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Radiation Control Coatings Installed on Federal Buildings at Tyndall Air Force Base

Volume 1

Pre-Coating Monitoring and Fresh Coating Results

Thomas W. Petrie and Phillip W. Childs

MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

ORNL/CON-439/V1

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February 1997

Prepared for the U.S. Department of Energy
Federal Energy Management Program
under the terms of
Stevenson-Wydler (15 USC 3710)
Cooperative Research and Development Agreement
ORNL96-0403
with
ThermShield International, Ltd.

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
managed by
Lockheed Martin Energy Research Corporation
for the U.S. Department of Energy
under contract No. DE-AC05-96OR22464

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Preface

The federal government is the largest single energy consumer in the United States. Government consumption approaches 1.5 quadrillion Btu/year of energy, at an annual cost valued at nearly $10 billion. The U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP) supports efforts to reduce energy use and associated expenses in the federal sector. One such effort, the New Technology Demonstration Program (NTDP), seeks to evaluate new energy-saving U.S. technologies and secure their more timely adoption by the U.S. government.

This report addresses the effects of radiation control coatings installed on federal buildings at Tyndall Air Force Base (AFB) in Florida. The project is a cooperative effort between the Buildings Technology Center (BTC) at Oak Ridge National Laboratory (ORNL) and ThermShield International, Ltd., a manufacturer of radiation control coatings.

Tyndall AFB and the Burger King Corporation made three buildings available and provided communication lines with which to do remote monitoring. Gulf Power Company, the electric utility serving Tyndall AFB, installed pulse-initiating kilowatt-hour meters for two of the buildings.

Other national laboratories were involved in this project. Pacific Northwest National Laboratory did an economic analysis based on information in ThermShield's technology submittal to the NTDP and provided input to an interlaboratory council. The council—which had representation from Lawrence Berkeley National Laboratory, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory—decided to choose the ThermShield coating technology and approved funding of ORNL's efforts. Lawrence Livermore National Laboratory provided most of the coating applied at Tyndall AFB from a supply purchased from ThermShield for evaluation of its effectiveness in various applications.

Summary

The U.S. Department of Energy's (DOE's) Federal Energy Management Program (FEMP) supports efforts to reduce energy use and associated expenses in the federal sector. One such effort, the New Technology Demonstration Program (NTDP), seeks to evaluate new energy-saving U.S. technologies and secure their more timely adoption by the U.S. government. Through a partnership with a federal site, the utility serving the site, a manufacturer of an energy-related technology, and other organizations associated with these interests, DOE can evaluate a new technology. The results of the program give federal agency decision makers more hands-on information with which to validate a decision to utilize a new technology in their facilities. The partnership of these interests is secured through a cooperative research and development agreement (CRADA), in this case between Lockheed Martin Energy Research Corporation, the manager of the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, and ThermShield International, Ltd., the manufacturer of the technology.

This is the first volume of a two-volume report that describes the effects of radiation control coatings installed on federal buildings at Tyndall Air Force Base (AFB) in Florida by ThermShield International. ORNL's Buildings Technology Center (BTC) was assigned the responsibility for gathering, analyzing, and reporting on the data to describe the effects of the coatings. This volume describes the monitoring plan and its implementation, the results of pre-coating monitoring, the coating installation, results from fresh coatings compared to pre-coating results, and a plan to decommission the monitoring equipment. By including results from roofs at Tyndall AFB and from an outdoor test facility at the BTC, the data cover the range from poorly insulated to well-insulated roofs and two kinds of radiation control coatings on various roof membranes.

The second volume will follow after another year of monitoring the Tyndall AFB buildings with the coatings installed. It will contain the results of comparing fresh and weathered coatings and generalizations from roof and whole-building models. The models will be calibrated to the buildings monitored at Tyndall AFB.

The BTC has tracked the solar reflectance and thermal performance of small samples of various radiation control coatings for several years. Using techniques gained from this experience, ORNL instrumented two locations on the roofs of each of three buildings at Tyndall AFB with thermocouples and heat-flux transducers to monitor outside-air and outside-surface temperatures, inside-surface temperatures, and heat fluxes through the insulation in the roofs. Two of the buildings, with moderately well insulated, rough-surfaced, low-solar-reflectance roofs, were coated entirely by ThermShield except for a 2 ft × 2 ft (0.61 m × 0.61 m) patch over one of the instrumented locations. This size of uncoated patch is ample to gather data throughout the project on the effects of no coating for direct comparison to data from the coated areas of the roof. Pulse-initiating kilowatt-hour meters monitored whole building electricity use in these two buildings. The third building already had a smooth-surfaced white membrane on its roof. One location on its roof was coated with the ThermShield coating, a latex-based product with ceramic beads added to improve solar reflectance. The other location was coated with an acrylic elastomeric coating with titanium dioxide added to improve solar reflectance. Side-by-side testing of two types of radiation control coatings on this well-insulated roof at Tyndall AFB complements side-by-side testing of these two types of radiation control coatings on poorly insulated test sections for that purpose on an outdoor test facility at the BTC.

The two locations on each of the three roofs at Tyndall AFB were instrumented in late November 1995, and the pulse-initiating kilowatt-hour meters were installed in January 1996, several months before the coatings were applied in mid-July. Continuous pre-coating monitoring was done for both buildings whose roofs would be coated entirely. Monitoring proved the reliability of the data loggers to process data collected at 5-min intervals and then stored as hourly averages. Procedures were also established for remote downloading of the data by modem from Tyndall AFB in Florida to the BTC in Tennessee. The pre-coating data established that comparable temperatures and heat fluxes at the two uncoated locations were identical within random fluctuations of 5°F (3°C) and 0.5 Btu/h·ft^2 (1.6 W/m^2), respectively. A history of the hourly electricity use of each building without roof coatings was also established.

Debris and loose gravel were removed from the two built-up roofs (BURs) prior to applying the coating. Rainy weather the week before had left some ponded water, which was removed with a vacuum cleaner. The coating, marketed under the brand-name Temp-Coat, was applied with an airless sprayer and covered about 5725 ft^2 (530 m^2) of rough BUR. The roughness of the surfaces, due to the small-sized gravel topping of the BURs, yielded coverage of only 40 ft^2/gal (1.0 m^2/L), not the usual 60 ft^2/gal (1.5 m^2/L). It took a crew of four about 12 h to do the job. The small patches on the smooth-surfaced third roof were brush-coated.

In order to determine freshly coated solar reflectance, we cut samples from special extra pieces of the respective roof membranes; these were coated along with the entire two BURs and the patches on the third roof. The rest of the pieces were left to weather on the respective roofs between the instrumented locations. An uncoated sample of the BUR membrane was also secured. The solar reflectances of the coated samples were measured with a laboratory technique used previously at the BTC and, as Table S.1 shows, were significantly improved over the uncoated sample's reflectance. Because of the roughness of the gravel topping on the BUR, it was not possible, even with 50% more product, to coat the BUR as completely as a smooth surface could be coated. Solar reflectances of Temp-Coat and an acrylic elastomeric coating on the smooth-surfaced third roof at Tyndall AFB measured from 0.22 to 0.28 higher than for Temp-Coat on the rough surfaces. The same elastomeric coating is being tested on a smooth-surfaced membrane at the BTC. It had the same freshly coated reflectance as at Tyndall AFB. A different ceramic at the BTC was slightly better than Temp-Coat. Weathered samples from ongoing tests at the BTC have measured solar reflectances in the range of fresh Temp-Coat on rough surfaces at Tyndall AFB.

A comparison of data for the uncoated and coated patches shows that the coating produced a definite decrease in both the outside-surface temperature and the heat flux through the insulation. Average sunlit outside-surface temperatures were generated using a criterion that included only those pairs of temperatures when a given uncoated patch was more than 5°F (3°C) warmer than its neighboring coated patch. Average sunlit heat fluxes were generated from pairs when the positive uncoated heat flux was more than 0.5 Btu/h·ft^2 (1.6 W/m^2) larger than the coated heat flux. The cutoff values were chosen in light of the random fluctuations observed in the pre-coating data. The sunlit criterion excluded nighttime data, data on cloudy days, and data when the uncoated patch on one roof was more strongly shaded in mid- to late afternoon on sunny days. Times when the coated patch was non-uniformly shaded on one roof enhanced the apparent performance of the coating on this roof.

Table S.1. Solar reflectances on roofs at Tyndall AFB and on test surfaces at the BTC

Sample and substrate	Solar reflectance
Uncoated BUR	0.09
Temp-Coat on BUR, Building 1	0.54
Temp-Coat on BUR, Building 2	0.52
Temp-Coat on smooth surface, Building 3	0.76
Acrylic elastomeric on smooth surface, Building 3	0.80
Acrylic elastomeric on smooth surface, BTC	0.81
Ceramic on smooth surface, BTC	0.85
Weathered coatings on smooth surfaces, BTC	0.52–0.57

The building with the effect of shading showed a 15% decrease in the average sunlit temperature of the coated patch; the other building, with no shading of the BUR patches, showed an 11% decrease. Decreases in the average sunlit heat flux were larger: 55% and 33%, respectively. These roofs have comparable R-values, about 12–13 $h\cdot ft^2\cdot °F/Btu$ (2.1–2.3 $m^2\cdot K/W$), but the building without shading has a thermally massive roof deck. By contrast, the same averages from the tests of comparably fresh coatings at the BTC show 26–28% decreases in outside-surface temperatures and 77–78% decreases in heat fluxes. The BTC data are for poorly insulated roofs with R-values of 1.5 $h\cdot ft^2\cdot °F/Btu$ (0.26 $m^2\cdot K/W$), and the solar reflectances of the coatings were higher than achieved on the rough BURs at Tyndall AFB.

The average power demand during occupied periods for the first month with the coating was 13% less than during the previous month without the coating for the simpler of the two Tyndall buildings, the one with no shading of the BUR patches. On the other building the whole-building electricity use before and just after the roof was coated did not clearly show savings due to the coating. For both buildings, the roof is only one component of the building heating or cooling load, and these roofs are already moderately well insulated. It may be difficult to get clear direct evidence of savings due only to the coating. We are continuing to monitor electricity use in these all-electric buildings to calibrate a model for the annual energy use of the buildings. Modeling results to be given in the second volume of this report will address the effect of roof R-value, geographic location, and solar reflectance, including the effect of weathering, on the performance of coated roofs. Site-specific effects such as shading and large thermal mass will be segregated.

Abbreviations and Acronyms

AFB	Air Force Base
APP	atactic polypropylene polymer (a modifier for bituminous roofing membranes)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
BTC	Buildings Technology Center (user facility at ORNL)
BUR	built-up roof
CRADA	cooperative research and development agreement
DOE	U.S. Department of Energy
EPDM	ethylene propylene diene monomer (a single-ply roofing membrane material)
FEMP	Federal Energy Management Program
NTDP	New Technology Demonstration Program
ORNL	Oak Ridge National Laboratory
RTD	resistance temperature detector
STAR	Simplified Thermal Analysis of Roofs (ORNL computer program)

1

Introduction

A cooperative research and development agreement (CRADA) was formed between Lockheed Martin Energy Research Corporation and ThermShield International, Ltd., in order to install, operate, monitor, evaluate, and report the results of the demonstration of radiation control coatings installed on federal buildings at Tyndall Air Force Base (AFB). Through a submittal to the New Technology Demonstration Program (NTDP) of the Federal Energy Management Program (FEMP) and a favorable economic analysis based on the submittal, ThermShield was selected as the manufacturer of the product to be applied to two entire roofs at Tyndall AFB in Florida. The Buildings Technology Center (BTC) at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, was assigned the lead role for carrying out the demonstration and reporting the results. Lawrence Livermore National Laboratory provided most of the radiation control coatings from a supply purchased from ThermShield.

The statement of work for the CRADA is included as the Appendix to this report. The period of performance for the demonstration is 2 years from the effective date of the CRADA, March 25, 1996. Additional time is allowed for report writing. In order to document the performance of radiation control coatings on whole roofs, the period of performance was divided into a short pre-coating phase, with the rest of the time for a post-coating phase. The roofs were coated on July 9 and 10, 1996.

This volume of the project report documents the design of the technology monitoring system for the demonstration; describes the delivery and installation of the system at Tyndall AFB; provides data from the pre-coating monitoring which show that the installation is functioning and providing proper monitoring; describes the coating installation; provides selected results from fresh coatings on the Tyndall AFB roofs; and describes a study that is ongoing on the roof of outdoor test facilities in the BTC to demonstrate the effects of fresh coatings on roof performance. A plan is presented for continued monitoring at Tyndall AFB for two more summers beyond the period of performance of the CRADA, ending in decommissioning of the technology monitoring system.

As noted above, the period of performance of the CRADA allows 2 years to monitor the pre-coating performance of roofs at Tyndall Air Force Base and then the performance of the roofs with radiation control coatings as they weather. For several years, the BTC at ORNL has been monitoring small areas of roofs covered with various radiation control coatings. This experience shows that there is a significant decrease in the performance of radiation control coatings due to weathering during the first 2 years after application. In this study the AFB roofs were coated less than 4 months into the 2-year period of performance of the CRADA. Therefore, the roofs will be monitored during most of the critical first summer after coating and all of the equally critical second summer.

After the coatings are in place and the monitoring system is functioning, it is convenient to get additional data on the effect of weathering beyond the period of performance of this CRADA. Barring unforeseen circumstances that would render the coatings unusable, the plan is to continue minimal monitoring through two more summers and then decommission the monitoring system. Since Tyndall AFB is located on the Gulf of Mexico, it occasionally experiences hurricanes. Losing roofs is thus not an uncommon experience there. The plans to carry on this demonstration and continue minimal monitoring beyond its period of performance are therefore contingent upon the survival of the coated roofs and the instrumentation installed in them.

