# Reduced Energy and Maintenance Costs Using Polyurethane as a Replacement Roof System

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## ABSTRACT

Reduction in maintenance and allied costs was the number one priority when Texas A&M University first considered polyurethane foam as a replacement roof for existing buildings. An investigation revealed that when properly applied, this system would solve most of the maintenance problems associated with built-up roofs. Standard specifications for this replacement roof were developed, requiring the application of 2 inches of polyurethane foam and 45 mils of a urethane coating. The result being a monolithic weatherproof cover for the roof. Additionly, with the application of polyurethane foam, a reduction in the energy used to air condition the building was noted. A method was developed for estimating maximum roof temperatures. Using the Heat Transfer Equation, $Q = U \times A \times dT$, roof loads before and after the application of the foam were calculated. With these loads, annual energy used was calculated and the savings resulting from the use of the foam were determined. 27 buildings were reroofed using polyurethane foam, totalling some 593,000 square feet at a total cost of $1,694,000. Annual energy savings were $327,500, for a payback of 5 years, 2 months, using the Simple Payback Method.

## INTRODUCTION

The majority of buildings on the Texas A&M University campus have built-up roofs (BUR). The materials that were used in the construction of this type roof are no longer providing the protection required without constant maintenance at ever-increasing costs.

The Texas A&M University Physical Plant Department developed a replacement roof system consisting of foamed polyurethane insulation protected by a tough, waterproof, weather resistant coating. The overall result was a superior roof system, virtually maintenance free, reducing maintenance and repair costs. Polyurethane foam with an average R value of 7.1/inch has one of the highest R values of commercially available insulation. The result was a substantial reduction in the energy used to heat and cool buildings. The savings become significant when considering the 1.1 million square feet of existing roof area that has this system. From 1980 through 1984, 27 buildings were reroofed using foamed urethane, totalling some 593,000 square feet at a cost of $1,694,000. Annual energy savings were calculated to be $327,000, having a 5 yr 2 mo simple payback. Assuming load reductions translate directly into energy savings.

## PROBLEM

Until some twenty years ago, most BUR systrems provided adequate protection with minimal maintenance. Commencing in the sixties, roofs began to fail earlier and more frequently. Several factors contributed to these failures:

1. lighter weight building construction
2. increased insulation in the roof system
3. increased number of penetrations - ductwork, piping, etc
4. degraded quality of materials - asphalt for coal tar, paper "felt"
5. application techniques

Asphalt becomes brittle more quickly than coal tar, reducing its ability to expand and contract without cracking. Rag content in roof felt has been replaced with paper or wood products, reducing its resistance to tearing or splitting. As a result, roof systems fail due to cracking or breaking of the vapor seal, allowing moisture to penetrate the system. Roof systems have become extremely complex, both in materials used and in the roof areas themselves. Numbers and types of penetrations have increased. In addition to the usual plumbing vent stacks and pipe, service piping and ducting in varying shapes and sizes, along with fans and other mechanical equipment, have been built into the roof system. All of this has compounded the problem of application, both in sealing penetrations and in flashing pipes and ductwork.

Prior to the wide-spread use of insulating materials in a roof system, temperatures could change rather rapidly across the system preventing major stresses from occurring. Increased use of insulation in the roof system stabilized temperatures within the system. This resulted in a build-up of stresses due to large temperature differentials developing when roof surface temperatures changed rapidly, such as a rain storm. The roof relieved these stresses by splitting or cracking the plies or by pulling apart at flashings or expansion joints. As a result the waterproof barrier was broken and the roof systems failed within a short time.

Roof maintenance crews were finding it increasingly difficult to maintain BUR roofs. Normal maintenance of a BUR system consisted of resaturating the felt, patching where failures had occurred and resealing and reflashing penetrations. In many instances roof crews were unable to accomplish a permanent fix without a major tear-off and replacement of the existing roof.



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SOLUTION

Commencing in 1974 and continuing through 1978, a retrofit roof foam system was developed which appeared to solve some if not all the maintenance and repair problems. Standard materials and application procedures were adopted which would provide an optimum solution to the increasing problems experienced with the typical built-up roof.

Specifications were developed utilizing these materials and procedures and periodically updated to assure the university of getting the best quality and installation available.

