Equivalent Uniform Annual Cost:

A NEW APPROACH TO ROOF LIFE CYCLE ANALYSIS

By James Hoff

INTRODUCTION

Life Cycle Cost Analysis and its Problems

Interest in life cycle cost analysis (LCCA) appears to be increasing among building owners and designers. Some of this attention may be attributed to a related and growing interest in "green" building technologies that rely in part on the durability and sustainability of building materials to minimize environmental impacts. The increasing economic sophistication required to finance modern construction projects may also be a contributing factor. Finally, new federal requirements for public construction may be stimulating the growing interest in LCCA.

Regardless of specific causes, however, the growing interest in life cycle costing is clearly reflected in changing attitudes within the construction industry. According to a recent survey conducted by *Building Design & Construction* ("White Paper on Sustainability," 2003), an overwhelming majority of the 70,000 building professionals surveyed agreed that building materials should be evaluated first and foremost on the basis of life cycle cost.

Unfortunately, although many building professionals are increasingly interested in learning about the life cycle costs of key building components, few tools currently exist to help them compare the almost unlimited choices of competing building materials. In the case of commercial roofing systems, designers and owners must select from a wide variety of roofing membranes, each with an equally wide choice of design and component options and warranted service lives, varying from five to over 30 years. The sheer complexity of modern roof system choices obviously makes it very difficult to develop simple analytical tools. However, the lack of effective life cycle cost programs also may be linked to other factors.

Problem 1: How Long Do Roofs Last?

The first challenge to effective LCCA is the lack of consensus regarding the service life of modern commercial roofing systems. As an example, two of the most comprehensive studies of service life conducted in the roofing industry arrived at sharply different conclusions regarding the longevity of various roofing systems. Based on a survey of over 400 roofing contractors, Carl Cash (1997) concluded that traditional multiple-ply asphalt roofing systems could be expected to provide an average service life of 17.4 years, while EPDM roofing systems could be expected to provide an average service life of 14.1 years.

In contrast to the Cash study, Schneider and Keenan (1997) surveyed over 20,000 actual roofing installations and concluded that the average service life of asphalt multiple-ply roofs was 13.6 years, while EPDM roofs provided an average service life of 17.7 years. Using the Cash study as a basis for LCCA may favor the use of multiple-ply asphalt roofing systems, while the data from the Schneider and Keenan study may favor single-ply systems.

How can the concerned building owner reconcile such conflicting estimates of roof service life? First, some of this apparent conflict may be due to the use of a statistical average. Within the population of both the asphalt and single-ply roofs, there may be roof systems that perform much better than the average, perhaps well in excess of 20 years. In addition, these better-performing roof systems may have included a variety of design and component augmentations that contributed to extended service life.

The published warranty offerings of roofing manufacturers may offer additional insight into the relationship between roof system design and roof longevity. Based on a review of the NRCA *Low-Slope Roofing Materials Guide* (2005), roofing systems appear to exhibit a consistent upgrading of components and application practices as the term of the warranty increases. As an example, almost all 20-year, multiple-ply, asphalt roofing systems require the use of high-strength, Type VI ply felts and redundant flashing details, while systems with lower warranty lengths allow the use of lower-strength felts and less redundant flashings. In a similar manner, the thickness of single-ply roofing membranes tends to increase as the warranty term increases (from 45 mils at 15 years; 60 mils at 20 years; and 90 mils at 30 years); while seaming and flashing requirements likewise increase as the warranty term is lengthened.

Although the nominal warranty term and relative durability of roofing systems

use, the building owner will suffer little if any loss of value in the sale of the building. In either case, the arbitrary 20-year study period may misrepresent the actual costs of ownership experienced by the building owner.

