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Standard Guide for Design of Sustainable, Low-Slope Roofing Systems[1]

1. Scope

1.1 This guide provides guidance and considerations related to designing sustainable low-sloped roofing systems, including exposed membrane roofs, membranes covered with vegetative (green) overburden systems, ballasted roofs, and protected membrane roofing assemblies. A sustainable roofing system minimizes environmental impact, conserves energy, and has maximized service life.

1.2 The primary purpose of a roofing system is to weatherproof the building's top surface. Implementing a sustainable roofing system is the intent of this guide.

1.3 This guide acknowledges that many factors outside the designer's control affect the longevity of a roofing system. The designer may rely on industry literature (X1.1) and personal experience with roofing systems to estimate the design life.

1.4 The premise of this guide is to focus attention on environmental and other factors that may affect the roofing system over its service life. By considering these factors and incorporating into the roofing system design certain features that mitigate these factors and their potential adverse effects on the roofing system, the roofing system would be expected to have a longer service life.

1.5 This guide includes materials used in roofing systems under jurisdiction of ASTM Committee D08 on Roofing and Waterproofing. The applicability of this guide to other systems and materials has not been determined.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1079 Terminology Relating to Roofing and Waterproofing

3. Terminology

3.1 *General*—Terms used in this guide are defined in Terminology D1079, except as defined below.

3.2 *Definitions:*

3.2.1 *design life*—the planned period of time during which the roofing system is expected by its designer to reliably perform its required functions, with minimal unplanned intervention.

3.2.2 *durability*—the ability of the roofing system to perform its required functions over a period of time within the environment for which it is designed and exposed.

3.2.3 *service life*—the period of time after installation during which a roofing system performs its required function(s) with minimal unplanned intervention.

4. Summary of Guide

NOTE 1—The sustainable roofing system design process consists of the following, sequential steps:

4.1 *Identification of Roofing System Demands, Functional Expectations, and Site Constraints*—The designer should determine factors, loads, and stresses that the roofing system must withstand as well as the impacts the roofing system may have on the environment the building interacts with. These factors apply limiting constraints for system and material selection and the associated installation process. There are also options for sustainable strategies and site and use constraints that will define the feasibility of sustainable strategies (for example, availability of sunlight for photovoltaic arrays).

4.2 *Determination of In-Service Performance Criteria and Functional Expectations*—The designer determines performance criteria and functional expectations of the roofing

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

system in response to the in-service roofing system demands, functional options, and site constraints. Performance criteria include wind-uplift resistance and fire resistance.

4.3 *Identification of Candidate Systems*—With the criteria for in-service performance and functional expectations established, the designer can compile a list of candidate systems that are capable of meeting the roof design requirements, and are compatible with desired sustainable features and functional expectations.

4.4 *Evaluation of Candidate Systems*—Candidate systems are analyzed with respect to each other and with respect to cradle-to-grave (life-cycle) environmental impacts through an environmental life cycle assessment, component recyclability, minimization of waste, durability, and anticipated lifespan.

4.5 *Design of Optimal Best-Fit Candidate*—The best-fit candidate system is selected for final design.

5. Significance and Use

5.1 This guide is intended to help the user identify and define demands made upon the roofing system by factors such as weather, climate, and building use, in light of the fact that many roofs are specified with secondary features that have quantifiable or non-quantifiable environmental or humanitarian benefit such as alternative energy generation, vegetation, or use as open space. Awareness of the roof's use as a platform for these secondary functions, as well as the additional demands they make upon the roof, is needed to specify a durable and sustainable roof.

5.2 It is the responsibility of the user of this guide to determine the appropriate prescriptive requirements for implementation of the sustainable roofing system based on considerations listed herein.

5.3 Codes and local ordinances set minimum requirements for roofing systems. Nothing in this guide should be construed to abridge or lessen requirements of codes and local ordinances. Other entities, such as building insurers and system manufacturers, may have requirements for the roofing system.

5.4 Sustainability of a roofing system is site and use specific. A roofing system considered sustainable for a certain site or application may not be sustainable in a different application. There may also be more than one roofing system that achieves an optimal level of sustainability for a given site and application.

