CONSTRUCTION OF EFFICIENT, COST-EFFECTIVE AND SUSTAINABLE MAINTENANCE FACILITIES

Best Practice Guide

PROJECT 792

Oregon Department of Transportation

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GENERAL INTRODUCTION

There are approximately 89 maintenance stations managed by the Oregon Department of Transportation (ODOT). Many of these maintenance stations are reaching the end of their usable life, beyond their life expectancy, inefficient, or functionally obsolete (e.g., unable to accommodate larger-size, modern equipment). There is an urgent need to systematically replace these buildings to support the agency maintenance mission. A typical maintenance station can cost up to \$8-\$9 million, representing a significant capital cost burden over the next several years. The Oregon DOT Facilities Leadership Team (representatives from all Highway Division Regions) has updated a 10-year plan prioritizing the renovation and replacement of maintenance stations (January 2014). The land purchase, design, and site preparation phase for one facility, and the construction phase of a second facility will be accomplished each biennium at funding of approximately \$12 million. An important consideration in these efforts are requirements for any new buildings constructed by authorized state agencies to exceed current building energy codes by 20% and for any public building costing over \$1 million to devote at least 1.5% to green energy technology. ODOT facilities are also required to adhere to the latest State Energy Efficient Design (SEED) rules. It is the intent of ODOT to exceed these latest regulations. In 2008 the Sisters maintenance station became the first in Oregon to incorporate renewable energy – in the form of geothermal heating and solar water heating. Even more sustainable and cost-effective solutions could have been accomplished by utilizing high performance design practices, sustainably produced materials, increased insulation, more efficient lighting, water-saving techniques, waste reductions, and other measures. ODOT wanted to develop guidance to realize such sustainable and cost-effective solutions in new construction for ODOT. The outcome of that desire was a funded research project, ODOT SPR 792 that ultimately led to the creation of this Sustainable Maintenance Facilities Design Guide, herein referred to as this Guide.

To create this Guide a wide survey of technical literature was done to pull current best practices and innovative solutions to sustainable design procedures. This included the main green building standards in North America (LEED, Living Building Challenge and Green Globes), journal articles, conference proceedings and other technical literature as well as sustainable practices done by other Departments of Transportation. In addition, the sustainability of two current ODOT maintenance stations (in Sisters, Oregon and Albany, Oregon) were evaluated to serve as case studies to help inform the research team and ODOT about the most effective and promising sustainability measures. A modified life cycle assessment (LCA) and a modified life cycle cost analysis (LCCA) were done on the two maintenance facilities. The modified LCA and LCCA focused on energy and materials use and impacts. The modified LCA provided quantitative data to illustrate the current base-case energy demands and how they have been met. This information was then used to identify the life cycle phases and processes that consume the most energy and, therefore, require improvement for environmental impact reduction. The focus on materials provided information about the environmental impacts of selected materials and alternatives to aid in choosing environmental-friendly materials that are also cost efficient. This suite of information was used to develop the Guide.

EXECUTIVE SUMMARY

From reviewing technical literature, green buildings standards and rating systems, other DOT regulations and from the two case studies as part of an ODOT research project (SPR 792) the following general best practices should be considered when constructing new or renovating existing maintenance facilities. This document outlines the best practices in a concise summary from an energy and materials standpoint. The first section of the guide gives the reader an overview of the most important best practices for the area of energy and then materials with respect to improving sustainability metrics as well as cost savings. The guide then gives a brief overview of two case studies: Albany Maintenance Facility and Sister's Maintenance Facility and provides concise recommendations in energy and materials that were found to result in improvements in sustainability, efficiency and cost savings from the results of ODOT SPR 792. Then there is a brief section on three of the most used buildings ratings systems: LEED, Living Building Challenge and Green Globes which highlights the best practices in energy and materials. This is followed by a brief discussion of the Oregon SEED requirements. Finally, an appendix is provided that gives a wide range of energy and materials options as determined by the OSU Energy Efficiency Center for the two case studies as part of this project. This provides incredible detail, options and resources to ODOT, future designers, engineers and contractors on maintenance facility reconstruction processes.

Energy Best Practices

Optimizing energy performance for a building is the perhaps the single most important sustainability feature that can result in significant cost savings as well as reducing the negative environmental impacts of a building. To optimize energy efficiency, it is important to do initial ***commissioning of building systems*** to ensure that the HVAC and electrical systems (that may include sensors) are operating per the manufacturer recommended specifications. Then using ***building energy simulation tools/software*** to optimize energy performance and to identify areas where energy can be saved, or waste energy can be harvested is recommended. Areas where energy savings can be recognized through best building practices include:

- Double paned or triple paned windows
- Use of skylights for natural lighting
- Use of geothermal & solar heating where possible
- Optimizing heating and cooling energy efficiency
- Specifying insulated doors especially for high bay garage type doors
- Insulating hot water piping systems
- Good labeling and organization of equipment
- Effective systems controls

- Motion sensors on lights
- Use of LED lighting
- Regular maintenance on energy systems

Materials Best Practices

Regarding materials, focusing on those that are: 1) used in the greatest quantity especially on a mass (density) basis and making improvements in their sustainability metrics result in the biggest improvements in overall sustainability performance. In conjunction with this, 2) prioritizing the use of regional materials for the most used building materials and especially those of greatest density also significantly reduces environmental impacts from transportation of those materials, as well as stimulating the local/regional economy. Different building standards use different metrics for what is defined as a local or regional material, but generally this ranges between 100-500 miles for the site of manufacturing of the material and often for the raw materials availability as well. Finally, (3) focusing on materials that provide synergistic benefits in energy saving is also important. For instance, selecting double or triple pane windows is both a choice for material as well as one for energy savings. The framing system and insulation are other examples of prioritizing synergistic impacts from the material selection coupled with energy improvement area. Other general best practices include:

- Use life cycle analysis software (SimaPro) to compare alternatives for environmental impacts
- Include materials with recycled components, provided that the durability of the material meets or exceeds the product/component it is replacing
- In the sections of the building where portland cement concrete is used, reduce the amount of portland cement as much as possible through replacement with fly ash, slag, finely ground limestone, metakaolin, silica fume, rusk ash, calcined clay, and other suitable supplementary cementitious materials. Ensure that replacement levels meet local codes and constructability requirements of the project. Since the portland cement concrete is such a significant portion of many maintenance facilities (e.g. foundation, slab, possibly structural elements) this can represent a significant reduction in the environmental impact of materials used in the structure
- Select materials that have service-lives, as documented by independent third-party studies, which will meet the intended service life of the structure or exceed it.
- Develop a maintenance plan to ensure materials function properly and are maintained throughout their lifespan.
- Limit water intrusion to the building elements through regular maintenance procedures and proper selection, design and construction efforts.

Case Studies –Albany and Sisters

Albany Maintenance Station

The Albany maintenance facility was built in 1995 and has three buildings on site including a main building, a maintenance bay, and a fuel station. The main office and the maintenance facility are within the main building, which is a 14,500 ft^2 pre-manufactured metal structure. Standing seam metal panels were used as the roof, and metal panels were also used as the external wall siding material. Insulation was applied to the interior surfaces of both the roof and the external walls of the building. A concrete apron was cast at each truck bay area. The maintenance bay is a 9,600 ft^2 wood pole structure. Metal roofing and metal siding were also used in this building. The interior bearing partition consists of 3-1/2" wood studs and gypsum boards on each side.

Electricity is the main power supply for the maintenance station. In addition, diesel is stored for backup fuel for maintenance vehicles. LED lights are used in the maintenance area of the main building. The station is occupied 24 hours a day in winter time and is somewhat less occupied during the summer (occasionally 24 hours a day). For waste water catchment, an oil filter and a rock filter system are used to control releases of contaminated runoff.

Energy Efficiency Center Recommendations

The OSU Energy Efficiency Center (EEC) made three main recommendations to improve the energy use, demands and source for the current Albany Maintenance Station. The improvements and benefits are outlined below:

The EEC recommended installing LED lighting in the Main Building Offices, Closed Garages, Open Garages and Outside Lighting. This will:

- Increase lighting efficiency and reduce associated annual energy consumption by **69%.**

The EEC recommended installing thermostats on the circuits that power the block heaters at the Albany station. Installing thermostats on block heaters will:

- Reduce operation time of the heaters,
- Reduce associated annual energy consumption by **68%**

The EEC also recommended the installation of a photovoltaic array on the roof of one of the buildings at the Albany site. The size array they proposed would:

- Provide energy production source for **55% of the facility's energy consumption** and reduce carbon dioxide emissions associated with electrical generation.

