FLAT ROOF CONVERSIONS
ABSTRACT

This study examines the cost-effectiveness of converting flat-roofed buildings to sloped-roof buildings as an alternative to repair or replacement of the existing roof. Alternative framing systems are shown and special problems explained. Benefits of roof conversions include better energy performance and improved building appearance. Conversions are cost-effective for small buildings and become an even better alternative when life-cycle costs are considered.

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TECHNICAL NOTE

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Many new systems and products have been developed for roofing and re-roofing flat-roofed buildings. In some buildings, however, it is more cost-effective to convert the flat roof to a sloped roof. A new superstructure is built above the existing flat roof. The new, sloped superstructure is covered with asphalt shingles or metal roofing.

Conversion is cost-effective, particularly for smaller buildings of 10,000 sq. ft. or less. This is particularly true when considering the life-cycle cost of a building. A roof conversion is usually no more expensive than re-applying a new flat roof. However, when roofing materials on the sloped roof wear out, the roof is much less expensive to re-roof. Also, roof conversions eliminate high maintenance costs associated with flat roofs.

A roof conversion has other benefits. Leaks caused by ponding, aging of the roofing membrane, or faulty application are eliminated. In addition, condensation problems occurring because of inadequate insulation and ventilation can be corrected.

A sloped roof not only provides positive drainage, it creates a space where inexpensive loose fill or batt insulation can be installed. Proper ventilation above the insulation can also be provided, bringing the building up to today's energy performance standards.

Careful architectural design in a roof conversion can often enhance the building's appearance and improve its energy efficiency. For example, a roof can be modified to provide overhanging eaves to shade the building in summer.

This report discusses the structural considerations that are important in planning roof conversions. It shows how roof conversions can be built using joists and rafters, trusses, or post and beam construction. Costs for each system were determined from interviews with contractors and architects specializing in roof conversions. Eight case studies were selected to demonstrate a variety of building types, and structural and architectural solutions.

BUILDING STRUCTURE

To convert a flat or very low-sloped roof to a pitched roof, a superstructure must be constructed above the existing roof. Both engineering and architectural considerations are important in planning the conversion.

Analyze Existing Loads

When re-fitting a building for a new, sloped roof, the architect or builder must analyze the existing structural system. The designer must determine whether the building, designed for a specific set of loads, can support additional dead loads created by the new framing and roofing. Then the designer must decide how to distribute the new set of loads to the existing structural system. An analysis of the existing structure may limit the designer's options.
Determine New Roof Structure

Roofs for conversions are constructed on the same basic principles as other sloped roofs. A roof shape which blends with the design of the building should be chosen. Basic roof shapes include gable, hip, shed, mansard, butterfly, gambrel, and two-story gothic.

The basic roof shapes can be achieved using one of the three basic roofing systems — roof truss, joist and rafter, or post and beam. Each system has advantages and disadvantages. All three systems can be built of metal or wood members.
These diagrams show three framing systems that can be used in roof conversions. Roof trusses and joist and rafter framing are the most common systems found in conversions.
In this illustration of load distribution within a truss, the members with short arrows are being squeezed (or in compression), and the other members with the longer arrows are being stretched (in tension). Consequently, the loads are resolved at each joint.

TRUSSES

A truss is an assembly of relatively small members, arranged in a triangle or combination of triangles, to form a rigid framework. Because trusses use lightweight framing members to carry substantial loads, they are efficient and cost-effective structural systems. A truss is able to support a load across a wide span because it distributes the load within its members. Trusses are particularly suitable for roof conversions because they can distribute the entire roof load to the perimeter of the building. Because the load is then carried on exterior walls, internal walls (which may or may not be load-bearing walls) will not be required to carry additional loads. Because trusses use lightweight framing members, they should be considered when the existing building structure cannot carry large additional loads.

Certain building types must use trusses. Flat-roof construction is often used on buildings with perimeter masonry bearing walls. Parapets support wood joists or steel bar joists framed between the walls. Conventional framing would apply too much lateral, or horizontal, load to the top of the parapet, causing the masonry work to break off. To use conventional framing, the parapets would have to be torn down flush with the roof, or a horizontal tie that would restrain the lateral loads would have to be used. For this case, trusses are the only logical and economical choice. A truss resolves all the horizontal loads within its members (primarily in the tensioned bottom chord), thus exerting only vertical loads on the structure below. Similarly, where the clear span exceeds the capacity of conventional framing, trusses are a logical choice. Trusses can be constructed of either steel or wood.

Metal Trusses

There are two basic types of metal trusses—heavyweight and lightweight. They are differentiated by the size of the metal components used to construct them.

A heavyweight truss uses standard structural steel components for its members. A typical heavyweight truss member is a 3 3/4" x 3 3/4" x 3/4" steel angle. Truss members can be bolted or welded together. These heavyweight trusses can support tremendous loads over large spans.

The other basic truss type is a lightweight truss. Lightweight trusses are built from light-gauge, rolled metal members, normally 16 to 26 gauge channels, C-sections, Z-sections, hats, tees, or tubes. These trusses are comparable to wood trusses in their spanning and load-carrying capacity.
A low-sloped metal roof, made of job-built metal framing members, provides an economical alternative to the school's leak-prone flat roof.

Wood trusses create a steeper roof pitch on this rectangular school building. The steeper pitch keeps children from climbing on the roof.

Where a non-combustible structural system is required, metal trusses can be used. In many cases, however, building code officials have not required non-combustible framing for roof conversions, even in buildings requiring non-combustible construction, such as schools. Code officials presume that the existing roof is constructed of noncombustible members and forms a fire barrier; therefore, construction of a new roof superstructure above the old roof does not affect the rest of the building.

Metal trusses are fabricated in a shop or factory and delivered to the job site. As with any truss system, metal trusses are able to span large areas, and they exert only vertical loads at their end points. Because connections between members are time-consuming and complicated (for heavyweight metal trusses), labor costs are high, as is the cost of steel.

Metal trusses can be combined with wood or metal purlins to support plywood and shingles or metal roofing material.

One of the disadvantages of some metal trusses is their weight. However, because steel is stronger than wood, metal trusses are able to span greater distances. In coastal regions where uplift winds are a serious consideration, heavyweight steel trusses can be a desirable choice for roof conversions.