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Technology Monitoring Design

Widespread use of radiation control coatings in the federal sector depends on their ability to perform near their initial level of solar reflectance long enough to justify the investment needed to install them. Because such coatings are a passive technology, no operating expenses are involved. The coatings become an integral part of the roof to which they are applied. Normal roof maintenance work to repair joints and flashings is not adversely impacted by the presence of the coatings so long as a compatible repair material, such as an elastomeric compound, is used. The period of performance for this project is not long enough to determine whether the coatings will cut down on maintenance requirements and extend the service life of the roofs to which they are applied, which are benefits often claimed for these coatings. While the additional sealing of the roof by the application of coatings is a bonus that contributes to the attractiveness of coatings, it does not directly contribute to anticipated savings in cooling costs, and it is savings in cooling costs as an overall measure of coating benefit that this project seeks to evaluate.

An evaluation of savings in cooling costs requires monitoring of both the thermal performance of the roofs to which the coatings are applied and the energy needed by the buildings which the coated roofs cover. The primary characteristic of roof coatings of interest for thermal performance is solar reflectance as a function of time. To measure roof thermal performance, heat flow through the roof as a function of inside and outside conditions is needed. To generalize this performance, however, it is also necessary to measure enough parameters to model roof performance. Our experience with calibrating models to the thermal performance of a variety of low-slope roofs indicates that the essential parameters are outside-air temperatures, inside-surface and outside-surface temperatures, and the heat flux through a plane internal to the roof. Measurement of the solar reflectance as a function of time provides a significant input variable in computer models to predict the measured performance and apply it to other situations.

Low-slope roof systems do not usually vary significantly in thermal characteristics over the area installed on a particular building. Therefore, only a few locations need to be monitored to ensure an accurate picture of the roof's changing thermal performance. The actual characteristics of existing roofs are difficult to ascertain, however. As-built drawings do not guarantee sufficient detail to correlate measured performance to radiation control coatings. Nor are the drawings necessarily kept up to date as repairs and modifications are made. Therefore, it is necessary to measure performance with and without coatings.

The approach adopted for this demonstration was to use two locations approximately 2 ft × 2 ft (0.6 m × 0.6 m) on each of the two roofs selected for coating. Areas of this size that are clear of local disturbances, such as penetrations for rooftop equipment, are sufficient to ensure that measurements in the middle of the area reflect one-dimensional heat transfer conditions. To obtain a continuous measurement of the effects of the radiation control coating, one location was coated while the other was left uncoated as a control surface throughout the period of the demonstration. Outside-air, outside-surface, and inside-surface thermocouples and a heat-flux transducer imbedded in the middle of the insulation were used as the instrumentation at each location.

The most severe disturbance of the one-dimensional heat flow is at the boundary between the uncoated and coated surfaces. We estimated the steady-state heat flow at the mid-plane of the insulation in the metal-decked roof of the Shoppette, one of the buildings at Tyndall AFB used for this project. At the boundary, the vertical heat flux was halfway between the uncoated and coated heat fluxes at locations 1 ft (30.5 cm) away. The horizontal heat flux from the uncoated to the coated side was 33% of the vertical heat flux. At 2.0 in. (5 cm) from the boundary on the uncoated side, the vertical heat flux had increased to the one-dimensional uncoated heat flux. The horizontal heat flux was 2.3% of the one-dimensional value. At 3.0 in. (7.6 cm), the horizontal heat flux had diminished to less than 0.5% of the vertical heat flux, and one-dimensional heat flow was achieved.

The solar reflectance of radiation control coatings changes as the coatings weather. Techniques to measure the solar reflectance of materials in situ on roofs are not fully developed. Hence, laboratory techniques must be relied upon, with samples of roofs that are covered by weathered coatings removed periodically from the roofs and brought to the laboratory. In this project, to ensure that the samples were coated like the rest of the roofs, pieces of the same type of roof as those available for coating were secured from a roof tear-off and replacement project at Tyndall AFB. Approximately 2 ft × 2 ft (0.6 m × 0.6 m) areas were stripped of adhered insulation and laid over one of the instrumented locations on each roof. Not only did this process ensure that the pieces were coated in the same way as the rest of the roof, but it also created an uncoated area underneath them that could serve as an uncoated test patch.

Figure 1 shows a coated piece that will be used for a solar reflectance sample on the roof of the Shoppette after the piece has been moved away from the area that lay under it during the coating process. This underlying area is the instrumented uncoated patch. The instrumented coated patch is as

Fig. 1. Uncoated patch (*upper right*) and coated piece (*upper left*) for solar reflectance samples on the Tyndall Air Force Base Shoppette roof.

far to the left of the piece for samples as the uncoated patch is to its right. Paver blocks, 1 ft × 1 ft × 2 in. thick (0.3 m × 0.3 m × 5.1 cm thick), are shown in place to mark a walkway to the coated piece. A corner of the coated piece has already been cut off to provide a sample of the freshly coated surface.

Part of the monitoring design was to be able to obtain information from the demonstration for two types of radiation control coatings—latex-based products with ceramic beads added to increase solar reflectance and acrylic elastomeric products with titanium dioxide added to increase solar reflectance. To accomplish this, the entire roofs of two buildings on the base, the Shoppette and the Veterinary Clinic, were coated with Temp-Coat, the latex-based product of ThermShield that had been selected for this demonstration program. Patches on the roof of a third building on the base were coated with Temp-Coat and an acrylic elastomeric coating.

The two buildings that received the latex coating have four-ply asphalt built-up roofs (BURs) with gravel imbedded in the bituminous topping, a common roof system on federal buildings but not one ideally suited for radiation control coatings because of its roughness. Solar reflectance is better on smooth surfaces, even though spray techniques can apply coatings uniformly to rough-surfaced roofs. Cross sections of the roofs of the buildings are shown in Fig. 2. Figure 3 shows the south sides of the Shoppette and the Veterinary Clinic. The two buildings are similar in architecture; both have stucco-covered cement-block walls and built-up low-slope roofs. The effect of the large tree shading the Shoppette can be seen in Fig. 1.

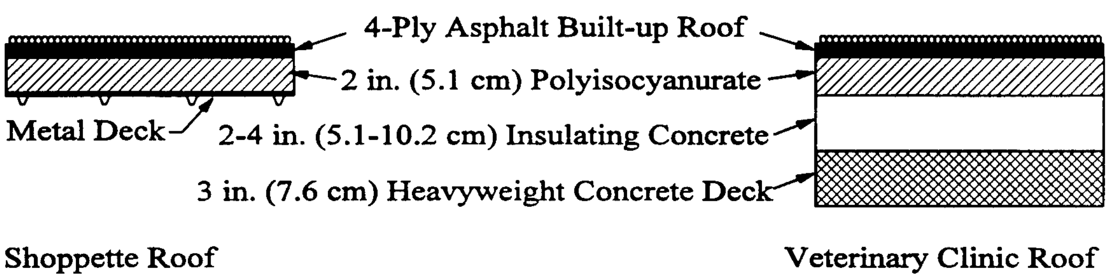

Fig. 2. Cross sections of built-up roofs for the Shoppette and the Veterinary Clinic.

The third building on base used in this demonstration program, Burger King, a fast food restaurant, has a smooth-surfaced, single-ply membrane roof. The smooth surface allowed patches of the roof to be brush-coated. Small extra pieces of single-ply membrane were coated and secured with paver blocks next to the coated patches on this roof to weather like the in situ patches whose thermal performance is being monitored. These techniques for side-by-side comparison of small coated and uncoated areas of roof membranes and use of a companion piece for laboratory analysis of solar reflectance have been successfully used for several years at the BTC.

Due to budget constraints, a simple approach was chosen to monitor the energy use in the buildings whose entire roofs were coated. The project design specified a single pulse-initiating kilowatt-hour electrical meter for monitoring the whole-building electricity use of each building. The buildings that ultimately became available for the demonstration are less suited to this simple approach than those available when the monitoring plans were formulated and the budget was proposed, but funds were not available for additional instrumentation. Two small buildings with approximately R_{US}-12 (R_{SI}-2.1) roof insulation and regular operating schedules were initially chosen but Hurricane Opal damaged their roofs, and the roofs needed to be torn off and replaced before the period of performance of this CRADA began.

One alternative chosen, the Veterinary Clinic, is a small building with a moderately well insulated roof, an irregular operating schedule, but little internal load. It is heated and cooled by an electric heat pump. A single electric power monitor is sufficient for it. The other alternative, the Shoppette (a convenience store), is a medium-sized building with a moderately well insulated roof, a 7-day-per-week schedule, but a significant internal load from refrigerators and freezers. It is cooled by direct expansion coils in insulated supply ducts and an uninsulated return plenum above a drop ceiling. Heating is by electric resistance coils in the supply ducts. There are so many pieces of internal equipment, with several outside condensers and compressors to serve them, that submetering would be very expensive.

Thanks to Gulf Power, the electric utility serving Tyndall AFB, the pulse-initiating kilowatt-hour meters had been put in place before the period of performance of the CRADA began. Thus, several months of data from the Veterinary Clinic and the Shoppette could be gathered before the coatings were actually applied. These baseline performance data and detailed descriptions of the Shoppette and the Veterinary Clinic will allow us to calibrate models of the hour-by-hour energy demand of the two all-electric buildings and use the models to discern the effect of the roof coatings.

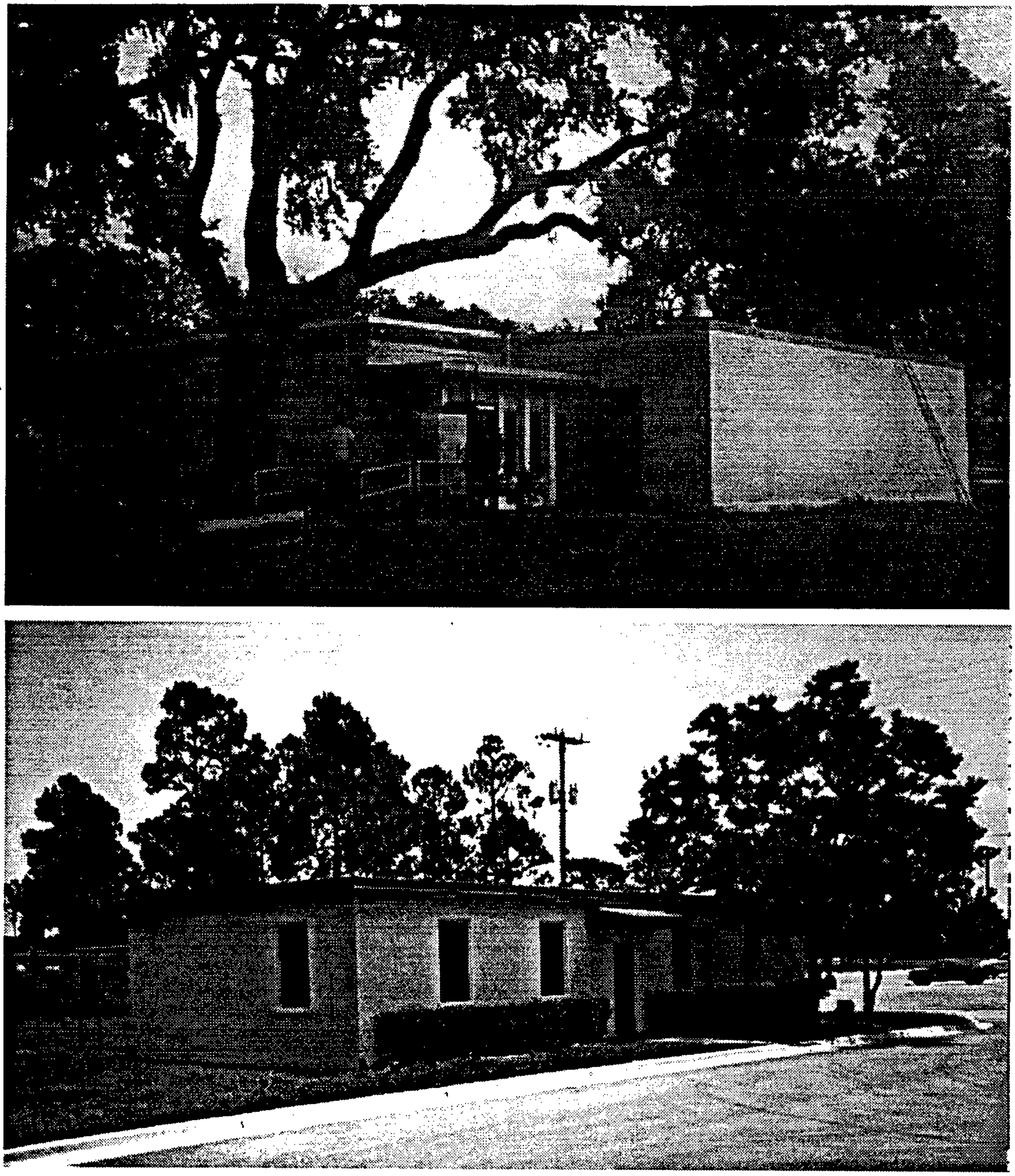

Fig. 3. Shoppette (*top*) and Veterinary Clinic (*bottom*) at Tyndall Air Force Base, Florida.

