DESIGN OF INTEGRATED ROOFING SYSTEMS

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Integrate: "To form into a whole; to unite, join or become united so as to form a complete or perfect whole; to unify."

Scientific: "The systematic application of knowledge and technical skills."

The task of the designer of roofing systems is to consider the effects of environmental design factors on his system; to determine the functional design conditions; to select system components that will withstand these factors and meet the conditions; and to integrate these components into a complete system—the perfect whole. The task is complicated by the complexities and inter-relationships of the design factors and conditions; the requirement of compatibility between the components; and availability of component product criteria, or standards. We often fail at the task. The primary factor is our failure to properly consider the design factors in relation to the components. We select components unsuitable for the task, or we combine components that are incompatible. Roof failures, due to design, can be attributed to simple causes. We use the wrong products in the wrong place at the wrong time.

These simple causal factors result because we are creatures of habit who create "comfort zones" that we do not wish to change. An architect may specify a system because it sufficed on a previous building; he does not consider that the requirements are different. A contractor avoids the use of new products and stays with the "old reliable", which may not be reliable in that instance. The consultant who selects systems by warranty to avoid risk, creating risk because warranties do not make systems perform. The manufacturer who allows untested products to be used in unsuitable circumstances. We all contribute to our failures by our reluctance to change, yet the drastic changes that are occurring in our industry require us to make dramatic changes in our selection process.

These changes require us to accept the role of a designer; to use the thought processes in applying reason, judgment and compromise in comprehending the design factors;to select components to meet these factors; and to integrate our roofing system in combinations of these components.

The process can be simplified if we become more systematic and approach the problem correctly. We often select the membrane component first, and then attempt to adjust all the other components to that membrane. While the membrane is primary in performing the function of providing shelter from the external environment, we must also be aware that we are creating another environment within the building that affects the system. We must be aware of these two environments in the design process and consequently, we must shift back and forth as we consider each aspect of the components and their relationship to the whole system—the perfect whole. Our starting point should be based on the critical design factors.

NEW CONSTRUCTION/REROOFING

There is basically no difference in the design process of new or existing roof systems. In new construction, the environmental design factors must be surmised. In reroofing, we can often ascertain the effects of these factors in the examination of the existing system. Reroofing requires more flexibility, ingenuity and compromise in the selection process, as the budget may control the correction of original design defects. New construction design should always consider the requirement for future reroofing.

ENVIRONMENTAL DESIGN FACTORS

Environmental design factors are those degenerative forces exerted on the roofing system by its exterior and interior surroundings. These forces constitute degradation factors that may work alone or in concert, which may destroy the system, often by attacking a single component. They are primary to design and must be identified and quantified by their severity.

1. Exterior/Interior Operating Temperatures
   a. Component operating temperatures
   b. Component humidity conditions
   c. Component interactions
2. Sunlight Exposure
   a. Ultraviolet
   b. Infrared
3. Maximum Rainfall
   a. Drainage capacity
4. Ice/Snow
   a. Loading
   b. Drainage
   c. Surface durability
5. Normal Wind
   a. Uplift
   b. Projectile potential
   c. Flexural forces
6. Storm Phenomena
   a. Catastrophic wind types
   b. Hail
7. Chemical Environment
   a. Atmospheric pollutants
   b. Generated by building function
8. Installation Environment
   a. Cold
   b. Heat
   c. Wind
   d. Precipitation

FUNCTIONAL DESIGN FACTORS

Functional design factors are those conditions affecting roof design that must be considered for proper function of the building for its intended use. These factors are interrelated to environmental factors and the two must be considered together.

1. Occupancy and Usage
   a. Health and safety
   b. Risk
2. Environmental Systems
   a. Temperature control
   b. Relative humidity
   c. Operating costs
3. Location of Mechanical Equipment
   a. Maintenance
   b. Roof system damage
   c. Ducted or plenum airspace
4. Building Codes
   a. Health and safety
5. Insurance Requirements
   a. Loss exposure
   b. Life-cycle costs
6. Roof Size
   a. Budget
   b. Construction schedule
7. Roof Height
   a. Wind design
   b. Installation
   c. Budget
8. Roof Accessibility
   a. Installation
   b. Damage/vandalism
   c. Budget
9. Site Location and Terrain
   a. Wind design
   b. Installation
   c. Material storage
10. Aesthetics
    a. Roof slope
    b. Surfacing
    c. Details
11. Budget
12. Risk

PRELIMINARY DESIGN PARAMETERS

Design parameters represent a merging of the environmental and functional factors with identification of minimal design requirements. At this step, they are preliminary, in that compromise may be required further along in the selection process.

