CONF-9610200--2

# Sustainable Roofs with Real Energy Savings

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To be published in the Proceedings of the
Sustainable Low-Slope Roofing Workshop
held at the Pollard Auditorium
Oak Ridge, Tennessee
October 9-10, 1996

MASTER

Research sponsored by
the Office of Building Technologies and
Department of Energy



Prepared by the
**OAK RIDGE NATIONAL LABORATORY**
Oak Ridge, Tennessee 37831
managed by
**LOCKHEED MARTIN ENERGY RESEARCH CORP.**
for the
**U.S. DEPARTMENT OF ENERGY**
under contract No. DE-AC05-96OR22464

## DISCLAIMER

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## ABSTRACT

This paper addresses the general concept of sustainability and relates it to the building owner's selection of a low-slope roof. It offers a list of performance features of sustainable roofs. Experiences and data relevant to these features for four unique roofs are then presented which include: self-drying systems, low total equivalent warming foam insulation, roof coatings and green roofs. The paper concludes with a list of sustainable roofing features worth considering for a low-slope roof investment.

Building owners and community developers are showing more interest in investing in sustainability. The potential exists to design, construct, and maintain roofs that last twice as long and reduce the building space heating and cooling energy loads resulting from the roof by 50% (based on the current predominant design of a 10-year life and a single layer of 1 to 2 in. (2.5 to 5.1 cm) of insulation. The opportunity to provide better low-slope roofs and sell more roof maintenance service is escalating. The general trend of outsourcing services could lead to roofing companies' owning the roofs they install while the traditional building owner owns the rest of the building. Such a situation would have a very desirable potential to internalize the costs of poor roof maintenance practices and high roof waste disposal costs, and to offer a profit for installing roofs that are more sustainable.

# SUSTAINABLE ROOFS WITH REAL ENERGY SAVINGS

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## INTRODUCTION

This paper addresses the general concept of sustainability and relates it to the building owner's selection of a low-slope roof. It offers a list of performance features of sustainable roofs. Experiences and data relevant to these features for four unique roofs are then presented. The paper concludes with a list of sustainable roofing features worth considering for a low-slope roof investment.

## SUSTAINABLE ROOF CONCEPTS

Sustainability is a useful concept but not a scientific term. Many inspiring definitions of sustainability have been given; the most popular is meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Relating sustainability to deciding what type of low-slope roof we should install requires a desire to educate ourselves rather than simply buy the roof with the lowest first cost that just meets minimum code requirements and comes with a piece of paper bearing the words "10-year warranty." With regard to environmental issues and energy efficiency, it means that we will not leave the entire decision to others: code officials, consultants, contractors. Federal facilities and some local and state building owners are increasingly selecting what they perceive to be sustainable roofs. Realizing that the 10-year-warranty, low-first-cost roof option results in serious negative environmental consequences, and that the pursuit of a sustainable roof can be a source of pride, significantly increases the likelihood we will insist on a quality roof. Each one of us should act according to the realization that our economy and environmental preservation are interrelated and compatible because our economic well being must be forged with finite environmental resources.

Sustainable roofs also should appeal to the insurance industry: Sustainable roofs reduce roof-related damage claims in the short term. They should appeal to everyone, especially the insurance industry, by increasing roof energy efficiency in the long term, thus reducing $CO_2$ emissions that contribute to global warming. The consensus among atmospheric scientists is clearly that global warming is real. Many atmospheric scientists believe that global warming is partially to blame for the increased instances of natural disasters such as hurricanes, which increase insurance rates.

Another concept underlying sustainability is the intrinsic value of the natural environment. Protecting the environment is compatible with long-term human interests. To the buyer of a roof, concern for the environment translates into more energy efficiency and minimum waste production, pollution, landfill space, and environmental risk. For the longer term, it might mean the use of best practices, implemented through codes, financial incentives, and education and information programs. High-efficiency appliances like refrigerator-freezers and room air-conditioners have been legislated into existence; the same could happen with low-slope roofs. What if the mandate came down, "Thou shalt install a roof that lasts the life of the building"?

From a sustainability perspective, the overall incentive to extend the service life of roofs is huge. In the United States alone, an increase in service life from 15 to 30 years should help the economy by reducing the current cost of roofing by \$5.4 billion/year—45% of the current cost—and help the environment by reducing the volume of reroofing by 0.16 billion $ft^3$/year (4.5 million $m^3$/year)—40% of current roofing waste and 1.6% of the total solid waste landfilled each year. If high-quality sustainable roofs could keep the insulation dry in low-slope roofs in the southeastern United States, we could eliminate the equivalent of one 900 MW coal-fired power plant currently needed because of the lost thermal performance resulting from trapped roof moisture (Kyle and Desjarlais 1994).

Roofs should be judged sustainable if in the long run they reduce waste, minimize the use of nonrenewable resources, and minimize global warming cost-effectively. Sustainability should not be used as an objective criterion. Rather, it should be used to broaden the selection criteria to integrate environmental concerns and economic considerations.

Granted, it is hard enough, when deciding on a low-slope roof, to broaden our focus to base a decision on life-cycle cost analysis, thereby including future energy savings. Sustainability encourages us to factor in additional environmental issues not reflected in the lowest-first-cost bid. As decision makers in developed countries, increasingly dependent on global cooperation to reduce environmental risks (e.g., global warming, loss of bio-diversity caused by destruction of the rain forests), we need to understand the impacts of our local decisions and educate ourselves to make globally sensitive choices.

The energy efficiency industry speculates that utility deregulation not only will result in a short-term drop in real energy prices, but also may slow down the progress being made toward continuous energy efficiency improvements. One hope is that insurance industry incentives will compensate for the slowdown and encourage more sustainable decisions. What better place to start than up on the roof? The \$1 million cooperative research and development agreement between the Roofing Industry Committee on Wind Issues (RICOWI) and the Oak Ridge National Laboratory (ORNL) signed in August 1996 may prove to be that start. This agreement includes about 25% participation from the insurance industry. The initial focus will be on learning from major high-wind incidents how to extend the service life and energy efficiency of roofs.

## SUSTAINABLE ROOFING FEATURES

### Energy Efficient

ORNL is studying the total equivalent warming impact of low-slope roofs. Preliminary results from this study show that in the United States, the total indirect $CO_2$ emissions of uninsulated low-slope roofs average 260 lb/$ft^2$ (1250 kg/$m^2$). By comparison, if the entire envelope of a commercial building is insulated according to ASHRAE Standard 90.1 except for the low-slope roof, which is left uninsulated, the total $CO_2$ emissions will average 560 lb/$ft^2$ (2750 kg/$m^2$). This suggests that insulating low-slope roofs would reduce the global warming impact of the entire average envelope by about 45%. Generally, the energy cost savings alone justify the added expenditure for insulation that meets the ASHRAE 90.1 standard. Clearly, given the large global warming impact of uninsulated low-slope roofs, the minimum requirement for a roof to be considered sustainable would be energy performance at least equivalent to that resulting from ASHRAE 90.1 prescriptive insulation levels.

### Reusable

The closer we can come to a low-slope roof that can be completely disassembled, the easier it will be to reuse the materials. The loose-laid, fully ballasted system is a good example. The absence of adhesives facilitates separation of materials and minimizes contamination and physical damage of the reusable products. Ballast is always easy to reuse and frequently can be used on site, minimizing hauling costs.

### Recyclable

A good example of recycling potential low-slope roofing waste is a demonstration project titled "Roofs to Roads" getting started at ORNL. The objective of the project is to demonstrate the feasibility of on-site processing of built-up roofing (BUR) and shingle waste into acceptable asphalt aggregate extender. The processed roofing waste will be mixed with gravel aggregate and fresh asphalt and used for capping on-site nuclear waste disposal sites on the Oak Ridge Reservation, repairing potholes, paving jogging/walking/biking paths, and possibly resurfacing parking lots.