5.5 Above-roof vegetative (green) systems and rooftop energy generation systems are discussed herein because they are frequently placed on roofs to reduce the building's overall environmental impact. These features do not generally contribute to the durability or longevity of the roof. These features may be detrimental to roof system performance and impair the roof's ability to perform its primary function of protecting the building if their impact is not accounted for in the roof design.

5.6 Design of above-roof systems is beyond the scope of this guide; however, consideration of their potential impacts is outlined herein.

6. Procedure

NOTE 2—The design process includes the following tasks, shared with prudent design of any roofing system but are included for completeness. An illustrative flow chart is provided in Appendix X2.

6.1 *Define Roofing System Demands, Functional Expectations, End User Requirements, and Site Constraints*—The sustainable roofing design process begins by determining and analyzing factors including, but not limited to: environmental and mechanical stresses that the roofing system will be subjected to, required functions and the uses of the roof, sensitivity of local environment to the effects of the roofing system, interaction of the roof with the indoor building environment, building use and design life, and site factors that may affect selection of various sustainable roofing strategies. Some of these factors may be specified by local building codes and ordinances but others will require determination on the part of the building and roofing system designers. To some degree the various constraints, demands, and expectations may overlap or may fall into more than one category. A partial list of such considerations includes the following:

6.1.1 *Roofing System Demands-Code Driven:*
6.1.1.1 Wind Velocity and Exposure,
6.1.1.2 Fire Risk,
6.1.1.3 Snow Loads,
6.1.1.4 Live Loads,
6.1.1.5 Roof Solar Reflectance and Thermal Emittance,
6.1.1.6 Hail Exposure,
6.1.1.7 Rainfall Rate, and
6.1.1.8 Thermal Loads/Stress.
6.1.2 *Serviceability Considerations:*
6.1.2.1 Long-Term Weather Resistance,
6.1.2.2 Foot Traffic/In-Service Abuse Level,
6.1.2.3 Chemical Exposure,
6.1.2.4 Building Design Life, and
6.1.2.5 Indoor Humidification/Building Pressurization.
6.1.3 *End User Requirements:*
6.1.3.1 Platform for Energy Generation System,
6.1.3.2 Platform for Vegetation,
6.1.3.3 Use by People/Planned Habitat for Wildlife, and
6.1.3.4 Enhanced Thermal Efficiency.
6.1.4 *Site Considerations:*
6.1.4.1 Building Use,
6.1.4.2 Surface Water Runoff Restrictions, and
6.1.4.3 Building Orientation/Latitude/Availability of Sunlight.

6.2 *Determine Required Physical Properties and Performance Criteria*—A sustainable roofing system satisfies the minimum design requirements defined by codes and ordinances, as well as the functional expectations and accommodate site constraints developed in 6.1. Functional expectations may not be dictated by applicable codes. Some functions are demanded by the end user. Some are determined by the roofing system designer. Some functional expectations, such as the roof's resistance to rooftop traffic, pollutants, and chemical attack, affect durability and serviceability of the roof. Another set of criteria limits the roof's interaction with the local environment and establishes feasibility of various sustainable roofing options. Some of these criteria, such as surface reflectance, may be prescribed by local ordinance. Other criteria are not required to meet minimum requirements and are difficult to quantify. Establishing these criteria or features should be based on a reasonable or qualitative determination of benefit in mitigating the overall impact of the building and its occupants on the environment. These criteria can include restoring vegetation displaced by the building footprint through use of rooftop plantings, runoff retention, or making available roofing space for alternative energy generation. Examples of performance criteria and functional concepts that address system demands, functional expectations, and site constraints include the following:

6.2.1 *Physical Properties and Performance Criteria to be Determined:*

6.2.1.1 Wind Uplift Resistance,

6.2.1.2 Fire Resistance,

6.2.1.3 Deck Structural Capacity,

6.2.1.4 Resistance to Heat and UV Exposure,

6.2.1.5 High Indoor Humidity/Building Pressurization,

6.2.1.6 Hail Resistance Rating,

6.2.1.7 Drainage and Slope Requirements,

6.2.1.8 Foot Traffic Resistance,

6.2.1.9 Chemical Resistance,

6.2.1.10 Required Roof Service Life (should be greater than design life of above-roof components),

6.2.1.11 Resistance to Potential Rooftop Uses, Vegetation, and Landscaping Activities (if applicable), and

6.2.1.12 Potential for Moisture Accumulation Within the Roofing Assembly (considering wintertime membrane temperature based climate, roofing emissivity and reflectance, indoor environment, and presence of vapor and air barriers).