3

Installation of Monitoring Equipment and Coatings

A list of federal building managers with a possible interest in the demonstration of radiation control coatings was solicited by contacting members of the Federal Roofing Committee. Following up on the leads provided, we approached energy management and maintenance personnel at Tyndall AFB in Florida. The captain then in charge, a civil engineer with a professional interest in energy conservation and alternative energy, volunteered cooperation and offered access to several buildings. Tyndall's location in the Florida Panhandle was considered ideal for a demonstration of the effects of radiation control coatings on roofs because of the high cooling load of buildings in this area.

After an initial list of available buildings was compiled and general descriptions of the buildings were provided, three potential candidates were selected. A short trip was made to Tyndall AFB to discuss the as-built drawings for the buildings and compare them to the actual buildings. Walk-throughs of the candidate buildings were conducted with particular attention to the type and thickness of insulation in the roofs.

Pairs of heat-flux transducers were calibrated in the same generic insulation material as was judged to be in the candidate roofs. Having the actual insulation material available for the calibration is most desirable, but this was not possible for the Tyndall AFB buildings because no surplus insulation was left over from installation. Calibrating pairs of heat-flux transducers in material with the same density as that in the application is adequate for the relative comparisons that are of primary interest in the technology monitoring. Thermocouples were made long enough to go from the locations on each roof to a conveniently placed data logger in each building. Data loggers were requisitioned along with compatible modems and software to communicate with the data loggers remotely from the BTC via standard telephone lines. Slow-speed (1200-baud) modems available from the data logger manufacturer were selected because of guaranteed compatibility with the proprietary software for the data loggers. Speed of transmission is not important for this demonstration. To ensure reliable data collection, rechargeable battery packs and chargers were purchased to operate the data loggers on battery power at all times. The batteries recharge whenever 120-VAC power is available. In the event of an AC power outage, data continue to be collected for several months on stored battery power. The batteries automatically start recharging when AC power is restored.

When approval of the project was obtained and negotiations for the CRADA were under way, the delivery and installation trip for the technology monitoring was scheduled. Hurricane Opal had hit near Tyndall AFB between the time of the survey trip and the scheduled installation trip. One of the three buildings originally selected had lost its low-slope BUR, which was immediately replaced with a new sloped metal roof. An alternative building, the Veterinary Clinic, was selected, and drawings were sent to allow planning for deployment of instrumentation in it. The Burger King roof had survived, so it remained on the list. A surprise awaited regarding the third building. Just before BTC personnel arrived at Tyndall AFB for the installation of technology monitoring equipment, it was discovered that the third roof had severe water damage and would be replaced before the period of performance of the

CRADA would begin. The Shoppette was selected from a very short list of remaining buildings considered suitable for the scope of the project.

Monitoring Equipment Installation Details

The first building in which monitoring equipment was installed was the Burger King. A location above its storeroom was available for the data logger. A few ceiling tiles were removed to gain access to the plywood deck under the 8-year-old roof of this building. An approximately 1-ft- (0.3-m-) square piece of plywood was cut out at two locations. Squares of the same size were also cut out of one of the two 2-in.- (5.1-cm-) thick polyisocyanurate insulation boards in the roof and removed. A depression for the heat-flux transducers was cut in the middle of the top of each removed piece of insulation. Small holes were drilled up through the remaining insulation, penetrating the single-ply membrane at one spot for each location. The thermocouples for the outside-surface and outside-air temperatures were pushed through these holes, and the remaining hole was sealed with silicone caulk. The outside-air thermocouple measuring junction extended about 3 in. above the roof surface. The outside-surface thermocouple was bent against the surface. Later, when these patches were coated, these surface thermocouples were buried under the coating.

The pieces of insulation with the heat-flux transducers in place were replaced, as were the pieces of plywood deck. Small plywood strips were cut to span the small gaps created by cutting the plywood. They were secured to the cut-out pieces and surrounding deck edges with screws. The inside-surface thermocouples were taped at the center of the cut-out pieces. The thermocouples and heat-flux transducer leads were directed toward the data logger and secured with staples to the deck for a short length. The leads were connected to the data logger, which was secured to a piece of plywood spanning adjacent metal supports for the ceiling tile. The Campbell Scientific Model 21X data loggers selected for the demonstration have built-in reference junction compensation for the T-type (copper-constantan) thermocouples we routinely use. AC power was connected to the battery charger, and a telephone line was plugged into the modem. The data logger was programmed and a check made that data collection was proceeding according to the program in the data logger. The program included constants to reflect the calibration of the pair of heat-flux transducers used in the Burger King roof.

The instrumentation for the Veterinary Clinic and the Shoppette was installed from the top of these roofs because of the difficulty of cutting out pieces of deck to get at the insulation in the roofs. The 10-year-old roof of the Veterinary Clinic has a 3-in.- (7.6-cm-) thick deck of heavyweight concrete covered by 2–4 in. (5.1–10.2 cm) of insulating concrete. The building was once a secure radar and communications center. Approximately 1-ft (0.3-m) squares of built-up membrane were cut out at two locations, exposing the 2 in. (5.1 cm) of polyisocyanurate insulation on top of the insulating concrete. The polyisocyanurate had been added when the building was reconfigured as a Veterinary Clinic. Squares of the top layer of foam insulation were also removed, and a depression was made in the bottom of each for the heat-flux transducers. After an unsuccessful attempt to drill through the heavyweight concrete, the lead wires for the heat-flux transducers and the outside-air and outside-surface thermocouples were buried in tracks scraped in the membrane. The gaps where cuts were made and the tracks in the membrane were filled with roof cement and sprinkled with gravel to restore the surface to essentially the same appearance as before the instrumentation was put in place. The lead wires were bundled by plastic ties once they extended beyond the roof edge and led through a wire mesh window into an unconditioned air handler room for the heat pump serving the building. Inside-surface thermocouples were attached to the underside of the concrete deck approximately under the instrumented locations. Wires were again attached directly to the data logger, which was placed on top of the air handler. AC power was connected to its battery charger, and a telephone line was plugged into its modem. The lead wires from the pulse-initiating kilowatt-hour meter were not yet available. They were connected later by the local electrical utility when the meter was installed. The data logger was programmed, and data collection proceeded according to the program in the data logger.

The 20-year-old Shoppette roof is divided into two areas, one about a foot lower than the other and separated from the higher roof surface by a divider with metal flashing. The upper area covers the original part of the building, once a recreation center but now the store area of the Shoppette. It has a wooden plank deck topped by a BUR. About 3.5 in. (8.9 cm) of foil-faced fiberglass batt insulation covers the top of a drop ceiling. Above the drop ceiling are insulated supply ducts, containing direct expansion cooling coils and electric resistance heating coils for space heating and cooling. The lower part of the roof, over an addition built as a storeroom for the Shoppette, has a metal deck topped by 2 in. (5.1 cm) of polyisocyanurate insulation and a BUR. The storeroom is heated and cooled by a through-the-wall heat pump. To make the Shoppette instrumentation installation similar to that in the Veterinary Clinic, we chose locations over the addition. Pieces of BUR were cut out, and the heat-flux transducers were installed in the middle of the insulation. The BUR was replaced, and gaps were filled with roof cement covered by gravel. The metal deck allowed holes to be drilled directly down into the storeroom; the lead wires from the heat-flux transducers and outside-air and outside-surface thermocouples were pushed through the holes. The inside-surface thermocouples were bundled with the other wires and led to the data logger in the storeroom. The installation was completed as it was for the Veterinary Clinic.

Pre-Coating Monitoring Results

Remote data collection via modems had been checked out for all three data loggers at the BTC. When telephone lines became available, data were downloaded from the data loggers. The telephone lines for the Burger King, a franchise operation, are provided by the local telephone company. Tyndall AFB did not permit direct access to the Burger King for installation of a Tyndall AFB communications line. Therefore, an agreement was made with the Burger King management to let the BTC make incoming calls on the Burger King's modem line. We simply call the Burger King voice line, and the manager on duty switches their modem line to our modem temporarily for downloading data and uploading corrections to the data logger program. Since this data logger was to be used to collect data from two different coated patches, it was not critical to get extensive pre-coating data. Pre-coating data were collected for a few days. All instrumentation appeared to be connected correctly and responding appropriately for its location.

Dedicated communications lines were installed by Tyndall AFB and assigned to the Veterinary Clinic and Shoppette modems. Data retrieval began in early December 1995. The pulse-initiating kilowatt-hour meters were installed in late January 1996, and data collection from them began in February 1996. Samples of these data, shown in Figs. 4–7, prove that the technology monitoring design and installation was successful.

Figure 4 shows 61 days of temperatures and heat fluxes from the hourly averages of values collected every 5 min at the two locations on the Shoppette roof before the coating was applied. The eight plots on this figure are arranged in pairs for the heat-flux transducers (HFTs), the outside-surface

(OS) thermocouples, the outside-air (OA) thermocouples, and the inside-surface (IS) thermocouples at each location. The plots labeled "Ctd" are for the locations that would be coated on July 10, 1996; "Unc" designates the locations that would remain uncoated throughout the project. During this pre-coating phase of the project, there should be no difference between the respective OS, OA, and IS temperatures at each location or between the heat fluxes at each location. This is true for all four pairs of sensors. The inside surface on the metal deck stays between 60 and 70°F (16 and 21°C) despite the relatively cold outside-air temperature, which is often near 30°F (-1°C) and dips as low as 20°F (-7°C). This fairly constant temperature is reasonable for this building, which is conditioned 7 days per week. The outside-surface temperatures track the outside-air temperatures closely throughout the time period shown in this figure. The roof surface gets slightly colder than the air temperature at night because of radiation losses to the night sky. The roof surface does not get very much warmer than the air during daytime except for a few sunny days in January. The heat fluxes are negative most of the time for these cold days and nights, indicating heat losses through the roof of the building. Only during short periods of sunny days are there heat gains.

Figure 5 shows the same data for the Veterinary Clinic. During this pre-coating phase of the project, until the Veterinary Clinic roof was coated on July 9, 1996, there should again be no difference between the outside-surface, outside-air, and inside-surface temperatures at each location or between the heat fluxes at each location. However, this is true only for the outside-air and outside-surface temperatures. Even so, these data are not identical to the respective data from the Shoppette. The outside-air temperature at the Veterinary Clinic is slightly lower on the coldest nights, but by at most only 5°F (3°C). This difference can be attributed to the fact that the Shoppette is located on the intercoastal waterway that borders the northern edge of the base, while the Veterinary Clinic is in the middle of the base, well away from moderating influence of the water. Otherwise, the variations over the whole time period are identical. For the Veterinary Clinic, the peaks of the outside-surface temperatures are noticeably higher than the air temperatures on sunny days. This is because the outside-surface thermocouples for the Veterinary Clinic were placed on top of the BUR and secured with roof cement, whereas those for the Shoppette were placed under the BUR.

The differences between the inside-surface temperatures and heat fluxes for the two locations in the Veterinary Clinic prompted a special analysis of the Veterinary Clinic data. The inside-surface temperatures for the uncoated location (Fig. 5) are from a spot on the ceiling in the small unconditioned air handler room. Those for the location that would eventually be coated are on the concrete ceiling in the unconditioned space above the ceiling tiles in an adjacent small storeroom. The desired spacing between instrumented patches on the roof did not allow both patches to be above the same storeroom. It is reasonable to expect that the temperatures in the better-ventilated air handler room are slightly cooler than the temperatures above the storeroom at times during typical late fall weather in northern Florida. Data collected later during the air conditioning season showed that the ceiling of the air handler room was slightly warmer than the ceiling of the storeroom for the same reason.

