh</i> (Hot Desert)	Los Angeles; Phoenix	Low	High - very high	Low/very low, mostly in winter	Design for maximum evapotranspiration by using an optimal plant mix and increasing leaf area index; use plants with a high albedo; maximize thermal mass to minimize diurnal temperature swings; use shading structures like a mesh walkway or solar panels; use no insulation to couple green roof with building environment; irrigate using captured rainfall or grey water (this is essential in water-stressed regions like the Southwestern United States)
<i>Cfa</i> (Sub-Tropical); <i>Am</i> (Tropical)	Houston; Miami	Very low - low	High	High, year round/mostly in summer	Design for maximum evapotranspiration by using an optimal plant mix and increasing leaf area index; use plants with a high albedo; orient green roof toward wind to maximize convective cooling; consider using a wetland ecosystem if structurally possible

2.8.2 GREEN FAÇADES AND LIVING WALLS

While many of the findings of green roof research could be applied to green façades and living walls, the energy effects of green façades and living walls have also been studied. It is important to note that due to the diversity of living wall and green façade designs, generalizations are sometimes made. However, hydroponic and growing medium-based living walls may not perform the same way, just as direct (building attached) and indirect (using a supporting structure) green façades may not perform the same way.

Living walls generally use many of the same methods of heat transfer and dispersal as green roofs – shading, evapotranspiration, increased albedo, convective cooling and potentially increased thermal mass – depending on the system. Depending on their design, green façades also use two other methods – providing a thermally insulating air cavity, depending on the distance of the façade to the wall; and convective shielding (reduced wind speed on the wall), which is particularly important at reducing heat loss in winter (Hunter et al., 2014).

Plant selection for green façades can be based on orientation; for example, planting deciduous vines on western, southern and eastern exposures (in the northern hemisphere) will maximize summer shading while allowing sunlight and heat gain in the winter. Using evergreen plants on northern exposures will trap an insulating layer of air against the building envelope, acting as a buffer against winter winds – a major contributor to convective heat loss. For naturally ventilated buildings, using living walls or green façades will reduce the temperature of air intake and act as a passive cooling device (Allen, 2013).

Kontoleon and Eumorfopoulou (2010) modeled the effects of plant-covered walls, finding that they would lead to superior interior thermal comfort, especially when walls are not insulated. They suggest using green facades or living walls to compensate for poorly oriented walls. They argued that plant coverage was the key variable, and east or west-facing walls were the most effective at reducing cooling requirements. Cheng et al. (2010) also argued for the importance of plant coverage, and found soil moisture to be another important determinant of cooling effectiveness.

In their analysis of eight different types of living wall (all growing medium-based) and one green façade system (supported by a mesh system) in Singapore, Wong et al. (2010) found they hold significant promise in cooling buildings. They also suggested that lower ambient temperatures would reduce the temperature of air conditioning intakes, also translating into reduced cooling costs. While they found that the living walls performed better due to the insulation and moisture retention offered by the substrate, the green façade also significantly reduced wall surface temperature. They suggest further research to analyze factors like physical structure, materials, plant species, etc. to determine which are most important in performance.

Tests conducted by Bass and Baskaran (2001) in Toronto, found that a garden set up against a sun-exposed, South-West facing slanted metal wall (essentially a very rudimentary living wall) reduced the wall surface temperature by up to 29° C (52° F). They suggest designing living walls unique to each context in order to optimize energy goals. For example, designing a south facing living wall as an awning (See figure 1), angled to take advantage of the different azimuths of the sun in summer and winter. This wall would shade the window from summer sun while still allowing indirect light, but allow winter light and heat gain.



Figure 4: A green wall window awning. (Bass and Baskaran, 2001)

Experiments by Tilley and Price (2010) compared experimental buildings covered in green facades with identical unvegetated buildings. They found that the facades reduced internal temperatures by 1° C (1.8° F) when they covered the south wall, and 2° C (3.6° F) when they covered the west wall. While the west-facing façade reduced heat flux more, and for a longer period of time, the south-facing façade reduced heat load by 70%, compared to 50% for the west façade. Because the west-facing façade reduces temperatures later in the day, there are implications based on the intended use of the building. Office buildings that are occupied during the day might benefit more from a south-facing green façade, while a residential building would probably benefit more from the west-facing green façade.

Carlos (2015) studied green facades in the winter in Portugal, and found that they have significant energy saving potential. His modeling found that evergreen facades oriented away from solar radiation (north, west and east) act as an insulation layer in the winter, augmenting the thermal resistance of the wall. Using denser foliage also helps to create a layer of air between the plants and the building, buffering convective heat losses from winds. Carlos did find that green facades on southern exposures reduce heat gain in the winter, increasing energy costs – he therefore suggests using deciduous plants on southern exposures. This will reduce undesirable heat gain in the summer, but allow for light and heat penetration in the winter.

Sandifer and Givoni (2002) studied a wide variety of green facades - vines growing on south and west facing walls in the hot-summer Mediterranean climate of Los Angeles, CA. They determined that vines grown against a building or on an adjacent pergola could reduce surface temperatures to slightly below ambient temperatures, reduce west-wall heat gain in the summer, shade glazed openings and provide a more comfortable exterior space next to buildings.