6.2.2 *Additional Considerations for Durability and Maintainability*—Given all other considerations of the life cycle analysis and in-service performance being equal, a durable roofing system, one with greater longevity or extendable service life through minor (that is, low environmental impact) maintenance will use fewer resources, have lower environmental impact and will therefore be more sustainable than a roofing system that requires more-frequent replacement. The roofing system should incorporate features recognized as improving the system durability by addressing local environmental stresses and building function as described above. The design should use materials and incorporate features that have been proven over time to provide durable performance and reduce the quantity of components that require maintenance in favor of low-maintenance or maintenance-free components. For many roof conditions, there exist detailing options with differing degrees of required maintenance and reliability.

6.2.2.1 *Roofing Terminations*—The design should minimize reliance on sealant at roofing membrane terminations at walls and parapets. Roofing terminations immediately below cavity walls or drainage type walls, including but not limited to portland cement plaster (stucco), brick masonry veneer or panelized rainscreen-type wall systems should be protected from water entry behind the roofing termination with a sloped, watertight flashing at the base of the wall. Similarly, roofing terminations below fenestration sills and door thresholds should be protected with a positively sloped, watertight sill flashing extending beneath the fenestration or door threshold. Edge securement should be specified and detailed to resist design wind loads.

6.2.2.2 *Drainage*—Positive slope to the primary drains, scuppers, or gutters should be provided for all roofing systems so that standing water does not remain on the roofing membrane 48 hours after rainfall, when the roof is subjected to ambient drying conditions.

6.2.2.3 Penetrations are unavoidable but should be minimized. Penetration pockets should be minimized because they typically require more maintenance and pose a higher risk of leakage than durable flashings. In the case of multiple small-diameter penetrating members, such as electrical conduit or refrigerant lines, it is often preferable to house them in a flashed enclosure that extends above the roof surface, where the penetrating elements can exit through protected openings in the side of the enclosure.

6.2.2.4 *Air Barrier System*—Substantial energy loss, condensation, and resulting damage to roofing components can be caused by infiltration or exfiltration of air through the roofing assembly or roof perimeter conditions. An independent air barrier system to prevent movement of extraneous air and moisture into the roofing system should be considered for buildings with high potential or design humidity and where pressure differentials that may drive indoor air into the roofing system may exist.

6.2.2.5 *Leak Detection*—Water leakage through roofing membranes causes premature deterioration. Early detection of leakage can prolong the service life of the roofing system. Leakage into roofing systems is often difficult to identify due to water absorption by the insulation, water collection on deck surfaces or vapor retarders, or water directed into concealed spaces. Timely identification of leakage provides an opportunity for repair before chronic leakage causes systemic damage to the roofing system. Leakage locations or minor defects, or both, that could become leaks are likely to be discovered during regularly scheduled maintenance programs.

6.2.2.6 *Maintenance Requirements and Plan*—The design should include instructions for planned future maintenance and covering replacement in a separate file to remain on site. This document should provide information specific to the roofing system, including the following: roofing system details and specifications, installation date, installer, manufacturer and materials, a schedule of planned maintenance covering the design life of the roofing system, identification of components requiring maintenance, inspection procedures and intervals and procedures for patching and local repair of damage, and specifying appropriate patching materials and method.

6.2.2.7 *Reflectance*—Dirt accumulation and organic growth on light-colored roofing membranes can lower the membrane's solar reflectance. Dirt collection is exacerbated by poor slope and depressions in the roof, which tend to collect dirt. Provision of a water source on the roof to facilitate cleaning of the membrane, as well as inclusion of washing requirements in the roofing system maintenance requirements, should be considered. Washing procedures must follow the roofing membrane manufacturer's recommended procedures. If reflectance is to be achieved by application of a coating, the potential environmental impact of repeated coating applications required for surface renewal should be considered.