In 1991, the three U.S. Department of Energy (DOE) facilities at Oak Ridge needed roof-related work worth more than an estimated $100 million dollars. Many of these buildings are now being repaired for lease and possible sale to private industry. One engineering cost estimate for the new roofs needed at ORNL alone exceeds an average of \$32 per $ft^2$ (\$344 per $m^2$) partly because of the high cost of disposing of roof waste. In 1991 ORNL had a total of 46 acres (186,000 $m^2$) of roofs, 32 acres (129,000 $m^2$) of which needed reroofing, which was projected to generate 15,000 $yd^3$ (425 $m^3$) of waste. The Oak Ridge K-25 site has another 150 acres (607,000 $m^2$) of roof. The Y-12 site in 1995 needed 100 acres (405,000 $m^2$) of new roof, which could generate another 33,000 $yd^3$ (934 $m^3$) of waste.

The preliminary plan for the Roofs to Roads project is to have ASTEC Industries, a Chattanooga, Tennessee–based manufacturer of recycling equipment, set up a transportable facility on the Oak Ridge Reservation when reroofing and repaving are at a peak. Coordinated infrastructure repair will minimize costs, storage, and handling time.

The Roofs to Roads concept internalizes the risks of offsite waste disposal and converts the waste into an on-site asset. Local government involvement in projects of this type can help generate market guarantees for the recycled product (e.g., parks, greenway paths, parking lots). Community governments have the authority to regulate landfill tipping fees and specify paving materials, and they own quite a few low-slope roofs.

### 30-Year Life

A recent report from the Civil Engineering Research Foundation states that the average service life of a roof is approximately 12–15 years (Civil Engineering Research Foundation 1994). In 1987 DOE established a national user facility for roof research at ORNL with an explicit focus on improving the thermal efficiency and service life of commercial and residential roof construction systems.

It has evolved into the current Buildings Technology Center (BTC). DOE invested more than $5 million dollars in capital testing facilities and suggested that half the operating budget come from private industry. The Roofing Industry Research Advisory Panel back in 1987 ranked the ten most important research areas that could extend service life. The word mentioned most often, found in seven of the top ten issues, was "moisture." The *National Program Plan for Building Thermal Envelopes* completed by the Building Environment and Thermal Envelope Council in 1994 also ranked moisture issues as number one (BETEC 1994). Any efforts to extend service life must include enhanced moisture control within the roof system.

### Marketable

A concept worth exploring is development of a volunteer rating/labeling proceedure for sustainable roofs, similar to the procedure being developed for testing and rating whole walls at the BTC (Christian and Kosny 1996). A whole wall's resistance to heat flow is measured using steady-state and dynamic testing in a guarded hot box. The test results are then entered into a simulation model, which predicts the thermal performance of the entire opaque wall including all thermal shorts. The whole wall R-value ratings allow builders and buyers to compare the thermal resistances of dissimilar walls. The wall performance information is placed in a database on the World Wide Web (http://www.cad.ornl.gov/kch/demo.html), and home designers, builders, realtors, and buyers can use it to predict ratings customized for their own building wall system alternatives. Major criteria could also be presented to help building owners select sustainable roof features.

In 1996 visitors came to the Buildings Technology Center from at least three cities striving to create more sustainable communities: Austin, Texas; Brownsville, Texas; and Chattanoga, Tennessee. We perceived the focus of all three delegations to be having, at the very least, educational materials to direct business to more sustainable development. The Roofs to Roads project was extremely interesting to these visitors. Many times community governments lack the technical information to make the right choices. For instance, several communities have tried to ban foam insulations over the last several years. Their intentions are good; however, a balanced set of criteria is needed to help select higher-quality roofs.

### Educational

An important element of sustainable roofs is connecting them to an educational opportunity. In fact, when a roofing project is labeled "research," it gets around many road blocks and may actually generate financial contributions from sources such as local, state, and federal government agencies; roofing-related industries; and waste regulatory agencies. For example, as part of a reroofing project for a school building, a data logger could be installed to monitor the lower roof surface temperature due to the installation of a white membrane instead of a black membrane. The students could follow the temperature records and learn the effects of one practical way to improve a roof. The educational aspect of the roofing project would make it research. Research is of interest to, for example, DOE, which has a program that builds energy-efficient modular school rooms. These structures could contain more sustainable roofs if they contributed to the research mission of DOE.

## EXAMPLES OF SUSTAINABLE ROOFS

### A. Roof Recovery and Dryability: ORNL Building 2518

#### Description

The sustainable features added to the existing roof on Building 2518 are more insulation and dryability. The 27-year-old existing roof on a steel deck over a single-story, 12,880-$ft^2$ (1,197-$m^2$) office building in Oak Ridge was re-covered with a spray-applied polyurethane (PUR) foam and a silicone top coat. The original roof was BUR topped by gravel ballast. The steel deck was covered with a felt layer and 0.625-in. (16-mm) fiberglass insulation boards. Over the years, the BUR membrane failed and water soaked into about 40% of the insulation. During the re-cover, the deck vapor permeability was increased to permit downward roof drying. Before the foam layer was applied, a 4 by 6 ft (1.2 by 1.8 m) section of the roof was removed and tested in ORNL's large scale climate simulator. In the dry condition, the overall R-value of the section was measured at 2.8 h•$ft^2$•°F/Btu (0.48 $m^2$•K/W). In the wet condition, it was measured at 0.5 h•$ft^2$•°F/Btu (0.09 $m^2$•K/W). From these values, it was estimated that the average R-value of the existing roof was 1.8 h•$ft^2$•°F/Btu (0.32 $m^2$•K/W). It is estimated that as the old wet roof dries, the roof R-value of the old roof will increase 1.0 h•$ft^2$•°F/Btu (0.18 $m^2$•K/W). Prior to foam spraying, all of the loose gravel was collected and used to help pave a parking lot (McLain, Christian 1995).

The PUR was sprayed on the roof at an average thickness of 1.84 in. (46.7 mm). The measured average overall R-value was 13.2 h•$ft^2$•°F/Btu (2.32 $m^2$•K/W). A silicone top coating, together with the whitest reflective granules available at the time of installation, was applied over the PUR. The solar reflectance of this coating was measured using a commercial solar reflectometer at 0.28.*

The building has suspended acoustical tile ceilings. Cooling is provided by packaged rooftop air-conditioning units with constant volume air handlers. Heating is supplied by district steam. The building has a fully operational energy management system that is programmed to run the building efficiently. The air handlers are operated only when needed from 6:00 A.M. to 6:00 P.M. on weekdays and shut down at night and weekends. The building has energy-efficient lighting with a power density of 0.75 W/$ft^2$ (8.1 W/$m^2$).

#### Energy savings measurements

The energy efficiency of the recovered roof was measured and used to calibrate a whole-building simulation model that is used to extrapolate the energy savings to other building types and climates (McLain, Christian 1995).

The building was instrumented to measure at 30-min intervals the energy consumption of the whole building and of the individual rooftop air conditioners, the roof heat fluxes, and the interior air and roof temperatures. These data were used to evaluate the energy effectiveness of the roof re-cover.

The energy savings analysis was done using the DOE-2.1E building simulation program, which was calibrated to match the measured data. The roof re-cover led to cooling energy savings of around 10%

*Solar Spectrum Reflectometer Model SSR-ER, Version 5, Devices and Services Company, 10024 Monroe Dr., Dallas, TX 75229.

and heating energy savings of around 50%.