The less-deep valleys for the heat-flux transducer at the uncoated location for days 8–10 and the higher peaks starting on day 17 are symptoms of a failing sensor. In subsequent months, this sensor indicated unreasonably high heat fluxes, of the order of 30–40 Btu/h·ft^2 (95–126 W/m^2), day and night. After that, the output varied randomly. During the on-site visit to apply the coating in July 1996, BTC personnel determined that the heat-flux transducer itself had failed, not the lead wires or connections. However, because of the approximately 16 days of reliable data that had been obtained from this

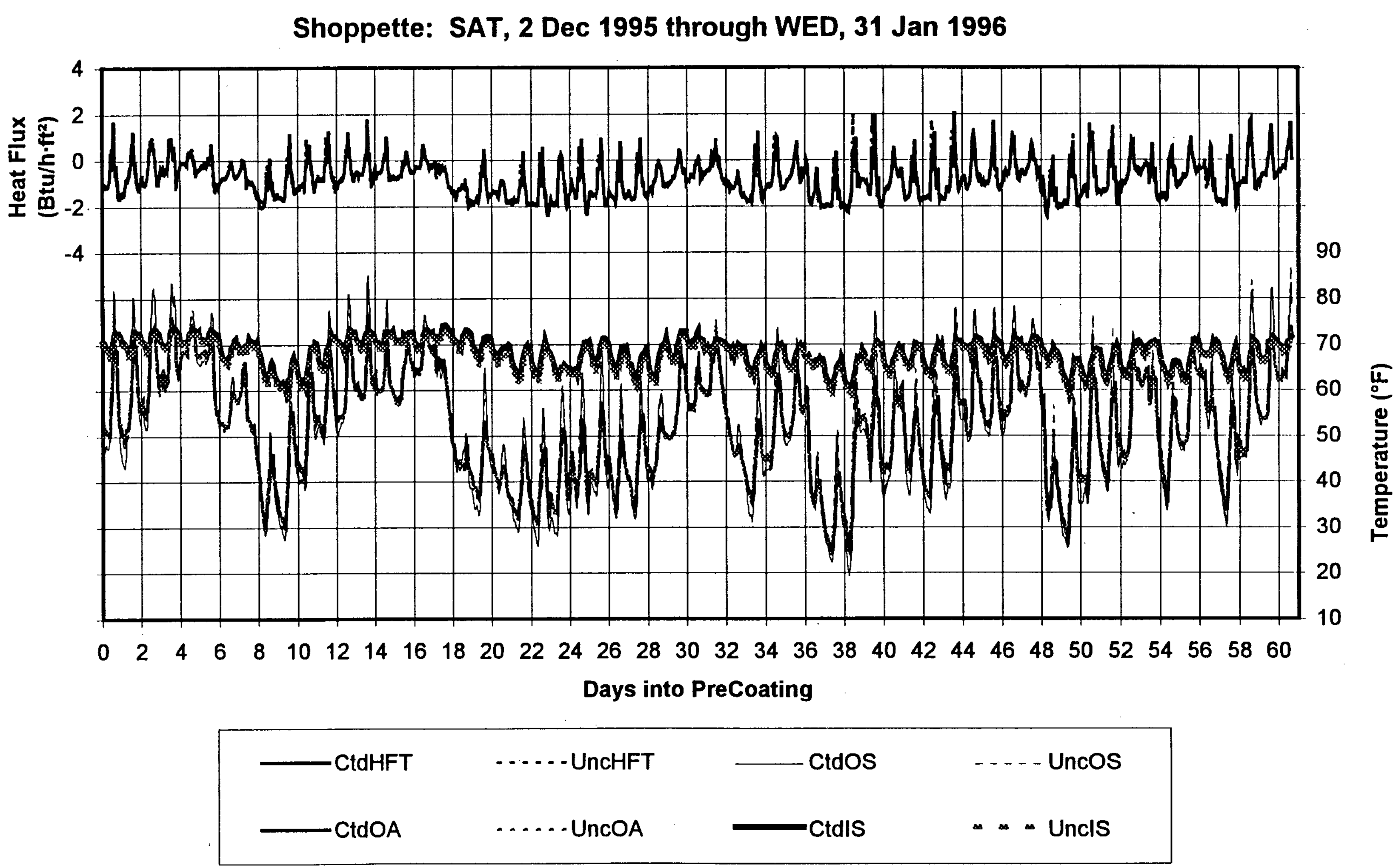

Fig. 4. Check on heat flux and temperature monitoring installation for the Shoppette before coating.

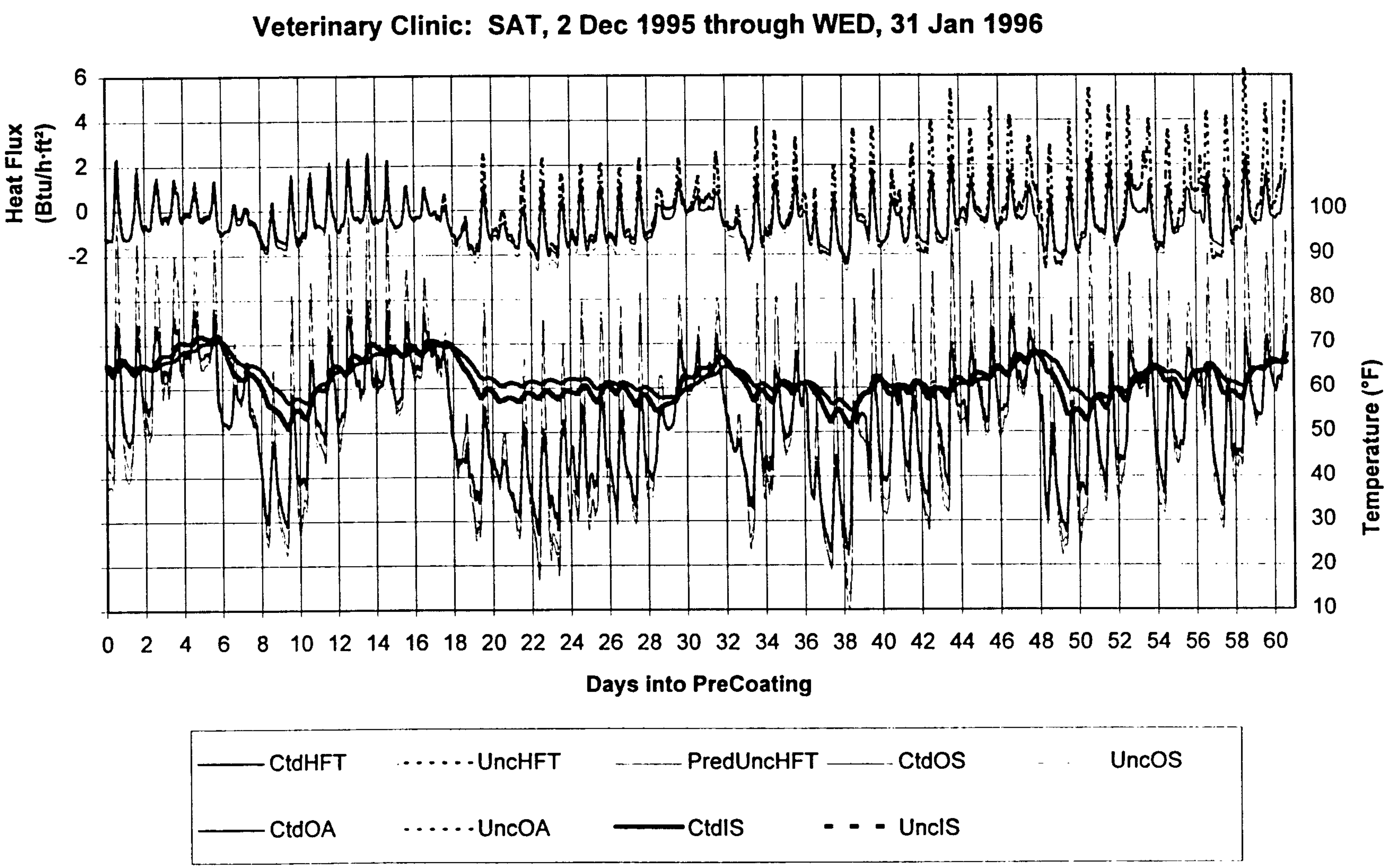

Fig. 5. Check on heat flux and temperature monitoring installation for the Veterinary Clinic before coating.

sensor, it was decided not to invest the time and expense during the next scheduled trip in November 1996 to replace this heat-flux transducer with a new one calibrated in polyisocyanurate insulation. The data obtained before the sensor failed are enough to use a computer program developed at ORNL (Wilkes 1989), Simplified Thermal Analysis of Roofs (STAR), to predict internal heat fluxes and temperatures when given the surface temperatures from the measurements and the roof geometry and thermal properties. STAR can produce the heat fluxes through the uncoated location for detailed analysis of data from the Veterinary Clinic in lieu of the more preferable measurements.

The data displayed in Fig. 6 verify that the geometry and thermal properties of the Veterinary Clinic roof are known well enough to predict the heat flux at the interface between the layers of polyisocyanurate insulation for the uncoated location. The outside-surface and inside-surface temperatures at the uncoated location are used as boundary conditions for the transient one-dimensional heat conduction equation programmed in STAR. The heavy solid line is the measured heat flux through the patch that would be coated on July 9, 1996. The heavy dashed line is the measured heat flux through the patch that is to remain uncoated for the whole project but has a failing transducer. The light solid line is the prediction of STAR for the uncoated patch. This line is the best match for the geometry shown on the as-built drawings for the Veterinary Clinic and the variations in thermophysical properties with material density given in the *ASHRAE Handbook of Fundamentals* (ASHRAE 1993) for polyisocyanurate insulation, lightweight concrete, and heavyweight concrete. The thickness of the BUR was varied, along with the density of the other materials, to generate a range of predictions from which to select the best match. The peak heat fluxes are reproduced exactly for all the reliable data; the light line showing the results of the prediction is on top of the heavier lines depicting the measurements. The minimum heat fluxes at night are reproduced adequately, especially since the greater interest is in the comparison between the coated and uncoated patches during the daytime, when solar loads are possible. The largest discrepancies between the predicted and measured heat fluxes occur when outdoor temperatures are coldest. Since thermophysical properties were put into the input file for STAR at room temperature and assumed to be constant, the discrepancies are thought to be related to the temperature dependence of the properties.

Figure 7 is a check of the pulse-initiating kilowatt-hour meters installed in the Shoppette and the Veterinary Clinic for February 1996, the first month that the pulse counts were available. At this time, the Shoppette was open for customers from 10 A.M. to 10 P.M. daily, plus a few early hours most days for stock work. Since August 1996, customer hours have been from 9 A.M. to 7 P.M. Monday through Saturday and from 11 A.M. to 5 P.M. on Sundays. Even when the Shoppette is closed at night, there is an appreciable, and irregular, demand for electricity, ranging from 15 kW to 22 kW. The February variations in nighttime electricity demand in the Shoppette could be related to the operation of electricity-using equipment or to the energy demand for heating.

By contrast, when the Veterinary Clinic is closed, its energy demand is essentially zero. Even when it is open, the electricity demand is low. Because of the clinic's erratic schedule and the low demand, a radiation control coating is unlikely to have a marked effect on total electricity use. While the loss of the heat flux measurement for the uncoated location is disappointing, Fig. 6 shows that it can be simulated. In fact, inside-surface temperatures from the storeroom location could be used with outside-surface temperatures at the uncoated location for a corrected uncoated heat flux. The functioning thermocouples at the uncoated location, augmented by the STAR prediction and by the functioning thermocouples and heat-flux transducers at the coated location, should provide data to complement the full set from both locations on the Shoppette roof. The functioning pulse-initiating kilowatt-hour meters for both buildings should allow relative comparisons when both buildings are being operated.

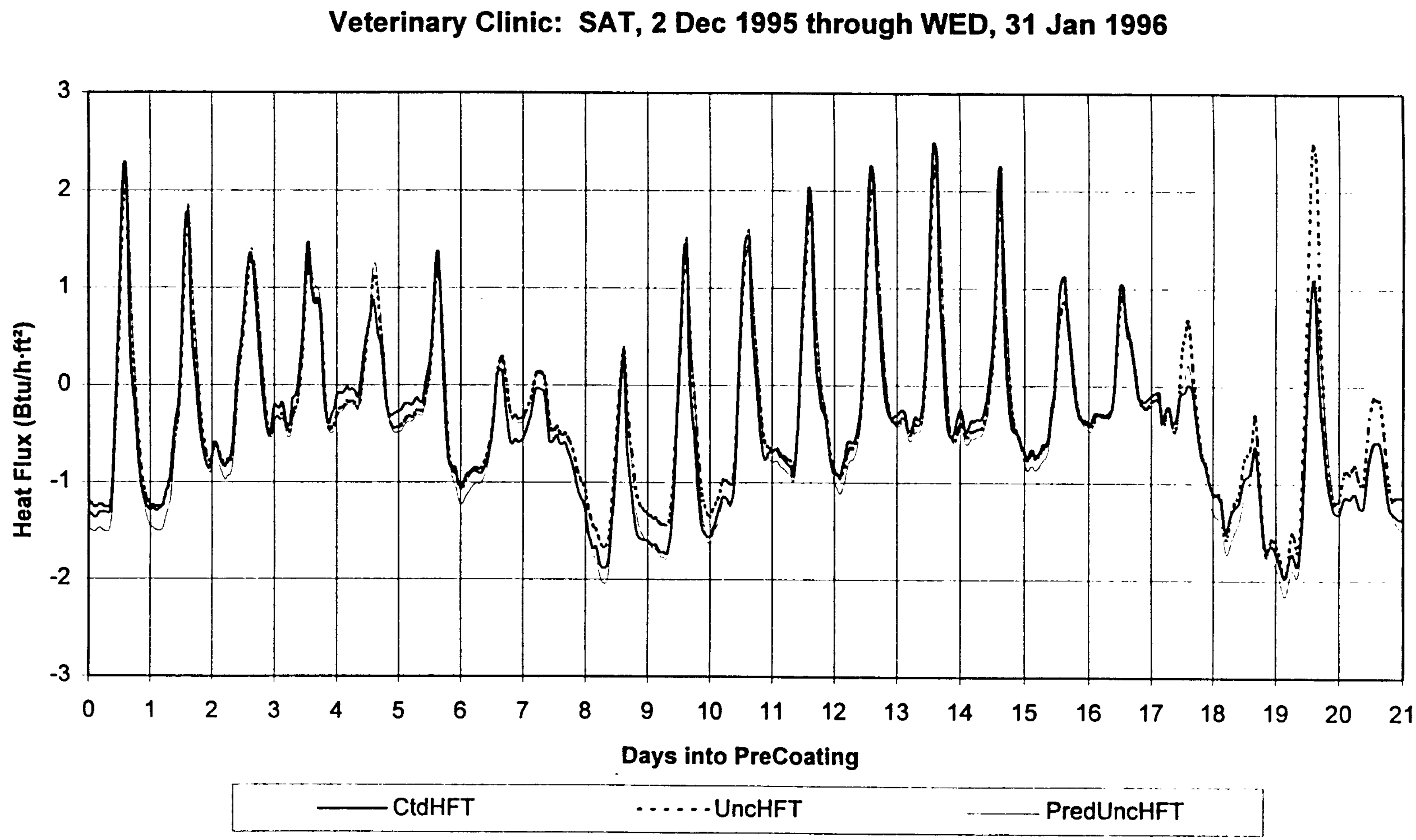

Fig. 6. Prediction by the STAR model of heat flux through the uncoated patch on the Veterinary Clinic.