Wood Trusses

As with steel trusses, wood trusses are prefabricated in a shop or factory and trucked to the site. Wood trusses have been fabricated for spans up to 100 feet in length, but are normally limited in length and height because of transportation difficulties. The shipping height of wood trusses cannot exceed twelve feet, the normal clearance for highway and railroad overpasses. In cases where the desired slope or height of the truss exceeds twelve feet, piggy-back trusses can be used. The normal, economical spans used range from 20 feet to 60 feet.

Wood trusses are economical for most roof configurations. Trusses work best when buildings are simple, rectangular shapes, but lose their cost advantage on complicated building shapes. In a roof conversion, where either trusses or conventional framing could be used, local labor costs are often the deciding factor. The trusses themselves cost more than the material required to frame a roof conventionally, but since trusses

Site-built wood trusses were an economical choice for this rectangular building. The roofing material is 26-gauge, white metal pan. A ridge vent provides ventilation.
Piggyback trusses are used for large spans or steep pitches. The trusses' height is limited because they must be shipped from the factory to the job site.

can be erected quickly, and the construction labor costs are lower, the slightly higher cost for materials is offset by reduced labor. In areas where labor costs are very high and the roof structure is simple, trusses are generally less expensive. Where labor costs are low or moderate, it is usually more cost-effective to use conventional framing.

Four wood truss systems are used to frame roof conversions. A step-down hip system is the most common complete truss system used to create a hip roof. This system employs three trusses and a mono truss (sometimes called a half- or sawtooth-truss.) The common trusses are used to frame the main body of the roof. The step-down truss is the same span as the common truss; however, it is truncated at the top to gradually decrease in height to form a sloping hip. The step-down trusses are used between the common trusses and the step-down girder. The step-down girder (two or more step-down trusses combined) carries the mono trusses which finish out the bottom of the roof. (See Case Study No. 2.)

The Dutch hip system combines a hip end and a gable end. A louver can be installed in the gable to provide attic ventilation, or it can simply enhance the building's appearance. This system uses common trusses and mono trusses. The small, hipped area is normally conventionally framed with a hip rafter and jack rafters.

The terminal hip system can be used for small-span applications. Thirty-two feet is the maximum span. This system combines common trusses
The *dutch hip system* uses a gable-end vent, but because of the additional finish work required to trim the vent area, is more expensive to build.

With a *step-down truss system*, only trusses are used to create a hip roof.

The most complicated system to use, the *terminal hip system* uses trusses, subtended trusses, and plate-connected framing members that are all factory-assembled. This system is rarely used.

The combination of trusses and *conventional framing* is often used for hip-roof framing. The body of the roof consists of identical common trusses. The more complicated parts of the roof — the hips and valleys — are site-built.

*(for the main body)* and long, bottom-chord mono trusses that function in the same way jack rafters do in conventionally framed hips. The hip rafter is a conventionally framed rafter, not a truss. The bottom chord of the mono truss is longer on one side of the hip rafter than the other. The top chords are cut on a bevel to tie into the hip rafter.

*Common trusses combined with conventional framing* offer the best of both systems. Common trusses are used to frame the main body of the roof. Economy is maintained through the repetition of identical common trusses. At the point where the hip begins, the trusses stop and the conventional job-built framing begins. The hip rafter and the jack rafters are conventionally framed.
JOIST AND RAFTER

The second basic roof system is joist and rafter, or conventional framing. When converting a flat roof, new rafters are erected and tied to the existing joists. The existing joists restrain the horizontal thrust caused by the rafters.

Fastening. The usual way to attach rafters to joists is to fasten a wood plate around the perimeter. The plate is nailed or bolted into the existing joists and deck. The rafters can either rest on top of the plate or notch over it, forming a more secure connection.

Flat roofs often have one or more inches of rigid insulation on the structural deck below the roofing material. The plates can be installed on top of the existing roofing, through the insulation and into the joist and deck. However, the insulation, which is a compressible material, can deform under long-term loading or when damaged by moisture. Indeed, moisture can cause insulation to deform unevenly. A better solution is to remove the roofing and insulation down to the structural deck. The plates can then be securely fastened directly to the existing deck.

This method assures secure fastening of the plates but creates another problem. To fasten the plates directly, a path of roofing and insulation several inches wider than the plate must be cut away to insure that the plate will be straight and true. Depending on the complexity of the roof, it could be several weeks before the work is completed. During this time the building is exposed to the weather. The problem of building vulnerability also occurs when trusses are used; but, the problem is less critical because of the shorter time required for the erection of trusses.

Length of Clear Span. One factor that determines whether or not joists and rafters can be used is length of clear span. The size of the rafters and their spacing dictates the allowable span. The larger the rafter, the longer the span. Similarly, the larger the piece of dimension lumber, the greater its cost per board foot. Thus, there is a point at which it becomes more economical to use a truss system. For instance, with a 40 pound live load requirement, 2x10’s spaced at 16” on center will span approximately 15 feet. In this case, the maximum building width cannot exceed 30 feet.

Knee Walls. If the building has intermediate supports, then the roof framing may not be limited to a single, simple span. In small-scale frame construction, there are often interior bearing walls. Bearing walls will support knee walls, which, in turn, can support the rafters, reducing their span. With a series of knee walls, the framing can be constructed of lightweight members and cover large areas. This system is very economical.

The dead loads imposed on a structure by this type of framing (wood rafters covered with asphalt shingles) are relatively light. Consequently, many types of existing structural systems can support these dead loads without having bearing walls directly beneath them. For example, a precast concrete deck, as seen in Case Study No. 1, is capable of supporting the relatively light loads imposed by knee walls.

Although knee walls are most commonly used to support rafters at their ends and at mid-spans, knee walls may be required in buildings...
over roof sheathing

A knee wall is located above a bearing wall. The knee wall carries the majority of the roof load to the bearing wall. Otherwise, an eccentric load, bearing down on the sub-fascia, could cause structural problems. Knee walls should be used where overhangs are provided.

that have cantilevered overhangs. If knee walls are not used, the new rafters would concentrate an eccentric load on the outermost point of the cantilever. A supporting knee wall must be placed above the exterior wall to take the majority of the rafter load. Then the only load bearing on the existing cantilever would be one-half the distance of the overhang of the new roof.