Application Procedures. Four major phases or steps are used in the installation of foamed polyurethane:

1. Surface Preparation. All loose gravel and debris are removed. Blisters, buckles and soft spots are cut out and loose areas are fastened. In areas where wet insulation is found, it is removed. The exposed area is allowed to dry, after which it is primed and foamed to existing surface. Should the area prove too large to repair, roof vents are installed to allow insulation to dry.

2. Application of Primer. After the roof is cleaned and repaired and is completely dry, a cutback asphalt or black urethane primer is applied to attain maximum adhesion. The black surface helps to elevate the surface temperature which aids the foaming action of the urethane.

3. Application of Spray Foam. Two inches of three pound density two-component polyurethane foam is applied. It is applied only under favorable conditions: calm, open weather, winds under 15 mph and temperatures above 50°F. The foam is applied in 3/4 inch lifts to a uniform thickness over the entire area, sloping only to facilitate drainage. Compressive strength of the foam is 55 LBS / Sq In. The foam is in a cream state when applied, flowing into and filling all cracks, holes and splits as the foaming process progresses, thus sealing the entire roof. The quantity of foam applied per day is limited by the capacity for applying a protective coating during the same day, so that no foam is left unprotected overnight.

4. Application of Protective Coatings. Coatings are applied in three layers of 15 mils each with each coat a different color, for a total thickness of 45 mils. The first layer or base coat is applied the same day that the foam is applied and is brown or black in color. The mid coat is tan or gray; and the top coat is white. The base and mid coats are two-component aromatic urethane elastomer. The top coat is a two-component aliphatic urethane elastomer, highly resistant to UV degradation. The coating system provides a waterproof monolithic cover with high tensile strength and elongation properties.

INSPECTION PROCEDURES. Each phase or step of the application is inspected and approved before proceeding to the next step. Coatings are periodically tested during application for proper curing. Final inspection consists of cutting sample plugs and recording these and measuring total depth

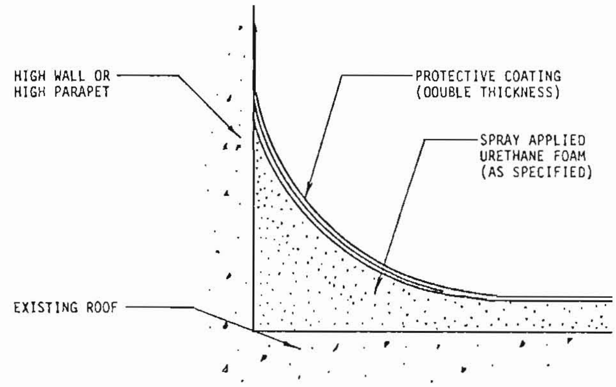


Figure 1 Detail of Wall or Parapet

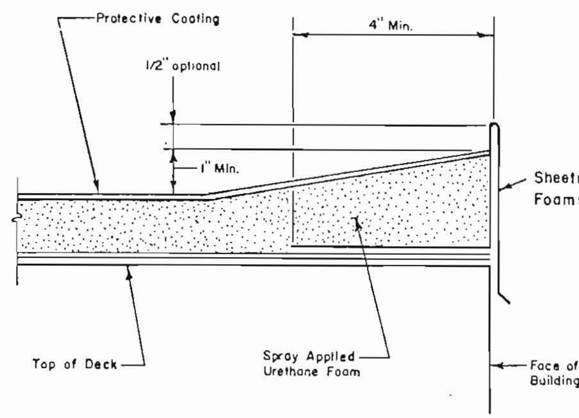


Figure 2 Detail of Foamstop

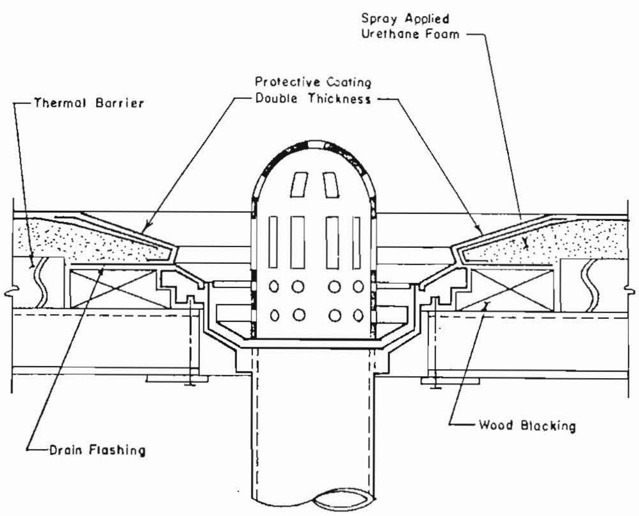


Figure 3 Detail of Roof Drain



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of foam and coatings. The roof is visually inspected for quality of the application. Particular attention is given to penetrations, flashings, edging, etc. Clean-up of the roof and surrounding area is closely supervised because of flammable solvents used to clean the nozzles, hoses and equipment.