The use of an arbitrary study period also makes it difficult to effectively compare the value of roofing systems with different estimated service lives. As an example, the true value of a 15-year roof may be understated as compared to a 20-year roof if a 15-year study period is selected that provides no economic value for the additional five years the 20-year system offers. Conversely, the true value of the 20-year roof could be significantly overstated if a 20-year study period is selected that requires the complete replacement of the 15-year roof but then understates the long-term value of the new replacement roof.

Both of these problems can be resolved by deducting the residual value of the roof from the life cycle cost calculation, but this may add unnecessary complexity to what started out to be a fairly simple statement of present value. A more effective alternative may involve the use of Equivalent Uniform Annual Cost (EUAC) in lieu of standard LCCA. Unlike LCCA, EUAC allows for the use of differing study periods by expressing costs as an annualized estimate of cash flow instead of a lump-sum estimate of present value:

$$\mathbf{EUAC = (A/P,\ i,\ n)}$$

Where:
EUAC = Equivalent uniform annual cost
A/P = Annualized cash flow or payment ($/sq. ft.)
i = annual interest rate (%)
n = service life (years)

In simpler terms, Equivalent Uniform Annual Cost is the "payment" required to fund the Life Cycle Cost over the service life. This "payment" is calculated using the same principles as mortgage financing. The Life Cycle Cost represents the "purchase price" and the Estimated Uniform Annual Cost represents the "mortgage payment" needed for a given interest rate to fully fund the Life Cycle Cost by the end of the stated service life.

Because EUAC costs are stated as an annualized amount, it becomes possible to compare roof systems with different service lives.

ROOF LIFE CYCLE ANALYSIS USING ESTIMATED UNIFORM ANNUAL COST (EUAC)

Step 1: Identifying Alternatives and Timeframes

Using the NRCA *2004-05 Low-slope Roofing Materials Guide* (2005) as a reference, a wide selection of roofing specifications was identified based on warranty length. In addition, specifications incorporated all major categories of low-slope commercial roofing systems, including traditional asphalt, modified bitumen, EPDM, and thermoplastic systems. In all cases, these roofing designs increased in redundancy and augmentation as the warranty term increased. As an example, a typical 15-year EPDM specification may allow the use of a 45-mil membrane, while 20-year and 30-year designs require minimum 60-mil and 90-mil membranes, respectively. In a similar manner, a typical 15-year modified bitumen system may allow the use of a non-modified fiberglass base sheet, while a typical 20-year system requires a modified asphalt base sheet.

For the purposes of this study, the nominal warranty period was also designated to be the service life period for each roofing system. It is very likely that the actual ser-

SYSTEM TYPE	SERVICE LIFE (SL) Based on Warranty Period (Years)	PRESENT VALUE REPLACEMENT COST (RCpv) PV Replacement Cost = (Disposal Cost + New Roof Cost) X Present Value Discount Factor (1)				
		Disposal Cost ($ / SF)	New Roof Cost ($ / SF)	Total Replacement Cost ($ / SF)	Present Value Discount Factor (1) (5% APR)	Present Value Replacement Cost ($ / SF)
Ballasted EPDM	15	$1.00	$2.85	$3.85	0.56	$2.16
Ballasted EPDM	20	$1.00	$3.00	$4.00	0.46	$1.84
Adhered EPDM	15	$1.00	$3.25	$4.25	0.56	$2.38
Adhered EPDM	20	$1.00	$3.45	$4.45	0.46	$2.05
Adhered EPDM	30	$1.00	$4.00	$5.00	0.31	$1.55
Mech. Attached EPDM	15	$1.00	$3.35	$4.35	0.56	$2.44
Mech. Attached EPDM	20	$1.00	$3.55	$4.55	0.46	$2.09
Mech. Attached Thermoplastic	15	$1.00	$3.40	$4.40	0.56	$2.46
Mech. Attached Thermoplastic	20	$1.00	$3.65	$4.65	0.46	$2.14
Modified Bitumen	15	$1.00	$3.25	$4.25	0.56	$2.38
Modified Bitumen	20	$1.00	$3.70	$4.70	0.46	$2.16
Built-Up Roofing	15	$1.00	$3.60	$4.60	0.56	$2.58
Built-Up Roofing	20	$1.00	$3.80	$4.80	0.46	$2.21

Table 3: Roof system, service life, and replacement cost.