1. Identification of Component Degenerative Factors
2. Listing of Design Functional Factors
3. Prioritized Listing of Component Design Criteria

ROOF ASSEMBLY CATEGORIES

Roof assemblies are categorized as to location of insulation (if any) to the roof deck. The deck may be "warm" (insulated and thermally stable) or "cold", according to the configuration. This distinction has been overlooked in the United States, where all systems are supposedly equal in performance. European design rightfully bases the roof system design on this distinction and recognizes the different attachments and components required. (European terminology is reversed, considering the membrane as either "cold" or "warm", instead of the deck). With either terminology, the point to consider is the relationship between the components: the effects of each component on the other when each is subjected to the design factors.

1. Insulated Deck
   a. Maximum membrane performance required
   b. Minimal thermal insulation performance required
2. Uninsulated Deck
   a. Minimal membrane performance required
3. Inverted Assembly
   a. Minimal membrane performance required
   b. Maximum thermal insulation performance required

SYSTEM COMPONENT TYPES

The roof system and each of the system components can be typed by recognizing different methods of attachment and component relationships. The components must be selected for compatibility with those adjoining, for resistance to degradation factors, and for meeting the functional requirements. Different methods can be identified for accomplishing these goals.

1. Complete Roof System
   a. Attached
   b. Partially attached
   c. Unattached
2. Thermal System
   a. Sealed (with vapor retarder)
   b. Breathing (no vapor retarder)
   c. Exposed (inverted)
3. Membrane System
   a. Adhered
   b. Mechanically fastened
   c. Ballasted
4. Surfacing Types
   a. Coatings
   b. Cap sheets
   c. Embedded aggregate
   d. Loose-laid aggregate
   e. Pavers
5. Drainage
   a. Internal
   b. External

COMPONENT PRODUCT PERFORMANCE CRITERIA (STANDARDS)

As we begin to select specific component products, we should compare our preliminary design parameters with specific component performance criteria. Product standards (physical properties and performance attributes) should be compared with the parameters using the prioritized listing. Example: the highest priority for a system could be resistance to puncture. The membrane should have a durable surfacing, have high puncture-resistance, and the insulation should have high compressive strength. If an adhered membrane type is to be considered, vapor transfer should be analyzed to eliminate blistering, which could contribute to a puncture problem. Base flashings should be protected by metal counterflashings. The next item in the prioritized parameter list should then be analyzed against your proposed system until all parameters have been considered. You may have to compromise in this selecton. You may have to reconsider assembly categories or system types. As you consider each component, you should refer to the parameter list to see if the component is affected. The selection of each component must be compatible with that previously selected.

ASSEMBLY COMPONENT DESIGN

Specific component design and selection can now be made, with continual reference to the preliminary design parameters. Product selection should be made by comparing the design parameters with product criteria. Products selected should be compatible with the other component products in performance and installation.

Decking

While decking is a component of the roof assembly it is also part of the structural system and is often controlled by structural considerations. These are also subject to environmental and functional factors. Deck selection should be made in close regard to the assembly category selected and may often dictate system component type. Because the deck is the foundation of the roof system, our consideration for design should be based on stability.

1. Structural System
   a. Often dictates deck type
   b. Environmental and functional factors
2. Low Structural Stability
   a. Use uninsulated deck assembly category—or—
   b. Use unattached roof system type if loading permits
   c. Use positive drainage slopes
   d. Use expansion-type flashing details
3. Low Thermal Stability
   a. Use insulated deck or inverted assembly category
   b. Use expansion type flashing details
4. Low Moisture Stability
   a. With high interior relative humidity, change deck type
   b. Use uninsulated deck assembly with vented airspace
   c. Use sealed vapor barrier type in ceiling
5. Combined Deck/Ceiling
   a. High thermal stability
   b. Insulated or inverted deck assembly
6. Sloping Capabilities
7. Roof System Attachment

Drainage

Sloping of structural decking allows the most flexibility for roof design. Roof saddles should be included in a deck-sloped system to ensure that all areas of the roof drain properly. Sloped insulation systems are less flexible due to compatibility problems with other system components. Camber and deflection should always be considered in slope design and drain placement, number and location.

1. Slope to Drains
   a. Structural
   b. Tapered insulations
2. Drainage Type
3. Capacity
   a. Size, number and location
   b. Overflows

Thermal insulation

Insulation type and location requires the most careful thought of all the components. It is the principal controlling factor for the interior environment and is most affected by it. In an insulated assembly category, it is the interface with the roof membrane and often controls membrane selection. Insulation design requires a thorough understanding of thermo- and hygrodynamics. No other component has a greater influence on the life-cycle costs of the building, or greater effect on the other components.