A summary of the associated cost savings and payback in years is shown in Table 1 for the efforts outlined above:

Table 1 Cost Savings Associated with Recommended Sustainability Improvements to the Albany Maintenance Facility.

#	Description	Percent Savings	Energy Savings	Cost Savings	Total Cost	Payback
			(MMBtu/yr)	(/yr)		(yrs)
1	Install Thermostat for Block Heaters	12.7%	52	$1,171	$581	0.5
2	Install Photovoltaic Array	51.6%	210	$4,802	$121,479	25.3
3	Upgrade Lighting	35.7%	145	$3,433	$34,000	9.9
Totals		**100.0%**	**407**	**$9,406**	**$156,060**	**16.6**

Sister's Maintenance Station

The Sisters maintenance facility was built in 2012. This facility includes two main buildings on site: a maintenance building and an equipment building. The maintenance building is a 10,260 ft^2 single-story metal structural building, which includes vehicle-maintenance bays and personnel support areas. The exterior walls consist of medium density overlay (MDO) plywood sheathing, glass fiber board insulation, and gypsum board. The interior partition wall consists of stud wood and gypsum boards on each side. The roof is made of metal. Solar panels and skylights are installed on the roof. The equipment building is a 5,400 ft^2 single-story wood pole building. This building is mainly used for equipment and de-icing salts storage (in a fluid tank). The siding materials and the roof used for the equipment building match the materials used in the maintenance building.

In 2004, Department of Administrative Services (DAS) issued the Sustainable Facilities Standards and Guidelines. Accordingly, all new state construction and major renovation needs to meet LEED Silver equivalency. In order to meet Oregon DAS LEED Silver equivalency, different actions were taken on the Sister's maintenance facility. For example, the facility was built with low-emitting volatile organic carbon (VOC) materials to improve indoor air quality. Also, a hybrid heating system, which consists of a solar-thermal heat system and a geo-thermal heat system, was installed in the maintenance facility.

<u>Energy Efficiency Center Recommendations</u>

The Energy Efficiency Center (EEC) investigation found that the Sister's Maintenance Facility was already performing quite while in terms of energy efficiency. They highlighted several best practices in the area of energy saving, waste reduction and productivity improvement practices. This included:

- Double Paned Windows
- Geothermal & Solar Heating
- Insulated Bay Doors
- Hot Pipes Insulated
- Good Labeling and Organization of Equipment
- Effective Systems Controls

- Motion Sensors on Lights
- Skylights

General Best Practice Recommendations for Energy Reduction

Energy

According to the International Energy Agency (IEA) (2013), the U.S. building construction industry should set the highest priority for advanced envelope technology, such as highly insulating windows and air sealing and insulation in cold climates. They also support a policy of deep renovation of existing buildings using a systems approach for implementing advanced envelopes and high-performance equipment. The second priority for the U.S. includes use of heat pumps for water and space heating and cooling, and the construction of new, zero-energy buildings by developing advanced holistic building design strategies with integrated renewable energy (IEA, 2013).

Commercial buildings account for about 46% of U.S building energy consumption (DOE, 2012). A total of 76.8% of this consumption is in the form of electricity (DOE, 2012). HVAC systems are the highest energy consuming systems in commercial buildings (space heating and cooling consumed 31.3% of site energy in the commercial sector in 2015, followed by lighting at 11.4% (DOE, 2012)).

<u>Windows</u>

- Selecting double pane windows or triple pane windows will result in significant energy savings
- Selecting windows with framing materials that are locally produced is also a best practice

<u>Strategies for reducing lighting energy use include (Omer 2008):</u>

- Penetration: collection of natural light inside the building;
- Distribution: homogeneous spreading of light into the spaces or focusing;
- Protect: reducing by external shading devices the sun's ray's penetration into the building;
- Control: control light penetration by movable screens to avoid discomfort.

<u>Strategies to improve building heating energy efficiency (Omer 2008):</u>

- Solar collection: collection of the sun's heat through the building envelope;
- Heat storage: storage of the heat in the mass of the walls and floors;
- Heat distribution: distribution of collected heat to the different spaces, which require heating;

- Heat conservation: retention of heat within the building.

An illustration of how alternative energy system can significantly reduce environmental impacts can be found in Figure 1. Impacts reduction by switching from natural gas to hybrid system for operational use at Albany facilityImpacts associated with materials for system's components and energy usage throughout the 50-year life cycle of hybrid solar-geothermal system is less than that of system using natural gas.

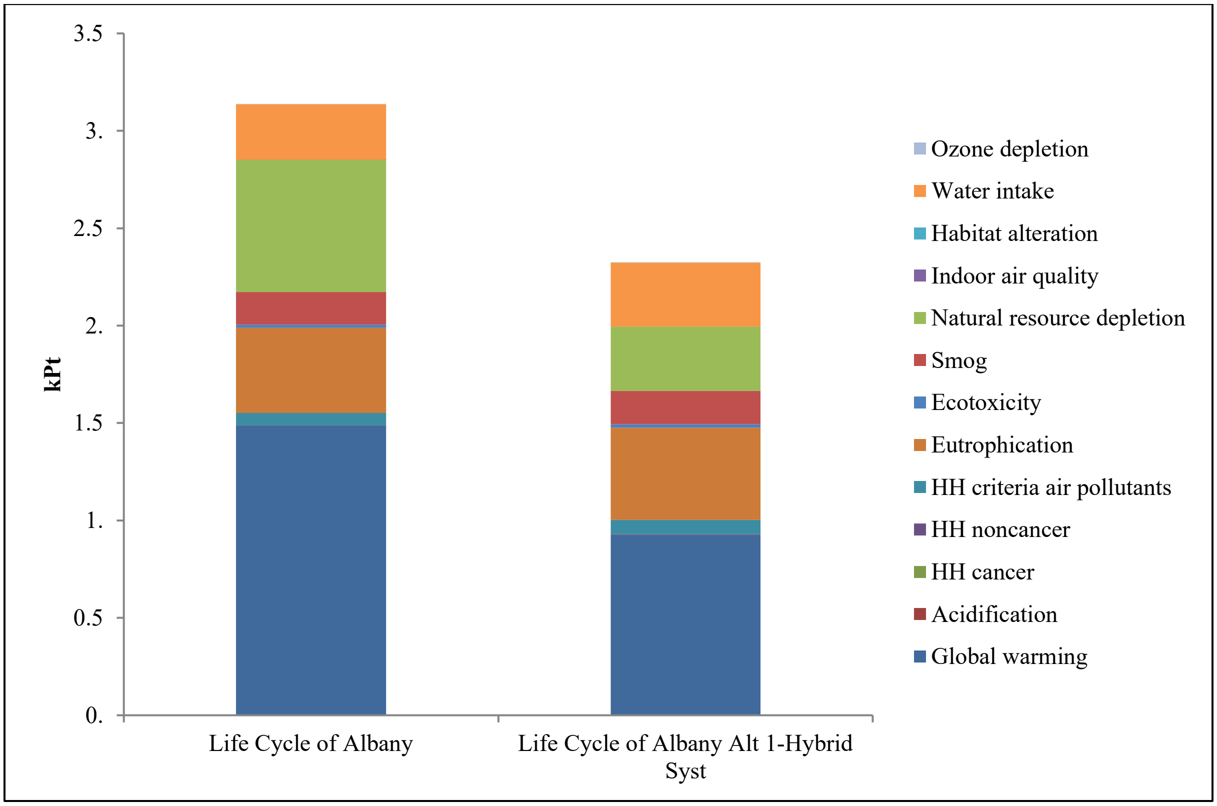


Figure 1. Impacts reduction by switching from natural gas to hybrid system for operational use at Albany facility

<u>Strategies to improve building cooling energy efficiency:</u>

- Solar control: protection of the building from direct solar radiation;
- Ventilation: expelling and replacing unwanted hot air;
- Internal gains minimization: reducing heat from occupants, equipment and artificial lighting;
- External gains avoidance: protection from unwanted heat by infiltration or conduction through the envelope (hot climates);
- Natural cooling: improving natural ventilation by acting on the external air (hot climate)

Solar energy storage systems

A comparative LCA among three different innovative solar energy storage systems - sensible heat storage in solid (high temperature concrete) storage media, sensible heat storage in liquid (molten salts) thermal storage media, and latent heat storage which used phase change material (PCM) (Oró, Gil, de Gracia, Boer, & Cabeza, 2012) found that the system based on solid media (high temperature concrete) showed the lowest environmental impact per kWh. The solid media thermal storage system has a storage capacity of about 350 kWh and can operate with maximum temperatures of 390 °C, with a tubular heat exchanger integrated into the storage material. The system consists of two modules with dimensions of 0.48 × 0.48 × 23 m. The design's simplicity of solid media system mainly contributed to the lowest environmental impacts.