Figures 1 through 5 show typical details of the application of foam and its coating.

MAINTENANCE AND REPAIR. Maintenance of urethane roof systems consists primarily of washing down to remove debris. Any holes or splits are caulked with urethane caulking compound. New penetrations for ductwork or piping are foamed to seal, then coated to protect the foam. The coatings are generally renewed every 10 to 12 years. Whenever recoating is needed, the Physical Plant roof crews handle small roofs. Large ones are recoated by contract.

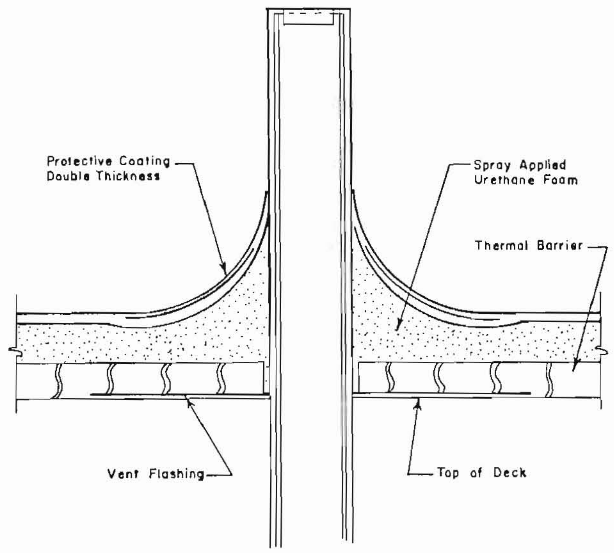


Figure 4 Detail of Mechanical Vent

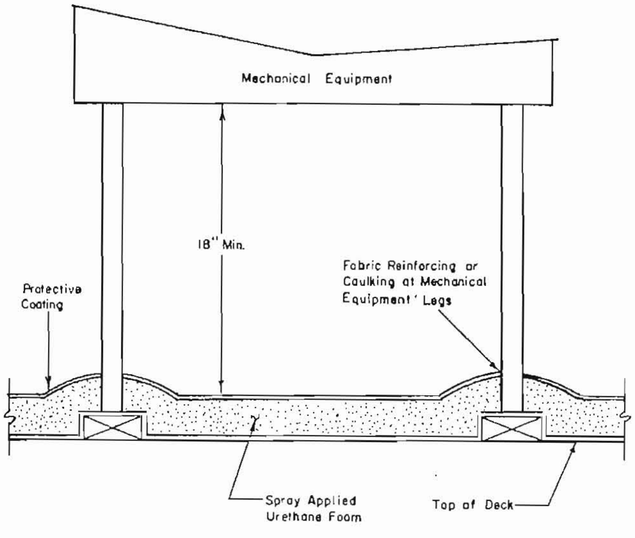


Figure 5 Detail of Mechanical Equipment Stand

ENERGY ANALYSIS

Texas A&M University is located in central Texas where cooling degree days are about twice heating degree days; and cooling costs are approximately 20% higher than heating costs. Consequently, the application of polyurethane foam to existing roofs provided a reduction in the energy used in conditioning buildings. With 1.1 million square feet of roof area retrofitted with polyurethane, the savings in energy and associated costs have become substantial.

Not all buildings on the A&M University campus are metered for energy consumption. As a consequence, an alternative method for determining energy consumption was required. Calculated annual energy requirements have been used for years. While calculated results are not as accurate as metered results, their accuracy is acceptable when used in making a comparative analysis. To document the reduction in energy consumption and subsequent savings, a method was devised whereby roof surface temperatures could be estimated and applied in the Heat Transfer Equation.