Another way to use plants to shade vertical surfaces is within the building envelope. Using plants in double-skin facades has been proposed for urban food production as well as for shading and glare mitigation. Some buildings, like the BIQ House in Hamburg, are even using algae growing between the two building skins, providing translucent shading while also producing biomass that can be harvested for energy (Allen, 2013).

Hunter et al. (2014) argue that while green facades hold significant potential, there are limiting factors that make them suitable under only certain conditions. They argue that extreme solar radiation patterns (intense sunlight and periods of dark shade), high wind speeds, low humidity and increased ambient temperatures are harsh conditions that only certain plants can survive. The authors suggest further research using standardized approaches to help understand and quantify the performance of green facades in different climates and using different building aspects. Many of their conclusions can be applied to living walls, as literature in the field is still nascent and quantifying energy performance is still inconsistent.

An additional level of complexity associated with measuring living wall performance is the diversity of technologies. Growing medium-based and hydroponic living walls are very different, but the performance differences between both types of systems are still relatively unknown.

2.8.3 INTEGRATION WITH BUILDING ENERGY SYSTEMS

Air conditioners work by taking in outside air, using a refrigeration cycle to absorb and remove heat from this air, and then discharging this heat back outside. Therefore, the input air temperature is an important factor in air conditioning efficiency. Reducing ambient air temperatures around air conditioner intakes and units can improve air conditioner efficiency (Mankiewicz and Simon, 2007). This could take the form of using green roofs or walls to increase evapotranspiration and albedo, or using vegetated structures to shade air intakes and air conditioner units. The moderation of heat transfer through the building envelope by living architecture can affect design decisions around building HVAC systems. By reducing heating and cooling loads, living architecture allows for a reduction in the size of HVAC systems. This can significantly reduce capital and life cycle costs of these systems (Webb, 2010).

In their study of an experimental roof on a Walmart store in Chicago (part green roof, part white roof), Moseley et al. (2013) found that summer air at rooftop HVAC units (3' above the roof surface) was significantly cooler on the green roof side. Similarly, winter air was mostly warmer on the green roof side, suggesting both heating and cooling savings. The researchers did find a similar, but less pronounced effect on air handling units located 5' above the roof surface, so they suggest locating air intakes as close to the green roof surface as possible to maximize the moderating effects of the plant layer on ambient temperature. This finding has implications for the potential of energy savings in tall buildings. While rooftop heat flux does not have as much of an impact on energy performance, these buildings often have HVAC equipment located on roofs.

2.8.4 INTEGRATION WITH RENEWABLE ENERGY SYSTEMS

It has been found that solar photovoltaic (PV) panels are less efficient as ambient temperatures rise. High rooftop temperatures increase the conductivity of a crystalline silicon panel's semiconductor, which in turn inhibits charge separation and lowers the voltage of the solar cell (Peck and van der Linde, 2010). PV panels are 0.4-0.5% less efficient per 1° C (1.8° F) increase in ambient temperature, above 25° C (77° F) (Chemisana and Lamnatou, 2014; Lazzarin et al., 2005).

A study by Hui and Chan (2011), modelled performance of a rooftop PV array along with that of a green roof-PV array on a low-rise commercial building in Hong Kong, and found that the green roof-PV array generated 8.7% more electricity than the PV array alone. They carried this into an experiment on a sunny summer day from 11 am to 2 pm, and found that the green roof-PV array generated 4.3% more electricity than the PV array alone.

A test by Chemisana and Lamnatou (2014) in Lleida, Spain, found that solar PV panels mounted on a bed of *Sedum clavatum* increased the maximum power output of the PV panels by 3.33%, compared to a gravel mounted PV installation.

DRAFT

3.0 REVIEW OF EXISTING BUILDING RATING SYSTEMS

A number of rating systems currently exist that provide the framework for the design of buildings and landscapes. One of the goals of the LAPT is to build upon, inform and align with these various rating systems. These systems include:

LEED (Leadership in Energy and Environmental Design) - A set of rating systems for green buildings and neighbourhoods developed by the U.S. Green Building Council (USGBC). LEED is by far the most popular green building rating system used in North America today. Its popularity can be attributed to its simplicity, as well as its adoption and support by various organizations and government agencies.

Sustainable Sites Initiative – A set of guidelines and performance benchmarks used to evaluate the environmental performance of sites, including open spaces and sites with buildings on them. The initiative is a collaborative effort by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Centre at the University of Texas and the United States Botanic Garden.

Living Building Challenge – A green building certification program run by the International Living Future Institute, the program is the most advanced measure of sustainability for buildings. Certified buildings and sites can claim a very high level of environmental performance. Because of its stringent criteria, very few buildings are certified Living Buildings.

Roofpoint – A green rating system developed by the Center for Environmental Innovation in Roofing to evaluate roofs based on long-term energy and environmental benefits.

Green Globes – A green building certification developed by ECD Energy and Environment Canada, an arms-length division of JLL (a commercial real estate management and investment firm). Green Globes is designed to be a comparable but more cost-effective alternative to LEED, because it is a self-assessment and does not require the use of outside consultants.

Envision - A rating system used to evaluate the sustainability and performance of infrastructure on all scales. Envision is a joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure.

BREEAM (Building Research Establishment Environmental Assessment Method) - A comprehensive rating system for buildings run by BRE (Building Research Establishment). Formerly a UK government body, BRE is now a private organization that carries out research, consultancy and testing for the construction and built environment sectors in the UK. The scheme is especially popular in the UK and Europe, but is also used globally.