General Best Practice Recommendations for Materials Sustainability

Energy savings and materials are closely linked and selection of the materials and components in the building should not only be environmentally friendly themselves but can often also contribute to improved energy efficiency. This is particularly important when selecting building insulation, window type and lighting. Selection of the building envelope and structural system can also serve a dual purpose in terms of meeting sustainability requirements for materials and enhancing energy efficiency.

Ooteghem and Xu conducted a study on LCA of a single-story retail building in Toronto, Canada. In this study, five building models were analyzed: (1) conventional hot-rolled steel structure, (2) heavy timber structure, (3) structure with pre-engineered steel components designed and built off-site, type using steel components wherever possible (4) and type (5) using wood components wherever possible. Types (4) and (5) mainly had different wall and roof materials but were based on the same structural system of type (1) and (2). The study found that commercial seam steel roofs had a high embodied energy. In addition, the type (3) structure showed the least total energy and global warming potential of all five different building models (Van Ooteghem & Xu, 2012).

Another study raised the issues with the true energy savings reportedly associated with current buildings certifications. An LCA was done on The Center for Sustainable Landscapes (CSL) office in Pittsburgh, PA, USA to evaluate life cycle environmental impacts (Thiel et al., 2013). The CSL office is a three-story, 24,350 ft^2 educational, research, and administrative office, and was compared with a standard commercial office building. CSL is a net-zero energy building and is designed to meet Living Building Challenge (LBC) criteria. The study found that the highest production-related environmental impacts were from concrete, structural steel, photovoltaic (PV) panels, inverters, and gravel. CSL was associated with 10% larger global warming potential and a nearly equal embodied energy per square foot, largely due to the PV system.

Figure 2 shows potential impacts contribution from building materials of major building components, using the case studies. By performing LCA, further attention can be drawn to high-impact components.

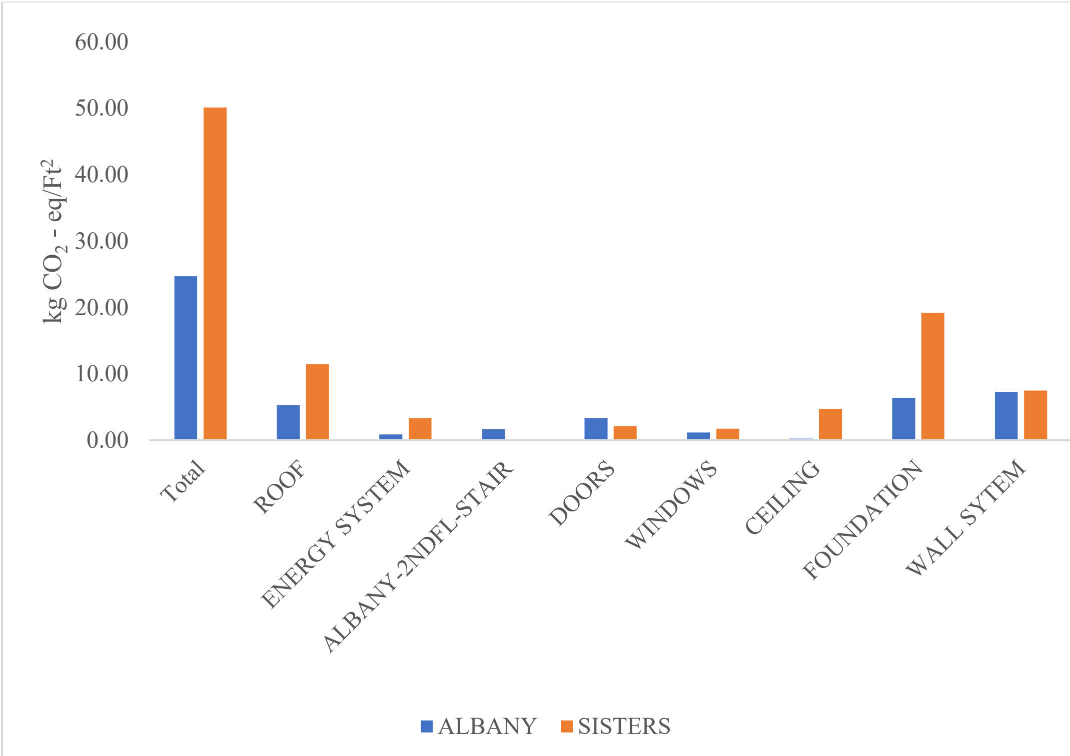


Figure 2. Global warming potential by sub-components

There is a higher global warming impact from several components of the Sister's facility including the foundation, the energy system and the roofing material from a materials standpoint. Even though the Sister's facility was shown to have significantly better energy efficiency than the Albany facility the materials that were used in Sister's had a higher impact on global warming potential. It is important to keep in mind that energy efficiency is realized throughout the entire life cycle of the building due to lower energy costs. Quantification of the longevity of materials used in each facility as well as end-of-life use would better quantify the up-front impacts from material selection at Sister's compared to Albany. The type of analysis was beyond the scope of this project.

Other best practice recommendations for the area of materials include the following:

<u>Foundation and Slab</u>

- Reduce the amount of ordinary portland cement in all concrete mixtures by using supplementary cementitious materials such as:
    - Fly ash
    - Ground granulated blast furnace slag (slag)
    - Silica fume
    - Metakaolin

- Finely ground limestone
- Calcined clays
- Rice husk ash
- Ternary or quaternary blends of the above materials with OPC

- Ensure modifications to the items above comply with local and regional building codes
- Ensure that the concrete is air entrained for any exposed concrete to freeze-thaw cycling for proper service life

Figure 3 shows the difference in environmental impacts between a 100% portland cement concrete foundation compared to a replacement of a the portland cement by 50% using blast furnace slag.

