Rooftop Tapered Design to Optimize Drainage Potential and Meet Building Code

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ABSTRACT

Proper tapered design in low-slope roofing applications is essential to the performance and longevity of the system. Design-for-slope varies widely due to influencing factors, including: codes, cost, building limitations, and designer preferences. Subtle design changes can have a large effect on the effectiveness of a design. A working knowledge of how to read and interpret a proposed tapered design is therefore a vital tool to a design professional. This presentation will aim to educate attendees on how to read a tapered drawing and analyze it for good drainage, as well as for proper wind, fire, and thermal code compliance.

SPEAKER

T.J. Stock is the design engineering manager in charge of the group supporting roofing consultants, architects, and other specifiers at Johns Manville. T.J. joined the company in 1998 as a project engineer working to install new roofing membrane and insulation plants in various locations throughout North America. From there, he was promoted into the New Product Development Group, becoming a Six Sigma Black Belt while helping to develop and launch new products such as CleanBond® Self-Adhering SBS, Invinsa® Roof Board, and GlasKap CR®. He was then promoted into the Application Systems Group to lead the Western Region in support of the specifying community for application inquiries regarding building science, rooftop design, code and regulation compliance, and product and systems specification. Finally, he was put in charge of the entire Design Engineering Group, which includes tapered Design, design assisted layouts, custom details, lead generation, and application engineering.

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Proper tapered design in low-sloped roofing applications is essential to the performance and longevity of the entire roof system. Designing for slope varies widely due to influencing factors, including codes, cost, building envelope limitations, and designer preferences (*Figure 1*).

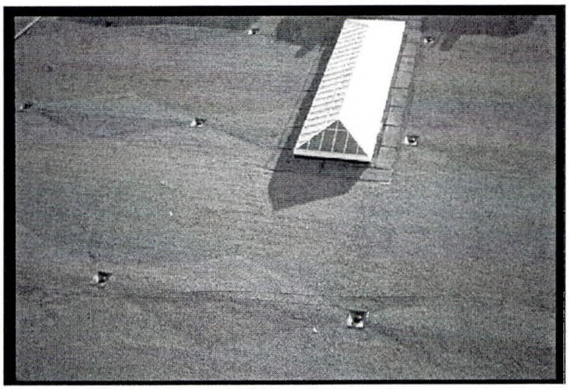

Figure 1 – Johns Manville file photo, 2007.

The 2006 International Building Code (IBC) has now been adopted, in various degrees, by all 50 states, and is therefore the driving force within the United States for both commercial and residential buildings. It regulates design, construction practices, construction material quality, location, occupancy, and maintenance of buildings and structures (*Figure 2*). Within these regulations are references to standards throughout the building industry for both process and contro,l including procedures and testing. This paper will explore how this body of codes relies on and relates to reference standards within the rooftop environment, and will illustrate how proper design involves a multiplicity of considerations in order to achieve the desired outcome.

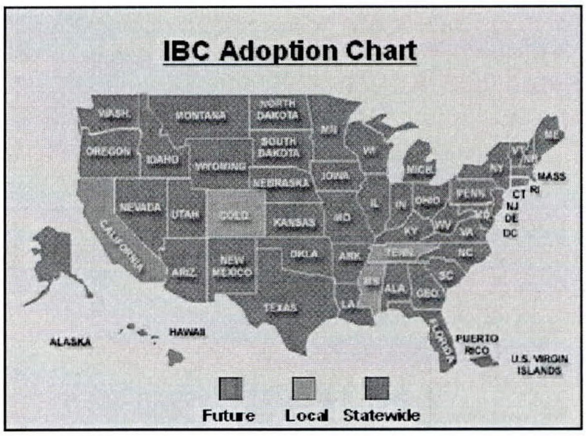

Figure 2 – International Code Council, updated 10/9/07.

Chapter 15 of the IBC is entitled "Roof Assemblies and Rooftop Structures," and sets many parameters to be followed with respect to the rooftop condition. An example of these parameters is the performance requirements, including the wind resistance of roofs, which are covered in Section 1504. The design parameters for uplift resistance must comply and be tested in accordance with FM 4450 (1989), FM 4470 (1992), UL 580-94, or UL 1897-98 (*Figure 3*). This will be the first reference to FM Approvals as a reference standard, and it will be pursued further as this study unfolds. As FM Approvals is a prominent reference standard, not only within Section 1504, but throughout the roofing portion of the IBC (and the roofing industry in general), the primary focus of this paper will be the relationship between the IBC, a designed slope system, and the FM Approvals standards. As they are the sole testing agency to provide a link between testing of roofing assemblies and insuring against failure of those same approved and installed systems, FM Approvals' testing and Approvals have become a standard of design as a reference throughout roofing specifications (*Figure 4*).