## Development of a calibrated simulation model

Building simulation models, such as DOE-2.1E, are functions of many parameters, which must be adjusted to predict the true physical behavior of the building (LBL 1981, 1993). This building simulation used extensive test data to describe the important physical features accurately. The development of the input data files for the model started with a detailed building survey that included occupancy, functional areas, office equipment, lighting systems, envelope construction, HVAC systems, controls, and zoning. The model results were compared with the experimental data collected at the building. The input parameters were adjusted, and the process was repeated until there was a good match between the simulations and the building data.

Thermocouples and heat flux sensors were embedded in the roof at three locations shown in Fig. 1. Air handler units were instrumented to measure the temperatures of the supply and return air. Circulating air flow rates were measured using pitot tube and heated-wire anemometer traverses. The operating power level of air handlers was also measured.

Site meteorological data were collected every half-hour. These data were used as the weather data for calibrating the DOE-2.1E model. They included ambient air temperature and humidity, wind speed and direction, and the total horizontal solar energy.

On a monthly basis, the agreement between predicted and measured electrical energy consumption for 1994 is reasonably good, as shown in Fig. 2. During June through September and in December, the agreement is within 5%. The model was judged sufficiently accurate for evaluating the impacts of the roof re-cover.

A second check on the model calibration was a comparison of the measured and predicted heat fluxes through the roof. Figure 3 presents the comparisons at the locations of the three heat flux sensors for the week of April 10–17, 1994. Figure 4 presents the comparisons at the locations of the southwest and northwest flux sensors for the week of July 10–17, 1994.

This calibrated model is considered a positive by-product of this roof research project because it gives the "next generation" roofing industry a powerful tool for estimating credible energy savings of other sustainable roofs in other locations.

## Sustainabity lessons learned

The energy savings calculation using the roof physical data listed above is defined as the *base case*. Additional energy savings calculations were then made for several building variables. The energy costs used, for evaluating the energy cost savings for the nation as a whole, were the national average rates of \$0.075/kWh for electricity and \$5.00/MBtu (\$0.017/kWh) for natural gas (EIA 1994). For calculating heating cost savings for the nation as a whole, it was assumed that the building was heated by a hot water boiler having an annual fuel use efficiency (AFUE) of 0.65.

**Base case recovered roof.** The cooling energy savings for the re-covered building assumed for the base case is \$0.035/ft$^2$ (\$0.38/m$^2$) of roof area or 10% of the original cooling energy consumption. About 53%, which is \$0.054/ft$^2$ (\$0.58/m$^2$), of the heating energy is saved.

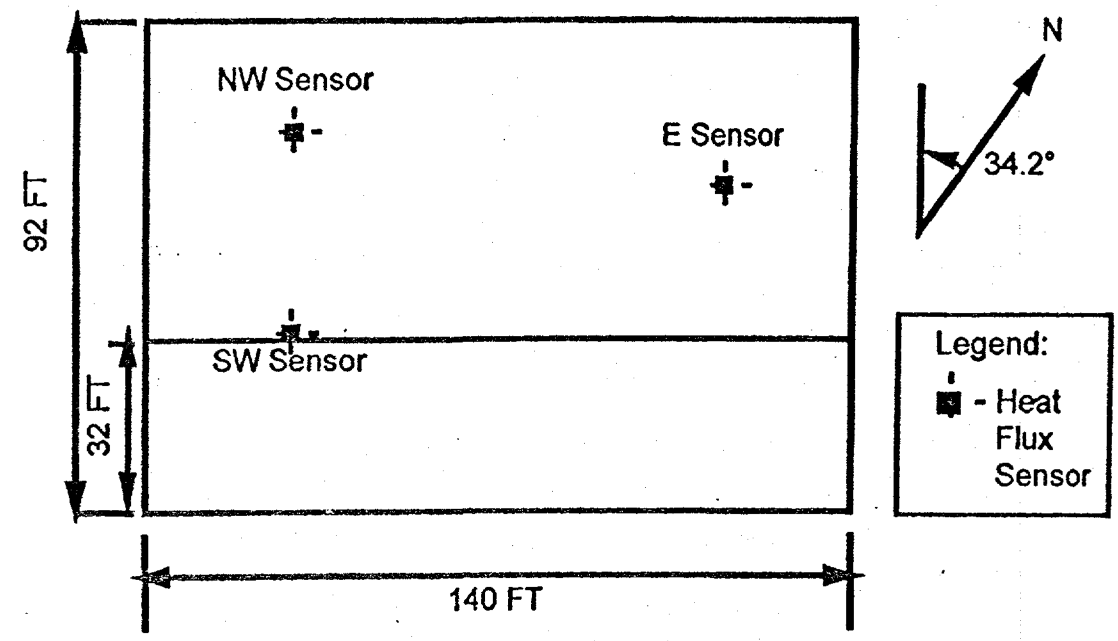


Fig. 1. Schematic plan view of ORNL Building 2518.

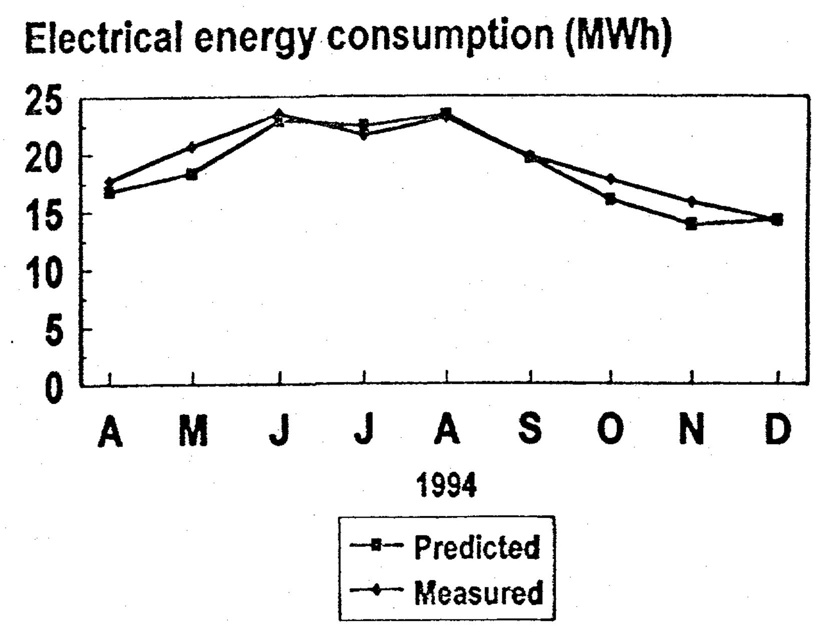


Fig. 2. Comparison of predicted and measured monthly electrical energy consumption for Building 2518.