The overall approach these systems take to energy conservation and generation is generally performance based, requiring a percentage reduction in energy use, as determined by whole building energy modeling. Systems like LEED also offer points for prescriptive, or design based

solutions, when projects are designed as per guides like the ASHRAE 50% Advanced Energy Design Guide.

The rating systems generally do not address living architecture performance, which presents an opportunity for the LAPT. The LAPT could complement and inform these rating systems and fill in their gaps by creating targeted, focused metrics for Living Architecture and energy conservation and generation.

Table B presents an overview of how these rating systems address topics related to energy conservation and generation. The number of possible points or overall weight within the rating system is provided. Each credit is assessed for its potential application to various forms of living architecture, based on case studies and the literature on energy conservation and generation as it relates to living architecture. Living architecture assessed here includes extensive/intensive green roofs, interior/exterior green walls and green facades. 'Other' includes living retaining walls, biofiltration systems, living machines and constructed wetlands.

Table B - Credits in existing rating systems that relate to Energy Conservation and Generation

Rating System	Description of Credit	Points	Measurement Standard / Basis	Relevance					
				Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Sustainable Sites v2	Use vegetation or vegetated structures to reduce total annual heating and cooling energy usage by 5-7% - OR -	2-4 out of 200		Y	Y	Y	?	Y	?
	Use vegetation or vegetated structures to shade 100% of the exposed surface area of all HVAC units within 10 years of installation AND Use vegetation to shade 30% of the surface area of roofs and 30-60% of the surface areas of west, southwest, east, and southeast facing building facades within 10 years	1-2 out of 200	Shade calculations must be based on the arithmetic mean of the percent wall and roof coverage at 10 a.m., noon, and 3 p.m. on the summer solstice.	Y	Y	Y	?	Y	?
	Use renewable sources (50-100%) for landscape electricity needs; either generated on site, in a community renewable energy system, or through the use of a contract to purchase green power or offsets	3-4 out of 200	Based on volume of power, not cost. The use of community renewable energy systems is allowed if: The project owns the system or has signed a lease agreement for a period of at least 10 years AND The system is located with the same utility service area as the facility claiming the use. Green power purchased must be qualified and have come online since 2005; contracts should be at least 5 years.	Y	Y	Y	Y	Y	?
	Reduce urban heat island effects by using vegetation and reflective materials	4 out of 200	Non-roof area (x 0.5) + High-reflectance roof area (X 0.75) + Vegetated roof area (x 0.75) ≥ Total site paving area + Total roof area Alternatively, use a Solar Reflectivity (SR) and Solar Reflectance Index (SRI) weighted average to ensure compliance	Y	Y	N	N	N	Y

Rating System	Description of Credit	Points	Measurement Standard / Basis	Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
LEED v4 NC	<i>Whole building energy simulation:</i> Using a whole building energy simulation, demonstrate an improvement of 5% for new construction, 3% for major renovations, or 2% for core and shell projects in the proposed building performance rating compared with the baseline building performance rating - OR -	Req.	Calculate the baseline building performance according to ANSI/ASHRAE/IESNA Standard 90.1–2010 (or a USGBC-approved equivalent standard for projects outside the U.S.), using a simulation model.	Y	Y	Y	?	Y	?
	<i>Prescriptive compliance: ASHRAE 50% Advanced Energy Design Guide:</i> Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1–2010 (or a USGBC-approved equivalent standard for projects outside the U.S.). - OR -	Req.	Comply with the HVAC and service water heating requirements, including equipment efficiency, economizers, ventilation, and ducts and dampers, in Chapter 4, Design Strategies and Recommendations by Climate Zone, for the appropriate ASHRAE 50% Advanced Energy Design Guide and climate zone For projects outside the U.S., consult ASHRAE/ASHRAE/IESNA Standard 90.1–2010, Appendixes B and D, to determine the appropriate climate zone.	Y	Y	Y	?	Y	?
	<i>Prescriptive compliance: Advanced Buildings Core Performance Guide:</i> Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1-2010, with errata (or USGBC approved equivalent standard for projects outside the U.S.). - OR -	Req.	Comply with Section 1: Design Process Strategies, Section 2: Core Performance Requirements, and the following three strategies from Section 3: Enhanced Performance Strategies, as applicable. Where standards conflict, follow the more stringent of the two. For projects outside the U.S., consult ASHRAE/ASHRAE/IESNA Standard 90.1-2010, Appendixes B and D, to determine the appropriate climate zone. 3.5 Supply Air Temperature Reset (VAV) 3.9 Premium Economizer Performance 3.10 Variable Speed Control	Y	Y	Y	?	Y	?