To determine the savings resulting from the application of the retrofit foam roof system, it was necessary to calculate the quantity of energy transferred through the roof system, using the heat transfer equation $Q = U \times A \times dt$. When Q is multiplied by a unit of time, T, in this case one year, the product becomes Total Quantity Qt, or ANNUAL LOAD.

"dt" is the temperature difference between the exterior surface of the roof and the interior surface of the roof system. Room temperature is used as the interior surface temperature. A correction factor for a ventilated or non-ventalated ceiling plenum is introduced in correcting the Cooling Load Temperature Difference (CLTD), which is the "dt" for summer. "dt" for winter would be the actual temperature difference.

T, unit of time, is referenced as Annual Equivalent Full Load Hours (EFLH), using the ratio of actual dt to design dt. The Dry Bulb BIN was used as the basis for determining exterior roof surface temperature.



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The following equations were developed to determine the Roof Temperature and EFLH.

ROOF TEMP (SUM) = (BIN DB - DESIGN OA)
+ (CLTD + RM TEMP)
(WIN) = BIN DB

$$EFLH = BIN\ HRS/YR \times \frac{(ROOF\ TEMP - RM\ TEMP)}{(DESIGN\ OA - RM\ TEMP)} \frac{(act\ dt)}{(des\ dt)}$$

Tables published in the ASHRAE Handbook 1989 Fundamentals along with area temperature data found in the U.S. Air Force Manual "Engineering Weather Data" were used in determining the values of the factors in the Annual Load Equation.

EXAMPLE

The roof of the Coke Building, Texas A&M University, was analyzed to verify the method for calculating energy savings. This is a two-story administrative office building with a basement. The building contains 22,500 square feet of floor space with 7620 square feet of roof area. The original roof system consisted of a 3-ply built-up roof over a 1" insulated board supported by a concrete deck, Figure 6.

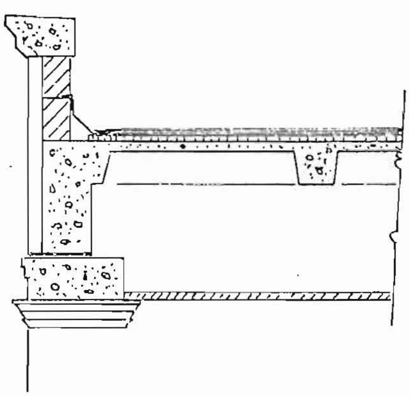



Figure 6 Coke Building
7620 sq ft Roof Area
Constructed 1951

DESIGN CONDITIONS FOR CALCULATING ROOF LOAD

| | SUMMER | WINTER |
|---|---|---|
| OUTSIDE TEMPERATURE | 96 DB | 20 DB |
| DAILY RANGE | | 20 DB |
| INSIDE TEMPERATURE | 75 DB/50%RH | 75 DB |
| URETHANE R = 7.1/IN | | |

I. U FACTOR

A. Uo FACTOR, ORIGINAL ROOF

| | |
|---|---|
| R - OA | 0.25 |
| INSUL | 3.45 |
| CONC | 0.32 |
| A SPACE | 1.00 |
| PLASTER | 0.47 |
| INSIDE A | 0.61 |
| Ro = | 6.43 |

Uo = 1/Ro = 0.156

B. Un FACTOR, NEW ROOF (2" urethane added)

Rn = 6.43 + 14.2 = 20.63, Un = 1/Rn = 0.0485

II. dt FACTOR - SUMMER: CLTD
WINTER: dt

A. ORIGINAL ROOF
CLTDo = CLTDc, CH. 26, ASHRAE, 1989 FUNDAMENTALS
CLTDo = [(38+2) x 1.0 + (78-75) + (88-85)] x 1= 46
dt = (75-20) = 55

B. NEW ROOF
CLTDn = CLTDc
CLTDn = [(38+2) x 0.5 + (78-75) + (88-85)] x 1= 26
dt = 55

III. T, EQUIVALENT FULL LOAD HOURS

With CLTD and dt determined, T was calculated as EFLH, using Air Force table "Mean Frequency of Occurrance of Dry Bulb Temperature with Mean Coincident Wet Bulb Temperature" for each Dry Bulb Range for the Bryan/College Station area. Computations were translated using BIN midpoint to list the hours per year each BIN occurred and to determine the surface temperature of the roof. A ratio of the actual temperature difference to the design temperature difference at each BIN was multiplied by the hours per year for each BIN to obtain the EFLH.