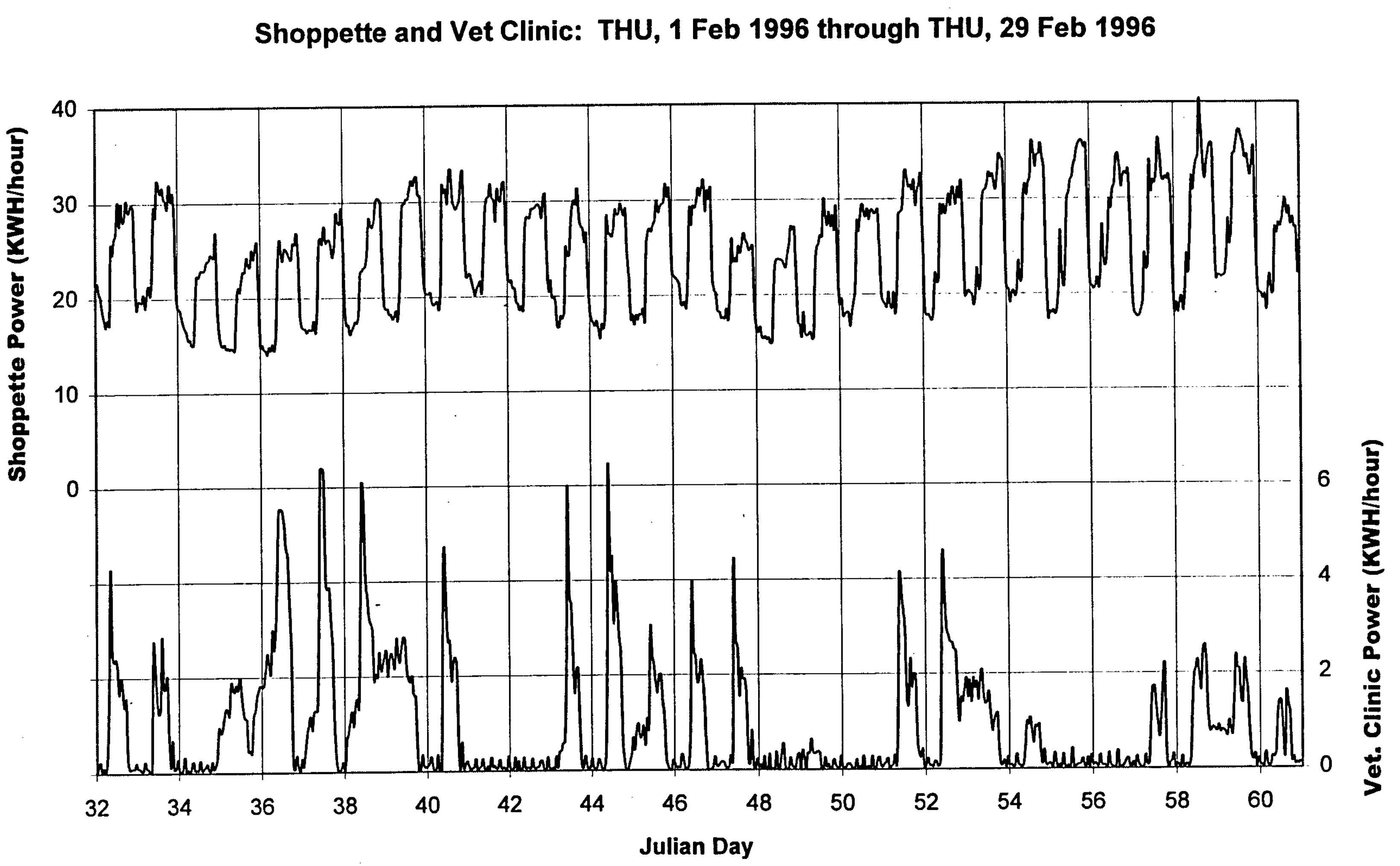

Fig. 7. Check of pulse-initiating kilowatt-hour meters for the Shoppette and the Veterinary Clinic before coating.

Installation of Coatings

After several months of pre-coating data collection from the Veterinary Clinic and the Shoppette, personnel from the BTC and ThermShield International met at Tyndall AFB to clean up the roofs, apply the Temp-Coat coating, and check that the monitoring technology was functioning after the coating. Rainy weather immediately before the coating work was scheduled caused both roofs to have areas of ponded water in addition to debris and loose gravel. The debris was picked up, and the loose gravel was either swept off with a stiff broom or blown off with a leaf blower. The remaining water and loose gravel were removed with a wet/dry vacuum.

The roof surfaces remained very rough despite removal of loose gravel. Airless spray equipment was used to apply a single coat of Temp-Coat to increase solar reflectance. Coverage to a thickness of about 0.015 in. (0.38 mm) is recommended by ThermShield. On a smooth surface this yields coverage of about 60 ft^2/gal (1.5 m^2/L) of coating. ThermShield personnel were experienced with the airless spray equipment that was used and applied the coating to a uniform thickness. Extra product was needed because of the rough surface due to the embedded gravel. Almost 135 gal (510 L) of product were used for 5725 ft^2 (530 m^2) of roof area. Coverage was therefore about 40 ft^2/gal (1.0 m^2/L). The current price for Temp-Coat in the GSA Muffin system is $166.95 per 5-gal (18.9-L) container.

The appearance of the roofs was changed markedly by the coating. The roofs appeared continuously white afterwards with some unevenness due to overlaps in the spray pattern. Figure 8 shows the roof of the Shoppette partway through the coating process. When this photograph was taken, the roof of the storeroom was completely coated, and application was beginning on the roof over the store itself. The extra piece of BUR for solar reflectance samples is still in place over what will be the uncoated patch as shown in Fig. 1.

The cleanup and coating application for the Veterinary Clinic and Shoppette roofs took about 12 h for four people. After completion of the work, one person went to the Burger King roof with a gallon (3.8 L) of the coating as it had been mixed and applied to the Shoppette roof. A gallon of an acrylic elastomeric coating with titanium dioxide added to increase solar reflectance had also been obtained from another manufacturer. Two areas of the white single-ply membrane on the Burger King roof, each approximately 2 ft (0.61 m) square and centered on the locations where thermocouples and heat-flux transducers had been installed, were cleaned with detergent. A strip of a similar membrane, approximately 9 in. wide by 3 ft long (23 cm wide by 0.9 m long), was laid beside each area. One area and its strip were coated in one direction by brushing on the ceramic coating and the other by brushing on the acrylic elastomeric. A second coat of each coating was applied in the perpendicular direction after the first coat had dried for about an hour in the sun. The ceramic coating brushed on much thicker than the acrylic elastomeric. The former was about 0.057 in. (1.4 mm) thick after two coats; the latter was only about 0.009 in. (0.2 mm) thick. After the second coat had dried for about an hour, pieces of the strips were cut off to take back to the BTC for measurement of the solar reflectance. The remaining strips were anchored by paver blocks and left on the Burger King roof to weather.

The monitoring equipment at all three locations was checked and readings were taken of the electric meters at the Shoppette and Veterinary Clinic immediately after the coating was completed. Approximately 9-in. (23-cm) squares were cut from the extra pieces to take back to the BTC as samples of the fresh coatings on the Veterinary Clinic and Shoppette roofs. A small square of uncoated BUR was also secured. As was shown for the Shoppette in Fig. 1, the remaining coated pieces were located between the instrumented locations, one of which was now coated and the other uncoated, on the two roofs. The pieces are heavy enough to stay in place without anchoring.

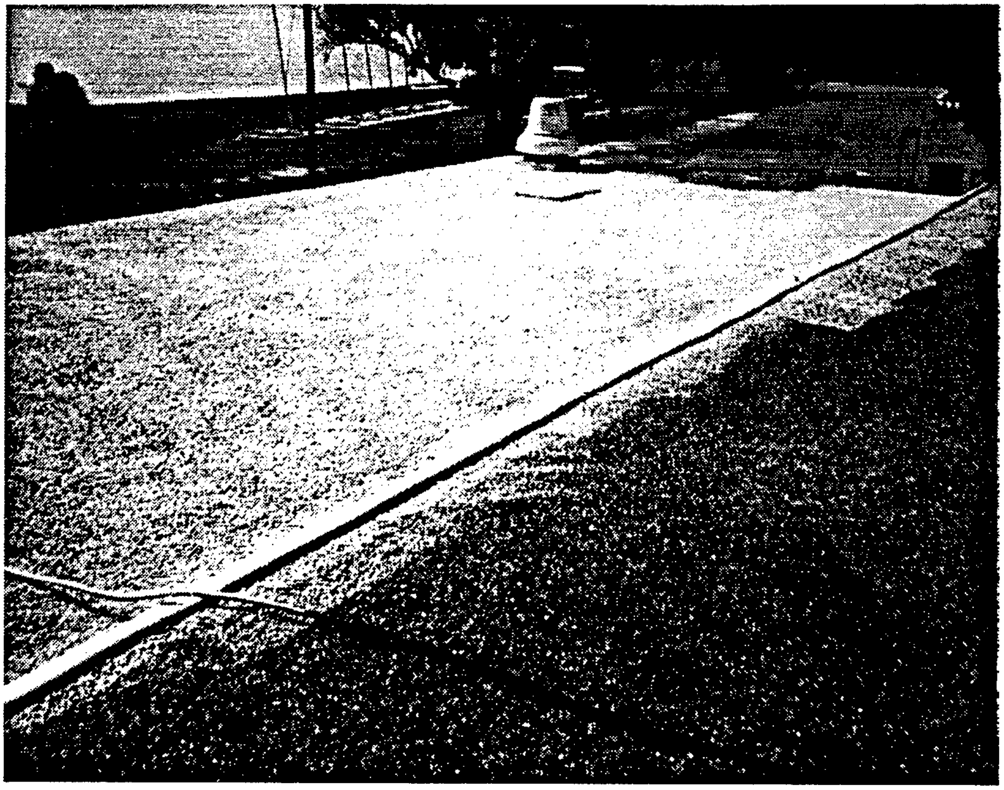

Fig. 8. Shoppette roof during coating process.

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Results with Fresh Coatings

The pre-coating monitoring at Tyndall AFB gave a false sense of the reliability of the data loggers. After we downloaded data from the loggers weekly for the first several months, we shifted to monthly downloading for the next several months without incident, the last time being at the end of June 1996. However, when we attempted to download data again at the end of July 1996, only the Shoppette and Burger King data loggers had data in their storage registers. The data collection program in the Veterinary Clinic data logger was corrupted. Inspection of the recovered data from the Shoppette and the Burger King showed that there was a severe disturbance, probably an electrical storm, on July 25. The Shoppette and Burger King data survived; the Veterinary Clinic data did not. The data collection program was reloaded, and data collection has proceeded uninterrupted since then, but now at weekly intervals for the Shoppette and the Veterinary Clinic.

To show the comparison for the Shoppette between pre-coating and post-coating temperatures, heat fluxes, and whole-building electricity use, we chose the period spanning the three weeks before coating to three weeks after the coating. For the Veterinary Clinic, data for June 1996 were compared to data for August 1996. For the Burger King, only post-coating data are of interest; therefore, the period chosen for comparison is from July 11 until July 31. Results for fresh coatings tested at the BTC are shown in the same time frame as the results from the Shoppette.

Table 1 shows the average of five measurements of solar reflectance with a Devices and Services Company Solar Spectrum Reflectometer over the area of the listed specimens (Yarbrough 1996). Included in the table are data for radiation control coatings and membranes at Tyndall AFB as well as for some coatings and membranes undergoing tests at the BTC in the climate conditions of East Tennessee. All the coatings at the BTC are about 0.020 in. thick except for sample TC1, whose thickness is 0.032 in. As long as the coating thickness exceeds about 0.020 in., thickness does not affect solar reflectance (Anderson et al. 1991). Only the coating RH3 is less than 0.020 in. thick, but it is the same coating as sample RH2, and the fresh values are essentially equal.

The solar reflectances, ρ, for the fresh coatings on smooth ethylene propylene diene monomer (EPDM) and atatic polypropylene polymer (APP) -modified bitumen surfaces—in Table 1, the Burger King samples designated as TC2 and RH3 and the BTC fresh samples called INS, RH1, RH2, SOL, and TC1—are in the range from 0.75 to 0.85 with small standard deviations, σ, of the five measurements from their respective averages. The samples on rough surfaces coated along with the Shoppette and Veterinary Clinic roofs (called SHP and VC in Table 1) have solar reflectances in the range from 0.50 to 0.55 with larger standard deviations for the five measurements. Due to the roughness of the gravel topping on the BURs, it was not possible, even with 50% more product, to coat the BUR as completely as a smooth surface. These solar reflectances are already in the range of those for two samples on smooth surfaces weathered for 2 years at the BTC (RH1 and INS in Table 1) and one weathered less than a year (TC1). They fall below the 0.65 to 0.70 range for two samples weathered less than a year (RH1 and INS). The uncoated smooth and rough surfaces (UNC1, UNC2, and UNC3 in Table 1) have solar reflectances of less than 0.10, and weathering does not appear to affect the solar reflectance.