(1) The Present Value Discount Factor is based on a 5% annual percentage rate applied for the length of the service life/warranty period. As an example, a 15-year service life requires 56% or 0.56 of the replacement cost "up front" as the present value of the future cost, while a 20-year service life requires only 46% or 0.46 of the cost "up front," due to the longer time period to accumulate interest on the initial amount.

equal to the amount of "cash on hand" that can grow at a given interest rate into the amount of "future cash needed" to fund the roof replacement. As an example, using an annual discount rate of 5%, the cash on hand or present value necessary to replace a roof in 15 years is equal to 56% of the future cash needed, while the present value of a roof that must be replaced after 20 years is equal to 46% of the future cash needed. (Please note that a discount rate of 5% was selected, as currently recommended by the Federal Energy Management Program. See Fuller & Rushing, 2005.) The present value or "cash on hand" replacement costs for each roof system specification are summarized in *Table 3*.

Maintenance Cost

As mentioned previously, annual maintenance costs were based on data from Schneider and Keenan (1997) and Cash (1997) that identified annual maintenance costs as varying between $0.09 and $0.19 per square foot. To simplify this current study, these costs were rounded up to $0.20 for every roofing system. In addition, the total maintenance cost for each roofing system was converted to present value (or "cash on hand") by calculating the discounted cash flow of the annual costs for the warranty period. As an example, the cash on hand required to fund a $0.20 annual maintenance cost for a 15-year warranty period is $2.18, while the same present value for a 20-year warranty period is $2.63. These present value maintenance costs are summarized in *Table 4*.

Step 3: Calculating Life Cycle Cost

Once the present values of all initial, maintenance, and replacement costs have been established, the calculation of Life Cycle Cost is simply accomplished by combining these costs into a single amount. *Table 5* summarizes all Life Cycle costs for all roofing systems identified in this study.

Step 4: Calculating Equivalent Annual Uniform Cost

The problem with a simple life cycle cost model becomes apparent in *Table 5*. The life cycle cost of many 15- and 20-year roofing systems is very similar, and in some cases, the life cycle cost of some 15-year systems is lower than the corresponding 20-year system. As an example, the present value cost of a 15-year modified bitumen system is only $7.81 per square foot, while the more durable and redundant 20-year modified bitumen system has a higher cost of $8.49 per square foot.

The problem, of course, is that the 20-year system provides a longer service life than the 15-year system, and the value of this additional service life can only be evaluated by annualizing the costs associated with both systems. This can be accomplished by expressing the costs of both systems as an annual cash flow or "payment" for the expected life of each system. This annualization of life cycle costs is achieved using the Equivalent Uniform Annual Cost (EUAC) method, as previously identified in this article. Using the same 5% discount rate as in the LCCA calculation, the EUAC for each roofing system is summarized in *Table 6* and graphically compared in *Chart 1*.

SYSTEM TYPE	SERVICE LIFE (SL) Based on Warranty Period (Years)	PRESENT VALUE MAINTENANCE COST (MCpv) PV Maint. Cost = Annual Maint. Cost X PV Adjustment Factor (1)		
		Annual Maint. Cost ($/ SF)	Present Value Adj. Factor (1)	Present Value Maintenance Cost ($/ SF)
Ballasted EPDM	15	$0.2000	10.90	$2.1800
Ballasted EPDM	20	$0.2000	13.15	$2.6300
Adhered EPDM	15	$0.2000	10.90	$2.1800
Adhered EPDM	20	$0.2000	13.15	$2.6300
Adhered EPDM	30	$0.2000	16.15	$3.2300
Mech. Attached EPDM	15	$0.2000	10.90	$2.1800
Mech. Attached EPDM	20	$0.2000	13.15	$2.6300
Mech. Attached Thermoplastic	15	$0.2000	10.90	$2.1800
Mech. Attached Thermoplastic	20	$0.2000	13.15	$2.6300
Modified Bitumen	15	$0.2000	10.90	$2.1800
Modified Bitumen	20	$0.2000	13.15	$2.6300
Built-Up Roofing	15	$0.2000	10.90	$2.1800
Built-Up Roofing	20	$0.2000	13.15	$2.6300