Metal Rafters. Metal members can be used to frame roof conversions. Although this approach is not as common as wood framing, contractors that use this system generally use it exclusively. Metal framing members most often used are lightweight members such as rolled C-sections. They are bolted, screwed, or welded together.

The job-built metal framing is characterized by different spacing than wood. (See Case Study No. 8.) The rafters are commonly 10'-20' o.c. The intermediate members or purlins are normally 5'-0" o.c.

The steeper the roof pitch, the greater the horizontal, outward thrust at the roof's edge. It is difficult to restrain very much outward lateral load because of the way the metal channels fit together. Thus, metal rafters are more effective on low-pitched roofs covered with metal roofing.

POST AND BEAM

Although not commonly used in roof conversions, post and beam construction is an alternative, under certain conditions. If post and beam construction were used, the building would have to be capable of supporting a concentrated load at each end under the beam, as well as uniform loads along both side walls. The building's length is the deciding factor. Even for small single-family residences, spanning the building's length would require a mammoth beam. Even a single, large beam would be tremendously expensive and difficult to set in place.

SHEATHING AND ROOFING

Very Low Slope. More roofing material is required to cover steeper slopes. Steeper slopes also require longer framing members. The use of additional material increases the cost of roofing and sheathing as the slope increases.

Metal framing systems with metal roofing materials can be used on pitches as low as 1/4/12. Metal framing systems, used on very low-sloped roofs, are generally covered with light-gauge metal roofing materials. Metal roofing is attached with sheet-metal screws and neoprene washers. The longer the piece of metal, the more it expands and contracts due to temperature change. This movement enlarges the holes around the screws or nails, eventually causing leaks. Concealed fastener systems can also be used; they can help eliminate leaking. However, concealed fasteners are also more expensive.

Low Slope. Wood framing, covered with metal roofing, can be used with slopes of 2/12 and up; however, asphalt or fiberglass shingles are not recommended until the roof slope reaches a 4/12 slope. An example of a wood framing system that can be used with slopes lower than 4/12 is a system that uses widely spaced mem-
Seen from the street, the wide fascia gives a uniform appearance to this commercial building. The fascia actually conceals a low-sloped metal roof.

This edge detail at the rear of the same building shows how the fascia disguises the actual roof height. The roof height is the same as the height of the fascia, although not seen in the picture above, and the roof drains to the rear.

CONSTRUCTION SYSTEMS AND COSTS

Construction costs depend on the type of work and the cost of labor. Expenses hinge on many variables — labor, price of materials, the distance travelled, and the nature and size of the job. Costs provided in this report are in 1983 dollars. An inflation factor or a current estimating guide should be used to update costs.

Labor costs often depend on the size of the job. Where wood is used as the structural material for either trusses or conventional, job-built framing, work is often supervised by a general contractor or carpenter. Most roof conversion contractors report that their labor is non-union. The work is usually done by small companies. Larger jobs require union wages be paid, but the construction companies are still non-union. Sometimes the shingling can be subcontracted to roofers. Other times it is completed by the general contractor. Case Study No. 1 is an example of a conversion that was entirely subcontracted, however, many other cases were not. Subcontracting is not a major factor in increasing the cost of the job.

Roof Configuration

Another important influence on the cost of conversion is the shape, or configuration, of the roof. The most economical style of roof is a hip roof because application of the new roofing material is the only finish work required. A hip roof can be framed inexpensively with conventional framing.

The cost of a roof conversion using wooden trusses depends on two factors — the configuration of the building and the distance the truss must span. The more often a single truss type is repeated, the less expensive the conversion will be per square foot. For instance, a simple, rectangular building would be the least expensive to convert because a single truss type can be repeated. Truss fabricators must set up a jig

This clerestory addition, added during a roof conversion, provides natural light to the building interior. A complex shape such as this can enhance the look of a house.
to build a truss. It is less expensive for them to produce 100 identical trusses than it is to set up and build several truss types.

The other factor affecting cost is the distance a truss must span. The cost of a truss is dependent on the size of the framing member used to make it. Dimension lumber costs more per board foot as the length and width of the lumber increases. The longer the span, the longer the framing members within the truss will be. This increases the cost of the truss per lineal foot.

**Wood Framing**

**Wood Trusses.** Wood trusses can be used economically on spans less than 60 feet. The in-place cost of trusses ranges from $3.00 to $5.50/sq. ft., with an average cost of $4.25/sq. ft. The step-down truss system, used to construct hip roofs, is generally slightly less costly than the dutch hip system. The dutch-hip roof requires gable and end finishing. The cost of the step-down truss system averages between $3.00 and $4.00/sq. ft. when the roof is not complicated.

Common trusses combined with conventional framing are particularly economical for long roofs in which many identical trusses are used. When the number of trusses is reduced, some of the economy is lost. The average cost of this system is $3.00/sq. ft.

**Joist and Rafter.** A conventional framing system is most economical if the rafters are built with small-dimension lumber. Knee walls are used to create the shorter spans. This approach costs between $2.00 and $4.00/sq.ft. with an average cost of $3.00/sq.ft.

Two items determine whether the job-built roof conversion will be at the high or the low end of the conversion price range: 1) the rafter size; and 2) the amount of work to be done on the fascia and soffit. Case Study No.1 has a minimum amount of soffit and fascia work and uses 2x4 rafters. The larger the rafter size and/or the more elaborate the soffit and fascia work become, the closer the final cost approaches $4.00/sq.ft.

Costs can be reduced by using single, simple spans and by attention to edge detailing. If the top of the new sloped roof ends at the top of the existing fascia, this eliminates any soffit and fascia work. In addition, the roof may look less like a conversion and more like an original roof.
This metal framing system is a hybrid, developed especially for retrofitting large, commercial-sized buildings with low-sloped metal roofs. The system uses a series of different-height knee walls, diagonally braced, to create the slope.

**Metal Framing**

**Metal Rafters.** Conventionally framed roof conversions using lightweight metal structural members are normally covered with some type of metal roofing, often standing seam or prefinished galvanized metal. Metal rafters are economical for larger applications where the roof slope is low. Completed costs range between $2.00 and $3.50/sq.ft., with an average cost of $3.00/sq.ft.

**Steel Trusses.** Steel trusses, made from standard structural steel members, can also be used to create a substructure. Heavyweight steel trusses (which may be needed for large buildings with long spans) can cost $5.80/sq.ft. or more.