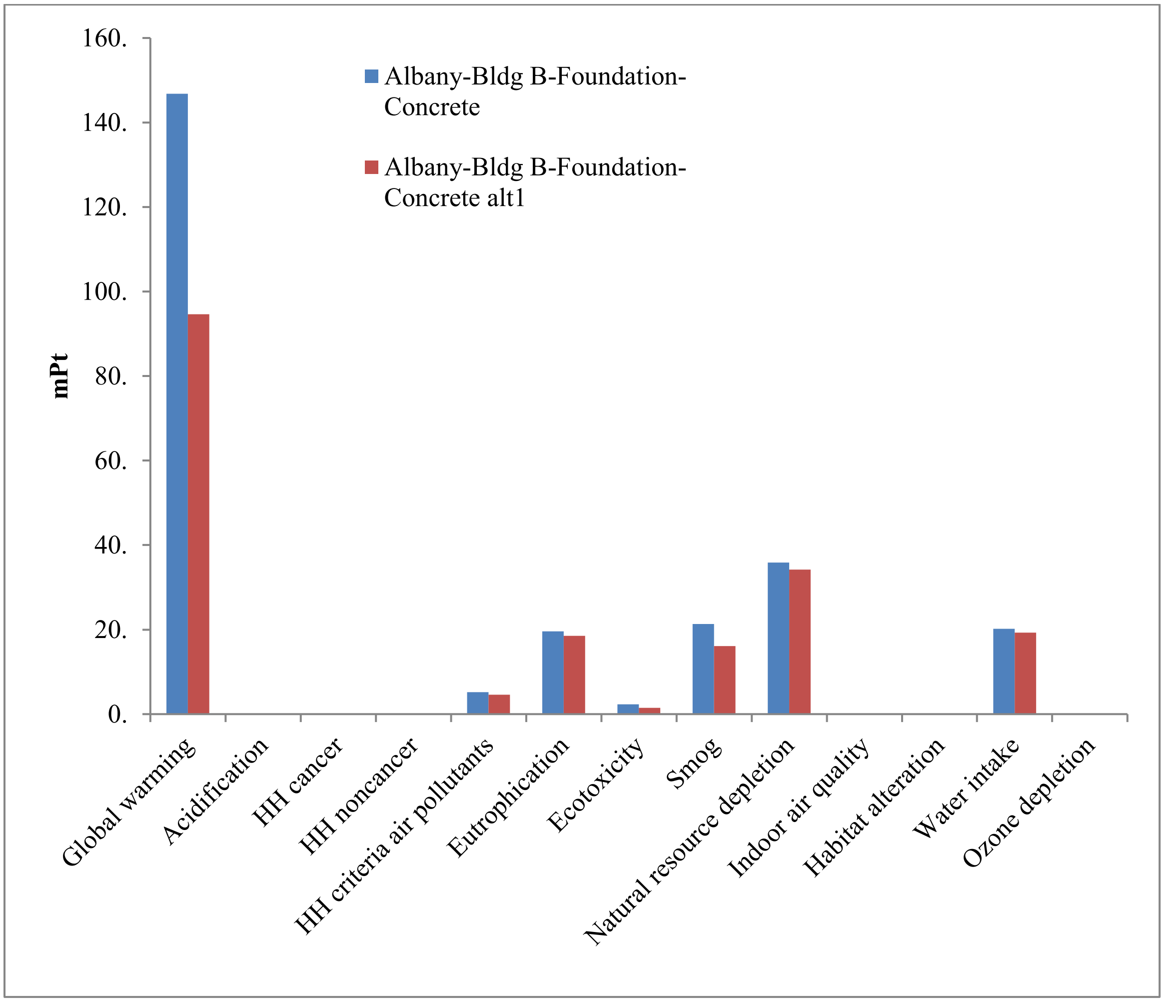


Figure 3. Impacts reduction by replacing Portland cement concrete to blast furnace slag concrete (alt 1).

In Figure 3 replacing 50% of the portland cement used in the foundation with blast furnace slag results in a significant reduction in the global warming potential as well as slight reductions in smog, natural resource depletion and water intact. This is linked to 50% reduction in the use of Portland cement in this foundation. Since the concrete makes up such a large quantity of materials used in many buildings it is an area where improvements to sustainability make significant improvements in overall building sustainability metrics and impacts.

Roofing

In terms of roofing including materials that are well insulated as well as low maintenance is a general best practice. From the results of the case study of the Sister's facility three different types of roofing material were compared.

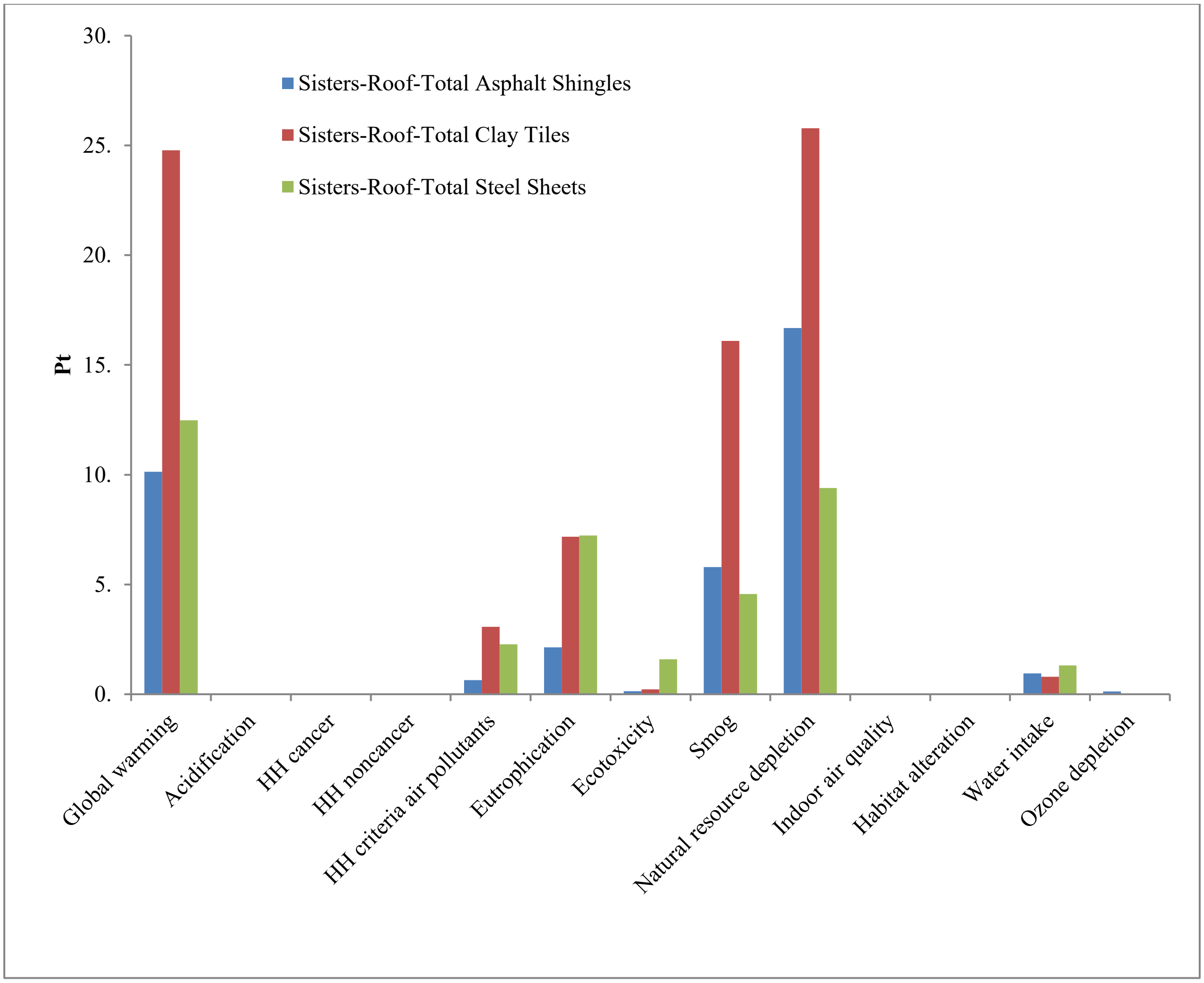


Figure 4. Environmental impacts of three different roofing materials on the Sister's maintenance facility

In this figure we can see that the current selection of using steel roofing on the Sister's facility is the best from an environmental impact assessment point of view. Asphalt shingles have an impact nominally in the middle between the clay tiles and steel sheeting. Clay tiles have the largest environmental impact. However, their life expectancy would be expected be on the same order of magnitude as steel sheeting and significantly greater than asphalt tiles.

Insulation

As far as building insulation and attractive alternative to traditional glass fiber insulation is the use of cellulose fiber as shown in Figure 5.