Rating System	Description of Credit	Points	Measurement Standard / Basis	Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
LEED v4 NC	<i>Canada:</i> Projects in Canada may instead demonstrate a percentage improvement in the proposed building performance rating compared with the baseline according to the National Energy Code for Buildings (NECB) 2011. The same percentage improvement in energy performance is required to meet the Prerequisite, and the same points for percentage improvement in energy performance are applicable for the Credit.		Comply with mandatory requirements of ASHRAE 90.1-2010; Apply fenestration area convention similar to ASHRAE 90.1-2010; Apply skylight area convention similar to ASHRAE 90.1-2010; Model proposed and reference outside air similar to ASHRAE 90.1-2010; Apply ASHRAE kitchen exhaust demand ventilation requirements; Apply ASHRAE's chiller heat recovery requirements; Apply supply air temperature reset controlled based on warmest zone; Account for uninsulated structural penetrations if they exceed 2% of net wall area; Follow ASHRAE/LEED rules for renovations to existing buildings; Account for all anticipated energy use in building	Y	Y	Y	?	Y	?
	<i>Whole building energy simulation:</i> Improve building energy performance 6%-50% compared to the baseline. Points are awarded according to a table based on energy reductions for new construction, major renovations, or core and shell construction, categorized by intended use of building (healthcare, schools and all others) - OR -	1-20 points of 100	Calculate the baseline building performance according to ANSI/ASHRAE/IESNA Standard 90.1-2010 (or a USGBC-approved equivalent standard for projects outside the U.S.), using a simulation model. Analyze efficiency measures during the design process and account for the results in design decision making. Use energy simulation of efficiency opportunities, past energy simulation analyses for similar buildings, or published data (e.g., Advanced Energy Design Guides) from analyses for similar buildings. Analyze efficiency measures, focusing on load reduction and HVAC-related strategies (passive measures are acceptable) appropriate for the facility. Project potential energy savings and holistic project cost implications related to all affected systems.	Y	Y	Y	?	Y	?
	<i>Prescriptive compliance: ASHRAE Advanced Energy Design Guide:</i> Comply with recommendations and standards set for different types of building. One point is awarded for each standard met.	1-6 points of 100	Implement and document compliance with the applicable recommendations and standards in Chapter 4, Design Strategies and Recommendations by Climate Zone, for the appropriate ASHRAE 50% Advanced Energy Design Guide and climate zone. For projects outside the U.S., consult ASHRAE/ASHRAE/IESNA Standard 90.1-2010, Appendixes B and D, to determine the appropriate climate zone.	Y	Y	Y	?	Y	?

Rating System	Description of Credit	Points	Measurement Standard / Basis	Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
LEED v4 NC	Use renewable energy systems to offset building energy costs (1-10%). The use of community renewable energy systems is allowed if: The project owns the system or has signed a lease agreement for a period of at least 10 years AND The system is located with the same utility service area as the facility claiming the use.	1-3 points out of 100	% renewable energy = Equivalent cost of usable energy produced by the renewable energy system/Total building annual energy cost	Y	Y	Y	Y	Y	?
	Purchase grid-source renewable power or carbon offsets (50-100%)	1-2 points out of 100	Green power and RECs must be Green-e Energy certified or the equivalent. For U.S. projects, the offsets must be from greenhouse gas emissions reduction projects within the U.S. Based on quantity of power, not cost.	N	N	N	N	N	N
	Reduce heat islands by minimizing paved and dark roof area by using vegetation or reflective surfaces - OR -	2 out of 100	Non-roof area (x 0.5) + High-reflectance roof area (X 0.75) + Vegetated roof area (x 0.75) ≥ Total site paving area + Total roof area. Alternatively, use a Solar Reflectivity (SR) and Solar Reflectance Index (SRI) weighted average to ensure compliance Non roof measures include plants that provide shade over paved areas within 10 years, shade structures with energy generating devices, open grid paving, etc. High reflectance roofs must meet minimum 3 year SRI values as prescribed	Y	Y	N	N	N	Y
	Place at least 75% of parking spots under cover	1 out of 100	Any roof used to shade or cover parking must (1) have a three-year aged SRI of at least 32 (if three-year aged value information is not available, use materials with an initial SRI of at least 39 at installation), (2) be a vegetated roof, or (3) be covered by energy generation systems	Y	Y	N	N	?	N

Rating System	Description of Credit	Points	Measurement Standard / Basis	Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Envision	Conserve energy by reducing overall operation and maintenance energy consumption throughout the project life cycle by 10%-70%+	18 out of 700	If applicable, project may use ASHRAE standards as the baseline. A life-cycle assessment (LCA), in accordance with the ISO14040, and ISO14044 standards is recommended	Y	Y	Y	?	Y	?
	Meet energy needs through renewable energy sources (<25%-100%+ renewable energy)	20 out of 700		Y	Y	Y	Y	Y	?
	Manage the urban heat island effect - 10%-100% of hardscapes meet shading, vegetation, or SRI requirements	6 out of 700	SRI >29	Y	Y	N	N	?	Y
BREEAM International 2013	Increase energy efficiency - using modelling software, determine the performance of a building compared to a baseline building with regards to reducing energy demand, meeting demand efficiently, and reducing CO2 emissions - OR -	15 out of 132 (9.5% weight)	Energy Performance Ratio for International New Constructions (EPRINC) is calculated using BREEAM's Ene 01 calculator Must use BREEAM approved modelling software Modelling must be conducted by an approved energy modelling engineer	Y	Y	Y	?	Y	?
	Use energy efficient design features (based on a BREEAM checklist)	10 out of 132 (6.3% weight)		Y	Y	Y	?	Y	?
	Building is modelled and found to be 'carbon-negative'	5 out of 132 (4.8% weight)		Y	Y	Y	?	Y	?
Living Building Challenge 3.0	105% of the project's energy needs must be supplied by on-site renewable energy on a net annual basis, without on-site combustion. Projects must provide on-site energy storage	Req.		Y	Y	Y	Y	Y	?