> **1504.3.1 Other roof systems.** Roof systems with built-up, modified bitumen, fully adhered or mechanically attached single-ply through fastened metal panel roof systems, and other types of membrane roof coverings shall also be tested in accordance with FM 4450, FM 4470, UL 580 or UL 1897.

Figure 3 – International Building Code, 2006, Chapter 15.

Section 1505 of the IBC focuses on fire classification, mandating that a roof assembly be classified as Class A, Class B, or Class C. This external fire test is governed by ASTM E 108-04 for FM Approvals, or Underwriters Laboratory's identical test, UL 790-98. The test utilizes a spread-of-flame apparatus for noncombustible decks to determine the propagation of a flame at a pre-determined slope. Slope is addressed by the IBC in Section 1507 - Requirements for Roof Coverings, where the design slope of built-up

SECTION 1505
FIRE CLASSIFICATION

1505.1 General. Roof assemblies shall be divided into the classes defined below. Class A, B and C roof assemblies and roof coverings required to be listed by this section shall be tested in accordance with ASTM E 108 or UL 790. In addition, fire-retardant-treated wood roof coverings shall be tested in accordance with ASTM D 2898. The minimum roof coverings installed on buildings shall comply with Table 1505.1 based on the type of construction of the building.

Figure 4 – International Building Code, 2006, Chapter 15.

roofing (1507.10.1), modified bitumen roofing (1507.11.1), thermoset single-ply roofing (1507.12.1), and thermoplastic single-ply roofing (1507.13.1) is set at a minimum of one-fourth unit vertical in 12 units horizontal (2% slope). The slope requirements are handled independently of drainage requirements, which are referenced in Section 1503 - –Weather Protection – as "Design and installation of roof drainage systems shall comply with the International Plumbing Code." However, the International Plumbing Code (2006) handles the conveyance of the water away from the roof only, and essentially addresses the rooftop environment from the drain bowl down. Slope is not addressed, and volumetric calculations based upon the total square footage of roof area combined with a 100-year, 1-hour rainfall intensity are the only ties to this consideration of a roof system.

Reroofing is addressed in IBC Section 1510, and states that reroofing shall not be required to meet the minimum design slope requirements in section 1507. Therefore, older systems with slopes more shallow than 1/4 inch may be grandfathered in through existing conditions, but any new facility will be held to compliance with the IBC slope parameters.

Slope, fire, and wind together represent the kinetic parameters that a roof system must overcome to be IBC compliant, and consequently are the very parameters by which FM Approvals systems are tested and approved. The IBC, by virtue of these approved systems, then regulates the design of roofs, including slope, through direct mandate and reference standards to ensure a consistently built environment. The key is to take into account these parameters throughout the project lifecycle, as compliance with the IBC is often emphasized in the front-end design and approval process, but may become less of a focus as the project cost and schedule progress.

Strict adherence to the guidance on the kinetic parameters defined by code is often loosened as the project life-cycle progresses, and designing for slope or tapered design is an element that can quickly become engulfed by "value engineering" stresses. Design professionals often realize the importance of slope as a component of the kinetic design and strive to meet at least the minimum code compliance throughout their design in the early stages of projects. Code influences their decisions regarding minimum slope, starting thicknesses, minimum properties, and desired R-value within the system.

Of all these influences, the most prevalent is driven by the current energy focus throughout the United States and embodied in the shortest chapter within the 2006 International Building Code. Chapter 13 of the IBC is titled Energy Efficiency, and sets the criteria that "Buildings shall be designed and constructed in accordance with the International Energy Conservation Code." In 2004, the International Energy Conservation Code (IECC) opened the requirements of energy efficiency for commercial buildings to ASHRAE/IESNA Standard 90.1 (2004). At that time, they became similar in their treatment of Climate Zones and the effects on a minimum R-value. Prior to that point, ASHRAE 90.1 had been a reference for compliance only if the parameters of the building were outside those given in the IECC.