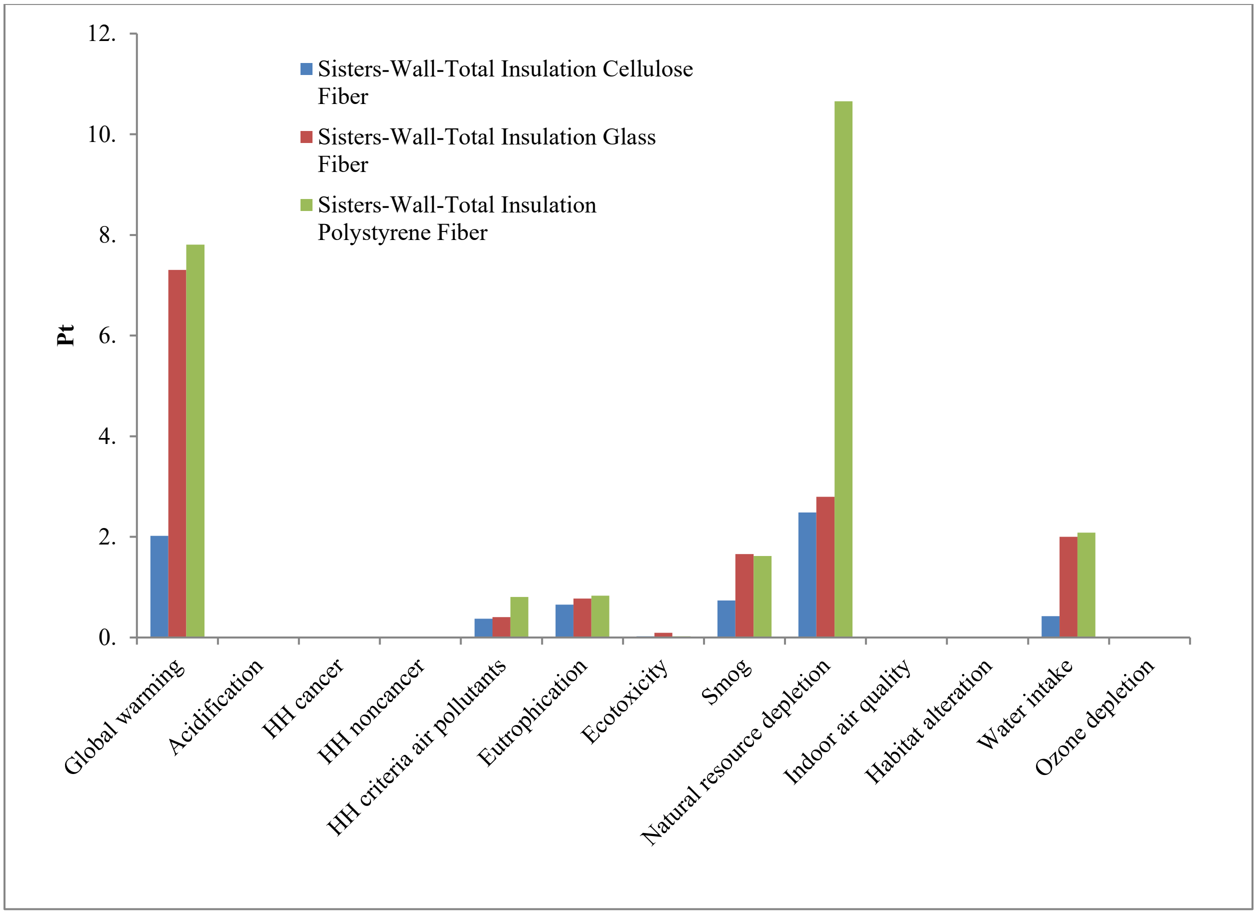


Figure 5. Environmental impacts of three different types of insulation used in the walls of the Sister's Maintenance Facility

Figure 5 shows that the use of cellulose fiber insulation would significantly reduce the global warming potential associated with polystyrene fiber or glass fiber insulation. In the other categories the impacts are relatively similar with cellulose fiber being marginally better. Polystyrene insulation has the largest impact in terms of natural resource depletion.

Doors

For doors either using solid, generally wood, doors or insulated doors are recommended from an energy efficiency standpoint as well as for soundproofing.

LEED Requirements (LEED Equivalency)

LEED stands for Leadership in Energy and Environmental Design. While current ODOT building guidelines do not require adherence to LEED it is important to highlight the main features of LEED for two reasons: 1) this provides great benefit if LEED status or LEED equivalency is required of ODOT facilities in the future and 2) the sustainability measures that are in LEED provide a strong reference for improvements that can be made to building efficiency and environmental impact.

The current version of LEED is Version 4 (v4). There are several different types of LEED rating systems depending on the type of construction. For this project, the LEED Building Design plus Construction rating system (LEED BD+C) is the most appropriate. In LEED BD+C there are eight different categories and a total of 110 points possible to achieve increasing levels of LEED certification. Among these categories, Energy and Atmosphere (EA) and Materials Resources (MR) are two major focuses, of which EA takes 33 points and MR has 13 points (USGBC, 2015). The points needed for different certification levels are shown in Table 2.

Table 2. Total Points Needed for Different LEED Certification Levels (USGBC, 2015)

Certification Levels	Points Required
LEED Certified	40-49
LEED Silver	50-59
LEED Gold	60-79
LEED Platinum	80+

We will not cover all the details of each point earning option within the respective categories in this Guide. We will highlight those that are the most applicable to maintenance stations and/or those that provided the most significant improvements in sustainability.

Energy and Atmosphere Category

To earn points in any of the eight different categories a varying number of prerequisites must be met. In the Energy and Atmosphere Category (EA) this includes:

- fundamental commissioning to ensure the building is designed, constructed, operated, and maintained in accordance with owner's requirement (USGBC, 2015, p. 64).
- Projects must demonstrate an improvement in energy performance through:
  - performing a whole-building energy simulation to compare the proposed building with the baseline building

    –Or-

  - ensuring compliance with the ASHRAE 50% Advanced Energy Design Guide

    –Or-

  - ensuring compliance with the ASHRAE Advanced Building Core Performance Guide (this option is only available for project of less than 100,000 $ft.^2$)

- chlorofluorocarbon (CFC)-based refrigerants are forbidden in new heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems (USGBC, 2015, p. 70).

Improving energy performance is one of the most effective ways to improve the environmental impact of any building and subsequently it provides one of the most effective ways to earn points in the LEED rating system.

The *Optimize Energy Performance* sub-category in LEED v4, accounts for 18 points out of 110 points for new construction (USGBC, 2015, p. 74). A project can gain credits if more than 6% improvement on energy performance for new construction, 4% for major renovation or 3% for core and shell is demonstrated through a whole-building energy simulation. To gain all 18 points for this category, a 50% improvement in new construction or a 48% improvement in a major renovation in energy performance is required.

In the *Green Power* sub-category. LEED v4 awards points for the use of renewable energy: one points will be credited if more than 1% energy is supplied by on-site renewable sources; full three credits are awarded if more than 10% energy is supplied by on-site renewable sources. Credits for enhanced refrigerant management can be achieved by either using no refrigerants (or low-impact refrigerants) or a calculation shows that refrigerant impact is blow required limits (USGBC, 2015, p. 82). LEED v4 encourages the use of green power and carbon offsets. To gain the credit in Green Power and Carbon Offsets, contracts with qualified resources need to specify that at least 50% of the project's energy is from green power, carbon offsets, or renewable energy certificates (RECs) (USGBC, 2015, p. 85).

Materials

The prerequisites in materials include:

- Dedicated storage areas for recyclable materials for the entire building are required.
- Construction and demolition waste management plan (USGBC, 2015, p. 87).

Once the prerequisites are met in the category of materials are met points can be earned in the sub-categories toward LEED certification.

Life Cycle Impact

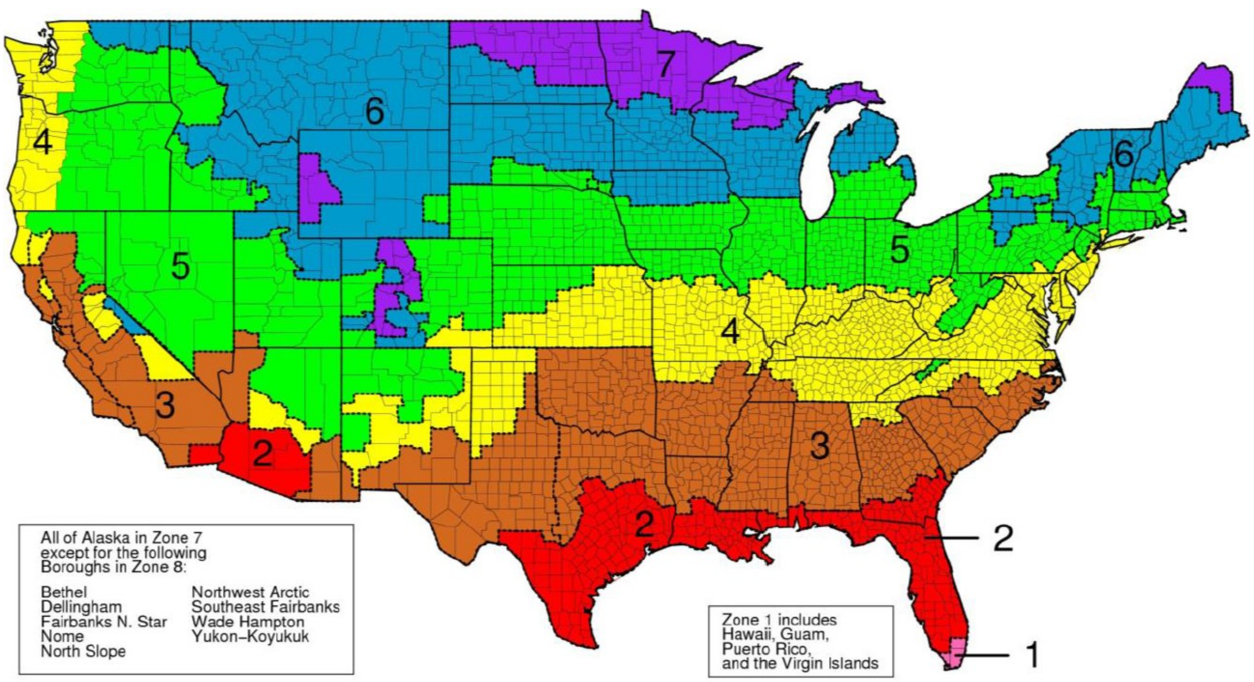
Among all sub-categories in MR, Building Life Cycle Impact Reduction comprises the highest percentage of points. LEED v4 encourages the use of historic buildings or abandoned buildings; the projects will gain points in this sub-category if a historic building is reused or if an abandoned or blighted building is renovated. If materials are reused or salvaged from old buildings at 25% or more of the project surface area, points will be awarded in this sub-category (USGBC, 2015, p. 90). Another alternative in this category is to conduct a whole building LCA to demonstrate a 10% reduction in at least three environmental impacts out of six (USGBC, 2015, p. 90).