Rating System	Description of Credit	Points	Measurement Standard / Basis	Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Faç.	Oth.
Roofpoint 2012	Install a roofing system with a minimum average thermal resistance. This varies based on the type of roof and the climate zone of the project.	Req.	Climate zones are as defined by the most recent ASHRAE 90.1 standard. R-Value calculations should be based on definitions and procedures in the most recent ASHRAE 90.1 standard.	Y	Y	N	N	N	N
	Use a combination of high-albedo, ballasted or vegetated roofing systems to reduce the urban heat island effect	Req.	High Albedo: Solar Reflectance Index (SRI) greater or equal to 78 and 3-year aged SRI greater or equal to 64. Ballasted: Minimum 15-22 lbs. / sq. ft., depending on climate zones as defined by the most recent ASHRAE 90.1 standard.	Y	Y	N	N	N	N
Green Globes NC	Minimize energy consumption for building operations and reduce the emissions produced as a result of the use of power	150 out of 1000		Y	Y	Y	?	Y	?
	Provide thermal resistance and effective thermal transmittance levels for roofs, above and below grade walls, slabs on grade; floors and opaque doors	7 out of 1000	Meet or exceed standards from the Model National Energy Code for Buildings (MNECB)	Y	Y	Y	?	Y	?
	Integrate renewable energy resources such as solar, wind, biomass or photovoltaics for 5-10%+ of the total load	20 out of 1000		Y	Y	Y	Y	Y	?
	Use natural cover or high reflectance roofing materials to reduce the urban heat island effect	14 out of 1000	Provide natural cover including trees that within 5 years will shade at least 30% of impermeable surfaces. At minimum, there should be one tree for every 100 m2 (1,000 ft2) of impermeable surface including parking, walkways and plazas; Where natural shading is not possible, install artificial shading such as covered walks, or light-coloured, high-albedo materials (reflectance of at least 0.3) over the site's impervious surfaces; Use either high-albedo roofing materials (reflectance of at least 0.65 and emissivity of at least 0.9 for a minimum of 75% of the roof surface), and/or a green roof	Y	Y	N	N	?	Y

4.0 THE 'REGION' QUESTION

An important consideration when classifying sites by region is the purpose of this classification. Sites could be classified differently based on different areas of performance evaluation. For example - when dealing with stormwater management, climate zones would likely be an appropriate measure, while ecoregions would be more appropriate when dealing with biodiversity.

There are several potential ways to classify sites by region already in use. Each contains different pros and cons:

- **Ecoregions** – Ecoregions are areas that contain distinctive assemblages of natural communities and species. The U.S. Environmental Protection Agency (EPA) has created Ecoregions of levels I, II, III and IV, with each successive level containing a finer grain of detail than the previous. Levels I, II and III are available for all of North America while Level IV Ecoregions are only available in the United States. EPA level III Ecoregions are used to distinguish regions within certain existing rating systems. For example, Sustainable Sites definition of 'native plants' is based on plants native to the Level III Ecoregion of a site, and LEED allows a project to obtain a credit related to preserving open space by making a contribution to a Land Trust located within the same Level III Ecoregion as the site.
- **Biomes** – Biomes are areas defined by similar plant life in relation to climatic conditions like temperature and rainfall, as well as soil conditions. While Biomes and Ecoregions often overlap, Biomes, however, do not account for genetic, taxonomic or historical similarities. Biomes (as classified by the Nature Conservancy) are used to distinguish regions within Sustainable Sites, where the number of credits awarded for restoring vegetation density to a site depends on the biome the site represents.
- **Climate Zones** – Climate classifications like the Köppen climate classification system are defined by patterns of average annual and monthly precipitation and temperature, as well as the seasonality of precipitation. While climate zones often overlap with ecoregions and biomes, they do not take into account natural species or communities of flora and fauna. Climate zones could be useful to classify sites when the temperature or precipitation patterns of a region are a consideration, such as stormwater management or reducing heating/cooling costs.
- **Degree of urbanization** – An urban-to-rural transect classifies sites on a continuum ranging from natural space and rural on one end, to dense urban areas on the other end. This could be useful when determining different impacts that living architecture could have depending on how urban the site is. For example, reducing the urban heat island is potentially a much more important consideration in denser urban areas than in rural areas. The Living Building Challenge classifies all sites along a degree of urbanization transect; the location determines what standards must be met across many of its categories.
- **Political boundaries** - Political boundaries like States, Provinces or EPA regions are easy to determine and administer. Using political boundaries would allow the LAPT to adapt to and take advantage of diverse policy requirements and incentives from different levels of

government. However, political boundaries do not align with ecological boundaries and are often arbitrary, reducing their applicability in many areas.