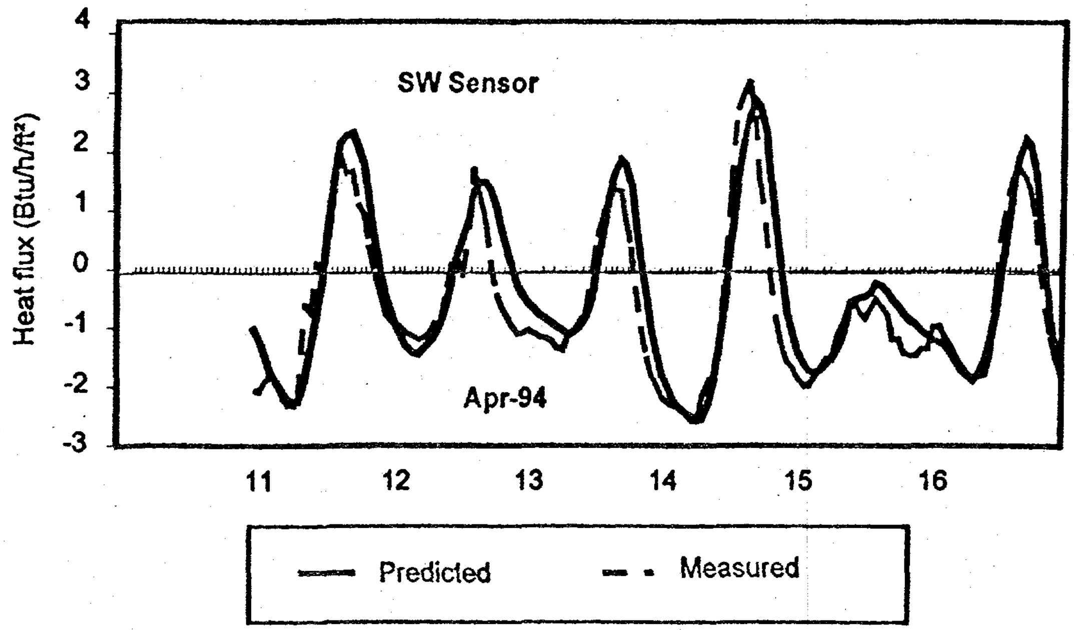


Fig. 3. Comparison of predicted and measured Building 2518 roof heat fluxes during April 10–17, 1994.

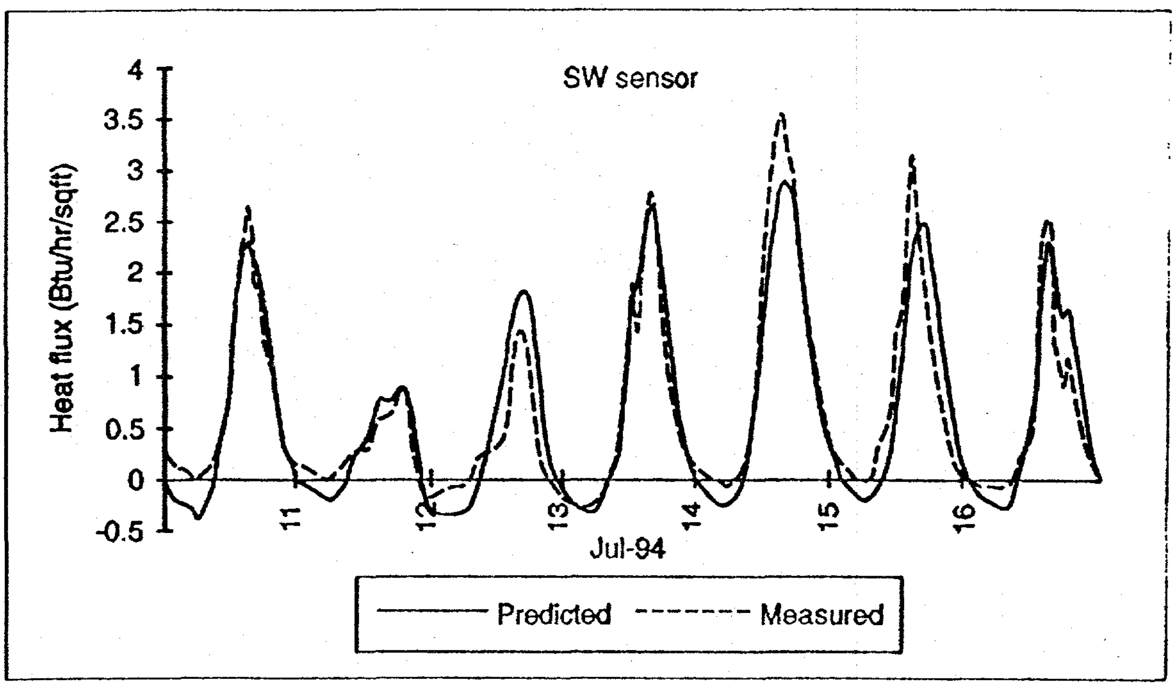


Fig. 4. Comparison of predicted and measured Building 2518 roof heat fluxes during July 10–17, 1994.

**Re-covered roof reflectivity impacts.** Analytically increasing the roof reflectivity from the base case of 0.28 to 0.70 increases the cooling energy savings by another $0.024/ft$^2$ ($0.26/m$^2$) to a total of 16% cooling energy savings. Decreasing the reflectivity from the base case of 0.28 to 0.05 reduces the cooling savings by $0.012/ft$^2$ ($0.13/m$^2$) to a total of 6%. The effect of reflectivity on heating is in the opposite direction, with 4% less (than 53%) savings for the higher reflectivity and 1% more (than 53%) savings for the lower reflectivity. The annual energy cost savings, using national average energy prices, of going from 0.05 to 0.70 reflectivity would be $0.007/ft$^2$ ($0.075/m$^2$) for the Knoxville climate for this roof.

**Addition of economizers.** Adding economizers and turning off the office equipment at night and on weekends would save about $0.075/ft$^2$ of floor area cooling energy plus another $0.055/ft$^2$ from re-covering the roof, for a total 20% energy savings. The impact of the economizers on the heating energy is negligible.

### Climate Impacts

The effect of the building climate on the energy saving effectiveness of the re-covered roof was calculated using typical meteorological year (TMY) weather data for Bismarck, North Dakota [9044 heating degree days (HDD)], Chicago (6497 HDD), Knoxville, Tennessee (3695 HDD), Miami (206 HDD), and Seattle (4650 HDD) (Air Force 1978). These results are shown for two building configurations: (1) using the base case building as modified to evaluate the re-covered roof energy savings (representing an energy-efficient building) and (2) using the base case building having HVAC system economizers (representing a highly energy-efficient building). The results are shown in Fig. 5 for configuration (1).

**Base case (energy-efficient) building.** For the re-covered roof, as shown in Fig. 5 for the energy evaluation base case building, the annual energy cost savings are in the range of $0.064/ft$^2$ ($0.69/m$^2$) (Seattle) to $0.15/ft$^2$ ($1.61/m$^2$) (Bismarck). For the base case building as configured to evaluate the re-covered roof energy savings, the cooling energy savings due to the re-covered PUR insulation are in the range of 7 to 11% for four of the climates. The greatest savings of about $0.083/ft$^2$ ($0.89/m$^2$) are for Miami. Seattle requires $0.008/ft$^2$ ($0.086/m$^2$) more energy expenditure because of the greater retention of the internal load energy during early spring and late fall. The heating energy savings are in the range of 40 to 50%. The greatest heating energy saving is about $0.13/ft$^2$ for Bismarck. In general, the heating energy savings are around 50% and the cooling energy savings are around 10%. The building internal loads and plenums were found to significantly affect the amount of energy saved. If the plenums are nearly dead air places, as they are in Building 2518, the energy savings benefits of the re-covered roofs are lower than for buildings with plenums allowing greater contact of the circulating air with the roof.