Table 1. Solar reflectances of coated and uncoated membranes

Location	Sample	Coated/ Uncoated	Substrate[a]	Fresh $\rho \pm \sigma$ [b]	Weathered ρ (if available)
Shoppette	SHP	Coated	Rough surface	0.544±0.073	
Vet. Clinic	VC	Coated	Rough surface	0.518±0.051	
Shoppette, Vet. Clinic	UNC3	Uncoated	Rough BUR surface	0.090±0.009	
Burger King	RH3	Coated	Smooth EPDM	0.797±0.004	
Burger King	TC2	Coated	Smooth EPDM	0.763±0.010	
BTC	RH2	Coated	Smooth APP	0.806±0.008	
BTC	SOL	Coated	Smooth APP	0.853±0.005	
BTC	TC1	Coated	Smooth APP	0.790±0.005	0.515 (after 37 wks)
BTC	UNC2	Uncoated	Smooth APP	0.060±0.001	
BTC	INS	Coated	Smooth EPDM	0.773±0.006	0.689 (after 42 wks) 0.539 (after 94 wks)
BTC	RH1	Coated	Smooth EPDM	0.809±0.002	0.662 (after 42 wks) 0.569 (after 94 wks)
BTC	UNC1	Uncoated	Black EPDM	0.068±0.001	0.072 (after 70 wks)

[a]EPDM = ethylene propylene diene monomer; APP = atatic polypropylene polymer
[b]ρ = solar reflectance; σ = standard deviation of measurements

The roofs at Tyndall AFB are considered moderately well to well insulated. The Veterinary Clinic roof has 2 in. (5.1 cm) of polyisocyanurate insulation over 2–4 in. (5.1–10.2 cm) of lightweight concrete, yielding an R-value of 12–13 h·ft²·°F/Btu (2.1–2.3 m²·K/W) (ASHRAE 1993). The deck is 3 in. (7.6 cm) of heavyweight concrete. Its high thermal mass tends to delay the effect of solar load to times later in the day than for roofs without high thermal mass. The Shoppette storeroom roof has 2 in. (5.1 cm) of polyisocyanurate insulation; the Burger King roof has 4 in. (10.2 cm) of polyisocyanurate insulation with R-values of about 11 and 22 h·ft²·°F/Btu (1.9 and 3.9 m²·K/W), respectively.

In tests at the BTC, various radiation control coatings have been applied to 4-ft- (1.2-m-) square samples of single layers of low-slope roof membrane materials. The membranes are sealed in frames and placed over roof decks comprising three sheets of 0.5-in.- (1.3-cm-) thick plywood, with thermocouples on the top and bottom of the assembly and a heat-flux transducer and thermocouple at the top of the middle layer of plywood. The thermal resistance of these roofs is about 1.5 h·ft²·°F/Btu (0.26 m²·K/W), only 7–14% of the R-values of the roofs at Tyndall AFB. Low thermal resistance maximizes the benefit of radiation control coatings to decrease the outside-surface temperature of the roof and the heat flux through the roof. Results from the BTC tests will provide perspective for the early results from Tyndall AFB before generalizations are available from detailed modeling.

Shoppette Results

Figures 9 and 10 compare outside-surface temperatures and heat fluxes, respectively, at the uncoated and the freshly coated locations on the roof of the Shoppette. The time frame is from June 19, 1996 (three weeks before the coating) to the end of July 1996. The day on which the coating was applied, July 10, is indicated by the vertical arrow and label. These figures show a significant decrease after the coating was applied in the daytime outside-surface temperatures and heat fluxes for the coated surface relative to the uncoated surface. No differences were expected between these values before the coating was done, but differences are observed. The data from which these figures were made show clearly the effect of the shadow seen in Fig. 1. During sunny days from 1400 to 1600 hours, the shadow from the live oak tree passes over the location that will be coated, causing it to be more strongly shaded. A corresponding but smaller effect is seen from 1600 to 1800 hours for the uncoated location.

The outdoor-air temperatures from both locations were identical before and after the coating was applied. There was a slight difference between them during the coating process itself because the extra piece for the solar reflectance samples and masking tape were over the thermocouples at times during the coating process and the day before. The outdoor-air temperatures at both locations are given on each graph for insight into weather disturbances and periods of unusual heat or cold that also affect the outside-surface temperatures and heat fluxes. For example, the five days before the coating was applied were unusually cool, indicative of a prolonged rainy period. The outdoor temperature on day 207 shows unusual behavior indicative of severe weather conditions. The outside air temperatures and heat fluxes generally show daytime peaks that vary like the outdoor-air temperatures. The nighttime spikes in the heat fluxes near day 179 and before days 195 and 199 are probably electronic noise unrelated to climatic conditions.

To highlight the beneficial effect of the coating on the outside-surface temperature of the roof and the heat flux through it, Table 2 lists average temperatures and heat fluxes for sunlit uncoated and coated membranes. The averages were generated in the spreadsheets containing the detailed data from which, for example, Figs. 9 and 10 were prepared. The first row of data in this table is for the time when the Shoppette roof was already coated, from July 11 through July 31. Columns of data were generated containing outside-surface temperatures for the uncoated and coated patches only for times when the uncoated temperature exceeded the coated temperature by 5°F (3°C). Pre-coating data and the plots in Fig. 9 show that the random fluctuations in the outside-surface temperatures are less than 5°F (3°C). If the uncoated temperature is more than 5°F (3°C) higher than the coated temperature, the cause must be solar irradiation. The averages of these sunlit roof values and the percentage difference between the averages are listed. For July 1996, uncoated sunlit surface temperatures on the Shoppette averaged 110.3°F (43.5°C), and coated sunlit surface temperatures averaged 94.0°F (34.4°C), a decrease of 14.8%.

For the average sunlit heat fluxes in Table 2 the criterion is that the uncoated heat flux must exceed the coated heat flux by 0.5 Btu/h·ft^2 (1.6 W/m^2). To eliminate the effect of the occasional negative spikes seen at night in the heat fluxes of Fig. 9, only positive uncoated heat fluxes were subjected to the criterion. On the Shoppette for July 1996, the uncoated sunlit heat flux averaged 3.22 Btu/h·ft^2 (10.2 W/m^2), and the coated sunlit heat flux averaged 1.46 Btu/h·ft^2 (4.6 W/m^2), a decrease of 54.6%.

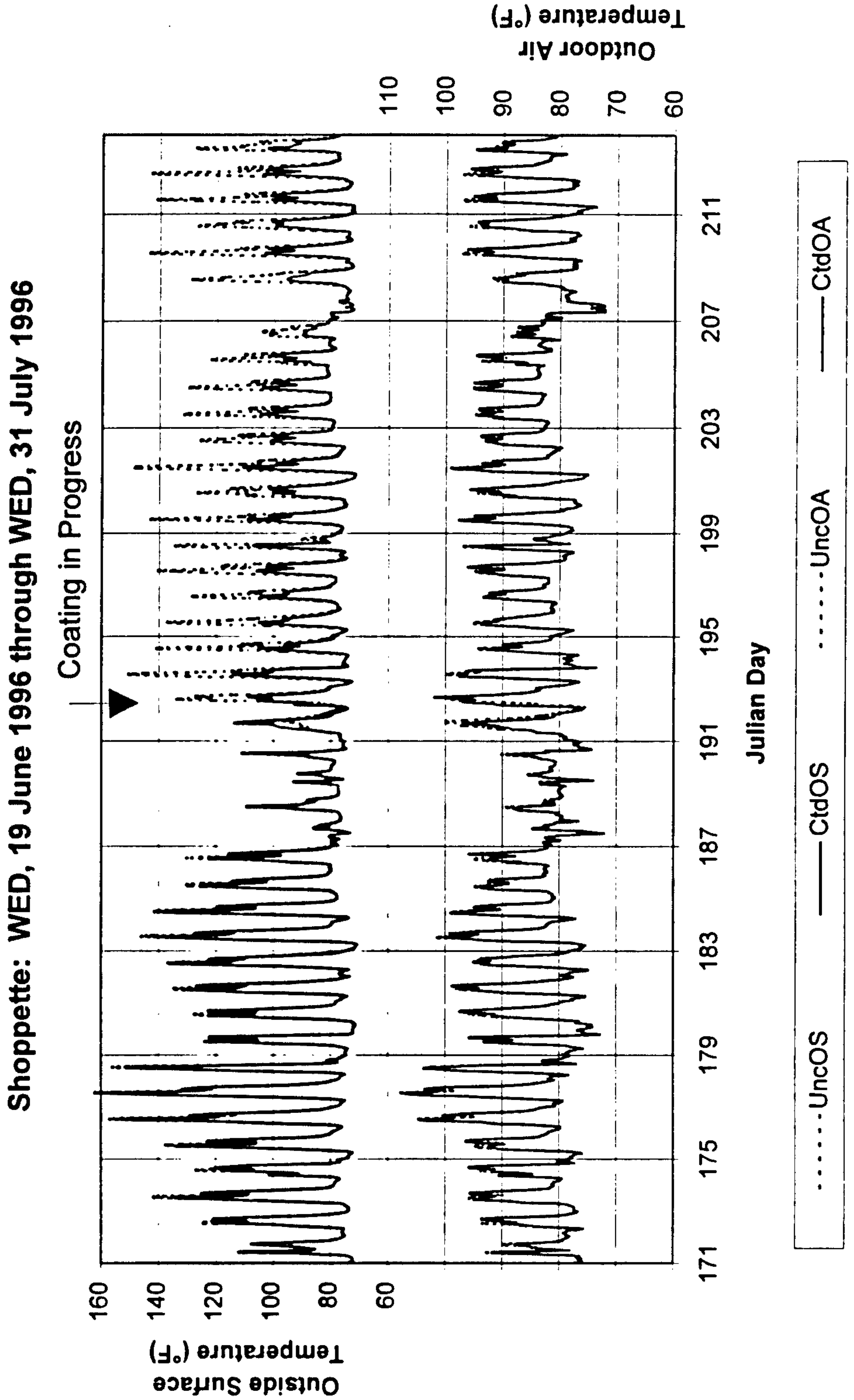

Fig. 9. Comparison of temperatures for uncoated and freshly coated Shoppette roof.

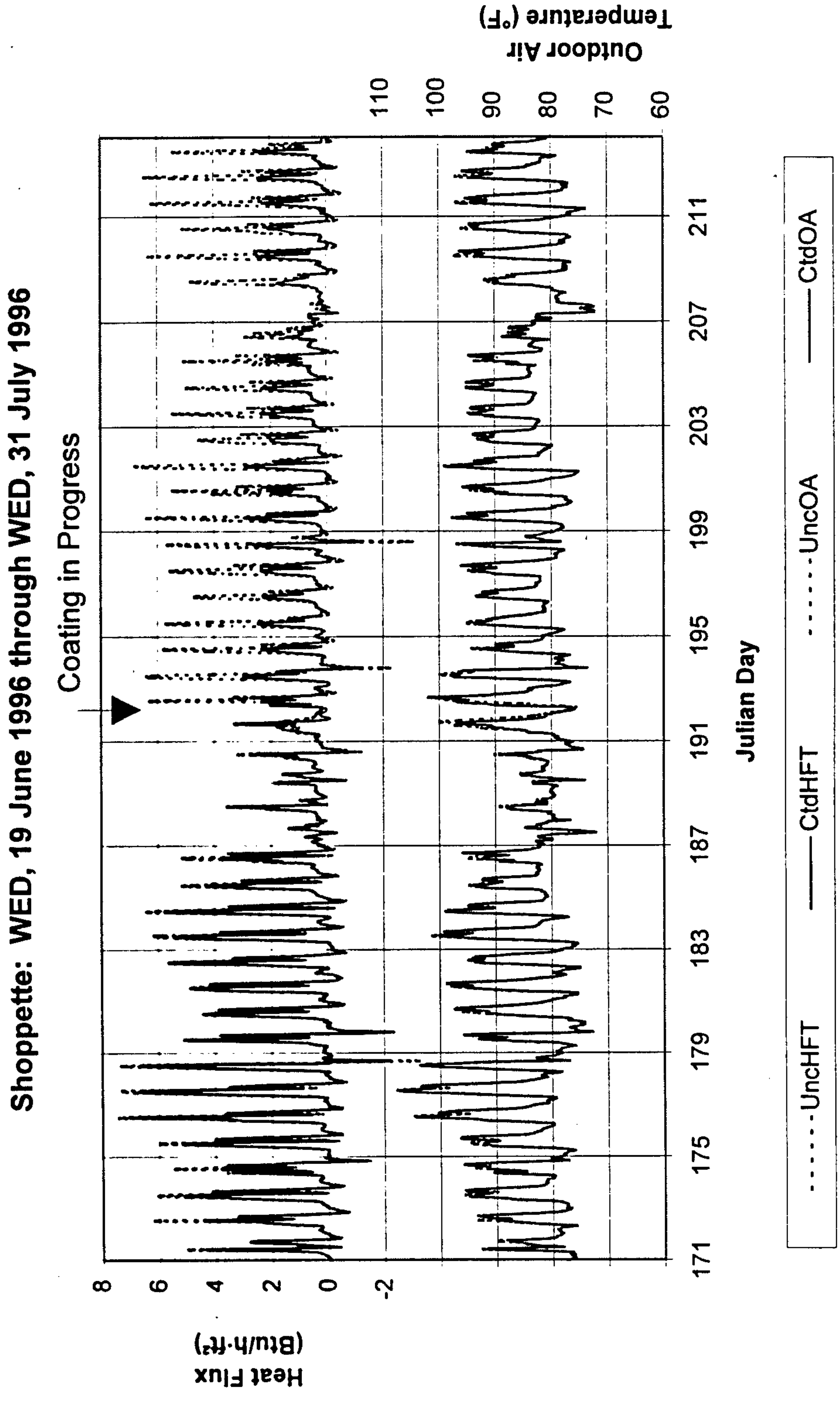

Fig. 10. Comparison of heat fluxes through uncoated and freshly coated Shoppette roof.