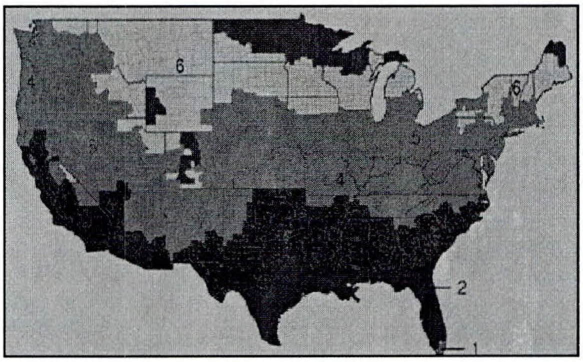

Figure 5 – Polyisocyanurate Insulation Manufacturers Association (PIMA), Energy Code/R-Value Map. Web site.

The United States is broken into eight Climate Zones, with the eighth Climate Zone being restricted to a number of boroughs within Alaska (*Photo 5).* This is significant, as all seven Climate Zones require a minimum R-value of 15.0 for continuous insulation entirely above the roof deck. Climate Zone 8 requires an R-value of 20.0. This would suggest that using average R-value would not be in compliance with the code. Continuous insulation is defined by ASHRAE 90.1 as "insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings." As a result of increasing research on the benefits of reflective membranes, an interesting deviation from the mandated minimum R-value is found within the Roof

Insulation Section 5.5.3.1, in which a Roof U-Factor Multiplier may be used if the solar reflectance is a minimum of .70 and the thermal emittance is a minimum of .75. The factor allows the U-factor to be adjusted by .77 in Climate Zone 1, .83 in Climate Zone 2, .85 in Climate Zone 3, and 1.0 in the rest of the Climate Zones. This multiplier recognizes the advantages of reflectivity below the Mason-Dixon Line (including California) and the diminishing effects that it has in the northern climates. R-value is the significant part of the ASHRAE 90.1 portion on roof insulation, and is therefore a driving factor in compliance with the IECC and, in turn, the IBC. This will be the first parameter that this paper focuses on as it has a significant effect on the approved system as related to a desired design outcome. R-value has a tremendous effect on the edge conditions of the roof, and therefore has the most influence on the limitations to slope and its design. R-value can be achieved through insulation - and at times coverboards - and often drives the overall tapered layout. Though it is such an important factor in the good design of a roof, and though it drives large portions of how to achieve proper drainage, the connection between R-value and code compliance is often left open for interpretation by municipalities throughout the United States.

Figure 6 – Johns Manville file photo, 2007.

California is an exception, with a mandated minimum R-value and the parameters needed to achieve it. California allows an average R-value to be derived from all of the insulation on the roof, taking into account crickets, tapered panel, and fills. California also recognizes that when heading into drains and low points, the minimum R-value will not, and should not, be possible. The Title 24 (2005) proposed 2008 Revision reads:

> *"Tapered insulation may be used which has a thermal resistance less than that prescribed in Table 149-A at the drains and other low points, provided that the thickness of insulation is increased at the high points of the roof so that the average thermal resistance equals or exceeds the value that is specified in Table 149-A."*

Unfortunately, this level of clarity often does not propagate throughout the country, as the legacy of "average R-value" continues due to numerous early codes defining minimum insulation in a vague manner. In the absence of formal IBC education, R-value decisions are often left to contractors, who may be given the design parameters, but not the actual code references. While most of the country has adopted the IBC, some local amendments remain that address this issue requiring a higher R-value when using a tapered average. Usually, however, using the average R-value in a tapered system in determining R-value compliance is not acceptable. Designing slope for a minimum R-value would be fairly simplistic if this were the only factor, however. The perplexing nature of defining slope according to the additional requirements of fire and wind add a further complexity to design (*Figure 6*). All of these factors must be taken into account and should be considered and fulfilled when designing the roof for slope. Not only does the design have to ensure positive roof drainage (the drainage condition in which consideration has been made for all loading deflections of the roof deck, and additional slope has been provided to ensure drainage of the roof within 48 hours of precipitation - IBC), but also has to take into consideration how the sloped design performs under the anticipated uplift loads, potential fire hazards, and minimum thermal values defined by local or national energy codes. It is not surprising, then, that when a third-party certification agency such as FM Approvals defines certain criteria or minimum requirements for what is considered to be an acceptable system, they are quickly held as a standard reference within the industry. With this as a backdrop, this paper will consider designing for slope further and investigate the pitfalls of a reference standard and the options available to those held to strict adherence and those who use FM Approvals solely as a qualified reference.