IV. CALCULATIONS

ANNUAL LOAD, Qt = U x A x dt x T

A. ORIGINAL ROOF
COOLING Qt = 0.156 x 7620 x 46 x 6494.0
= 355,099,190 BTU/YR
HEATING Qt = 0.156 x 7620 x 55 x 750.5
= 49,067,389 BTU/YR

B. NEW ROOF
COOLING Qt = 0.0485 x 7620 x 26 x 2401.0
= 23,071,737 BTU/YR
HEATING Qt = 0.0485 x 7620 x 55 x 1524.6
= 30,989,553 BTU/YR

LOAD REDUCTIONS

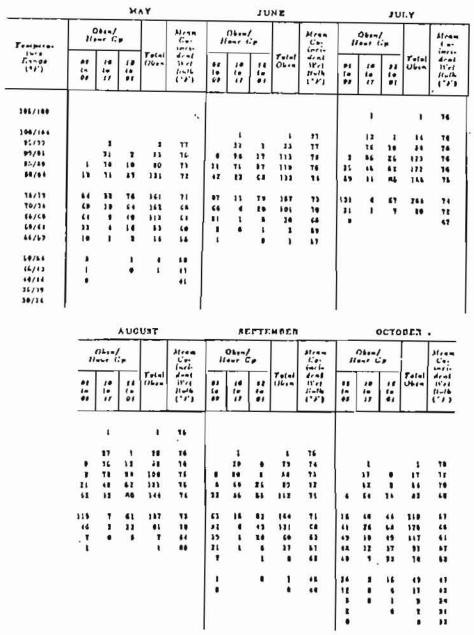
COOLING 355,099,190 BTU/YR
- 23,071,737
332,027,460 BTU/YR

HEATING 49,067,389 BTU/YR
- 30,989,553
18,077,836 BTU/YR

1980 ENERGY COSTS
COOLING - CHILLED WATER $4.72/MMBTU
HEATING - HOT WATER $3.79/MMBTU

ENERGY COSTS SAVED
REDUCED COOLING 332,027,460 BTU/YR @ $4.72/MMBTU
= $1567.17
REDUCED HEATING 18,077,836 BTU/YR @ $3.79/MMBTU
= $ 68.50
TOTAL ENERGY COSTS SAVED $1635.67

cooling season



heating season

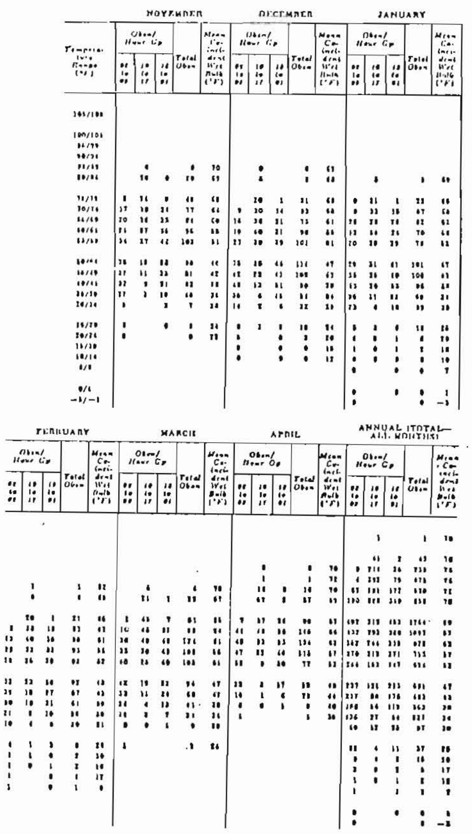


Figure 7 Mean Frequency of Occurrence of Dry Bulb Temp with Mean Coincident Wet Temp, (°F) Bryan / College Station, Texas