**Addition of economizers (highly energy-efficient building).** Adding economizers increases the energy savings of the roof by from $0.09/ft$^2$ ($0.97/m$^2$) for Seattle to $0.16/ft$^2$ ($1.72/m$^2$) for Bismark. Air economizers can help increase the cooling energy savings because they mitigate the effect of the added insulation's trapping the heat generated internally when ambient air conditions favor direct dissipation of heat to the atmosphere. Assuming that the economizer is activated at outside air temperatures below 68°F (20°C), the air

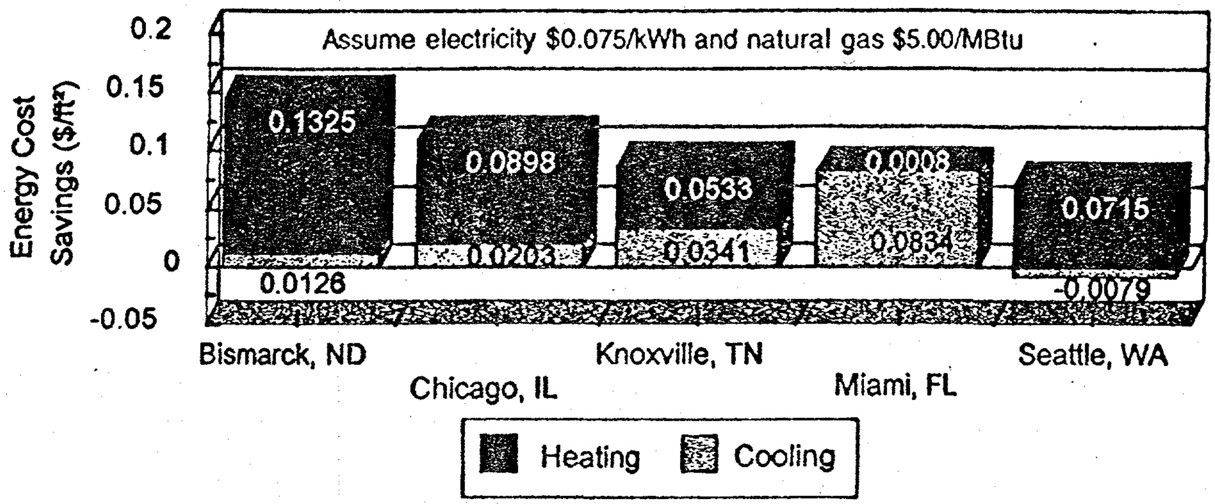


**Fig. 5. Re-covered roof energy cost savings for Building 2518 (as modified for energy savings evaluation) at selected locations.**

conditioner energy requirements are reduced and the cooling energy savings associated with the re-covered roof PUR insulation are greater. For Seattle, the energy savings increases from about $0.008/ft² ($0.086/m²) to about $0.013/ft² ($0.14/m²). The benefit of the economizer in Miami is small. For the remaining three locations, the energy savings increase between 7 and 16%. The impact of the economizers on the heating energy consumption is negligible for all the climates.

## B. NRCA Weathering Farm

### Description

In 1991 the ORNL BTC and the National Roofing Contractors Association (NRCA) initiated a 10-year study on a unique low-slope roof covering an office building in Chicago called the NRCA Roof Weathering Farm. The roof assembly consists of a galvanized steel deck, insulation mechanically fastened to the deck, 0.75-in. (1.9-cm) perlite insulation, and one layer of fiberglass base sheet (each adhered in continuous hot asphalt moppings), followed by torch-applied atactic polypropylene (APP)-modified bitumen. The focus of the study is to evaluate the performance of APP-modified bitumen membranes covered with various liquid-field applied solar reflective coatings. The roof with the various coatings applied is shown in Fig. 6. The objective is to measure the impacts of the coatings on the thermal performance of the building and the membrane service life extension.

Three types of reflective coatings commonly applied to bituminous roof membranes are being studied:

**Asphalt emulsion:** Reflective emulsified asphalt coatings consist of asphalt particles and aluminum pigments dispersed in water with clay.

**Aluminum reflective:** Reflective solvent-based aluminum asphalt, when applied, contains a solvent liquefied asphalt and aluminum flakes. The

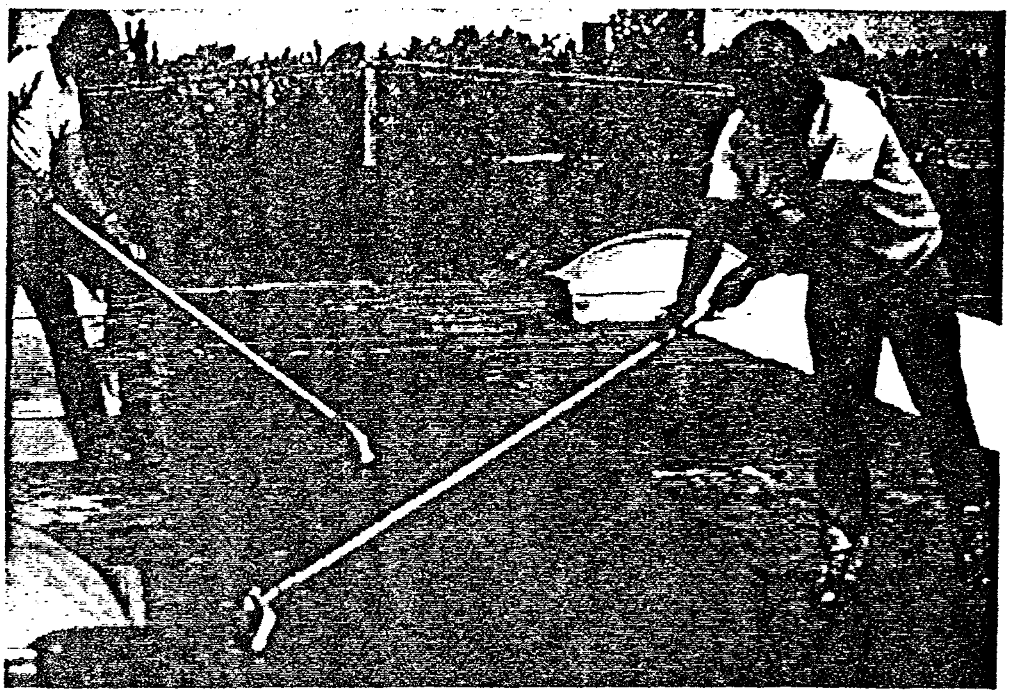

Fig. 6. The various roof coatings applied to several different types of APP-modified membranes on the NRCA Weathering Farm.

solvent-based aluminum coatings dry to an aluminum or silver hue.

White latex: The water-based latex roof coating contains acrylic polymers.

### Roof surface measurements

Figure 7 shows solar reflectivity measured in August, 1991, when the coatings were first applied, and in October 1994. The white latex reflectance has decreased about 20%, whereas the the other two coatings have remained relatively stable for the first 4 years on the roof.

Figure 7 also shows weekly average membrane temperatures for five membranes, including data for an ethylene propylene diene monomer roof system with 1.5-in. (3.8-cm) river-washed ballast. The plots show the average weekly sunlit temperatures of each membrane from day 214 (August 1) through day 280 (October 7). The recorded hourly temperatures are included in the average only if the temperature of the black membrane was at least 5°F (2.8°C) warmer than the white membrane during the hour. This criterion removed the effect of nighttimes and cloudy periods from the average. During the first 4 years, the highest hourly black membrane temperature that was recorded exceeded 170°F. The white-coated membrane reached at most 141°F (61°C). The weekly averaging lowers the reported level of membrane temperatures so that the highest weekly black membrane temperature is no more than 125°F (52°C). However, requiring that the black membrane be 5°F (2.8°C) hotter than the white membrane for inclusion in the average made for much higher weekly averages than if all data were averaged.