**LIFE-CYCLE COSTS**

**The Bottom Line**

To see whether it makes economic sense to convert a flat-roofed building to a pitched roof, the life-cycle cost of replacement vs. conversion should be calculated. Using data from the case studies, it can be shown that the cost of re-roofing, using either a single-ply or built-up system, is approximately equal to a complete roof conversion. The real payback occurs when a re-roofing is needed (approximately 15 years.) At this later date, the roof is merely reshingled. Shingling is much less expensive than providing a new, flat-roof membrane. It is approximately one-fifth the cost.

**Example of Life-Cycle Cost**

A sample problem will illustrate how life-cycle costing can be used to show the real-world payback of roofing alternatives. Case Study No.1 was chosen as an example because the owner took competitive bids on several different systems. Accurate cost information was available, based on the bids the owner received.

**Building Description.** The building in Case Study No. 1 was 33'x108' or 3,564 sq.ft. Before conversion, the existing roofing system was a built-up roof with gravel, installed over 1-inch rigid insulation. The roof structure was a precast concrete deck supported by masonry bearing walls. There were no parapet walls. The edge detail consisted of a sheet metal gravel stop. The roof had leaked for some time: The insulation was wet and had to be replaced.

The building was about fifteen years old. A building with masonry bearing walls and precast concrete floors and roof has a projected life expectancy (for life-cycle cost purposes) of 60 years. Three roofing systems were considered as reroofing alternatives: Roof conversion with asphalt shingles; conventional built-up roofing; and a single-ply system. Asphalt shingles normally provide 15 years of trouble-free service. Built-up roofing with a gravel surface has a life expectancy of 15 years, according to a recent ASTM-STP study. Single-ply roofing systems are relatively new, and quantitative data are not yet readily available. A 15-year life expectancy is assumed.

**Bids Received.** The owners took competitive bids for different single-ply roofing systems and a roof conversion. A 45-mil EPDM, ballasted, synthetic rubber membrane, was estimated at $2.36/sq. ft. The owners had had so much trouble with the existing built-up roofing system that they eliminated the built-up system from consideration.

The owners selected the roof conversion system because it solved their problems and had the lowest initial cost. However roof conversions will not always be less expensive than alternative systems. Maintenance costs for the remaining years of a building's life must also be considered.

To get a true picture of long-term maintenance costs, the remaining 45-year life of the building in Case No. 1 was examined. Presuming that asphalt shingles last 15 years, they will need to be replaced twice after the conversion. Other
roofing systems would require replacement at the same intervals. Assuming inflation remains constant at about 4% compounded, the replacement roof cost in 15- and 30-year intervals would be:

**Roof Conversion**

Today's cost of asphalt shingle replacement = .60¢/sq. ft.

\[ 60¢ \times (1 + .04)^{15} = \text{future amount in 15 yrs.} = F_1 \]
\[ F_1 = \$1.08/\text{sq. ft. for asphalt shingles for first replacement} \]

\[ 60¢ \times (1 + .04)^{30} = \text{future amount in 30 yrs.} = F_2 \]
\[ F_2 = \$1.95/\text{sq. ft. for asphalt shingles for second replacement} \]

**Single-Ply Roofing**

Today's cost of single-ply replacement = $2.36/sq. ft.

\[ $2.36 \times (1 + .04)^{15} = \text{future cost in 15 yrs.} = F_1 \]
\[ F_1 = \$4.25/\text{sq. ft. for single-ply for first replacement} \]

\[ $2.36 \times (1 + .04)^{30} = \text{future amount in 30 yrs.} = F_2 \]
\[ F_2 = \$7.65/\text{sq. ft. for single-ply second replacement} \]

To accurately compare life-cycle costs, built-up roofing should also be considered. According to the 1983 Means Construction Cost Data, using the correct area multiplier, 3-ply built-up roofing with 2" of insulation cost $1.98/sq.ft., plus an estimated $0.75/sq.ft. for removal of existing roofing. The total cost is $2.73/sq.ft. (These figures can be updated to today's prices by using the current Means Construction Cost Data.) Using the same 4% compounded inflation rate, the cost of 15-year-life roofing over 45 years is:

**Built-up Roofing**

Today's cost of built-up replacement = $2.73/sq. ft.

\[ $2.73 \times (1 + .04)^{15} = \text{first replacement} = F_1 \]
\[ F_1 = \$4.92/\text{sq. ft. at 15 years} \]

\[ $2.73 \times (1 + .04)^{30} = \text{second replacement} = F_2 \]
\[ F_2 = \$8.85/\text{sq. ft. at 30 years} \]

### LIFE-CYCLE COST OF ROOF CONVERSION

<table>
<thead>
<tr>
<th>ROOF CONVERSION</th>
<th>1st REPLACEMENT COST (15 yrs)</th>
<th>2nd REPLACEMENT COST (30 yrs)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITIAL COST</td>
<td>$8,068.84</td>
<td></td>
<td>$18,867.76 or $5.29/sq. ft.</td>
</tr>
<tr>
<td>SINGLE-PLY ROOFING</td>
<td>$8,400.00</td>
<td>$15,147.00</td>
<td>$50,811.60 or $14.26/sq. ft.</td>
</tr>
<tr>
<td>BUILT-UP ROOFING</td>
<td>$9,729.72</td>
<td>$17,534.88</td>
<td>$58,806.00 or $16.50/sq. ft.</td>
</tr>
</tbody>
</table>
The total cost for the projected 45 years of life remaining in the building in Case Study No. 1 is:

<table>
<thead>
<tr>
<th>Roof Conversion</th>
<th>Total Cost (45 yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Ply</td>
<td>$58,806.00</td>
</tr>
<tr>
<td>Built-Up</td>
<td>$50,811.60</td>
</tr>
<tr>
<td>Roof Conversion</td>
<td>$18,867.76</td>
</tr>
</tbody>
</table>

Money spent at some future date is worth less than money spent today. Calculating the future value of money by the Single Payment Present Worth (SPPW) method allows us to include the interest earned on a given amount of capital from today until the money is spent. When we have calculated the SPPW, we know what the money is worth in today’s terms.