Though independent testing is an integral part of the IBC, FM Approvals testing correlates perhaps better than any other, and has become a reference standard for a large number of roofing specifications. However, many people in the industry are often unaware that most tapered layouts may not be FM Approvals compliant due to changes occurring throughout the design stages or in the component make-up that are considered at the time to be quite minor. The designer, if an architect, must know a tremendous amount of information, including not only roofing components, but often all facets of the building envelope. Questions for an architect responsible for the entire building envelope regarding roofing often center around obvious

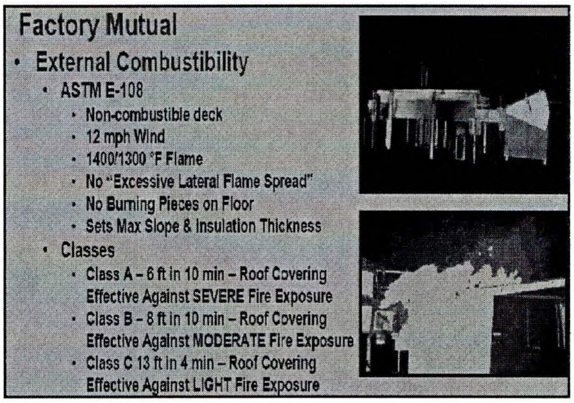

Figure 7 – Johns Manville file slide, 2007.

efficiency and installation parameters such as what minimum thicknesses of insulation are required for a given deck and the attachment combination to achieve the desired uplift resistance. Without the services of a dedicated roofing consultant, the roofing design in minute detail is often overlooked for the overall performance criteria demanded by the building envelope. When considering the rooftop design, therefore, heavy credence is given to existing testing agencies and guidelines that are used as a standard reference to ensure a solid design. FM Global has been the prominent resource for this reference, as it tests and publishes the results of numerous assemblies, and therefore influences heavily the design parameters of roofing systems. Additionally, as previously mentioned, FM's testing [though generic in nature, such as ASTM E 108-04 (*Figure 7*)], has found its way into the International Building Code as a reference standard. This inexorably ties code compliance to FM Approvals in this regard and requirements for an FM Approved system must therefore hold merit throughout the roofing industry.

There are three distinct areas that often need clarification when addressing FM Approvals compliance with respect to the sloped design of a roof utilizing tapered insulation. The first is a minimum approved thickness and how this affects a tapered design in areas requiring near-zero thickness for drainage. The second is the approved fastening layer and fastening placement in relation to other layers within the assembly. The third is tapered panel approval over an approved fill layer. These will be addressed in succession.

FM Approvals approves systems with a steel deck, according to Approval Standards 4450 (1989) - Approval Standard for Class 1 Insulated Steel Deck Roofs and 4470 (1992) - Approval Standard for Class 1 Roof Covers. FM 4470 governs FM 4450, with FM 4450 providing further guidance on steel decks. These Approvals will always involve a minimum thickness of insulation when over the steel deck. The minimum thickness of polyiso that will meet the test criteria is most often set at 1.5 in. With this set as a minimum, what can or should be done with a tapered system heading into low portions of the roof, such as drains, scuppers, etc. (*Photo 8*)?

The answer is varied, but good news is that common sense often prevails. FM Global approaches each situation on an individual basis, owing to FM Global representatives being responsible for territories that can guide and accept but not approve these areas. Usually, drains in the field of the roof are of little concern in this category as common roofing practice in sumps is an understood and accepted practice. When these locations are moved to the perimeters and corners of the roof, awareness and concern are raised, and therefore the local FM Global representative places more importance upon the review for compliance. For the majority that reference FM Approvals standards, common sense and good roofing practices must prevail and become the basis of the Accepted roof. When using sumps at or near a roof edge, especially in a high wind region, the tapered-edge strips used to form the sumps should be solidly adhered if possible or have additional mechanical attachment at a minimum. Over steel decks, the use of low-rise foam adhesive on the top deck flanges in conjunction with mechanical attachment may be necessary. Continued roof monitoring, in-progress inspections, or other quality assurance programs may be needed to ensure these areas conform.