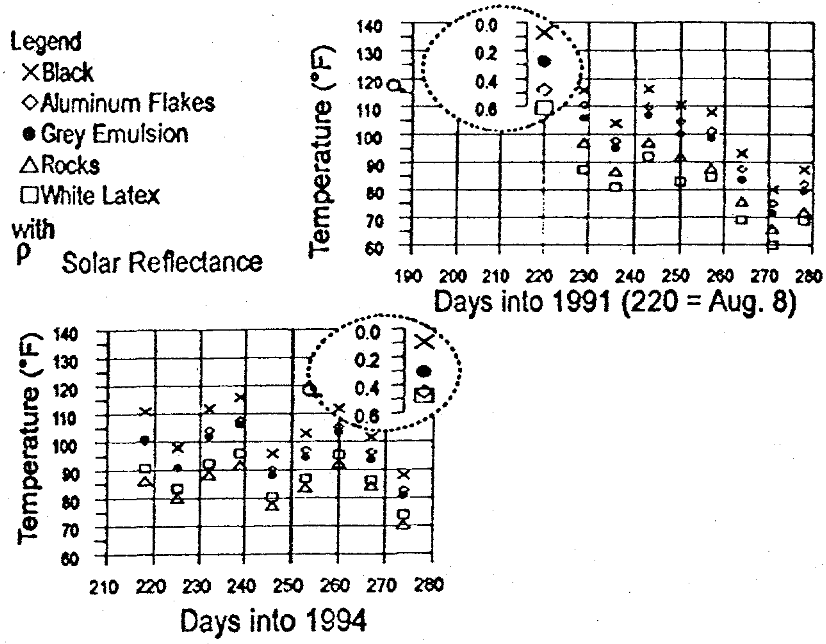


Fig. 7. Reflectivity and average weekly surface temperature comparisons of five different surface treatments for several weeks in 1991 and 1994.

### Sustainability lessons learned

Typically, the higher the reflectivity, the cooler the roof surface. However, this is not true with the reflective emulsion coating: It has a lower reflectivity than the aluminum-pigmented asphalt coating, yet the membrane surface temperature is somewhat cooler under the reflective emulsion. Also, note that the average weekly sunlit temperature of the membrane under the gravel ballast in the 4-year-old weathered roof is actually lower than the highest reflective roof coating system. This result illustrates that the long-term thermal performance is a function of other variables than reflectivity, such as the mass of the coating or ballast applied above the membrane.

This roof actually contains seven different types of APP-modified bitumen membranes and four different types of coatings. The fourth coating was from a manufacturer that is no longer in business. This coating did not adhere well to most of the membranes. Periodic visual inspections of the Weathering Farm clearly reveal that the long-term durability of the coating is also a function of the type of substrate to which the coating was applied. It is apparent from the lessons being learned from this roof that an overemphasis on one aspect of a roof system, such as reflectivity, can potentially be a misleading indicator of long-term roof sustainability. It is apparent that roof system durability that includes both membrane and coating performance must be the metric of choice to lead to more sustainable roof selections.

## C. Recoated Existing Roofs: Tyndall Air Force Base Shoppette and Veterinary Clinic

### Description

In 1995 ORNL, ThermShield International, Tyndall Air Force Base

(AFB), and Gulf Power Company formed a collaborative research team to investigate the effects of radiation control coatings applied to existing BUR roof systems with relatively rough surfaces. The sustainable feature added to this roof is the application of a highly reflective coating despite the existing relatively rough surface. Figure 8 shows photographs of the south sides of the shoppette and veterinary clinic located at Tyndall Air Force Base on the Florida panhandle. Both buildings have natural shading from nearby trees, especially the shoppette, a 4000-$ft^2$ (370-$m^2$) convenience store. About 40% of its roof, where instruments were installed, has a gravel ballast BUR with 2 in. (5.1 cm) of polyisocyanurate (PIR) insulation on a metal deck. The remaining 60% of the roof is a gravel ballast BUR over a wood plank deck. The veterinary clinic is a 1750-$ft^2$ (160-$m^2$) building with a gravel ballast BUR, also having 2 in. of PIR but on a heavyweight concrete deck. In July 1996, the loose gravel and debris were removed with a wet/dry vacuum, and a 0.015-in. (0.38-mm) thickness of a latex-base coating with ceramic beads was sprayed on to increase solar reflectance. Because of the relatively rough roof surface, the coverage was only about 40 $ft^2$ per gallon (1.0 $m^2/L$), compared with coverage of about 60 $ft^2$ per gallon (1.5 $m^2/L$) on a smooth surface. The cleanup and coating application for both buildings took 48 man-hours.

### Roof surface measurements

Measured solar reflectances for the ceramic coating as installed on the two rough-surface BURs are 0.52 and 0.54. This is in the range of reflectances for coatings weathered 1 to 2 years on smooth surfaces which have been measured at the ORNL BTC. On small pieces of smooth-surface membranes coated at the same time as the roofs at Tyndall AFB, the ceramic coating and an acrylic elastomeric coating had initial reflectances of 0.76 and 0.80, respectively. The same acrylic elastomeric and a different ceramic coating at the BTC showed initial reflectances of 0.81 and 0.85, respectively. These reflectances are in the same range as those measured initially for other ceramic and acylic elastomeric coatings on smooth surfaces at the BTC.

The solar reflectance of a coating and the thermal characteristics of the roof on which it is installed affect the temperatures of the coated surface and the heat fluxes through the roof. Figure 9 shows the average decreases for sunlit surfaces of hourly averaged membrane surface temperatures and heat fluxes through the insulation. To generate the data for Fig. 9, small instrumented patches were left uncoated next to the instrumented locations on the coated roofs. Surface temperatures are included in the average only if the uncoated surface temperature exceeds the coated surface temperature by 5°F (2.8°C). Positive heat fluxes through the uncoated roof must be 0.5 Btu/h•ft2 (6W/$m^2$) larger than through the coated roof to be included in the averages. The R-12 ($R_{SI}$-2.1) insulated roof with shading effects at the instrumented locations on the shoppette showed average decreases of 15, 13, and 10% for coated surfaces for the first 3 months after the fresh coating application in July. The heat fluxes through the coated patches yielded average decreases of 55, 54, and 51% in the same months.

The heavyweight concrete deck roof on the veterinary clinic with the same insulation thickness but no shading

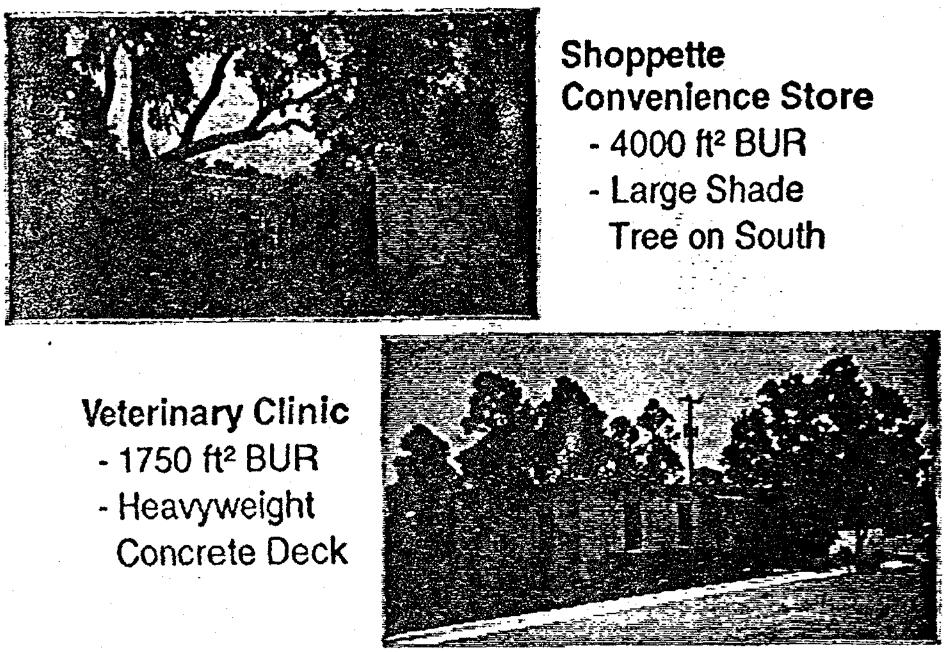


Fig. 8. The Tyndall Air Force Base buildings with coated low-slope roofs.