Waste Management

Beyond the prerequisites for waste management, LEED v4 requires diverting at least 50% of the total construction and demolition material; the diverted materials must include as least three materials streams (USGBC, 2015, p. 106).

Green Globes

Green Globes is an assessment program to evaluate the environmental performance and sustainability of buildings of different types. Green Globes has three evaluation systems: New Construction, Existing Building, and Sustainable Interiors. Green Globes for New Construction (Green Globes NC) is developed for new construction, major renovation, and additions, which applies to the needs of this project. In Green Globes NC, points are distributed in seven different categories, and total 1000 points. Among them, Energy accounts for 390 points, which is nearly 40% of the total points, while Materials and Resources account for 125 points (GBI, 2015). Table 3 shows the levels and required points for certification in Green Globes NC. In Green Globes NC, the performance of the building is assessed based on the local climate. The climate information is obtained from ASHRAE/IES Standard 90.1-2013 as shown in Figure 2



Energy

In Green Globes NC, one of the most important focuses is assessing energy performance, which has 100 points out of 390 points. There are four different paths to assess the energy performance of the building: (1) Energy Star® Target Finder; (2) ANSI/ASHRAE/IES Standard 90.1-2010, Appendix G; (3) ANSI/GBI 01-2010 Energy Performance Building Carbon Dioxide Equivalent Emissions (CO_2e); and (4) ASHRAE Building Energy Quotient (bEQ) rating system. Similar to LEED, the energy performance needs to be evaluated. Compared with LEED v4, Green Globes provides more options for energy performance evaluation. However, the whole building LCA is not included as an option as it is in LEED (GBI, 2015, p. 68).

Table 3. Percentage of Points Needed for Certification Levels in Green Globes for New Construction

Certification Levels	Percentage Required
One Green Globes	35-54%
Two Green Globes	55-69%
Three Green Globes	70-84%
Four Green Globes	85-100%

Green Globes NC encourages practitioners to estimate and anticipate energy use on an annual basis, and an energy conservation plan that includes reducing passive demand and power demand is desired (GBI, 2015, p. 75). For passive demand, there is a requirement for the minimum heat capacity of the building envelope gross wall, interior partitions, and return air plenums (5 Btu/ft.2). Passive demand also requires a thermal energy storage system to offset the peak cooling demand more than 30%. For power demand, the rating system requires an increase in monthly power demand factor (low volatility in power usage) and a reduction in total power demand (GBI, 2015, p. 76).

Green Globes NC encourages building-level metering of electricity, heating fuels, and steam. In addition, sub-metering awards points on lighting, plug loads, major electric HVAC equipment, chilled water generation, on-site renewable energy power generation, heating water or steam generation, specialty or process electrical equipment, and critical HVAC controls (GBI, 2015, p. 82). Green Globes NC specifies the R-value and U-/C-/F-factor for different construction components based on the climate zone where the project locates (refer to Table 3.3.4.1.1-A and Table 3.3.4.1.1-B in the Green Globes NC) (GBI, 2015, p. 88). The orientation of the building is taken into consideration in Green Globes NC as well; points are awarded if the ratio of the north/south fenestration area to the east/west fenestration area is between 1.25 and 2.00. In addition, the U-factor of the fenestration needs to be less or equal than a specified value (as seen in Table 3.3.4.3 in the Green Globes NC) (GBI, 2015, p. 90).

The lighting condition for a building is evaluated by total lighting power density (LPD). LPD is the load of lighting in a defined area (ASHRAE, 2013). In Green Globes NC, LPD needs to meet the required value through either the building-area-method or space-by-space method (description of the methods can be found in ANSI/ASHRAE/IES Standard 90.1-2010). Interior automatic light shutoff controls, light reduction controls, and daylighting are encouraged (GBI, 2015, p. 91). For exterior lighting system, lamps with an initial efficacy of at least 60 lumens per watt, LED lamp sources, lamp sources with no mercury content, and lighting systems with photo sensors or an astronomical time switch are encouraged (GBI, 2015, p. 97).

<u>HVAC Recommendations</u>

The HVAC design should minimize or eliminate reheating and recooling (GBI, 2015, p. 110). A control to shut down the outdoor air and exhaust air dampers when the system is not operating is desired (GBI, 2015, p. 111). A leakage rate less than 5% of the air handling system is required (GBI, 2015, p. 111). The duct systems should also meet the requirements on noise level (GBI, 2015, p. 112). The use of flexible ductwork should consider the limitation on length, position and support (GBI, 2015, p. 113). The duct joints should be sealed, and the leak rate should not exceed 5%. For the fans used in HVAC systems, the motors should meet NEMA's Premium Energy Efficiency Motor Program, and the speed of the variable speed fans should be controlled by a duct pressure set-point or an energy management control system (GBI, 2015, p. 114).

Operations
For ventilation, occupancy and CO2 sensors should be installed to monitor the occupancy rate and thus control the ventilation rates (GBI, 2015, p. 115). The sensors should be calibrated every year to keep the error within 2%. Pressure-drop impact on fan power, bypass for economizer operation and MERV 13 filtration should be considered for the ventilation heat recovery system. Variable refrigerant flow system technology should be utilized in the HVAC design (GBI, 2015, p. 115). Energy efficient lighting fixtures, lamps, ballasts, motors and other equipment are preferred in the Green Globes NC (GBI, 2015, p. 117).

Renewable Energy
On-site renewable energy technology, such as wind, biomass, geothermal, photovoltaics, and solar, are encouraged to be used in the project (GBI, 2015, p. 118). On-site renewable energy feasibility studies are preferred, and the recommendations from feasibility studies should be implemented. Additionally, points can be awarded if off-site renewable energy, such as certified green power or renewable energy certificates (RECs) is used for at least 10% of the electrical consumption for a minimum of three years (GBI, 2015, p. 119).

Materials and Resources

Product Declaration
Green Globes NC suggests assessing building core and shell based on the materials used for the building. There are two typical paths described in Green Globes NC, one is the performance path, which uses LCA to assess the environmental impact of the core and shell; and the other is the prescriptive path, which identifies materials and products that have EPDs, third-party certifications, third-party LCA or third-party sustainable forestry certifications (GBI, 2015, p. 142). For the prescriptive path, at least 10% of materials and products need to be qualified for certification requirement as mentioned above to gain points. For interior fit-outs assessment, Green Globes NC also suggests two paths: one is the performance path based on LCA, and the other is the prescriptive path based on the EPDs and third-party certifications (GBI, 2015, p. 147).

Materials Reuse and Waste Management
Similar to LEED v4, Green Globes NC encourages the reuse of existing structures (GBI, 2015, p. 151). At least 10% reuse of facades, 10% reuse of current structures, or 10% reuse of non-structural elements or existing furnishings can contribute to awarding of points. More points can be awarded if a higher percentage reuse rate is achieved in each one of the categories mentioned above (GBI, 2015, p. 152).

As far as waste control, Green Globes NC awards points if more than 25% construction wastes are diverted. Reuse of existing on-site materials is also encouraged (GBI, 2015, p. 154). For operational waste, an operational flow for waste handling and storage is needed. Storage areas for recyclable waste should be set at both pick-up areas and points of service. In addition, operational flow for handling and storage facilities for composting is required (GBI, 2015, p. 155).