1. Material Properties
   a. Compressive
   b. Coefficient of expansion
   c. Modulus of elasticity
   d. Fire resistance
   e. Maximum exposure temperature
   f. Dimensional stability
2. Moisture Sensitivity
3. Type
4. Location
5. Thermal Resistance
6. Attachment
7. Sloping Capabilities

Vapor barrier

The requirement, type and location of a vapor retarder/barrier is made after thermal insulation selection, as the physical properties and location of the insulation dictate the use of vapor control materials. The term "retarder" has been substituted by the industry in recognition of the permeability of all products. I continue to use the term "barrier" to distinguish the extent or quality of a vapor control material, and suggest that if you must control water vapor passage to avoid detrimental effects, materials of very low perm ratings (vapor barrier) should be selected. If you select "retarder" materials you must hope that if vapor can get in, it also has a path to get out, and insulation materials are not moisture-sensitive. Type and placement of vapor barriers is directly affected by the roof system component types. No penetration of a vapor control material should be allowed.

1. Assembly Category
2. Insulation Properties
3. Location and Dew Point
4. Type
5. Installation and Protection

Roof membrane

The membrane is the easiest component to design, if it can be considered after the other components are selected. The choice is often dictated by the other components. While all environmental and functional factors must be considered, I believe ease of application should be predominant, since the best design can be foiled by workmanship. If the membrane must be penetrated and frequently joined, a membrane that is easily fabricated should be used. If heat, cold, wind or moisture will affect installation, a membrane that compensates for these factors should be selected. If construction schedules require fast installation, or may result in the roof system becoming a work platform for other trades, membranes should be selected for high installation performance, or resistance to damage. Temporary roofing should always be considered as an option for the latter. It is apparent that when membrane selection is done first in the design process, all components must be adjusted to conform to the membrane. We are forced to compromise and may overlook detrimental factors. When the membrane can be selected last, we have greater flexibility in selecting the other components, and can be more assured that we've considered all the design factors.

1. Convention Built-Up Roof
2. Modified BUR
3. EPDM
4. PVC
5. Other

Surfacing

Surfacing must only deal with the exterior environmental or functional factors. Since surfacing serves to protect the membrane, our only problem is to make sure it is compatible with the membrane and offers the required protection. In ballasted system types, however, the ballast also serves as the attachment device and wind-uplift design procedures should be followed. Particle size determines projectile potential and quantity of ballast for membrane coverage. Small particles are most susceptible to wind loss, but require lesser quantities for coverage. Larger particles produce better wind resistance, but result in greater weight loading for adequate coverage. Manufacturer design specifications do not make this distinction and only refer to minimums. Actual loading may be up to five times the minimum! Surfacing aggregates are natural materials and should be available locally to remain economical. Special aggregates and pavers become very expensive.

1. Exposed
2. Coatings
3. Cap Sheets
4. Aggregates
5. Pavers

Flashing

Base flashing selection should conform to the membrane selected. If ease of application is a criteria, be aware that base flashing cost and application varies between the membrane types. If a high (flashing/roof area) ratio is involved, flashing may dictate the membrane type. Metal flashing gauges and types must be designed for wind and flexural forces.

1. Base Flashing
   a. Movement potential
   b. Element protection
   c. Material type and installation method
2. Metal Counterflashing
   a. Metal type, girth and gauge
   b. Shapes and details

SUMMARY

Roof system design problems can be alleviated by: careful evaluation of environmental factors and functional conditions; selection of components that withstand these factors and meet the conditions; selection of compatible components; and by integration of these components into a working system. The design process can be assisted by systemizing our approach to the problem and applying reason, judgment and compromise at each step of the process.

FOOTNOTE

The author wishes to acknowledge the following comments on this paper by John Van Wagoner, Prospect Industries, Sterling, Va.:

Design of Integrated Roofing Systems is a well-organized, logical, thorough outline for roof system design. While excellent in concept, the author requires the roof designer to exercise extraordinary judgment in the consideration of design forces and related component performance. He is forced to do so by the failure of our industry to collectively determine performance criteria for the components of a roofing system; to quantify those criteria; to collectively determine adequate uniform testing procedures, and to develop consistent product performance standards.

Instead of developing consensual quantifications of degradation forces, our splintered industry has simply changed or introduced new component products with no regard for the type or extent of these forces. When standards were established, they were often selected without consideration of those forces and simply conformed to existing product attributes. Instead of uniform testing procedures, we developed self-serving tests that alleviated comparisons with other products. Instead of collective standards, each product developer determines his own.

The major thrust of this paper is that roof systems are composed of components that must be integrated to perform. It is long past time for this industry to reach consensus, integrate, and commit our technical expertise to the establishment of meaningful system standards.