6.2.2.8 *Vegetative Roofing Systems*—Vegetative roofing systems differ from traditional roofing systems in that the membrane system and flashings may not be easily maintained. Therefore, a highly durable membrane capable of functioning in a wet environment should be provided. These roofs should avoid sealant-based terminations and nonflashed penetrations for waterproofing where they cannot be accessed for maintenance.

6.2.2.9 *Consideration for Roof-Mounted Energy-Generating System Components*—Roofs may provide large areas of otherwise unused space, suitable for placement of roof-mounted energy-generating systems such as photovoltaic panel arrays or solar water heating systems. The design process should study the feasibility of such systems and their potential adverse effects on the roofing system. These may include added maintenance traffic, added structural loads, and penetrations through the roofing system. The design life of the roofing system should be equal to or greater than the expected service life of any rooftop energy generation system. If evaluating an existing roof for rooftop energy generation, the anticipated remaining service life of the roof should be greater than the design life of the roof-mounted energy generation system components, with the consideration that added maintenance and installation may damage the roof or reduce the roof's remaining service life.

6.2.2.10 *Thermal Efficiency*—Improving the thermal efficiency of the roofing system generally reduces building energy consumption. The roof surface properties such as reflectance and thermal emissivity can also affect thermal impact on the surrounding environment by minimizing heat island effects, but can result in colder wintertime membrane temperatures. The roofing system design should consider thermal performance of the building envelope. The roof insulation thickness should be optimized together with the overall thermal efficiency of the building envelope. Energy modeling should be performed to determine the optimal insulation thickness and solar reflectance based on the thermal conductance (U-factor), thermal mass, and solar reflectance of the roof as well as the energy performance of the whole building. Improving overall thermal performance of the building envelope by adding insulation to the roof may be more technically feasible than adding insulation to walls when the ratio of roof-to-wall areas is relatively high. However, if walls are thermally inefficient and have a high area relative to the roof area, increasing roof insulation thickness provides less benefit.

6.2.2.11 *Insulation Placement*—Insulation should include a minimum two layers of roughly equal thickness, not including cover board, with joints staggered a minimum of 6 in. to minimize thermal bridging and heat loss due to gaps in boards.

6.2.2.12 *Insulation Considerations for Reroofing*—When reroofing, addition of insulation to uninsulated or poorly insulated roofs may increase snow load on the roof and supporting structure due to lower melting rates. In these circumstances an analysis of the roof structure to determine structural capacity and whether structural upgrades should be performed. Addition of insulation may also change the hygrothermal performance of the roofing and increase the possibility of condensation depending upon building use, indoor ambient conditions and climate. An analysis as discussed in 6.2.2.10 should be performed. Insulation should be attached to resist current wind uplift loads.

6.2.2.13 *Thermal Bridges*—Roofing appurtenance such as curbs, equipment frames, drains, parapets, and related structural supports can create thermal bridges that reduce the overall thermal performance of the roofing insulation. These details should be insulated or thermally broken based on an analysis of the overall impact on thermal performance and condensation potential. Computer-thermal modeling of details may be performed to determine the most-efficient detail geometry to limit the thermal influence of adjacent conditions, to maximize insulation benefit, to reduce condensation potential, and to determine optimal locations of thermal breaks and to reduce energy loss and condensation risk.

6.2.2.14 *Moisture Control*—The designer should assess need for vapor retarder to protect the roofing system from latent moisture in concrete decks and from the building interior. An example of such analysis is a transient, one-dimensional computer-based analysis of the heat and moisture flow through the roofing assembly that can be performed on the roofing system to predict the likelihood of condensation within the roofing system under seasonal climatic (including outdoor ambient and expected roofing membrane temperatures) and indoor ambient humidity conditions. The designer should consider that increased insulation thickness (as discussed above) and use of reflective membrane may result in colder membrane temperatures in winter. If analysis shows risk of condensation within the roofing assembly under these conditions, then a roof deck vapor retarder on the winter-warm side of the insulation should be used.