A. Original Roof

| BIN | MID PT | HR/YR | CLTD | ROOF TEMP* | RATIO (act-dt)/(des-dt) | EFLH,T |
|---|---|---|---|---|---|---|
| 105/109 | 107 | 2 | 46 | 132 | 132-75=57<br>96-75 21 | 5.4 |
| 100/104 | 102 | 44 | | 127 | 52x1<br>55 | 109.0 |
| 95/99 | 97 | 239 | | 122 | 47 | 535.0 |
| 90/94 | 92 | 475 | | 117 | 42 | 950.0 |
| 85/89 | 87 | 630 | | 112 | 37 | 1110.0 |
| 80/84 | 82 | 858 | | 107 | 32 | 1307.4 |
| 75/79 | 77 | 1264 | | 102 | 27 | 1625.1 |
| 70/74 | 72 | 1093 | | 97 | 22 | 1145.0 |
| 65/69 | 67 | 928 | | 92 | 17 | 751.2 |
| 60/64 | 62 | 753 | | 87 | 12 | 430.3 |
| 55/59 | 57 | 654 | | 82 | 7 | 218.0 |
| 50/54 | 52 | 591 | | 77 | 2 | 56.3 |
| | | | | | | 6494.0 |
| 45/49 | 47 | 483 | | (72)* | 47-75=-28<br>20-75 -55 | 245.9 |
| 40/44 | 42 | 363 | | | -33x-1<br>55 | 217.9 |
| 35/39 | 37 | 227 | | | 38 | 156.8 |
| 30/34 | 32 | 97 | | | 43 | 75.8 |
| 25/29 | 27 | 38 | | | 48 | 33.2 |
| 20/24 | 22 | 15 | | | 53 | 14.5 |
| 15/19 | 17 | 4 | | | 58 | 4.2 |
| 10/14 | 12 | 1 | | | 63 | 1.1 |
| 5/9 | 7 | 1 | | | 68 | 1.2 |
| | | | | | | 750.5 |

Figure 8 Original Roof EFLH Calculations

B. New Roof

| BIN | MID PT | HR/YR | CLTD | ROOF TEMP* | RATIO (act-dt)/(des-dt) | EFLH,T |
|---|---|---|---|---|---|---|
| 105/109 | 107 | 2 | 26 | 112 | 112-75=37<br>96-75 21 | 3.5 |
| 100/104 | 102 | 44 | | 107 | 32x1<br>21 | 67.0 |
| 95/99 | 97 | 239 | | 102 | 27 | 307.3 |
| 90/94 | 92 | 475 | | 97 | 22 | 497.6 |
| 85/89 | 87 | 630 | | 92 | 17 | 510.0 |
| 80/84 | 82 | 858 | | 87 | 12 | 490.3 |
| 75/79 | 77 | 1264 | | 82 | 7 | 421.3 |
| 70/74 | 72 | 1093 | | 77 | 2 | 104.1 |
| | | | | | | 2401.1 |
| 65/69 | 67 | 928 | | (72)* | 67-75=-8<br>20-75 -55 | 135.0 |
| 60/64 | 62 | 753 | | | -13x-1<br>55 | 178.0 |
| 55/59 | 57 | 654 | | | 18 | 214.0 |
| 50/54 | 52 | 591 | | | 23 | 247.1 |
| 45/49 | 47 | 483 | | | 28 | 245.9 |
| 40/44 | 42 | 363 | | | 33 | 217.8 |
| 35/39 | 37 | 227 | | | 38 | 156.8 |
| 30/34 | 32 | 97 | | | 43 | 75.8 |
| 25/29 | 27 | 38 | | | 48 | 33.2 |
| 20/24 | 22 | 15 | | | 53 | 14.5 |
| 15/19 | 17 | 4 | | | 58 | 4.2 |
| 10/14 | 12 | 1 | | | 63 | 1.1 |
| 5/9 | 7 | 1 | | | 68 | 1.2 |
| | | | | | | 1524.6 |

*When roof temp is above rm temp, use sum roof temp.
When roof temp is above rm temp, use win roof temp.

Figure 9 New Roof EFLH Calculations

VERIFICATION

A portable Energy Monitoring system was installed prior to reroofing the Coke Building to record the OA temperatures and tons of air conditioning used. Figure 10 was recorded Sunday, May 18, 1980 to establish a building base load. At 75 OA temperature, the load was 45 tons. Wednesday, May 14, was selected to provide a typical load, Figure 11. Figure 12, shows the resultant decrease in load due to the application of foam; about 6 tons at OA design temperature. Figure 13 was developed from Figures 11 and 12, showing the cooling load as a function of OA temperature. Cooling savings of $1740.20 were calculated from this graph and compared with calculated savings of $1567.17. Calculated savings were 10% less than graph generated savings, which was acceptable. It would be a coincidence if one year coincided with the BIN temperatures.