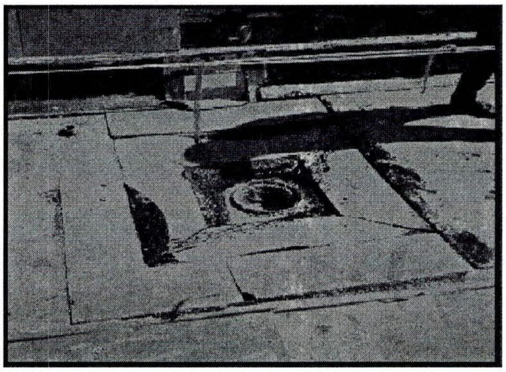

Figure 8 – Johns Manville file photo, 2007.

When a tapered panel is installed over a fill panel of Approved thickness, that tapered panel nearly always starts at a thickness under the Approved

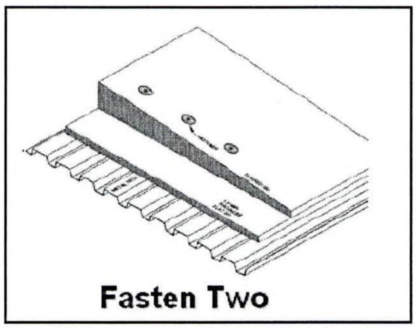

Figure 9 – Johns Manville file slide, 2007.

thickness (*Figure 9*). FM Global representatives may treat the fill layer and the tapered layer as two different layers if they will be independently fastened with different methods of attachment (*Figure 10*). If the tapered panel is polyiso, which has increased greatly in popularity, it may not be an FM Approved system. Often, manufacturers will test differing layers of flat insulation (usually all polyiso) together, in which a minimum thickness is associated with each layer – often 1. 5 in. On the FM 12 ft x 24 ft test deck, the framework is attuned to testing flatstock. Therefore, Approval of tapered insulation is based on performance of the flatstock. Alternatively, a manufacturer will test a constant thickness coverboard on top of an insulation, also of constant thickness. The vast majority of the time, these coverboards are under 1 inch in thickness, and certainly less than the 1.5-inch minimum usually approved when considering high-thermal insulation boards. If the coverboard tested is a perlite or gypsum based coverboard, the Approval is for a minimal thickness of that material only; and it therefore may not apply to a two-layer system of polyiso insulation and a layer of polyiso tapered insulation. The desired assembly of a polyiso tapered panel over a polyiso insulation panel must, therefore, be tested independently, and this is often the most confusing and therefore overlooked portion of a designed slope approval.

On a typical project where a fill or base layer of insulation is installed, the subsequent tapered polyisocyanurate board with less than 1.5-in thickness is often not Approved by FM Approvals. The same generally can be said of the first few thin panels fully mopped to a concrete deck. If using full application adhesive, the designer should have some comfort in knowing that the performance of

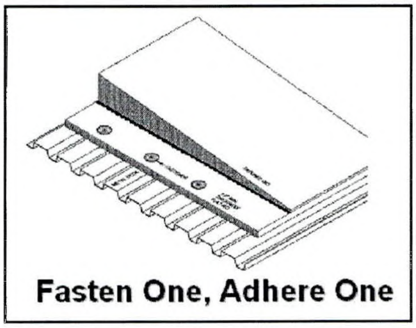

Figure 10 – Johns Manville file slide, 2007.

the thinner polyiso is fairly good and more than likely wind uplift performance should be maintained. Mechanical attachment and ribbon adhesive scenarios are typically much more complicated and will be discussed shortly. One option, however impractical, is to substitute tapered insulation for the flat-stock approval mentioned earlier while still observing the minimums (usually 1.5 in) and maximums. The one caveat is that all the panels used must start at a minimum of 1.5 inches. This approach can result in thicker overall averages due to the thicker fill panels required. While this is not common practice, it can be FM Approved and an effective way of designing a high performance system. FM Global-insured jobs may have more stringent compliance with these guidelines, and may have to resort to strict adherence. But the rest of the roofing world often has some leeway in this regard. When these types of instances occur on roofing jobs without an FM Global insured status, the options increase, as manufacturers will often provide assistance and guarantees without having to resort to the drastic options covered here.