Table 4: Roof system, service life, and maintenance cost.

(1) Present Value Adjustment Factor based on a 5% annual percentage rate applied for the warranty period or service life of the system. As an example, the initial present value or "up-front" funding necessary to cover annual maintenance costs for a 15-year service life requires 10.9 times the annual maintenance cost, while the "up-front" funding for a 20-year service life requires 13.15 times the annual maintenance cost.

SYSTEM TYPE	SERVICE LIFE (SL) Based on Warranty Period (Years)	INITIAL COST (IC) ($ / SF)	REPLACEMENT COST (At Present Value) (RCpv) ($ / SF)	MAINT. COST (At Present Value) (MCpv) ($ / SF)	LIFE CYCLE COST (LCC) ($ / SF)
Ballasted EPDM	15	$2.85	$2.16	$2.18	$7.19
Ballasted EPDM	20	$3.00	$1.84	$2.63	$7.47
Adhered EPDM	15	$3.25	$2.38	$2.18	$7.81
Adhered EPDM	20	$3.45	$2.05	$2.63	$8.13
Adhered EPDM	30	$4.00	$1.55	$3.23	$8.78
Mech. Attached EPDM	15	$3.35	$2.44	$2.18	$7.97
Mech. Attached EPDM	20	$3.55	$2.09	$2.63	$8.27
Mech. Attached Thermoplastic	15	$3.40	$2.46	$2.18	$8.04
Mech. Attached Thermoplastic	20	$3.65	$2.14	$2.63	$8.42
Modified Bitumen	15	$3.25	$2.38	$2.18	$7.81
Modified Bitumen	20	$3.70	$2.16	$2.63	$8.49
Built-Up Roofing	15	$3.60	$2.58	$2.18	$8.36
Built-Up Roofing	20	$3.80	$2.21	$2.63	$8.64

Table 5: Roof system life cycle cost (LCC).

Step 5: Analyzing Results: The EUAC Method of Life Cycle Costing

Long-term Value of Specification Enhancements

The EUAC method of life cycle costing may help to identify the real benefits inherent in roof systems that have been enhanced to extend service life. Based only on a comparison of the basic LCC of 15- and 20-year roofing systems in this study, the benefits of enhanced specification might be questioned because the LCC costs were so close. However, the EUAC cost method identifies that 20- and 30-year systems may hold an advantage more than sufficient to justify the additional up-front expense. As an example, the EUAC calculations indicate that the 20-year roofing systems in the study may offer long-term costs at 10% to 15% lower than their 15-year counterparts. In addition, the EUAC of the single 30-year system studied offers a cost savings of 12% beyond a similar 20-year system.

The EUAC data in the present study appear to support the proposition advanced by many roof consultants that the investment in enhanced system design may provide a real economic return to the building owner. As perhaps best stated by Richard Boon (2001) in *Roofing Contractor* magazine, "…the higher up-front costs of premium roofing systems can be fully justified through long-term savings."