Green Globes NC suggests a preliminary Building Service Life Plan that includes the expected service life of the building (GBI, 2015, p. 156). In addition, a plan of replacement of structural systems, building envelope, and hardscape materials is suggested. During the service life, the mechanical, electrical, plumbing and energy generation systems need to be inspected for replacement (GBI, 2015, p. 157). Green Globes NC encourages the design of projects that specify the use of prefabricated, preassembled, and modular products and minimize the use of raw materials (GBI, 2015, p. 158). The design should use raw materials efficiently, when compared with typical construction practice, and examples of efficient use of raw materials should be given. The design should incorporate assemblies which perform multiple functions. The design should consider the future deconstruction, demounting, and disassembly (GBI, 2015, p. 160).

Building Envelope.
Green Globes NC has very specific requirement on design, field testing, and installation for building envelopes (GBI, 2015, p. 161). The roof membrane assemblies, flashing, metal sheet, cladding, and other materials for building envelopes should be installed according to manufacturer's instructions or recommendations, and the installation should be inspected by manufacturer technical personnel or a certified third-party inspector (GBI, 2015, pp. 162–176). A moisture management design on roof and wall openings should be established according to industry requirements, such as AAMA/WDMA/CSA 101/I.S.2/A440-8, or industry best practice (GBI, 2015, p. 171). The air barrier material and vapor retarders (if used) should be documented in the construction documents. The compliance of the continuous air barrier for the opaque building envelope should be tested by one of the following standards: ASTM E 2178-11, ASTM E 2357-11 and ASTM E 779-03 (ASTM International, 2010, ASTM International, 2011b, ASTM International, 2013; GBI, 2015, p. 177).

Living Building Challenge

Similar to LEED and Green Globes, the Living Building Challenge (LBC) is a certification program which initiates advanced measures to assess the sustainability of the built environment. However, certification as a Living Building is based on actual performance, after 1 full year of monitoring, before the certification can be achieved. LBC focuses on seven performance categories (petals): places, water, energy, health and happiness, materials, equity, and beauty. Each sub-category under the petals is imperative. A project can be certified in three paths: Living Building Certification, Petal Certification, and Zero Energy Building Certification (International Living Future Institute, 2015). Besides evaluating the sustainability of the building, LBC also focuses on the interaction between the human and built environment, as well as the social impacts of the building. However, due to the defined scope of this project, only the specifics in the energy and materials petals of LBC are discussed.

Net Positive Energy

In terms of energy the Living Building Challenge has the most stringent requirements. For a building to be certified as a Living Building 105% of project energy must be produced by renewable energy (no combustion-based) annually. To meet the requirement, the energy must be provided on-site, and on-site energy storage facilities must be used. It also requires the process of energy production in a safe and pollution-free manner. Net Positive Energy requires an energy storage facility in case of the need of emergency lighting for up to one week. All energy-consuming equipment and systems need to be included in the energy budget. Purchasing off-set REC is not an option for this challenge (International Living Future Institute, 2014a, p. 8). All major energy uses must be sub-metered. If the whole building system cannot be sub-metered, the HVAC system (heating, cooling, and fans) should be sub-metered for its energy. The building performance period is considered for a consecutive 12-month timeline after full occupancy. Requirements of the Net Positive Energy challenge must be met during the performance period (International Living Future Institute, 2014a, p. 9).

Materials

In the Materials petal, LBC encourages using materials that are non-toxic, ecologically regenerative, transparent, and socially equitable.

Red List

The LBC Materials Petal Handbook listed 22 harmful/toxic chemicals, which are categorized as red list materials (seen in Table 4). These chemicals are not allowed in the project, except for products that contain these chemicals naturally. The Chemical Abstract Service (CAS) number is required for every known chemical. All wet-applied products must meet the requirements of volatile organic compounds (VOCs) emissions standards. The VOC level must be below the South Coast Air Quality Management District (SCAQMD) Rule 1168 for Adhesive and Sealants or the California Air Resources Board (CARB) 2007 for Architecture Coatings. Declaration is required for building materials. Information from the Cradle-to-Cradle Certified Product Standard (C2C), Health Product Declaration (HPD), and Pharos database can be used (International Living Future Institute, 2014b, p. 8)

Table 4. Red List Items - Living Building Challenge

Alkylphenols	Halogenated Flame Retardants (HFRs)
Asbestos	Lead (added)
Bisphenol A (BPA)	Mercury
Cadmium	Perfluorinated Compounds (PFCs)
Chlorinated Polyethylene and Chlorosulfonated Polyethylene	Polychlorinated Biphenyls (PCBs)
Chlorobenzenes	Phthalates
Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs)	Polyvinyl Chloride (PVC)
Chloroprene (Neoprene)	Polyvinylidene Chloride (PVDC)
Chromium VI	Short Chain Chlorinated Paraffins
Chlorinated Polyvinyl Chloride (CPVC)	Wood treatments containing Creosote, Arsenic or Pentachlorophenol
Formaldehyde (added)	Volatile Organic Compounds (VOCs) in wet applied products

Embodied Carbon Footprint

In LBC 3.0, embodied carbon needs to be reduced by using different strategies. Total embodied carbon (tCO2e) must include the carbon generated from construction materials and processes (International Living Future Institute, 2014b, p. 23). One of the commonly used strategies is purchasing Certified Emission Reductions (CERs) or Verified Emission Reductions (VERs) through an approved program to offset the total construction-based carbon contribution (International Living Future Institute, 2014b, p. 23).

Responsible Industry

The focus of this imperative is on limiting environmental and social impacts caused by natural resource extraction and plant cultivation. All materials used must be certified by third-party certified standards and fair labor practices. In addition, one Declare product is required for every 500 square meters of gross building area. Declare is an online building materials database, which discloses the ingredients of materials (International Living Future Institute, 2014b, p. 26).

Living Economy Sourcing

To support the local economy, LBC encourages the use of locally manufactured materials. The restrictions applied are shown in Table X.

Table 5: Restriction in the Living Building Source Imperative (International Living Future Institute, 2014b, p. 34)

Materials construction budget	Distance from construction site
20% or more	Within 310 miles (500 km)
Additional 30% or more	Within 620 miles (1000 km)
Additional 25% or more	Within 3,100 miles (5,000 km)
Additional 20%	No restriction

In addition, consultants hired for the project must come from within 1,550 miles from the construction site.

Net Positive Waste

A Waste Conservation Management Plan must be incorporated from the design phase to the construction phase, and then from the operation phase until the end of life phase. Construction teams are encouraged to develop innovative approaches to reduce the amount of waste produced. For every 5380 $ft.^2$ (500 m^2), at least one salvaged materials must be used. More than 90% of materials must be diverted from landfills; detailed requirements can be found in the Materials Petal Handbook (International Living Future Institute, 2014b, p. 40). Hazardous materials are not included in this requirement. All hazardous materials need to be documented and dealt with properly (International Living Future Institute, 2014b, p. 40).

Comparison of LEED, Living Building Challenge and Green Globes

In Green Globes NC and LEED v4, projects are certified by accumulating points in each of several categories, which vary between the standards. Certification is awarded based on the total points earned by the project. Each category is broken down into different sub-categories.

Therefore, these rating systems are easy to follow, and project teams can take advantage of this to optimize the funding and resources to maximize the total points. In these two rating systems, the categorization methods and focuses of interest are different. Green Globes NC provides more details and specifics than LEED v4. However, LEED v4 is more recognized both nationwide and worldwide. On the other hand, under LBC 3.0 certification is not awarded through accumulation of points, but rather based on if the project accomplishes the required challenge. In most cases, it is not specified how the project team should achieve the requirement. Compared to the other rating systems, LBC leaves project teams more flexibility in achieving sustainable construction. Based on the reviews of the three rating systems, similarities and differences are shown in Table 6 and Table 7.

In summary, these three rating systems have different focuses. However, it is clear that all three rating systems have an agreement on using renewable energy and products with LCA certification or EPD certification. A best practice guide on a sustainable maintenance facility should be provided with a combination of the recommendations from these three systems. Therefore, a single rating system should not be strictly adhered to, since each of them has its benefits and limitations. In this way, the best practice guide can provide flexibility for ODOT on the design and building of sustainable maintenance facilities.