6.2.3 *End of Roof System Service Life*—Low-slope roof system components have finite service lives. Service lives of some roof system components and accessories may be shorter than others, for example a roof membrane's service life may be shorter than service lives of the metal flashings and counterflashings, skylights, and vapor retarders. Where a roof system component near the end of its service life cannot be replaced as part of planned maintenance, it is a service life-limiting component of the system. Also, a low-slope roof system's service life may be shorter than the service lives of components interfacing with or installed above the roof system such as air barriers, elevated walkways and rooftop mechanical equipment. Designers should include consideration of the following items when making plans for managing a low-slope roof system's end of service life. A file remaining on site should provide the end-of-life design specifications.

6.2.3.1 *Reuse and Recycling Plan for Roofing System Components*—The designer should specify a protocol identifying end-of-life expectations for reuse or recycling of roof system components.

6.2.3.2 *Rehabilitation of the Roofing System*—In roof system replacement scenarios, it is common industry practice to remove all existing roof system components, including materials that may be serviceable, to the structural deck or substrate. This practice produces waste. Alterations of above roof deck construction such as recovering or removal and replacement of roof covering material and roof system components at the end of their service lives while leaving in place serviceable roof insulation, metal flashings, and vapor retarder reduce the user of resources to reconstruct and dispose of substantial quantities of construction components. The designer should categorize roof system components as wearable parts subject to replacement or durable or protected parts and specify a protocol for roof system rehabilitation. Roof-mounted mechanical or energy-generating components should be designed and installed to provide sufficient clearance for roof system inspections, maintenance, and recover or replacement installation. Alternatively, these roof-mounted components may be housed in purpose-built enclosures or mechanical wells.

6.2.3.3 *Recyclability*—The roofing system design should include an analysis of materials that are likely to end up as waste or in landfills and of components that currently are or are likely to be recyclable. The energy and environmental impact of recycling these materials into a reusable or reinstallable condition should be considered along with the environmental impact of their manufacture and installation; however, the assessment of sustainability of nonroofing end-use products is outside the scope of this guide.

6.3 *Identification of Candidate Systems*—With the criteria for in-service performance and building operation established the designer can begin to compile a list of candidate systems that are capable of meeting the criteria established above and are compatible with desired sustainable features. There may be a multitude of systems that fulfill the desired set of criteria and evaluating all possible systems and permutations that may satisfy them is beyond the limits of practicality. Therefore, the designer should exercise judgment and experience to identify the possible system candidates and narrow down the set of possible candidates into a set of several systems that may best fulfill the required roles. These systems will be subject to further analysis, including Environmental Life Cycle Assessment, to identify system(s) that can be optimized to provide minimized environmental impact, maximized longevity, and greatest compatibility with planned roof functions.

6.4 *Life Cycle Assessment*—Roofing system selection should attempt to minimize overall environmental impact and maximize roofing system service life. The design should recognize the finite service life of the roofing system and should facilitate rehabilitation, repair, reuse, and recycling of materials.

7. Keywords

7.1 environmental impact; roofing insulation; roofing system maintenance; roofing system recovering; sustainability; sustainable roofing

APPENDIXES

(Nonmandatory Information)

X1. SUPPLEMENTAL INFORMATION

X1.1 The following publications provide additional discussion related to design of and considerations for sustainable low-slope roofing systems:

X1.1.1 Center for Environmental Innovation in Roofing: *RoofPoint, Guideline for Environmentally Innovative Nonresidential Roofing*, Washington, DC, 2012.

X1.1.2 Cash, Carl G., "The Relative Durability of Low Slope Roofing," Proceedings of the Fourth International Symposium of Roofing Technology, Gaithersburg, MD, 1997.

X1.1.3 CIB W083 / RILEM 166-MRS Joint Committee on Roofing Materials and Systems (2001). *CIB Publication 271 – Towards Sustainable Roofing*. Rotterdam, The Netherlands: International Council for Research and Innovation in Building and Construction (CIB).

X1.1.4 FM Global Property Loss Data Prevention Sheet FM 1-35, "Green Roof Systems," January 2007.

X1.1.5 Proceedings of the Sustainable Low-Slope Roofing Workshop, CONF-9610200, Oak Ridge National Laboratory, Oak Ridge, TN, 1997.