Economic Similarity of Major Roofing Systems

The EUAC method also suggests that the major types of commercial roofing systems used throughout the United States today provide a very similar economic benefit. Although roofing industry professionals may hold widely divergent opinions regard-

SYSTEM TYPE	SERVICE LIFE (SL) Based on Warranty Period (Years)	INITIAL COST (IC) ($ / SF)	REPLACEMENT COST (At Present Value) (RCpv) ($ / SF)	MAINT. COST (At Present Value) (MCpv) ($ / SF)	LIFE CYCLE COST (LCC) ($ / SF)	EQUIVALENT ANNUAL UNIFORM COST (EUAC) ($ / SF)
Ballasted EPDM	15	$2.85	$2.16	$2.18	$7.19	$0.69
Ballasted EPDM	20	$3.00	$1.84	$2.63	$7.47	$0.60
Adhered EPDM	15	$3.25	$2.38	$2.18	$7.81	$0.75
Adhered EPDM	20	$3.45	$2.05	$2.63	$8.13	$0.65
Adhered EPDM	30	$4.00	$1.55	$3.23	$8.78	$0.57
Mech. Attached EPDM	15	$3.35	$2.44	$2.18	$7.97	$0.77
Mech. Attached EPDM	20	$3.55	$2.09	$2.63	$8.27	$0.66
Mech. Attached Thermoplastic	15	$3.40	$2.46	$2.18	$8.04	$0.77
Mech. Attached Thermoplastic	20	$3.65	$2.14	$2.63	$8.42	$0.68
Modified Bitumen	15	$3.25	$2.38	$2.18	$7.81	$0.75
Modified Bitumen	20	$3.70	$2.16	$2.63	$8.49	$0.68
Built-Up Roofing	15	$3.60	$2.58	$2.18	$8.36	$0.81
Built-Up Roofing	20	$3.80	$2.21	$2.63	$8.64	$0.69

Table 6: Roof system Equivalent Uniform Annual Cost (EUAC).

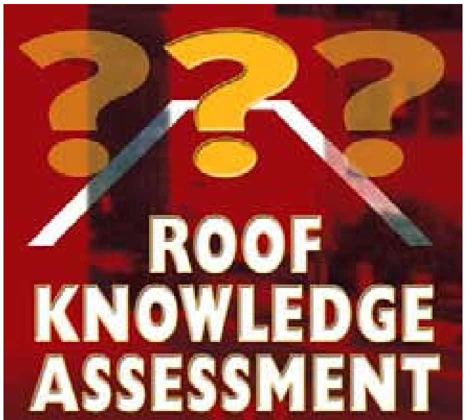
Note: Equivalent Uniform Annual Cost is the "payment" required to fund the Life Cycle Cost over a service life. This "payment" is calculated using the same principles as mortgage financing. The Life Cycle Cost represents the "purchase price" and the Estimated Uniform Annual Cost represents the "mortgage payment" needed for a given interest rate to fully fund the Life Cycle Cost by the end of the stated service life.

Test your knowledge of coatings with the following questions, developed by Donald E. Bush Sr., RRC, FRCI, PE, chairman of the RRC Examination Development Subcommittee.

1. **What are the five major reasons why galvanized steel is painted?**
2. **What is the most common reason for painting galvanized steel?**
3. **Which three basic components do protective coatings contain?**
4. **What are the three mechanisms by which coatings protect a substrate?**
5. **Which structural design features may contribute to coating failure?**

Reference: ***Corrosion and Coating,* The Society for Protective Coatings**

Answers on page 12



Answers to questions from page 11:

1. • **Synergistic effect**
   • **Aesthetics**
   • **Added protection**
   • **Color coding**
   • **Safety markings**

2. **Aesthetics**

3. • **Pigment – provides body.**
   • **Binder – provides important film properties.**
   • **Solvent – reduces viscosity for easy application.**

4. • **Barrier protection.**
   • **Inhibitive pigment protection.**
   • **Sacrificial protection.**

5. • **Water traps – configurations with pockets that collect water.**
   • **Sharp edges – coatings retract from sharp edges, leaving only film.**
   • **Crevices – at bolted seams and back-to-back angle iron.**
   • **Dissimilar metals – accelerated corrosion of more chemically reactive metal.**
   • **Areas difficult to access – lack of sufficient coating.**