Once sites are classified by region, the next step would be to determine how to treat sites in different regions differently. There are several potential ways to approach this, and they may be used in combination with each other:

- **Regional priority credits** – Offer additional credits in certain areas that are important regionally. These could be in the form of additional points for existing credits (for example, additional points for conserving water in an arid area like Southern California) or entirely new credit categories (like preserving or creating habitat for a regionally important animal). LEED utilizes this approach, with the regional priorities determined by local chapters of the U.S. Green Building Council. There are up to six regional priority credits, and projects can earn up to four bonus points (in addition to the 100 regular points).
- **Different requirements for different regions** – Alter the requirements in certain credit areas to account for regional differences (for example, reduce stormwater management requirements in areas with historically low levels of infiltration). Sustainable Sites uses this approach – for example, credits are awarded for restoring plant biomass to different levels depending on the biome of the site.
- **Use tiered performance based measurements** – Measurements based on performance (for example, sites must manage stormwater from the 95th percentile of local rain events, or reduce heating or cooling costs by 20%) inherently consider regional differences. By using percent or ratio based tiered targets instead of absolute numbers, one can account for regional variation. LEED uses this approach in certain areas. For example, it mandates an outdoor water use reduction by 30%, regardless of where the site is located.
- **Provide flexibility for unique circumstances** – When regional issues prevent a site from meeting a target, there should be flexibility to award a credit if the intent or aim of the credit can be met using an alternative strategy (for example, if managing stormwater on site would adversely affect local hydrology). Sustainable Sites uses this approach throughout their system.

5.0 METRICS

Living architecture designs can vary dramatically, so it is extremely important to design for specific performance goals, not based on assumed performance attributes. Metrics form the basis of which we can evaluate the performance of living architecture. The potential metrics described here are based on metrics used by existing building rating systems, as well as factors that contribute to improved energy performance as determined by the research community.

Potential metrics fall into two categories – both have their advantages and disadvantages:

- **Performance-based** – these metrics are based on a living architecture project or component of a project meeting or exceeding a benchmark of performance (For example, a credit is awarded where a green roof retains 75% of annual precipitation or reduces energy use by 10%). This could be tested on site, in a laboratory or modeled using building simulation software, like EnergyPlus or Energy Analysis. The largest advantage of performance based testing is that it allows designers and manufacturers to meet standards without dictating how they do so, allowing them the freedom to innovate and integrate technologies and techniques. The chief disadvantage of performance-based metrics is the potential for increased cost and complexity, especially when on-site or laboratory testing is concerned. Test methods and models will have to be selected, established and monitored for real world effectiveness
- **Design-based** – these metrics are prescriptive, and reward projects that meet certain design criteria that have been found to correspond to improved performance (For example, a green roof is awarded more points for using plants with a higher leaf area index, because research suggests that this leads to improved energy performance and stormwater management). The advantage of design-based metrics is that they are cheaper and easier to administer than performance-based metrics, and potentially fill the gaps of many other rating systems that do not address living architecture. The disadvantage is that they can increase project costs, make the program too regimented and stifle innovation. Additionally, research findings are constantly evolving, and there is no consensus on the effect of some green roof variables.

Table B provides a number of potential metrics that could be applied to living architecture. The table includes the intent of the metric, how it could be measured, and a basis from research on living architecture and energy, or from existing rating systems or guidelines.

Each potential metric is assessed for its application to various forms of living architecture. Living architecture assessed here includes extensive/intensive green roofs, interior/exterior green walls and green facades. ‘Other’ includes living retaining walls, biofiltration systems, living machines and constructed wetlands.

5.1 PROPOSED METRICS

Metrics form the basis of which we can evaluate the performance of living architecture. The potential metrics described here are based on metrics used by existing rating systems, as well as factors that contribute to increased energy conservation and generation potential as determined by the research community.

Table B provides an overview of potential metrics that could be applied to living architecture. The table describes the metric, its measurement basis, and its potential application to different types of living architecture. Living architecture assessed here includes extensive and intensive green roofs, interior and exterior green walls and green facades. 'Other' includes living retaining walls, biofiltration systems, living machines and constructed wetlands.

The metrics are then described in detail, with a rationale grounded in literature and/or a presence in other rating systems like LEED, Sustainable Sites, etc.

Intent	Metric	Type and Measurement Guidelines	Potential Application					
			Ext. Roof	Int. Roof	Ext. Wall	Int. Wall	Façade	Other
Optimized thermal performance - whole building parametric modeling	Percent energy reduction for heating and cooling compared to baseline, percent reduction in thermal flux through the building envelope	Performance-based modelling using EnergyPlus or similar	Y	Y	Y	N	Y	?
Optimized thermal performance - design guidelines	Leaf area index, vegetation coverage, minimum stomatal resistance, plant height, growing medium thickness, etc.	Design guideline or on-site testing and validation post-construction	Y	Y	Y	N	Y	?
Use living architecture to reduce the urban heat island effect	Albedo, leaf area index, vegetation coverage, etc.	Design guideline or on-site testing and validation post-construction	Y	Y	Y	N	Y	Y
Use living architecture to improve HVAC efficiency	Optimized location, orientation, and shading of HVAC units and air intakes, Integration of interior living wall into HVAC system	Design guideline	Y	Y	Y	Y	Y	?
Integrate living architecture with renewable energy generation	Presence of solar PV panels, wind turbines, etc; net-positive energy building	Design guideline or on-site testing and validation post-construction	Y	Y	Y	N	Y	?

5.1.1 OPTIMIZED THERMAL PERFORMANCE - WHOLE BUILDING PARAMETRIC MODELING

Intent	Optimize Design for Thermal Performance
Metric	Percent energy reduction for heating and cooling compared to baseline, percent reduction in thermal flux through the building envelope
Measurement Method	Whole building modeling using EnergyPlus or similar building modeling software
Rationale	

Wark (2011) argues that whole building modelling is essential to discovering the actual amount of energy savings from a green roof. He argues that the interdependence of building design, utilization and location are always interdependent and unique to every project; even a small change in building envelope or mechanical systems can affect predictions in a way that only parametric modeling can capture.