The method thus developed was sufficiently accurate for use in making an analysis of a roof system retrofit using polyurethane foam and the resulting energy savings generated by its use.

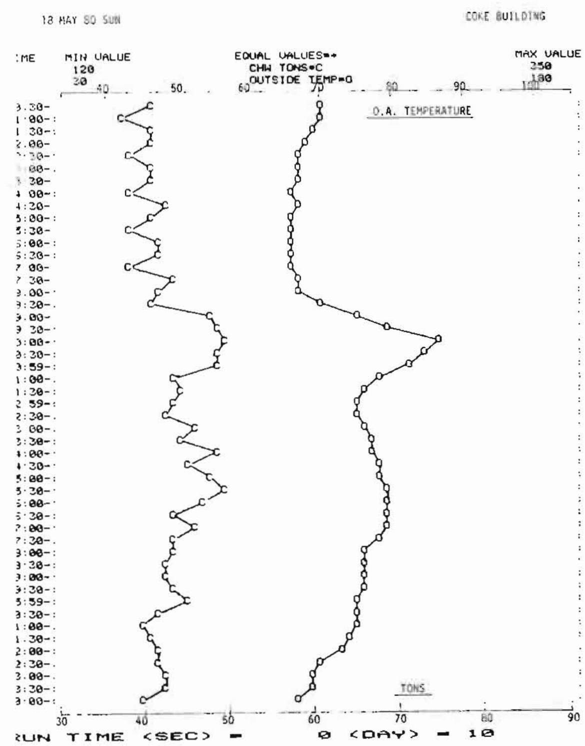



Figure 10 Building Base Load Tons vs OA Temp

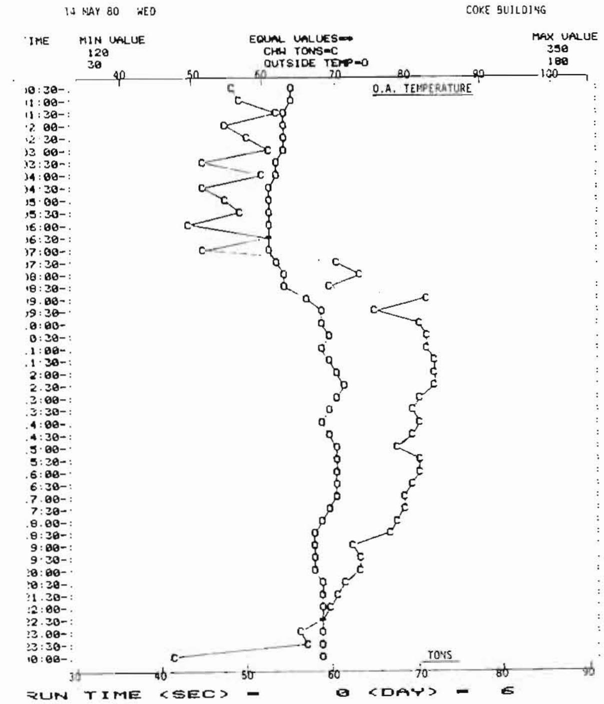



Figure 11 Typical Building Load, before foam roof, Tons vs OA Temp

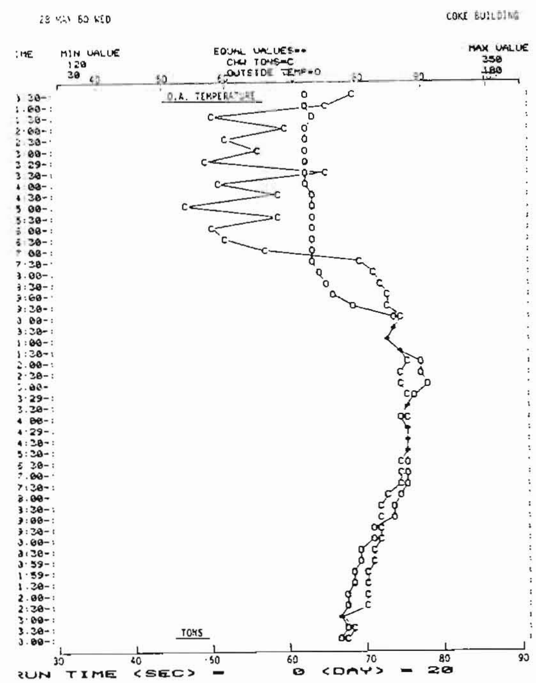



Figure 12 Building Load, after foam roof, Tons vs OA Temp



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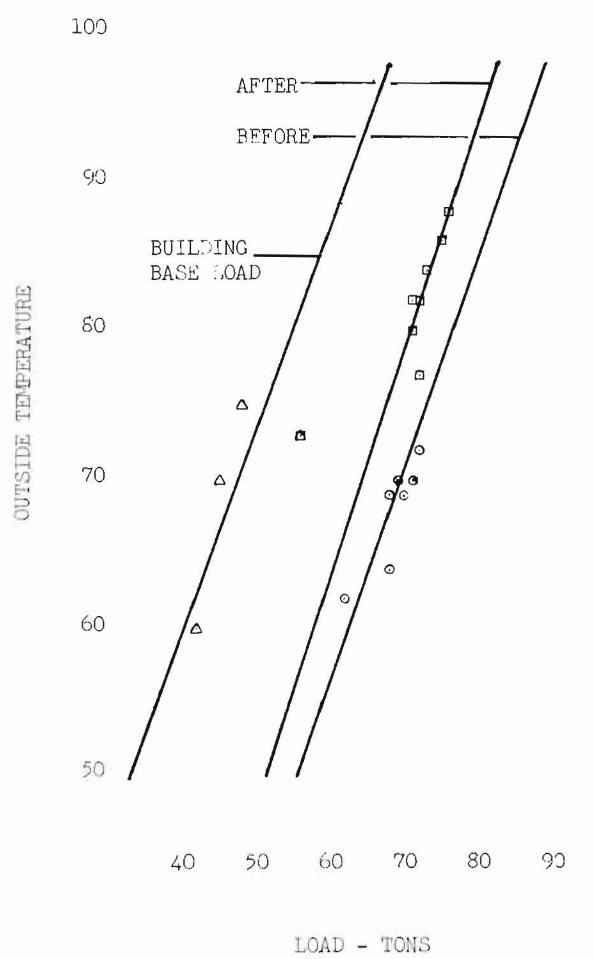


Figure 13 Building Load Summary Tons vs OA Temp

ENERGY SAVINGS

From 1980 through 1984, 27 buildings on the Texas A&M campus were reroofed, using polyurethane foam, totalling 593,500 square feet. This period was chosen because of the number of buildings reroofed and the diversity in age, type of construction and use.

The cost of reroofing these buildings totalled $1,694,400. The annual savings in energy costs were $327,500, calculated by this method. The payback for these buildings was 5 years, 2 months, using the simple payback method.

| Year | # of Bldg | Roof SF | Cost to Construct | Energy Saved | Simple Payback |
|---|---|---|---|---|---|
| 1980 | 7 | 61,563 | $164,214 | $76,055 | 2 y 2 m |
| 1981 | 4 | 75,670 | 184,304 | 16,532 | 11 2 |
| 1982 | 3 | 44,280 | 126,400 | 31,144 | 4 |
| 1983 | 8 | 163,516 | 414,135 | 74,048 | 5 7 |
| 1894 | 5 | 248,500 | 805,346 | 129,681 | 6 3 |
| TOTAL | 27 | 593,529 | $1,694,399 | $327,460 | 5 2 |

Actual energy used depends on several factors other than heat gain or loss through the structure itself. Factors such as: type and efficiency of the HVAC system, simultaneous use of the heating and cooling mediums, the form of energy used ( chilled water, dx,etc) and the method of distribution. These factors would affect the payback period somewhat, perhaps lengthening it.

CONCLUSIONS

Experience gained by Texas A&M University since 1974, when this program began, indicates no major problems and very few minor ones exist in the polyurethane foam roof systems. And the pay-back is such that the program could be self-perpetuating. Accounting procedures have not been set up to show this.

As a result of this experience, at least from the maintenance and repair stand-point, the Texas A&M System Facilities Planning Department modified the specifications developed by the Physical Plant for use in new construction. In the retrofit system, the urethane foam was applied to the existing roof system, which added to any pre-existing insulation, thus increasing the over-all insulating character of the roof system. In new construction, urethane foam is used within the roof system to the thickness required to comply with ASHRAE standards 90.1989.