The formula is:

\[
P = F \times \frac{1}{(1 + I)^N}
\]

Where

- \( P \) = the present value of the money that is spent in the future
- \( F \) = the known (or approximated) future expenditure
- \( I \) = current interest rate paid by a safe investment = 8.5%
- \( N \) = number of periods in years

SPPW = INITIAL EXPENDITURE + \( P_1 + P_2 \)

Where

- \( P_1 \) = present value of first roof replacement
- \( P_2 \) = present value of second roof replacement

### Single-Payment Present Worth (SPPW)

#### Roof Conversion

\[
P_1 = \frac{3,849.12 \times 1}{(1 + .085)^{15}}
\]

\[
P_1 = \$1,132.18
\]

\[
P_2 = \frac{6,949.80 \times 1}{(1 + .085)^{30}}
\]

\[
P_2 = \$601.28
\]

\[
\text{SPPW} = \text{INITIAL EXPENDITURE} + P_1 + P_2
\]

\[
\text{SPPW} = \$9,802.30
\]

#### Single-Ply System

\[
P_1 = \frac{15,147.00 \times 1}{(1 + .085)^{15}}
\]

\[
P_1 = \$4,455.34
\]

\[
P_2 = \frac{27,264.60 \times 1}{(1 + .085)^{30}}
\]

\[
P_2 = \$2,358.88
\]

\[
\text{SPPW} = \text{INITIAL EXPENDITURE} + P_1 + P_2
\]

\[
\text{SPPW} = \$15,214.22
\]

#### Built-Up System

\[
P_1 = \frac{17,534.88 \times 1}{(1 + .085)^{15}}
\]

\[
P_1 = \$5,157.71
\]

\[
P_2 = \frac{31,541.40 \times 1}{(1 + .085)^{30}}
\]

\[
P_2 = \$2,728.90
\]

\[
\text{SPPW} = \text{INITIAL EXPENDITURE} + P_1 + P_2
\]

\[
\text{SPPW} = \$17,616.33
\]
SUMMARY OF SPPW

<table>
<thead>
<tr>
<th>ROOF CONVERSION</th>
<th>INITIAL COST</th>
<th>TOTAL COST (45 yrs)</th>
<th>SPPW</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ROOF CONVERSION$</td>
<td>$8,068.84</td>
<td>$18,867.76</td>
<td>$9,802.30</td>
</tr>
<tr>
<td>SINGLE-Ply</td>
<td>$8,400.00</td>
<td>$50,811.60</td>
<td>$15,214.22</td>
</tr>
<tr>
<td>BUILT-UP</td>
<td>$9,729.72</td>
<td>$58,806.00</td>
<td>$17,616.33</td>
</tr>
</tbody>
</table>

When the total roofing cost for the life of the building is converted into present value, the roof conversion still proves to be the best choice. If the discount rate for using borrowed money is included in the total life-cycle cost of the roof, the difference between the SPPW figures is even greater.

CASE STUDIES

Case studies showing various re-roofing strategies are shown in this report. To obtain cost data for the report, builders and architects who had completed several roof conversions were interviewed. Many of them specialized in roof conversions. A complete list of those interviewed can be found in Table 1.

One metal building contractor in southern Georgia had completed thirty roof conversions in the past five years. He used job-built framing systems with galvanized lightweight metal C-channels as rafters and purlins. Most of the roofs were covered with 26-gauge prefinished metal, screwed (with neoprene washers) into the C-channels. His costs ranged from $2.00 to $3.50/sq.ft. for conversions.

An architectural firm in the Philadelphia area has coordinated several larger scale roof conversions. (See Case Study No.6.) They have converted a dozen school buildings using wood trusses and asphalt shingles. Good design has been a major consideration in their conversions. Along with conversions, they have sought to: 1) provide maintenance-free finishes; 2) provide proper overhangs to shade large glass areas; 3) pitch roofs steeply to prevent children from climbing on them; 4) improve the appearance of the building by bringing the soffits in flush with the top of the window heads.

An international wood truss manufacturer has collaborated with Redland Roof Tile Ltd., an English concrete roof tile manufacturer, to take advantage of a program in England that encourages repairs to pre-1919 houses. Concrete tiles, frequently used in England, provide a 100-year guarantee. Heavier loads imposed by the concrete tiles are taken up by larger trusses. Concrete tiles cost about $250 per 100 sq.ft. in the United States, or about 3 1/2 times more than asphalt shingles; but, they last five times as long. Thus, the cost of roofing with tile is actually less expensive over a projected 100-year building life.

A firm located in Randolph, Ohio has developed a roof conversion system that is being marketed in the United States. The system was invented by a metal building contractor and is competitively priced. The system uses 16-gauge galvanized framing components covered with a 16-gauge standing seam roof. The framing consists of a series of sub-purlins (knee walls) running perpendicular to the new roof slope on 5'-0" centers. The knee walls are then diagonally braced. The framing is constructed from hat sections, tubes, furring tubes, angles, "cees", "cees" with flange tracks, and eight different connectors to provide the flexibility to cope with most situations. The system is particularly good for large industrial buildings. The use of 1/4 to 12 slope allows coverage of large areas economically. The system adds less than 3 pounds per sq.ft. of dead load, which is about a third of the weight of a comparable wood system. The owner/inventor states the total installed costs range from $2.75 to $3.50 per sq.ft.

These examples, and the case studies that follow, show that a roof conversion can be adapted to almost any building.
CASE STUDY #1

TYPE OF CONSTRUCTION: 10' concrete block bearing walls with precast concrete (Flexicore) deck, no parapets.

EXISTING ROOFING SYSTEM: Built-up, gravel surface over 1" of rigid insulation.

BUILDING SIZE: Two identical apartment buildings separated by a 12' light well. At the roof level, the two buildings are connected at each end by a strip of roof 2'-6" wide. Only one roof has been converted at this time, but the owners plan to convert the other roof.


REASON FOR REPLACEMENT: Leaking

SYSTEMS USED: 2x4 rafters at 2'-0" o.c. to create a hip roof with a 4 in 12 slope. The rafters are supported by 2x 4 knee walls at the midpoint of their span. The existing built-up roofing and the rigid insulation were cut away from the precast concrete deck around the perimeter and under the supporting 2 x 4 knee walls to provide positive fastening of the 2 x 4 plates. 1 x 6 redwood fascia was fastened directly to the existing metal fascia; therefore, there is no soffit.

ATTIC VENTILATION: The attic space is ventilated with a continuous ridge vent. Ten circular mushroom vents were used at the base of the roof around the building.