Modeling the thermal performance of green roofs requires the study of several interacting variables. While these models can be quite simple and incorporate only one or a few factors, complex models have been developed that better simulate real-world conditions. Parametric models are those that are aware of the interactions between variables. For example, in a parametric building modeller, when the pitch of a roof is changed, the walls automatically follow the revised roofline.

Del Barrio (1998), Kumar and Kaushik (2005), Lazzarin et al. (2005) and Feng et al. (2010) have all developed green roof models of differing complexity. Jaffal et al (2012) argue that Sailor's model is well adapted to evaluate the performance of green roofs. Sailor's model is also integrated into the US Department of Energy's EnergyPlus building simulation software program. His model includes the following variables:

- *plant height*
- *leaf area index* – a dimensionless measure of the projected leaf area per unit area of soil surface
- *leaf reflectivity* – the fraction of incident solar radiation reflected by the individual leaf surfaces
- *leaf emissivity* – the fraction of incident solar radiation reflected by the individual leaf surfaces
- *minimum stomatal resistance* – the resistance of the plants to moisture transport in units of s/m
- *roughness* – a character string that defines the relative roughness of a particular material layer
- *thickness* – depth of the growing media in metres
- *conductivity* – the thermal conductivity of the (dry) growing media in W/(m-K)
- *density* – the density of the (dry) growing media in units of kg/m³
- *specific heat* – the specific heat of the (dry) growing media layer in units of J/(kg-K)
- *thermal absorptance* – the fraction of incident long wavelength radiation that is absorbed by the growing media
- *solar absorptance* – the fraction of incident solar radiation that is absorbed by the (dry) growing media

- *visible absorbance* – the fraction of incident visible wavelength radiation that is absorbed by the growing media

LEED and BREEAM award credits for improved energy performance as based on building parametric modeling. While they also offer credits for improved performance as based on meeting or exceeding design guidelines, they award more points when improved performance is modeled due to the improved accuracy.

5.1.2 OPTIMIZED THERMAL PERFORMANCE – DESIGN GUIDELINES

Intent	Optimize living architecture performance by maximizing evaporative cooling, convective cooling, albedo, thermal mass and shading
Metric	Leaf area index, minimum stomatal resistance, vegetation coverage, plant height, growing media thickness, etc.
Measurement Method	Design guideline and/or on-site testing and validation post-construction
Rationale	

In some scenarios, a project has a limited scope or budget, and/or parametric modeling is undesirable or unfeasible for other reasons. In these cases, a series of design guidelines can be established and weighted based on their contributions to the factors that affect living architecture thermal performance, as determined by research. Only a select few variables could be selected for simplicity, or this could be expanded if greater accuracy is desired. It is very important to consider regional climatic factors when selecting design factors to maximize living architecture energy performance.

Evapotranspiration: Lazarrin et al. (2005) modelled the role of evapotranspiration in green roofs, and found that wet roofs are twice as effective at reducing heat flux into a building. Additionally, they also acted as passive coolers, drawing heat out from the building. Jaffal et al. (2011) found that increased LAI decreased summer indoor air temperatures and cooling demand.

Convection: Ayata et al. (2011) found that convection from the canopy to the atmosphere was an important factor in heat dissipation, especially during periods of low soil moisture when evapotranspiration is low. Carlos (2015) found that denser foliage helps trap a layer of air between the plants and the building, buffering winds and minimizing convective losses in winter.

Albedo: Gaffin et al. (2005) found that the exposed area of a black tar roof can be up to 80° C (176° F), the same area under a green roof is only 27° C (81° F). They argue that the 'equivalent albedo' of a green roof is 0.7-0.85. Wark (2011) suggests that succulents like sedums have a naturally variable albedo, changing from waxy and shiny during hotter periods to smaller and less shiny and emissive during the winter.

Thermal Mass: Liu and Minor (2005), found that substrate thickness improved thermal performance, and was a more important contributor than vegetation in reducing heat gain and loss. Del Barrio (1998) modelled the summer cooling potential of green roofs in Athens, finding that soil thickness and density were important factors in thermal performance. Greater thickness and less

dense soil reduced heat flux. Wark (2011) argues that sedums and other water-holding plants contribute to additional thermal mass.

Shading: Sailor (2011) and Jaffal et al. (2011) found that the increase in planting density and fractional vegetation coverage particularly effective at increasing performance by shading the roof from solar radiation. Fioretti et al. (2011) stated that factors like leaf area index and plant height influence the level of shading, and during periods where heat gain is desirable, it may be a good idea to use plants that go dormant or shed foliage. Clay et al. (2012) studied the effects of green roofs in a hot, semi-arid climate, and found that adding a mesh walkway 150mm over the surface of a green roof reduced temperature variations, most likely due to its shading effects while still allowing air, water and sunlight to the plants below.

LEED and BREEAM award credits for improved energy performance as based on design guidelines when modeling is not carried out. While these guidelines are generally based on the building envelope, the principles can be applied here. Meeting or exceeding a series of guidelines leads to credits awarded in the category.