Oregon DOT Policies

In Oregon, concept of sustainability is defined in Oregon Revised Statues (ORS) 184.421 (ORS, 2013a). The goals regarding sustainability was described in ORS 184.423 (ORS, 2013b). One of these goals is to improve the efficiency of the use of energy, water and resources; another is to invest in facilities, equipment and goods with highest feasible efficacy and lowest life-cycle cost (ORS, 2013b). To pursue these goals, different codes, standards and policies were developed. Building Code Division has implemented policies, standards, and regulations on energy efficiency, use of renewable energy, and water conservation (Oregon Building Codes Division, 2008).

Table 6: Comparison of LEED v4 BD+C, Green Globes NC, and Living Challenge 3.0 (Energy)

		LEED V4 BD+C	Green Globes NC	Living Challenge 3.0
Prerequisites		Yes	No	No
Commissioning		Yes. Enhanced system commissioning, enhanced monitoring-based commissioning and envelope commissioning are required.	Yes, but the points are counted in Project Management instead of Energy category.	Not specifically mentioned. No specific document required.
Building Energy Performance		1. Building energy simulation is used to calculate improvement of energy performance; 2. ASHRAE Design Guide.	1. Energy Star Target Finder; 2. ASHRAE 90.1-2010 Appendix G; 3. ANSI/GBA 01-2010; 4. ASHRAE bEQ.	No specific requirement on energy performance.
Metering	Whole building metering	Yes.	Yes.	Yes.
	Sub-metering	For individual energy end uses that represent 10% or more of the total annual consumption of the building.	Lighting, plug loads, major HVAC equipment, chilled water generation, on-site renewable energy generation, heating water and steam generation, specialty or process electrical equipment.	HVAC system needs to be metered if the whole unit cannot be metered.
Demand Response		Yes. Participation in demand response program is specified.	Not specified. The requirements of passive demand reduction and power demand reduction are specified.	Not specified.
Renewable Sources of Energy	Renewable energy	Yes. Also have requirement on production.	Yes.	Yes. However, no combustion is allowed. Net positive energy is required.
	RECs or carbon offsets	At least 50%.	Yes.	In Materials petal, embodied carbon needs to be offset.
Building Envelope	Opaque envelope	Included in enhanced commissioning and energy performance simulation.	R-values, U-, C-, F- factors.	Not specifically mentioned.

	Orientation	Mostly included in Integrative Process.	Yes. Orientation factor.	No requirement.
Lighting	Lighting power density	Included in Indoor Environmental Quality.	Included for points award.	No requirement.
	Auto shutoff controls	Included in Indoor Environmental Quality.	Included for points award.	No requirement.
HVAC Systems	Building automation system	Not specified for points award.	Included for points award.	Not specifically mentioned.
	Other HVAC systems and control	Included in whole building simulation.	Detailed specifications for major HVAC equipment.	No specific requirement.
Refrigerant Management		No refrigerants or low-impact refrigerants.	Included in Emission and Other Impacts.	Yes. Specified in Red List.
Energy Efficient Transportation		Included in Sustainable Site.	Yes. Specifications on location selection.	Yes. Specified in Human Power Living.

Table 7: Comparison of LEED v4 BD+C, Green Globes NC, and Living Challenge 3.0 (Materials)

		LEED V4 BD+C	Green Globes NC	Living Challenge 3.0
Prerequisites		Yes.	No.	No.
Life-cycle impact	Historic building reuse	Yes.	Yes. Structural element.	Strongly encouraged.
	Renovation of abandoned or blighted building	Yes.	Not specifically mentioned.	Strongly encouraged.
	Building material reuse	Yes.	Yes. Non-structural element. Also in waste management plan.	At least one salvaged material must be used for every 5380 ft.2 gross area.
	Whole building life - cycle impact	Yes. But only a small portion.	Yes. Performance path for building core and shell & interior outfits. Relatively important.	C2C product standard can be used for materials certification.
Building Product Disclosure and Optimization	EPD	At least 20 different permanently installed products from five different manufacturers.	Yes. Prescriptive path for building core and shell, and interior outfits.	EPD is not specifically mentioned.
	HPD	Not specifically mentioned.	Not specifically mentioned.	Yes. HPD can be used to exclude materials that contain chemicals in red list.
	Declare product	Not required.	Not required.	Required in Responsible Industry. At least one Declare product must be used for every 5380 ft.2 of gross project area.
	Multi-attribute optimization	Third-party certified products showed reduction in multiple environmental impacts or USGBC approved program.	Yes. Prescriptive path for building core and shell and interior outfits.	At least one salvaged material must be used for every 5380 ft.2square meters gross area.
	Report source of the materials	Yes. Extraction report or leadership extraction practices.	Yes. Resource conservation. Specify the source of raw materials.	Yes. Specified in Responsible Industry.

	Materials ingredients	Ingredients reporting or ingredient optimization or supply chain optimization.	Not specifically mentioned.	Yes. Mostly used to exclude materials containing chemicals in Red List.
Waste Management		Diversion or reduction of total waste material.	At least 25% diversion.	Yes. A Material Conservation Management Plan should be developed to minimize the waste. Over 90% construction waste should be diverted
Building Service Life	Building service life plan	Mentioned in whole-building life-cycle assessment.	Yes. Detailed plan on service life, maintenance and repair is needed.	Not specifically mentioned.
Resource Conservation	Multi-functional assemblies	Not mentioned in LEED.	Yes.	Not mentioned in LBC.
Building envelope		Mostly included in Indoor Environmental Quality.	Yes. Specifics on roofing, flashings, cladding, wall openings, barriers and foundation.	No specific requirement.

SEED Rules

ODOT agencies are required to adhere to ORS 276.900-915. ORS 276.900-915 established the State Energy Efficient Design program, which requires energy use in newly constructed or significantly remodeled state agency buildings to be minimized through the incorporation of the Optimum Energy Conservation Measures, and that buildings be designed to use 20% less energy than an equivalent code level building. In SEED rules (OAR 330-130), there are two building classes: Class 1 buildings and Class 2 buildings. Class 1 buildings are new buildings, additions, or renovations of 10,000 $ft.^2$ or more of heated or cooled floor area or building additions that increase the existing building to 10,000 $ft.^2$ or more. Class 2 buildings are new buildings or renovations that occupy less than 10,000 $ft.^2$ (Oregon Department of Energy, 2004).

The SEED program has specific requirements at each phase, from the initial project meeting to the occupancy phase. The procedures for Class 1 and Class 2 buildings are different. Class 1 projects require that the agency work with an energy analyst to select energy conservation measures and document through a building simulation model that the proposed building will perform 20% better than an equivalent code level building. The goal of "20% better than the state energy code" should be included in the contract and discussed in initial meetings (Oregon Department of Energy, 2004). ODOT must coordinate an Initial meeting with ODOE early in the programming phase of the project. During this Initial Meeting, the scope of the project will be discussed and preliminary discussions regarding the project design, integrated energy design approach, the modeling approach, and the systems performance verification plan will take place. At the Scoping Meeting, the energy conservation measures (ECMs) are selected for baseline incorporation or analysis. During the design development phase of the project, modeling of the ECMs takes place to determine energy savings of the selected measures, measure cost estimates are obtained and cost-effectiveness of individual ECMs are determined. With this information, an ECM package is selected that ensures that the proposed design will perform at least 20% better than a code equivalent building. The Preliminary SEED Energy Analysis report is then sent to ODOE for review. After review of the report, an ECM review meeting is held to discuss selected ECMs, the performance verification plan and the metering plan. During the construction documents phase, it is incumbent on ODOT to verify that the selected ECMs are included in the drawings and specifications. The Energy Systems Verification Plan is developed, along with the Metering plan. Construction documents must be submitted to the Oregon Department of Energy, no later than at 90% design completion to allow for ODOE review and feedback before the project is bid. The energy systems performance verification plan, metering plan and final SEED energy analysis report need to be submitted in this phase. In the construction phase, the commissioning agent needs to verify that all ECMs are installed properly and operating efficiently. Upon occupancy of the building, the energy use needs to be monitored for at least 18 months and reported to ODOE. If significant differences between the actual energy use and the model predictions result, the agency must investigate to find the cause, so that an adjustment can be made to the operation of the building; or an explanation for the difference can be found that is acceptable to the agency and the department. (Oregon Department of Energy, 2017). The building will be given the SEED Award if it complies with the SEED rules and meets the standard of a "highly energy efficient building."