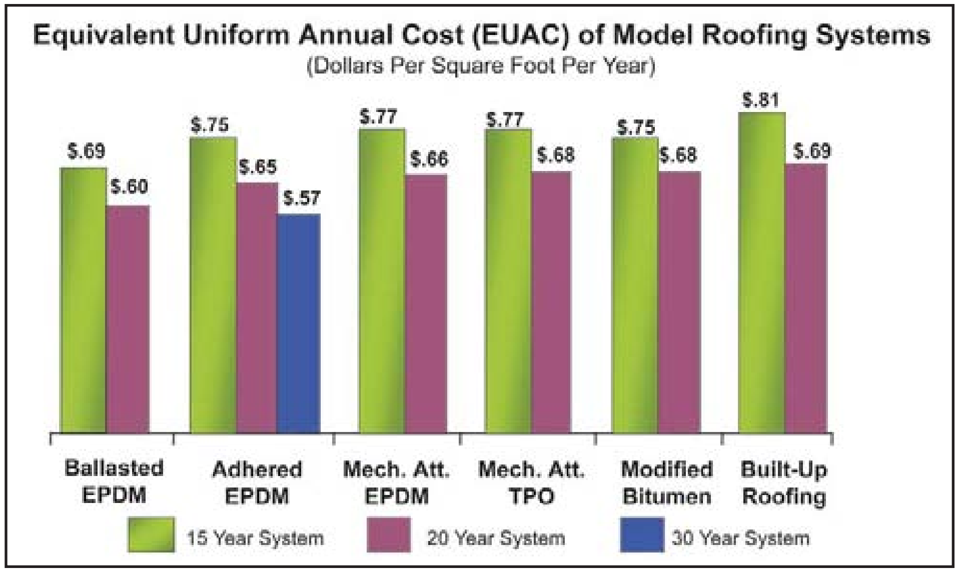


Chart 1: Equivalent Uniform Annual Cost (EUAC) of Roofing Systems

ing the relative performance of EPDM, thermoplastic, modified bitumen, and built-up roofing systems; the relative similarity of these systems in terms of EUAC may indicate that no single system offers an unassailable economic advantage. Perhaps this is why each of these major approaches to roofing enjoys a respectable share of today's commercial roofing market.

EDITOR'S NOTE: A copy of the Excel workbook used to calculate life cycle cost using the Equivalent Uniform Annual Cost (EUAC) method may be obtained by e-mailing Jim Hoff at hoffjames@firestonebp.com. This paper was originally presented at the RCI 21st International Convention and Trade Show in Phoenix, Arizona, in March 2006.

REFERENCES

Boon, R. A., "Better Roofs are Less Expensive," *Roofing Contractor*, November 2001.

Cash, C.G., "The Relative Durability of Low-slope Roofing," *Proceedings of the Fourth International Symposium on Roofing Technology*, pgs. 119-124. National Roofing Contractors Association: Rosemont, IL, 1997.

Fuller, S. K., and Rushing, A. S., "Energy Price Indices and Discount Factors for Life-cycle Cost Analysis," April 1, 2005 to March 31, 2006, *Annual Supplement to NIST Handbook 135 and NBS Special Publication 709* (NISTIR 85-3273-20). Gaithersburg, MD: National Institute of Standards and Technology, 2005.

2004-05 Low-slope Roofing Materials Guide, Rosemont, IL: National Roofing Contractors Association, 2005.

Means Building Construction Cost Data, Kingston, MA: R.S. Means, 2005.

Schneider, K.G., and Keenan, A.S, "A Documented Historical Performance of Roofing Assemblies in the United States, 1975-1996, *Proceedings of the Fourth International Symposium on Roofing Technology*, pgs. 132-137, Rosemont, IL: National Roofing Contractors Association, 1997.

"White Paper on Sustainability," *Building Design & Construction*, November supplement, 2003.

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