On an FM-Approved assembly over a steel deck, there will always be a mechanically fastened layer to transfer the loads from the roofing assembly to the structural frame of the building (*Figure 11*). In these instances, FM Approvals requires a mechanical fastener into steel decking that penetrates a minimum distance into the top of the flange. Years of insuring adhesive-type fasteners has afforded them the ability to determine that the problems associated with adhesives, whether workmanship- or material-based, is not yet worth the risk in re-instituting approvals. Therefore, each Approved system assembly over a steel substrate will contain a layer that is hard fastened to the substrate.

But what of subsequent layers in the roofing assembly? What if, as is common practice, the designer would like the second layer of insulation in an adhesive to break thermal shorts or ease installation? These fastener and adhesive combinations are allowed only if that configuration has been Approved as a FM assembly in that combination, making special note of the minimum thickness requirements noted above. Although there are numerous assemblies meeting these requirements, if no approval is available, such as a fill layer fastened and a tapered layer in hot asphalt, then the uppermost layer must be the fastened layer and must be of the required thickness. Often, the required solution is to "invert" the assembly, installing the thinner fill panels below and the approved thickness fill panels on top (*Figure 12*) The assembly is then mechanically

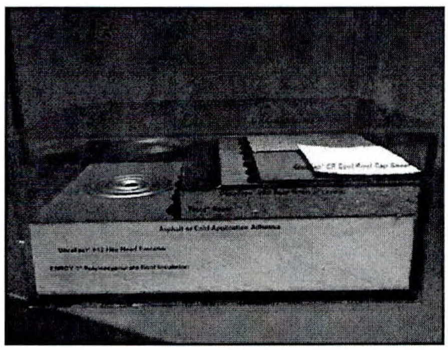

Figure 11 – Johns Manville file photo, 2007.

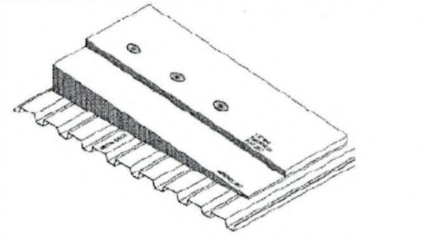

Figure 12 – Johns Manville file slide, 2007.

fastened from the fill layer through the tapered and into the deck. Systems incorporating a coverboard in adhesive have often been tested and can then be installed if required. This has not solved the issue of breaking the thermal shorts, however. If the designer truly wants to incorporate a fasten one/adhere one system, it will be necessary to either locate an FM-Approved system (of which there are many), invert the tapered as described above and add an approved coverboard assembly or deviate from FM Approvals requirements, and install the thinner tapered panels with particular attention being paid to the wind uplift requirements of the project.

With all these issues at hand and the reality of value engineering, how does a roofing designer review and compare tapered layouts? There are two commonly used tapered layouts: four-way slope and two-way slope with crickets. Four-way sloped designs are clearly the most effective means of draining a roof, as their design maintains the chosen slope. Two-way designs utilize crickets to bring the water to drain. The slope in the valley of the cricket of these designs will be less then the design slope. There are several reasons that a two-way slope can be justified. The drain layout or building configuration may not be conducive to constructing the constant 45-degree valley lines necessary on a four-way design. Edge conditions may dictate a constant perimeter or there may be high point restrictions at a perimeter, large unit, bulkhead door, etc. The location of rooftop penetrations may require the use of extended low points or sumps, and unique or changing valley lines. Finally, tapered insulation systems represent a significant cost and are often targeted for value engineering, especially when a two-way slope will work.

Understanding that a four-way slope is the most efficient means of draining a roofing system but is less likely to be employed, how can one design the best possible two-way layout? The most critical factor is the cricket width. Cricket width affects the slope in the valley. The cricket valley slope is a simple function of rise over run. The rise in this case is the roof surface slope multiplied by half the cricket width. The run is the actual length of the valley. Wider crickets increase the slope in the valley, creating better draining designs. A solid design will have a cricket length-to-width ratio of 3:1. The minimum considered should be 4:1. A 2:1 ratio can produce an excellent draining design, but at a greater cost. Ratios less than 4:1 often produce ponding areas and can have a distinct effect on the life of many roof systems.