Table 2. Average temperatures and heat fluxes for sunlit uncoated and coated membranes

Location and time period	Average $T_{unc}OS$ (°F)	Average $T_{ctd}OS$ (°F)	% Decrease	Average HFT_{unc} (Btu/h·ft²)	Average HFT_{ctd} (Btu/h·ft²)	% Decrease
Shoppette 7/11–31/96	110.3	94.0	14.8	3.22	1.46	54.6
Shoppette 8/1–31/96	103.1	90.0	12.7	2.70	1.25	53.7
Shoppette 9/1–30/96	95.5	85.9	10.0	2.17	1.06	51.4
Vet Clinic 8/1–31/96	109.6	97.7	10.9	2.53	1.68	33.4
Vet Clinic 9/1–30/96	105.2	93.7	10.9	2.51	1.70	32.2
BTC/SOL 6/19–7/31/96	111.5	80.8	27.5	18.15	4.14	77.2
BTC/RH2 6/19–7/31/96	111.5	82.1	26.4	18.05	4.05	77.5

The shadow that is seen to affect the afternoon data in Figs. 9 and 10 before the coating was applied continued to affect the data afterwards. On sunny days, it appeared to more strongly shade the coated patch early in the afternoon and move onto the uncoated patch later in the afternoon. This leads to more apparent benefit of the coating, especially in the heat flux decrease. Table 3 shows a portion of the spreadsheet columns for typical daylight hours without and with the sunlit criterion applied. Inspection of the data for sunny days shows that the criterion for sunlit temperatures causes data for hour 1600 to be missing occasionally from consideration, indicating that the uncoated surface is more strongly shaded. This shading of the uncoated surface causes most heat fluxes from 1500 to 1700 hours not to be included in the sunlit average. The percentage decrease for hour 1400 is typically near 70%, indicating that the apparent effect of the coating is being helped by the shadow in early afternoons of sunny days.

Table 2 shows the same sunlit averages for other situations. The Shoppette data for August and September 1996 show that the average temperatures and heat fluxes are decreasing, which is reasonable because solar input peaks in June. However, the respective percentage differences between the average uncoated and coated temperatures and the average uncoated and coated heat fluxes are also decreasing, albeit slowly. This is taken as evidence that the shading effect is present but is fairly constant. Since shading of structures is a common phenomenon, it is valuable although more complicating to have the effect present in the data from the uncoated and coated patches on the Shoppette. Other features of the data in Table 2 will be discussed when the data upon which they are based are presented.

Figure 11 shows the power demand for the Shoppette for the same time interval as Figs. 9 and 10. The outside-air temperatures for both locations on the roof are again shown for explanation of possible weather-related peaks and valleys in the total building electricity use. The severe weather on day 207 caused a power outage in the Shoppette. The erratic nighttime behavior of the power demand is puzzling.The figure seems to show a weak relationship between nighttime demand and outside temperatures.

Table 3. Typical daylight hour data for the Shoppette with and without sunlit criterion

Julian day	Time	UncOS	CtdOS	If Unc- ctd > 5, T's to avg.		% decr.	UncHFT	CtdHFT	If Unc-Ctd > 0.5, Ctd > 0, Q's to avg.		% decr
204	700	80.9	80.1				0.62	0.484			
204	800	84.5	82.3				1.242	0.812			
204	900	94.6	87.9	94.6	87.9	7.1	2.477	1.421	2.477	1.421	42.6
204	1000	104.2	93.2	104.2	93.2	10.6	3.471	1.815	3.471	1.815	47.7
204	1100	120.1	100.9	120.1	100.9	16.0	4.755	2.313	4.755	2.313	51.4
204	1200	129.4	104.4	129.4	104.4	19.3	4.943	2.083	4.943	2.083	57.9
204	1300	126.5	100.5	126.5	100.5	20.6	3.02	1.179	3.02	1.179	61.0
204	1400	113.5	92.5	113.5	92.5	18.5	1.409	0.456	1.409	0.456	67.6
204	1500	104.2	92	104.2	92	11.7	0.603	0.857			
204	1600	98.7	100.2				0.926	2.096			
204	1700	107.7	100.7	107.7	100.7	6.5	2.644	1.539	2.644	1.539	41.8
204	1800	105.9	96.8	105.9	96.8	8.6	1.609	0.959	1.609	0.959	40.4
204	1900	98.7	92	98.7	92	6.8	0.622	0.545			
204	2000	89.5	85.8				-0.203	0.107			
204	2100	83.9	82.3				-0.17	0.137			

A correlation of all power data against outside-air temperature from 2300 to 0600 hours and from January 31 through July 31, 1996, is shown in Fig. 12. The correlation yielded was

$$power = 0.249 \times outside\ air\ temperature\ (°F) + 5.95,$$

with a correlation coefficient, r, of 0.72 ($r^2 = 0.52$). More electrical power is used as nighttime outside temperature increases, but the scatter about the line of best fit is large.

Days 185 and 186 before the coating and days 203 and 204 after the coating have similar outdoor-air temperature profiles and nighttime power demands, as Fig. 11 shows. Daytime power demands did not significantly decrease after the coating was applied. More data and analysis beyond the scope of the work undertaken for this first volume of the project report are needed to ascertain the effect of the coating on the energy use for cooling in the complicated Shoppette with large internal loads and a moderately well insulated roof as one component of the cooling load.

Veterinary Clinic Results

Figures 13 and 14 show temperature and heat flux data for the Veterinary Clinic. They compare the temperatures and heat fluxes for both uncoated locations in June 1996, and for one location that was coated while the other remained uncoated in August 1996. A discontinuity in the plots and abscissa labels indicates the end of the June data and the start of the August data. Data for the Veterinary Clinic from the entire month of July were lost, apparently due to an electrical storm in late July. The very slight discrepancies between the outdoor-air temperatures at the two locations evident in

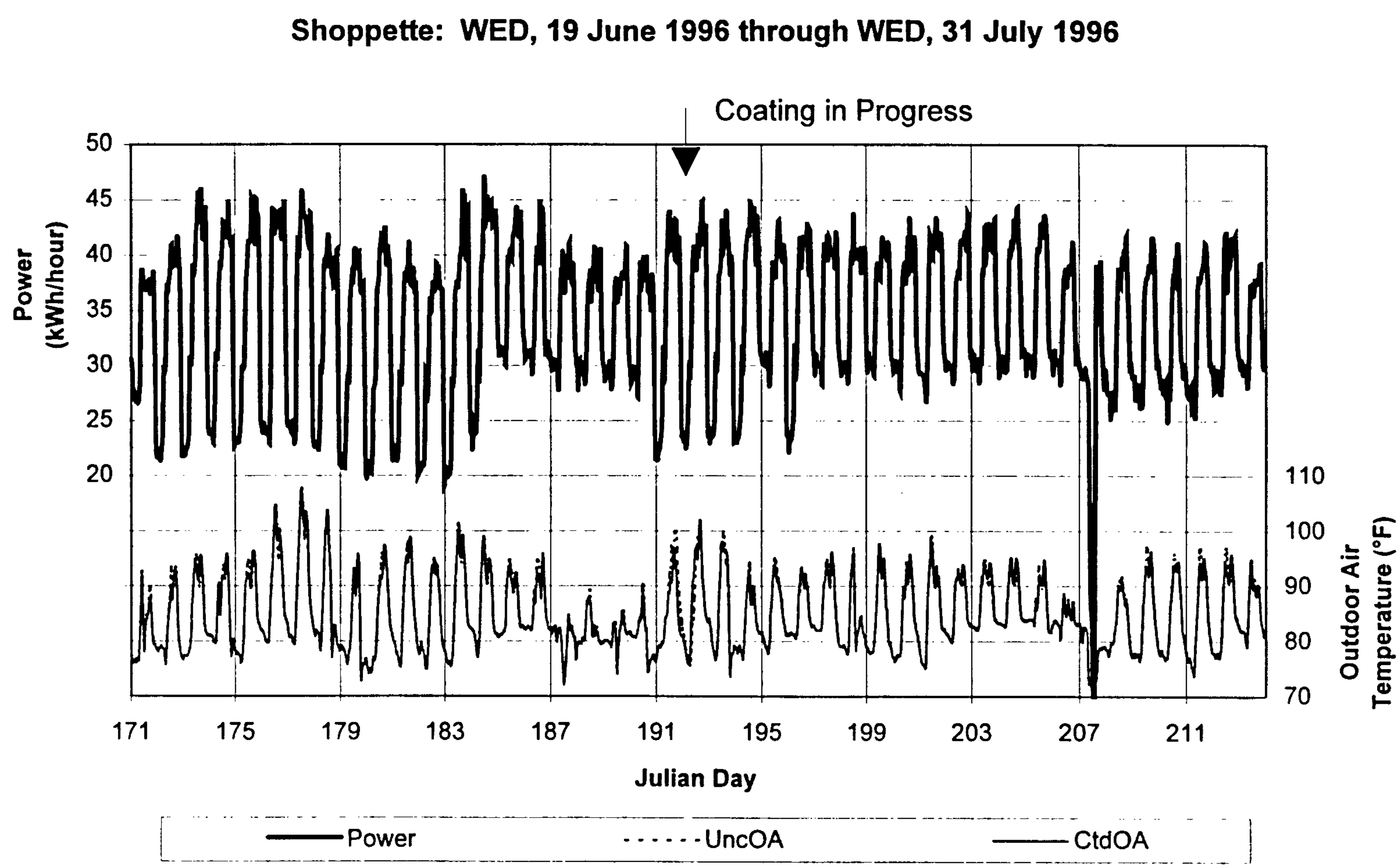

Fig. 11. Power demand for the Shoppette before coating and after the roof was freshly coated.

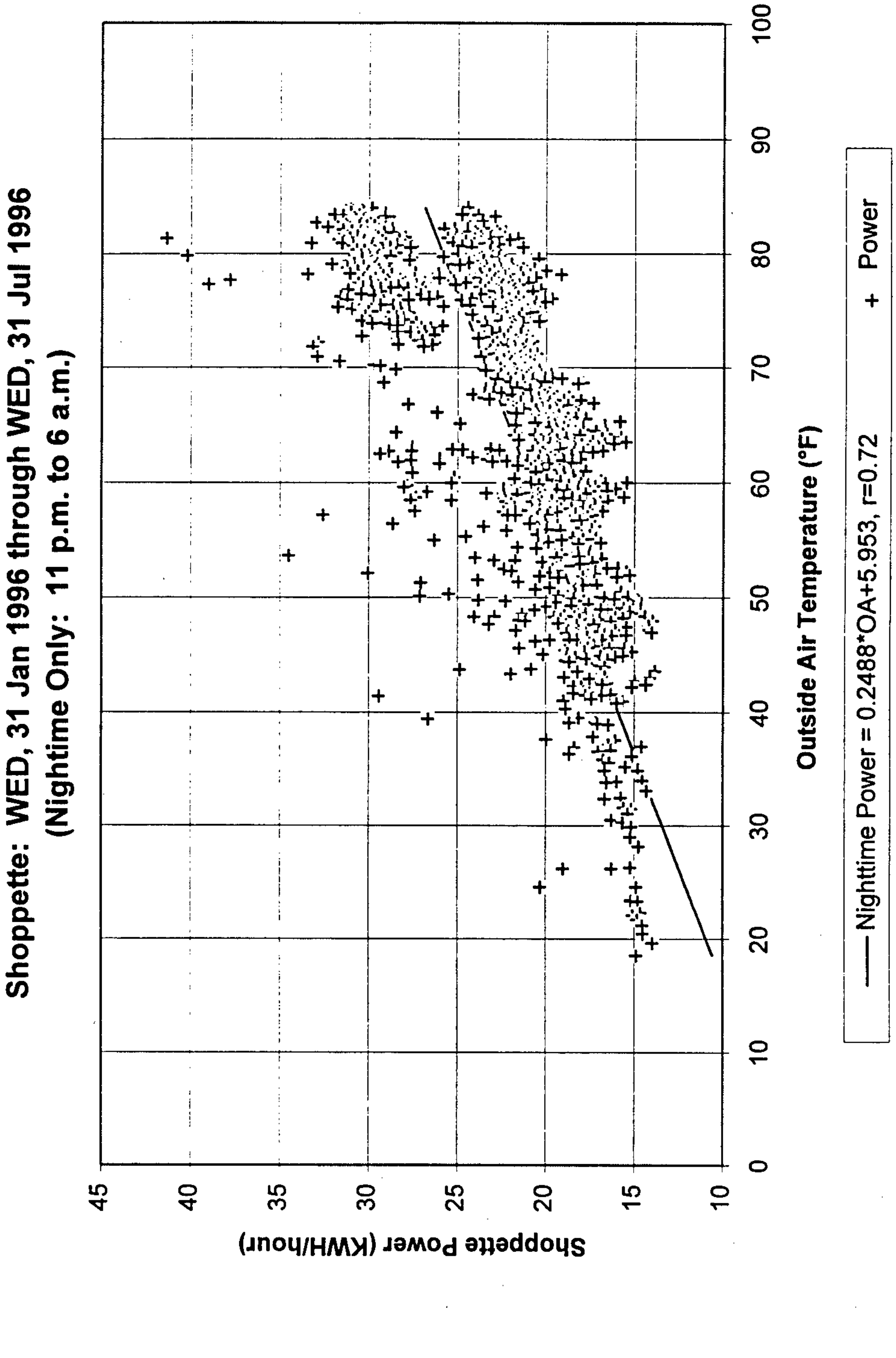

Fig. 12. Correlation of nighttime power demand for the Shoppette with outside-air temperature.