GUTTERS: No gutters were used at this time. One long wall was previously guttered and the gutter remains.

COST: $8,068.84 or $2.26/sq. ft.
2 x 4 rafters at 2'-0" o.c.

2 x 4 ridge pole

2 x 4 knee wall

2 x 6 hip rafter

access hole

2 x 4 perimeter plate

open well between buildings

ROOF FRAMING PLAN
12
4

ridge pole
continuous ridge vent
235# asphalt shingles
½" plywood with clips

2 x 4 rafters at 2'-0" o.c.
2 x 4 knee wall
existing 1" rigid insulation

insulation cut away to allow positive plate attachment
existing concrete bearing walls
existing precast concrete deck

SECTION THROUGH BUILDING
Temporary supports are placed under the ridge and also under knee walls. Because the work was done in February, weather was not dependable. The temporary supports were removed after the roof was sheathed. Then the existing roofing and insulation were cut back to allow the $2 \times 4$ plates to be securely fastened.

The use of knee walls and the relatively steep pitch of the roof permitted the use of $2 \times 4$ rafters, spaced 16" o.c.
From the front, it can be seen that the new, hipped roof is relatively inconspicuous when viewed from ground level.

From the rear, the new roof can be compared to the existing flat roof on the adjacent building.
CASE STUDY #2

TYPE OF CONSTRUCTION: Haydite concrete block bearing walls supporting steel bar joists and metal deck.

EXISTING ROOFING SYSTEM: Built-up gravel surface over 1" insulation

BUILDING SIZE: 52' x 32' = 1,662 sq.ft.

CONFIGURATION: The main roof is rectangular. Also, a smaller roof (el. 3'-6" above main roof) covering an exterior loading dock.


REASON FOR REPLACEMENT: Leaking

SYSTEM USED: 2 x 4 prefabricated step-down hip truss system. Existing roof left intact, as trusses were supported on a 2 x 6 plate anchored to the top of the parapet wall.

ATTIC VENTILATION: Continuous ridge vent, 6" vent soffit (aluminum) around entire perimeter of building. Roof extended 6" beyond outer walls.

GUTTERS: 5" aluminum (seamless)

NOTE: There are six similarly designed Post Office buildings in this area. Three of the buildings have been reroofed with sloped systems and the remaining three will be converted in the near future.

COST: $6,277.80 or $3.74/sq.ft.
step down Howe trusses

truss doubled to form girder

existing flat roof to remain unchanged

existing parapet wall

2 x 6 plate fastened to top of parapet

2 x 6 framing

Howe trusses @ 2'-0" o.c.

sawtooth trusses @ 2'-0" o.c.

2 x 4 blocking

2 x 4 stub wall bearing on existing framing

valley

hip framed with 2 x 6's

ROOF PLAN
(stepped down hip truss system)
235# asphalt shingles over
15# felt over ½" CDX plywood
girder formed by doubling trusses
sawtooth trusses @ 2'-0" o.c.
new stub wall
existing framing

12
4

2 x 4 blocking
ridge vent
stepped trusses @ 2'-0" o.c.

Howe trusses @ 2'-0" o.c.

2 x 6 plate

existing flat roof to remain unchanged
hipped roof cricket to divert water away from wall
continuous soffit venting
existing masonry parapet wall

LONGITUDINAL SECTION THROUGH THE ROOF
Because of the unsupported overhang, sawtooth trusses were needed on the front portion of the building. The sawtooth trusses allowed the load to be carried back to the full-length step truss.

Step trusses, not rafters, are being used to create a hip roof that will rest on the masonry parapet and the wood parapet wall.
The bottom plate was bolted to the top of the parapet. The parapet wall provides a deep, clear area in which to install insulation.

The sloped roof can be more easily maintained. In addition, the added insulation beneath it improves the energy efficiency of the building.
CASE STUDY #3

TYPE OF CONSTRUCTION: Wood frame; brick veneer and panel exterior, wood roof deck.

EXISTING ROOFING SYSTEM: Built-up tar and gravel over 1" roof insulation.

BUILDING SIZE: 50' x 71' = 3550 sq. ft.

CONFIGURATION: Rectangular with notches cut out at the corners and centered on one axis.

DATE: Construction began February 20, 1983, construction completed March 30, 1983

REASON FOR REPLACEMENT: Leaking

SYSTEM USED: 2 x 8 rafters framed 2'-0" o.c. created a hip roof with a slope of 4 in 12. Knee walls were used for support at the mid-span of the rafters.

ATTIC VENTILATION: 18 mushroom vents at the base of the roof and 20 lineal feet of ridge vent.

GUTTERS: 4" seamless gutter added around the perimeter connected the existing downspouts.

INSULATION ADDED: 6" of paper-faced fiberglass installed on top of existing roof.

COST: $13,504 or $3.80 per sq. ft.
2 x 8 rafters @ 2'-0" o.c.

2 x 8 hip rafter

2 x 4 supporting knee wall below

36" x 30" access door

existing flat roof below

2 x 4 plate around perimeter

flat soffits filled in where offsets occur

ROOF FRAMING PLAN
235# shingles over 15# felt on ½" wafer board with metal clips @ 2'-0" o.c.

edge metal

1 x 8 redwood

remove existing roofing to provide secure plate fastening

existing roof edge detail

TYPICAL CORNICE DETAIL

continuous ridge vent

2 x 8 rafters @ 2'-0" o.c.
mushroom vents @ 9'-0" o.c.; 4'-0" from roof edge

2 x 4 knee walls above load-bearing partition walls below

existing insulation cut away to allow 2 x 4 plates secure fastening to roof

SECTION THROUGH ROOF
Before conversion, this flat roof showed evidence of deterioration—ponding, missing gravel, and worn patches. In addition, the existing roof deck was poorly insulated. Upstairs apartments were hard to cool in summer. Mechanical equipment, located on the existing roof, had to be elevated.