5.1.3 URBAN HEAT ISLAND REDUCTION

Intent	Use living architecture to reduce the urban heat island (UHI) effect
Metric	Albedo, leaf area index, vegetation coverage, etc.
Measurement Method	Design guideline and/or on-site testing and validation post-construction
Rationale	

The urban heat island effect is caused by an alteration of surfaces in urban areas, and the replacement of natural and vegetated landscapes with artificial ones that have different thermal properties. Restoring vegetation to urban areas can decrease the amount of solar radiation absorbed, increase evapotranspirative cooling and improve urban microclimates (Peck and Richie, 2009). Alexandri and Jones (2008) found that using green roofs and walls in dense urban areas could reduce ambient air temperatures and energy use. Bass et al. (2003) found that using green roofs on a large scale could reduce summer temperatures by up to 2 °C.

Sailor (1994) argues that latent heat loss through evapotranspiration is the most important factor in green roof reduction of UHI; Scherba et al. (2011) found that even when latent heat loss is not considered, green roofs significantly outperform conventional black roofs at reducing surface and near-air temperatures.

5.1.4 LIVING ARCHITECTURE-INTEGRATED BUILDING ENERGY SYSTEMS

Intent	Use living architecture to improve the efficiency of building heating, ventilation and cooling (HVAC) systems
Metric	Optimized location, orientation and shading of HVAC units and air intakes using living architecture, integration of indoor living walls into HVAC systems

Measurement Method	Design guideline
Rationale	

Reducing ambient air temperatures around air conditioner intakes and units can improve air conditioner efficiency. (Mankiewicz and Simon, 2007). Moseley et al. (2013) suggest locating HVAC units and air intakes less than 3' from the roof surface to take advantage of air temperatures moderated by the green roof. Sustainable sites awards points for shading the surface area of exposed HVAC units. Allen (2013) claims that interior green walls can be integrated into HVAC systems, cleaning the air, removing pollutants, optimizing humidity and reducing the number of air changes required.

Sustainable sites also offers credits for shading HVAC units with vegetation.

5.1.5 LIVING ARCHITECTURE-INTEGRATED RENEWABLE ENERGY GENERATION

Intent	Integrate living architecture with renewable energy technologies
Metric	(1) Net-zero or net-positive building operation; (2) Presence of solar photovoltaic panels, wind turbines, etc.
Measurement Method	(1) Whole building modeling using EnergyPlus or similar building modeling software; (2) Design guideline
Rationale	

Using green roofs in combination with solar PV arrays brings together the benefits of both green roofs and solar PV panels while realizing synergies between both systems (Lamnatou and Chemisana, 2015; Peck and van der Linde, 2010). PV panels are 0.4-0.5% less efficient per °C increase in ambient temperature, above 25° C (77° F); reducing ambient temperatures using living architecture could improve PV efficiency. A test by Chemisana and Lamnatou (2014) in Lleida, Spain, found that solar PV panels mounted on a bed of Sedum clavatum increased the maximum power output of the PV panels by 3.33%.

Wind turbines have the potential to be integrated with living architecture. Building height and form often contribute to increased, but unpredictable and turbulent wind (Allen, 2013). While conventional wind turbines cannot harness this wind, innovations in vertical axis wind turbines allow them to harness turbulent wind without regard to orientation (Eriksson, 2008). Placing turbines on the edges of green roofs could take advantage of the windiest locations, while also buffering winds, allowing for a more moderate microclimate. Allen (2013) also argues for the potential for harvesting biomass growing on green roofs or walls, or even within the envelope of a building. The use of biochar or other methods of carbon sequestration could also help to contribute to creating a net-zero building.

LEED, Sustainable Sites, BREEAM, Green Globes and Envision all award credit for generating renewable energy on site. Living Building Challenge mandates the use of on-site renewable energy for 105% of the project's energy requirements.

6.0 CONCLUSION

The next steps that need to be taken are the selection and refinement of metrics. Table B outlines the various potential metrics that could be used to determine the energy conservation and generation performance of living architecture. Metrics could be combined, refined and modified to fit different forms of living architecture.

Objectives must be determined – is an overall reduction in non-renewable energy use the main objective, or are we aiming to reduce peak energy demand in the heating or cooling seasons? Potential metrics must be evaluated as to their ability to measure performance related to the stated objective(s), while also considering the cost of measurement and accuracy. Can multiple goals be met with one metric or do we need several? Are metrics design-based or do we use parametric modelling? If we use modelling, how can we ensure accuracy while reducing unnecessary complexity? These steps are crucial, and multiple priorities (alignment with objectives, cost, accuracy, complexity) will need to be delicately balanced.

The issue of how to deal with regional differences would then have to be approached, (this paper offers ways to approach this in section 4.0). Following that, each metric must be weighted, with consideration given to how energy conservation and generation is weighted within the entire system. The following chart shows how energy conservation and generation is weighted within other rating systems. It is important to note that some credits contain many different facets, so this is far from a precise measurement.

Rating System	Energy Conservation and Generation Weight
Sustainable Sites v2	6%
LEED v4	25% plus regional priority credits (if applicable in region)
Living Building Challenge 3.0	Difficult to quantify, but embraces energy conservation and generation at a higher level
Roofpoint	8.7%
Green Globes	19%
Envision	6%
BREEAM International 2013	21%

Following the weighting of metrics, a pilot version of the LAPT can be created. Pilot projects can be evaluated, and through constant monitoring, feedback and evaluation, a version for the public can be released.

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