Cricket Ratio	Slope in the Valley*
1:1	.177
2:1	.112
3:1	.079
4:1	.061
5:1	.049

***Based on 1/4-inch deck slope.**

In reviewing the resulting valley slopes for a given cricket ratio, one begins to understand how critical this choice is, as the slopes are not very high, even in the more ideal ratios. Subtle deck deflections and even membrane laps can reduce the valley slope to zero or even negative numbers. Adjusting cricket width is the easiest way to produce a tapered design that will appear very similar to a well functioning design and have a reduced cost. As stated above, the downside will be a roof that drains very slowly with a high probability for ponding water. This can be particularly detrimental to roof systems incorporating a granule-surfaced cap sheet, coating, or tape seams.

Another means of reducing tapered costs is the omission of crickets behind curbed roof-top equipment. On smaller units, this may have a minimal effect, but it can result in very poor drainage on larger penetrations. A third means of reducing tapered costs is to extend the low area at drains. By creating an extended flat area at the low point before starting the tapered panels, the overall average thickness is reduced. In some cases where a maximum height can't be exceeded, this may, in fact, be beneficial if the system and layout are designed for the flat sump area. An understanding of these critical issues allows a roof designer to choose the design most fitting to a project and understand how subtle differences between one layout and another can have a dramatic effect. If the design of the tapered system must be compromised for whatever reason, the type of roof membrane chosen may be the designer's only other option to create a system that will have long-term performance and a reasonable life-cycle cost. When a small degree of ponding or slow drainage is expected, thermoplastic membranes or bituminous multi-ply systems with gravel may be chosen to bolster the performance of a less than ideal tapered design.

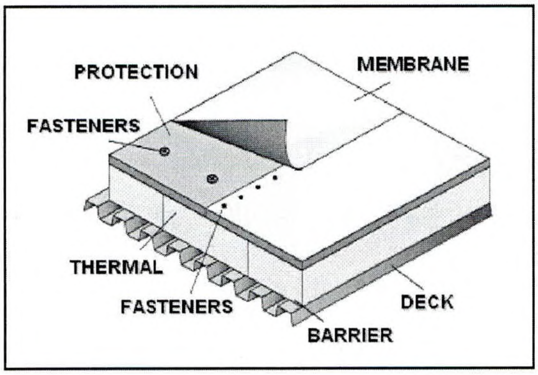

Figure 13 – Johns Manville file slide, 2007.

The system approvals given by FM Approvals and UL involve specific assemblies over specific decks, passing specific parameters (*Figure 13*). These are almost always the basis of design in specifications and start the project off with an eye to compliance with the International Building Code as well as other building codes within the jurisdiction of the project. However, designers and consultants alike must realize that strict adherence to these reference standards may come at a much higher cost, and that often insurance agencies such as FM Global allow deviations or definitive design enhancements to occur in the field where policy may not be as clear-cut as most would expect. Using these agencies and guidelines as reference standards is an excellent idea, but the consultant's role will become critical in deciding where policy or practice should ultimately rule. Common sense and good roofing practice usually span the gap between the unknowns or unfinished portions of the specified project, and in absence of an insurance body such as an FM Global representative, the roof consultant becomes a guiding hand. Usually, the project is subject to several design iterations as well the competitive bidding process further down the project lifecycle. These stages may have a tremendous impact on the original compliance of the project to code. Each iteration of slope variation, component substitution, or building envelope modification may invalidate the original system approval and intent. Value engineering during the bidding process may benefit the bottom line, but the resulting mix of products may have never been tested nor approved together and therefore would not comply with 1505.1 of the 2006 IBC requiring all roofing assemblies to have a Class A, B, or C rating. Subtle design changes can have a big effect on the effectiveness of a design and the ultimate life cycle cost of the roofing system.

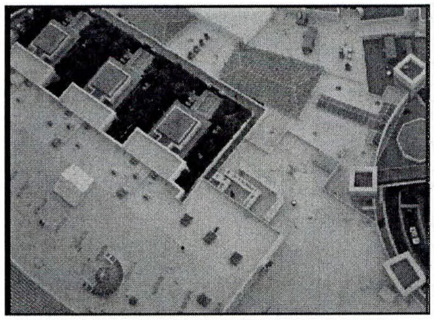

Figure 14 – Johns Manville file photo, 2007.

Proper tapered design does more than establish drainage (*Figure 14*). It is an integral link to properly specifying a roofing system that will meet the requirements of the owner, code bodies, and performance standards set in the design stages. Although designers create plans and specifications according to a working knowledge of how to read and interpret, a proposed tapered design is a vital tool for today's roofing designer.