For this rectangular, flat-roofed building, the most economical conversion proved to be a hip roof, framed with rafters. The design called for the unshaded, third-floor windows to receive some shading from the new soffit.
Mechanical equipment can be seen on top of the new roof. The third floor windows are partially shaded.
## CASE STUDY #4

<table>
<thead>
<tr>
<th><strong>TYPE OF CONSTRUCTION:</strong></th>
<th>Masonry bearing walls supporting a wood frame roof</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXISTING ROOFING SYSTEM:</strong></td>
<td>Built-up tar and gravel</td>
</tr>
<tr>
<td><strong>BUILDING SIZE:</strong></td>
<td>5,400 Sq. Ft.</td>
</tr>
<tr>
<td><strong>CONFIGURATION:</strong></td>
<td>L-shaped</td>
</tr>
<tr>
<td><strong>DATE:</strong></td>
<td>Winter of 1982-83</td>
</tr>
<tr>
<td><strong>SYSTEM USED:</strong></td>
<td>A combination of wood scissors trusses, conventional framing, and Howe trusses were used. Three different systems were used because of both the existing conditions and design solution. The existing building had a portion of the roof raised to provide clerestory windows. The scissors trusses and conventional framing were used to get up over the existing clerestory, rather than removing it. (See drawings) Conventional Howe trusses were used elsewhere. The final 5/12 slope was covered with asphalt shingles.</td>
</tr>
<tr>
<td><strong>ATTIC VENTILATION:</strong></td>
<td>Continuous ridge vent and soffit vents were used.</td>
</tr>
<tr>
<td><strong>GUTTERS:</strong></td>
<td>A complete new guttering system was added.</td>
</tr>
<tr>
<td><strong>COST:</strong></td>
<td>$25,609 or $5.25/sq.ft.</td>
</tr>
</tbody>
</table>
In the roof plan for this conversion, three types of trusses and conventional framing were used.
Scissors trusses are used to span the higher portion of the existing roof. The only two bearing points are located directly above the outside walls.
An isometric diagram of the roof framing shows the locations of the framing members and the angles of the roof.

**DIAGRAMMATIC ISOMETRIC OF ROOF FRAMING**
235# asphalt shingles over 15# felt over ½" CDX plywood

trusses @ 2'-0" o.c.

new soffit with a continuous vent

existing roof framing

A detail of the roof edge shows how the truss extends past the existing overhang.
beveled siding

fiberglass shingles on 15# felt on ½" CDX plywood

2 x 4 knee wall supporting roof structure

framing 16" o.c.

2 x 4 plate

existing elevated portion of roof

SECTION THROUGH ROOF
The long, horizontal lines of this building dictated the design of the new roof. A portion of the existing roof was higher than the rest of the roof. Scissors trusses and conventional framing were used to frame above the high section of the roof.

Clerestory windows can be seen just above the lower roof level. The clerestory glass was removed and the windows were filled in. Also, notice the deep overhangs shading the windows.
A side view of the completed conversion shows the new roof line.

From the front, the elevated portion of the roof, and the change in color and texture between the cedar siding and the roofing material, make the roof line more interesting.
CASE STUDY #5

TYPE OF CONSTRUCTION: 12' concrete bearing walls and wood ceiling joists framed between parapet walls.

EXISTING ROOF SYSTEM: Built-up, gravel surface.

BUILDING SIZE: 1,620 Sq. ft.

CONFIGURATION: Basically rectangular, with various offsets.

DATE: February, 1983

SYSTEM USED: Wood trusses at 2'-0" o.c. bearing on 2 x 4 plates attached to the top of the parapet walls. On the back side there was a parapet (to provide for drainage). In this case a wood frame wall was constructed to the same level as the parapet walls to provide bearing for the trusses. The final 4 in 12 sloped roof was covered with asphalt shingles. The gables were covered with prefinished aluminum. The soffit and fascia were covered with prefinished aluminum.

ATTIC VENTILATION: The attic space was ventilated with gable louver vents.

COST: $7,614 or $4.70 per Sq. ft.
A section view of the house shows that one section of the existing roof had a slight pitch to aid drainage. Parapet walls were needed to even the slight elevation difference of the existing roof and bring the wall up to the same height as the remainder of the roof so that trusses could be used.

The roof plan shows the location of the parapet wall. It also shows how gables are used to tie projections into a rectangular building.
The view of the house under construction shows that the lower portion of the roof belonged to a garage.

The new roofline ties the garage and house together, making the house appear larger and more substantial.
From the rear of the house one can see the framed parapet wall, used to level uneven walls.

The completed structure is seen from the rear.
CASE STUDY #6

PROJECT DESCRIPTION: This project is part of Camden County College, Blackwood, New Jersey, and consists of five separate buildings linked together. The buildings are different sizes and shapes, and they are constructed from different materials. Several of the buildings had leakage problems. The architects proposed converting to sloped roofs on all of the buildings.

TYPE OF CONSTRUCTION: Two of the buildings (Wilson West and East) are steel frame with concrete roof decks. Two other buildings (garage and Roosevelt Hall) have masonry bearing walls with wood-frame roof structures. Wilson Center has steel columns supporting concrete barrel vaults.

EXISTING ROOF SYSTEM: Built-up, gravel surface, used on the garage and on both Wilson East and Wilson West. Roosevelt Hall, which already had a sloped roof, was covered with asphalt shingles. Roosevelt Hall was re-roofed. Since each building was slightly different, the buildings will be treated individually in this case study.

ATTIC VENTILATION: All buildings were provided with continuous soffit vents and gable or ridge vents.

GUTTERS: New gutters were required on all buildings.

COST: $204,457 or $5.25/sq.ft.
CASE STUDY #6a

BUILDING: Wilson Center

TYPE OF CONSTRUCTION: Steel columns supporting a series of concrete barrel vaults.

EXISTING ROOF SYSTEM: A liquid-applied product that forms a membrane on the concrete.

SYSTEM USED: Columns were located on the concrete roof directly above the existing structural columns supporting the roof. The new columns carry a beam running perpendicular to the vaults. The beam is made of four parallel-chord trusses tied together at the top with plywood. The two beams (one on each side of the building) in turn support the trusses which run parallel to the vaults.

BUILDING SIZE: 64' x 150' = 9,600 Sq. ft.

BUILDING CONFIGURATION: Rectangular

ATTIC VENTILATION: Continuous ridge and soffit vents.
PRE-MODIFIED ROOF PLAN OF CAMDEN COUNTY COLLEGE COMPLEX
The roof conversion plan for the vaulted roofs of Wilson Center is shown.
235# asphalt shingles over 15# felt over \( \frac{1}{2}'' \) CDX plywood

4 horizontal wood trusses tied together at the top with \( \frac{3}{4}'' \) plywood to support wood truss @ 2'-0' o.c.