X2. ILLUSTRATIVE FLOW CHART

X2.1 See Fig. X2.1.

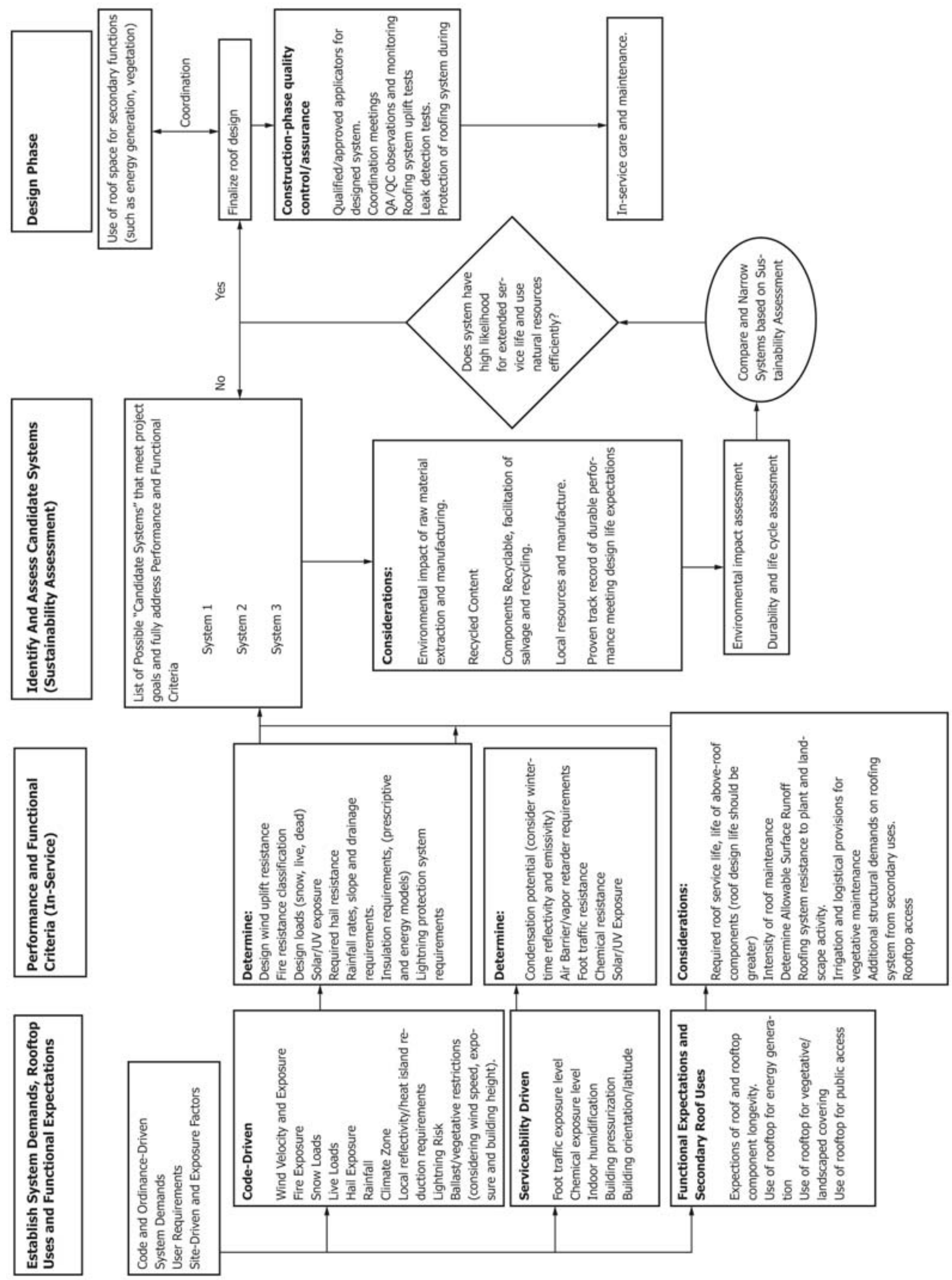

FIG. X2.1 Guide for Design and Considerations Related to Sustainable, Low Slope Roofing Systems