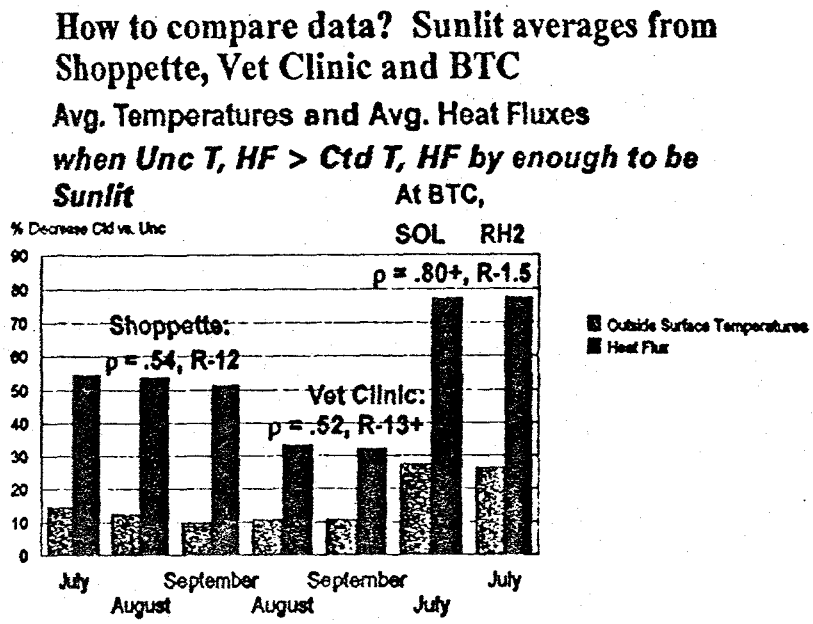


Fig. 9. Decreases of average sunlit roof surface temperature and heat-flux reductions resulting from the application of reflective coatings, compared with uncoated surfaces. The coatings were applied to two buildings at Tyndall AFB and on the ORNL Roof Thermal Research Apparatus.

effects at the instrumented locations showed 11% outside surface temperature decreases on the coated surface in August and September 1996. The heat flux average decreases were 33 and 31%, respectively. On the poorly insulated unshaded test sections coated with higher solar reflectance materials at the BTC, results were more dramatic. The ceramic coating with 0.85 initial solar reflectance showed a 28% decrease in surface temperature and a 77% decrease in heat flux for July 1996. The acrylic elastomeric coating with 81% reflectance showed a 26% decrease in sunlit surface temperatures and a 78% decrease in heat fluxes for the same month.

The effect of the radiation control coating on the electricity use in the Tyndall AFB buildings is not as clear as the effect on outside roof surface temperatures and heat fluxes through the insulation. Figure 10 shows that for the shoppette, the whole-building electricity use is sensitive to outdoor temperature, but it is not easy to see the effect of the highly reflective roof coating. Study of the shoppette and veterinary clinic roof is expected to continue for another year, during which a whole-building model will be calibrated to the building similar to the model illustrated for the Building 2518 case described earlier.

### Sustainability lessons learned

Application of the coating to a rough surface increases the material cost about 50% and reduces the initial reflectance benefit by about 0.3 compared with a smooth surface such as an APP-modified membrane. Ceramic coatings have about the same initial reflectance as acrylic elastomeric coatings. The effect of the fresh coating on the heat fluxes of the two Tyndall AFB R-12 ($R_{SI}$-2.1) roofs during sunlit hours appears to be significant: a reduction of about 50% for the roof with a metal deck and shading effects, and a reduction of about 30% for the roof with a masonry deck. However, a pronounced impact on the continuously monitored energy consumption for the whole building was not observed with the limited data collection available at the time this paper was prepared. The fact that these roofs had R-12 ($R_{SI}$-2.1) insulation and some shade from nearby trees may be contributing factors that tend to minimize the apparent space cooling energy savings of the radiation control coatings. Reduction in reflectance of coatings similar to those under investigation at Tyndall AFB but on smooth surfaces has been observed over a 1- to 5-year period to be between 20 and 35%. Dirt accumulation and general discoloration seem to cause the reduction. It is generally believed by advocates that a major benefit of coatings will be the extended surface life of the roof system attributable to the coating. This may enhance the motivation of the building owner to maintain the roof with at least a light power washing each year before the cooling season.

## D. Earth-Covered Roof: Joint Institute Dormitory

### Description

A green roof is an area of planting, on a waterproof substrate, that is separated from the ground by a manmade structure. A typical green roof is composed, from the interior side outward, of a structural deck, an insulation layer, a waterproofing membrane, a drainage layer, soil, and vegetation. (Hendriks 1994). An alternate method, referred to as the inverted roof (insulation is above the membrane), has also been employed. (Christian 1983)

The Joint Institute office and dormitory building at ORNL is a passive solar building with earth berm walls and

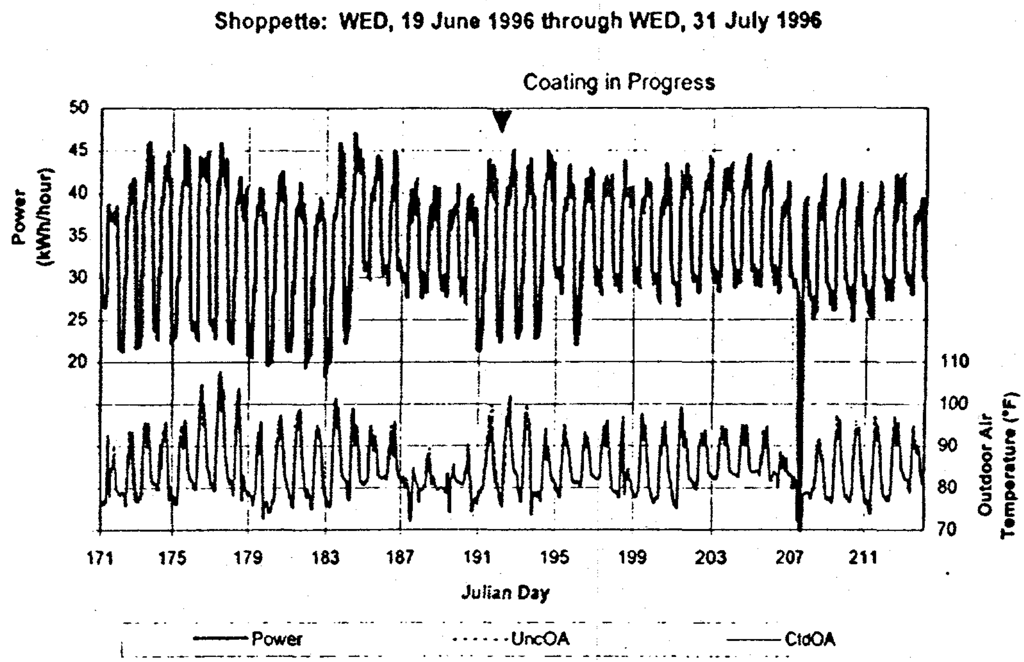


Fig. 10. The whole-building electricity use shows sensitivity to outdoor temperature, but not the effect of coatings.