SECTION THRU ROOF EDGE

In this section, looking through the roof edge, the existing supporting columns carry the weight of new roof trusses via a new, braced wood column and metal shoe.
The concrete barrel vaults on the Wilson Center could not support a new roof structure.

The solution was a stub column, used to support a fabricated supporting beam that spanned the distance between the columns.
Due to the size of the building, piggy-back trusses were needed. Full-height trusses would have been too tall to transport.

The finished roof will provide better protection against weather than the concrete roof.
Between the columns, the existing barrel vaults remain in place. Above the tops of the columns, the glass is painted black.
CASE STUDY #6b

BUILDING: Wilson West

TYPE OF CONSTRUCTION: Steel frame with concrete roof deck.

EXISTING ROOF SYSTEM: Built-up, gravel surface.

BUILDING SIZE: 56' x 184' = 10,304 Sq. ft.

CONFIGURATION: Rectangular

SYSTEM USED: Wood trusses at 2'-0" on center bearing on 2 x 8 plates fastened through the roof. Due to the width of the building and a line of skylights running down the center of the building, two trusses were used. The two trusses were connected at the peak after they were in place. This solution allowed the skylights to remain (see building section). One-piece trusses would have required removal of the skylights and would have cost more.

ATTIC VENTILATION: Continuous soffit vents, ridge vents, and gable vents.
The diagram shows the roof framing plan for Wilson West, another building in the complex.

This conversion was accomplished by using two trusses joined at the peak. This system was possible because of the existence of the two interior bearing walls.
This view shows Wilson West before construction.

Looking down the roof as the trusses are placed, one can see a row of skylights at intervals in the roof. The skylights were one reason the unique, two-truss system was chosen. One truss could have been used to span the whole roof, but it would have interfered with the skylights.
When the new roof was completed, it actually enhanced the appearance of the building.

The three converted roofs at Camden County College, Blackwood, New Jersey are shown.
CASE STUDY #7

TYPE OF CONSTRUCTION: Concrete masonry bearing walls supporting precast concrete joists with masonry between.

EXISTING ROOF SYSTEM: 42' x 70' = 2,940 Sq. ft.

CONFIGURATION: Rectangular

SYSTEM USED: A previous addition on the south side of the building had a sloped (2 in 12) metal roof. The new roof conversion tied into the existing sloped roof at the same slope to form a single continuous roof. The new metal roof is supported with wood trusses 4'-0" on center, which are bearing on 2 x 6 plates attached around the building perimeter. The 3' wide, 26-gauge prefinished metal pans were nailed (with neoprene washers) into 2 x 4 purlins on 2'-0" centers which rested on top of the trusses.

DATE OF WORK: December, 1982

ATTIC VENTILATION: One 24" x 30" gable vent

COST: $9,125 or $3.10 per Sq. ft.
prefabricated wood trusses @ 4'-0" o.c.

26 ga. metal pans fastened with nails and neoprene washers

Maintaining the roof slope of a previous addition, the new roof used wood trusses over the main section of the building.

new sloped roof to tie into existing sloped roof

existing flat roof

existing addition with 2/12 roof slope

THRU BUILDING SECTION

previous addition with sloped roof

existing parapet wall below

26 ga. prefinished metal roof panels

With widely-spaced trusses (4'-0" o.c.), the metal pans required additional support from purlins.

2 x 4 purlins @ 2'-0" o.c.

wood trusses @ 4'-0" o.c.

ROOF PLAN
The new, sloped metal roof tied the addition to the original building. The back section of the building was an addition which had been designed to have a sloped roof.
**CASE STUDY #8**

<table>
<thead>
<tr>
<th>EXISTING ROOF SYSTEM:</th>
<th>Built-up, gravel surface over 1-inch rigid insulation over steel deck supported by steel bar joists.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUILDING SIZE:</td>
<td>31' x 132' = 4,092 Sq. ft.</td>
</tr>
<tr>
<td>CONFIGURATION:</td>
<td>Rectangular</td>
</tr>
<tr>
<td>DATE OF WORK:</td>
<td>June 1982</td>
</tr>
<tr>
<td>SYSTEM USED:</td>
<td>26-gauge, 3'-0&quot; wide Tech-Rib (pre-finished galvanized steel) panels were screwed to a supporting steel frame. The framing consists of 7&quot; steel “C”-channel rafters, 12'-0&quot; o.c., with 7&quot; steel “C”-channel purlins welded between at 5'-0&quot; o.c.</td>
</tr>
<tr>
<td>GUTTERS:</td>
<td>5&quot; prefabricated gutters were added to the top and bottom. The top gutter was to pick up water from a roof above.</td>
</tr>
<tr>
<td>INSULATION:</td>
<td>R-19 fiberglass batt insulation was added on top of existing roof.</td>
</tr>
<tr>
<td>COSTS:</td>
<td>$12,000 or $2.90 Sq. ft.</td>
</tr>
</tbody>
</table>
continuous dbl. 7" galv. C-channel rafters @ 12'-0" o.c.

7" galv. C-channels @ 5'-0" o.c.

existing wall

SECTION THRU ROOF

A section view of this conversion shows how steel C-channel was used for rafters and purlins. Proper ventilation was provided at low and high end of the roof.

7" galv. C-channels framed between @ 5'-0" o.c.

existing wall

3' wide white tech ribbed panels fastened with screws and neoprene washers

dbl. 7" galv. C-channels @ 12'-0" o.c.

gutter

existing roof line below

ROOF PLAN

The plan view of the roof shows the arrangement of rafters, purlins, and metal roofing panels.
7" channel, framed between rafters @ 5'-0" o.c.  Double 7" channel rafters @ 12'-0" o.c.

This view of the framing shows how the welded, metal C-channel provides a solid substructure for the non-structural metal roofing.

In this detail, the column is shown bolted to the existing root.
The 3-foot wide by 31-foot long, white, tech-rib metal roofing is being installed.

A view of the completed roof shows how a very low slope roof, using metal framing, was able to blend into the long, horizontal lines of the existing building.
On the front of the building, a wide fascia was used to hide the roof conversion. On this main portion of the building, the highest point on the roof is as high as the top of the fascia.

This detail at the rear of the building shows how the fascia disguises the actual roof behind it. In this case, the sloped roof drains to the rear of the building.