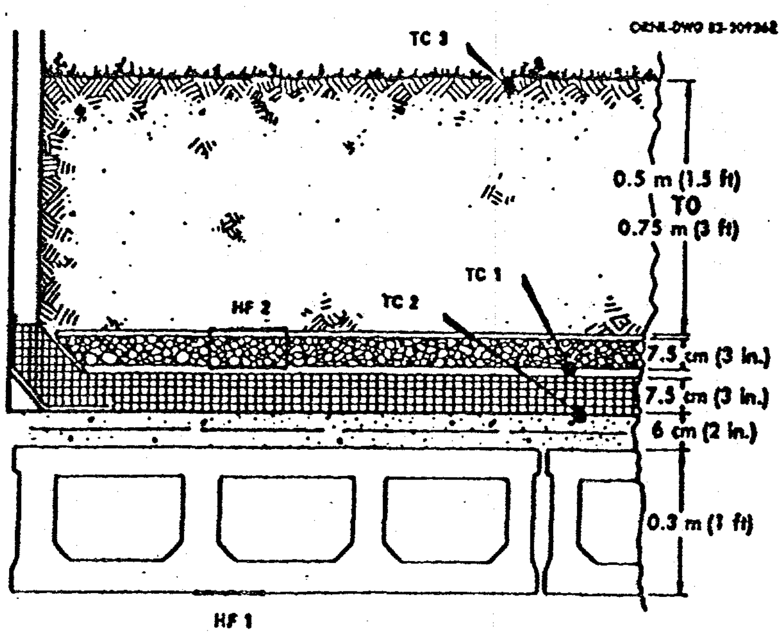


Fig. 11. Cross-section of a green roof at the ORNL Joint Institute Dormitory.

a sod roof. The roof cross-section, shown in Fig. 11, consists of precast concrete covered by 2 to 3 in. (5.0 to 7.5 cm) of poured concrete to provide a smooth adhesive surface for a waterproof membrane. The membrane is covered by 3 in. (7.5 cm) of extruded polystyrene insulation, filter paper, gravel, filter paper, and 1.5 to 2.5 ft (0.46 to 0.76 m) of soil.

### Roof measurements

The Joint Institute green roof has 3 in. of insulation and a nominal R-value of 15 h•ft²•°F/Btu (2.6 m²•K/W). A heat flux meter and thermocouples in the roof measured the entire roof performance as if the roof system R-value were 31 ($R_{SI}$-5.5). In the summer, because of the extensive mass, the green roof does not trap heat in the building; rather, it neutralizes the radiant gain from the summer sun and almost eliminates any net heat gain. Figure 12 compares the rooftop surface temperature of a conventional BUR with a green roof. Notice that the temperature just above the insulation in the green roof remains at about room temperature, even with ambient air temperatures exceeding 90°F (32°C).

### Sustainability lessons learned

A careful study of this whole building concluded that the green roof reduced the peak sensible cooling needs by about 25% (Christian 1984). In the winter, the roof acts as if it actually has 50% more resistance than steady state estimates. Yet in the summer, the roof does not have a cooling penalty like high roof insulation levels have in commercial buildings. The transpiring vegetation and thermal mass combine to virtually eliminate the

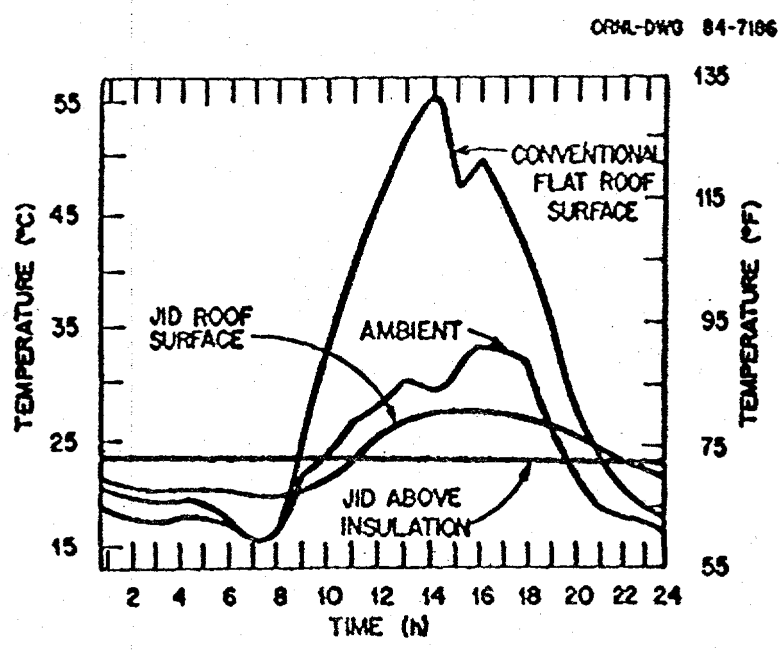


Fig. 12. Green roof temperatures compared with those of a conventional built-up roof system on a hot summery day.

downward heat flow from the roof into the building. This roof is now 18 years old and shows no aging. The roof of the adjacent building, similar in size but more conventional in structure, was replaced in October 1996 after a life of only 13 years. The membrane had shrunk and pulled away from perimeter fasteners.

People need solitude, a quiet place to think, where the air and noise pollution are minimal. Roof terraces are in many areas the only way to accommodate such a place. A green roof could attract tenants to buildings in neighborhoods that are not safe. There are cities such as Paris, France, that because of the intense evolution of development have few green spaces left. This situation has resulted in zoning requirements that a new building owner add a green space. These requirements have increased the demand for plaza decks and earth-covered roofs. The structural requirements are an impediment, but with care, these types of roofs can indeed deliver roof service life equivalent to building lifetimes.

In 1995 the U.S. Green Building Council developed a proposed Green Building rating system (U.S. Green Building Council 1995). We compared the sustainability requirements of the Green Building rating system that could be applied to a green roof (energy efficiency, water conservation, waste water utilization, environmentally preferable building materials, minimal construction debris, landscaping, and maintenance) to determine whether a green roof should be part of a green building. In this study, we reported that the environmental benefits of a green roof include reduction of rain water loads on waste systems, enhanced storm water control measures, urban dust control, absorption of $CO_2$, increased acoustic and thermal insulation, creation of micro-climates for urban plant/animal conservation, improved durability, and amenity value (Desjarlais and Christian 1995). The study found that the issues of energy efficiency, utilization of waste water, minimized construction debris, and enhanced landscaping addressed by the Green Building rating system are satisfied by the green roof. The literature reviewed contains references to green roofs that have performed for over 60 years. However, a green roof has a higher first cost because of increased structural requirements and a more complex roofing system. The complexity arises from the potential need for irrigation systems, drainage layers, and root protection; increased maintenance costs; and increased water consumption.

## PROMISING SUSTAINABLE ROOFING TECHNOLOGIES

This paper presented measurements and analyses of several promising roof technologies that enhance the sustainability of low-slope roof systems:

- Self-drying systems
- Low total equivalent warming foam insulation
- Roof coatings
- Green roofs

All of these technologies have existed for some time. Building owners and community developers are showing more interest in investing in sustainability. The potential exists to design, construct, and maintain roofs that last twice as long and reduce the building space heating and cooling energy loads resulting from the roof by 50% (based on the current predominant design of a 10-year life and a single layer of 1 to 2 in. (2.5 to 5.1 cm) of insulation). The opportunity to provide better low-slope roofs and sell more roof maintenance service is escalating. The general trend of outsourcing services could lead to roofing companies' owning the roofs they install while the traditional building owner owns the rest of the building. Such a situation would have a very desirable potential to internalize the costs of poor roof maintenance practices and high roof waste disposal costs, and to offer a profit for installing roofs that are more sustainable.

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