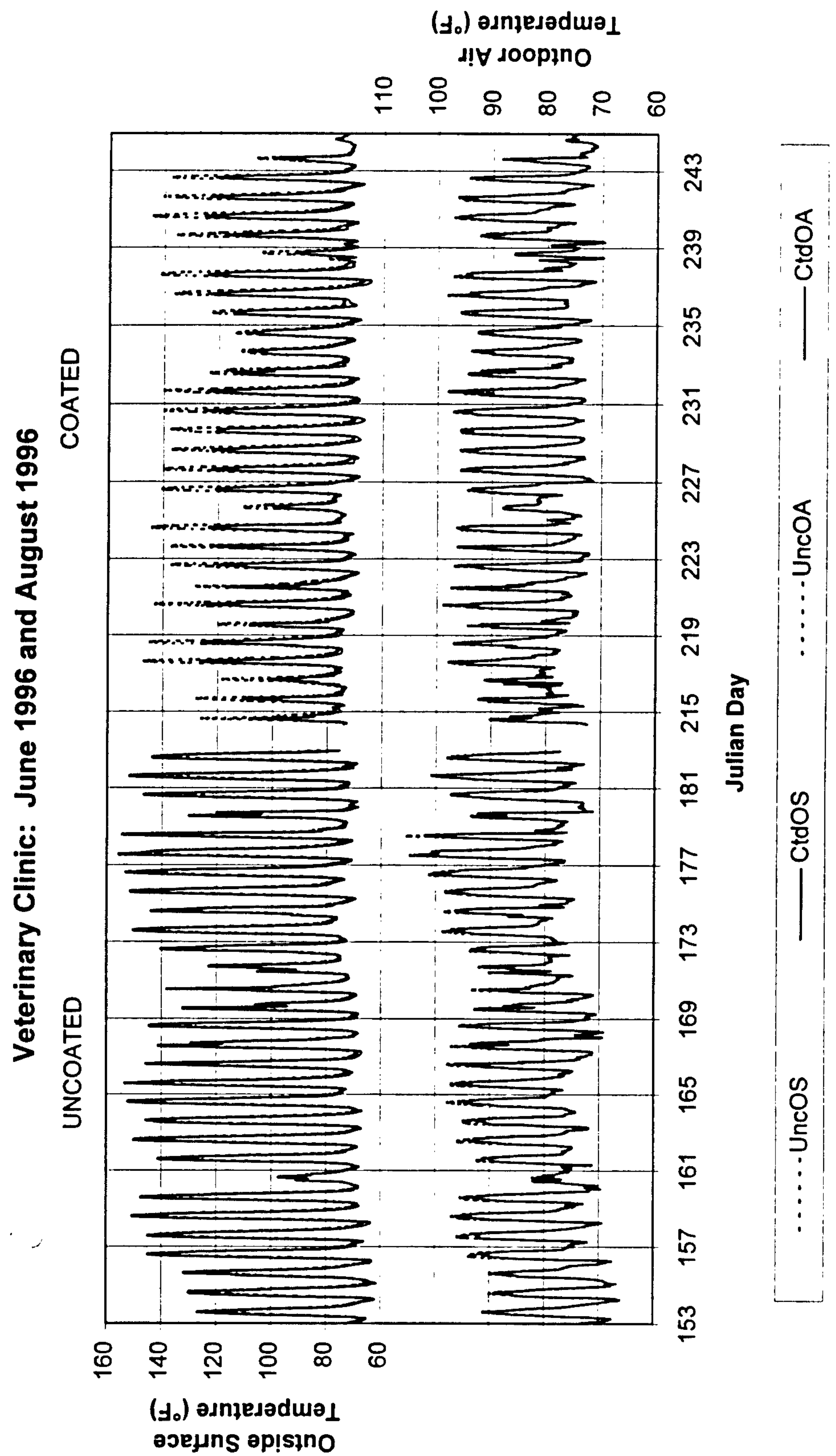

Fig. 13. Comparison of temperatures for uncoated and freshly coated Veterinary Clinic roof.

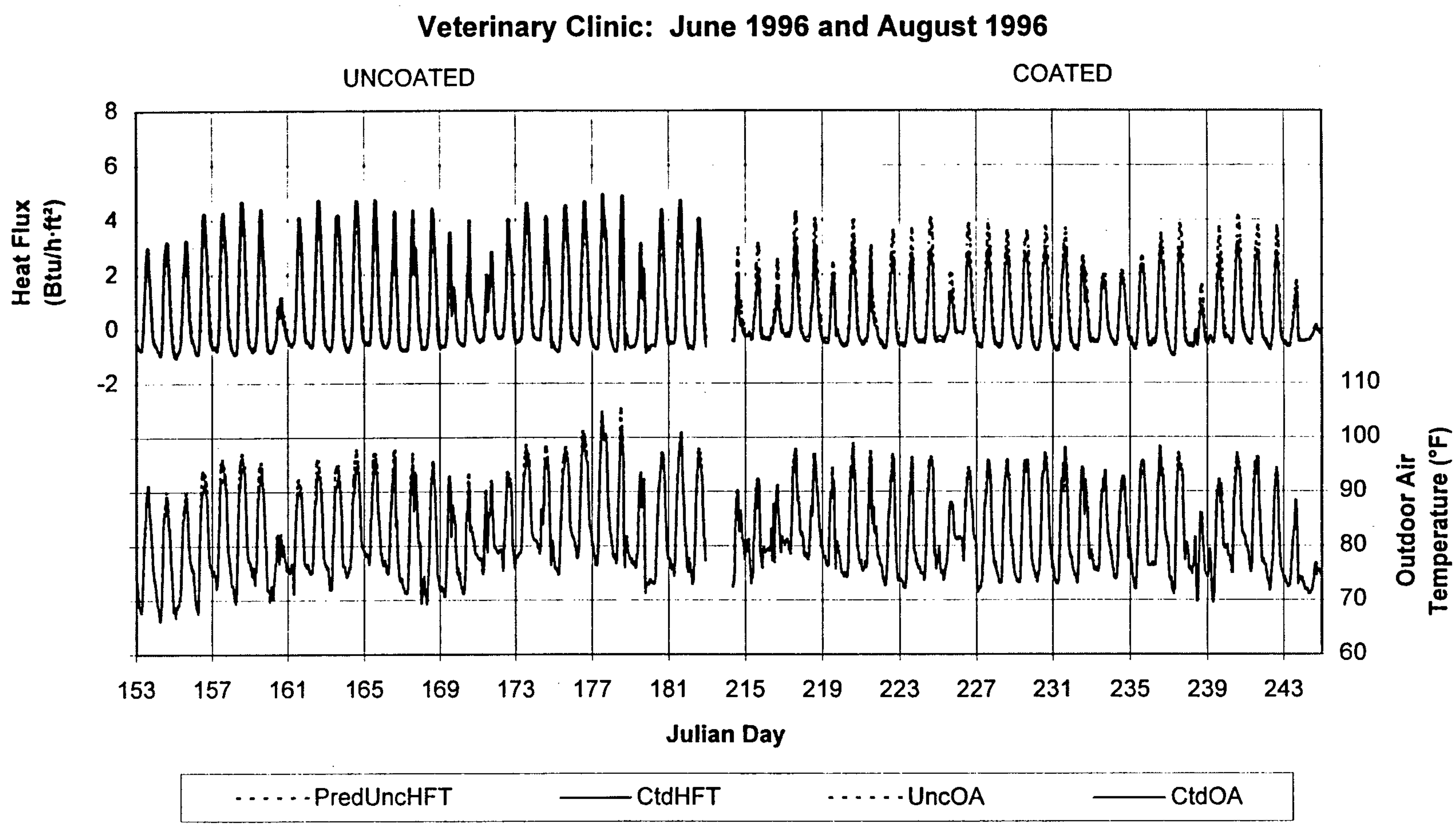

Fig. 14. Comparison of heat fluxes through uncoated and freshly coated Veterinary Clinic roof (including predicted heat fluxes for the uncoated patch).

June have disappeared in August, indicating that the air temperature thermocouples may not have been protruding from the roof identically in June but were adjusted properly after the roof was coated.

During June, when both locations were uncoated, no effect of shadows is evident in the surface temperatures, which are directly measured, or in the heat fluxes, of which the uncoated value is predicted by the STAR program from the surface temperatures at the uncoated location. The uncoated and coated heat fluxes agree better at night than they did in Fig. 6. This is evidence that the discrepancy in Fig. 6 between the measured and predicted heat fluxes at night is the effect of the temperature dependence of thermophysical properties. The percentage differences between the averages of the outside-surface temperatures and the heat fluxes for the uncoated and coated locations on the Veterinary Clinic roof were given in Table 2 for August and September. The decrease in surface temperatures is about the same as it is for the same months at the Shoppette, while the decrease in heat fluxes is about 20% less. The roof on the Veterinary Clinic is more thermally massive because of its heavyweight concrete deck, but its instrumented locations were not shaded. Modeling with a calibrated model that accounts for shading and thermal mass effects should segregate the site-specific effects at these buildings.

Figure 15 shows the power demand of the Veterinary Clinic for June (before coating) and August (after coating). Nighttime demand does not drop off to zero as it did during the winter months (Fig. 7), but the base demand is much more regular than the Shoppette's. The heavyweight concrete deck is under the insulation. The heat fluxes through the insulation under the uncoated and coated patches showed a 33% decrease for August (Table 2), but heat fluxes are not the same through the concrete in transient conditions. As additional analysis of the data in Fig. 15 indicates, the average power for times when the power is greater than 1.5 kW (to eliminate effects of days when the clinic was closed and less air-conditioned) is 3.02 kW in June and 2.63 kW in August, a 13% decrease. As in the case of the Shoppette, more data and analysis are required for conclusions regarding the whole cooling season.

Burger King Results

A direct comparison of the acrylic elastomeric and ceramic radiation control coatings (designated in Table 1 as RH3 and TC2, respectively) for July 11 through the end of July 1996 is presented in Figs. 16 and 17. Because the Burger King roof was already covered by a white, single-ply membrane, there is no uncoated, low-reflectance surface to generate comparative data about its roof. For this reason, Table 2 has no entries for coatings RH3 and TC2. Figures 16 and 17 show that the outdoor-air temperatures above both coatings are identical except for a few days near the end of the month (days 209 and 212), after the severe weather on day 207. The maximum outside-surface temperatures and heat fluxes for the acrylic elastomeric coating are slightly lower than those for the ceramic coating for many more days. This is consistent with the slightly higher solar reflectance for the acrylic elastomeric coating RH3 compared to the ceramic coating TC2 (Table 1).

Buildings Technology Center Results

Figures 18 and 19 complement the data in Figs. 16 and 17, comparing the same acrylic elastomeric coating (except on a different substrate, APP-modified bitumen) to a ceramic coating SOL also on APP-modified bitumen. As Table 1 shows, the ceramic coating SOL has slightly higher solar reflectance than the coating RH2. Moreover, the fact that the assemblies in which these coatings are tested at the BTC at ORNL have very low thermal resistances maximizes the effects of radiation control coatings. Nevertheless, there appears to be no discernible effect on heat fluxes of the slightly higher solar reflectance of SOL compared to RH2. The effect on surface temperatures is slight but consistent with the higher solar reflectance of SOL.

The instrumentation available at the BTC includes a weather station next to the test location. The ambient temperatures from the shielded resistance temperature detector (RTD) in the weather station are shown as outdoor-air temperatures on Fig. 18 for comparison to the outside-surface temperatures. Readings of solar irradiation from an Eppley Precision Solar Pyranometer are labeled as solar input on Fig. 19 for comparison to the heat-flux measurements. The peaks and valleys in both the surface temperatures and the heat fluxes seem to track outdoor-air temperature better than solar irradiation. Solar irradiation is exactly zero at night; outside-air temperature and radiation to the night sky determine nighttime membrane temperatures and heat fluxes. Solar irradiation is very sensitive to cloud cover, whereas surface temperatures and heat fluxes, even for these low R-value assemblies, do not fluctuate as quickly during the daytime.

Each of the coated specimens at the BTC has its own control surface, the uncoated half of a 4 × 8 ft (1.2 × 2.4 m) piece of membrane material. For the SOL and RH2 specimens, APP-modified bitumen is the substrate. No significant difference in the response of these uncoated membranes is evident in Figs. 18 and 19 except for a few days after rain showers (evidenced by days with unseasonably cool outdoor air temperatures and relatively low peak solar irradiation). There is some ponding of water on the uncoated sides of the specimens. The specimens are tilted slightly with the coated sides up to ensure that the coated sides drain. Water ponds near the metal rim on the lower end, backing up at times over the instrumentation at the middle of the uncoated side.

The average response of the uncoated sides is compared to the responses of the coated sides of the specimens to generate the data in Table 2 for the BTC specimens. Compared to the data for the Shoppette and Veterinary Clinic roofs, the larger differences between uncoated and coated outside-surface temperatures and heat fluxes are caused by the much lower R-value of the BTC assemblies compared to the Shoppette and Veterinary Clinic roofs and the higher solar reflectance of the SOL and RH2 coated surfaces compared to their counterparts at the Shoppette and Veterinary Clinic. Quantifying how much of the difference to ascribe to each cause will require further analysis with the program STAR.

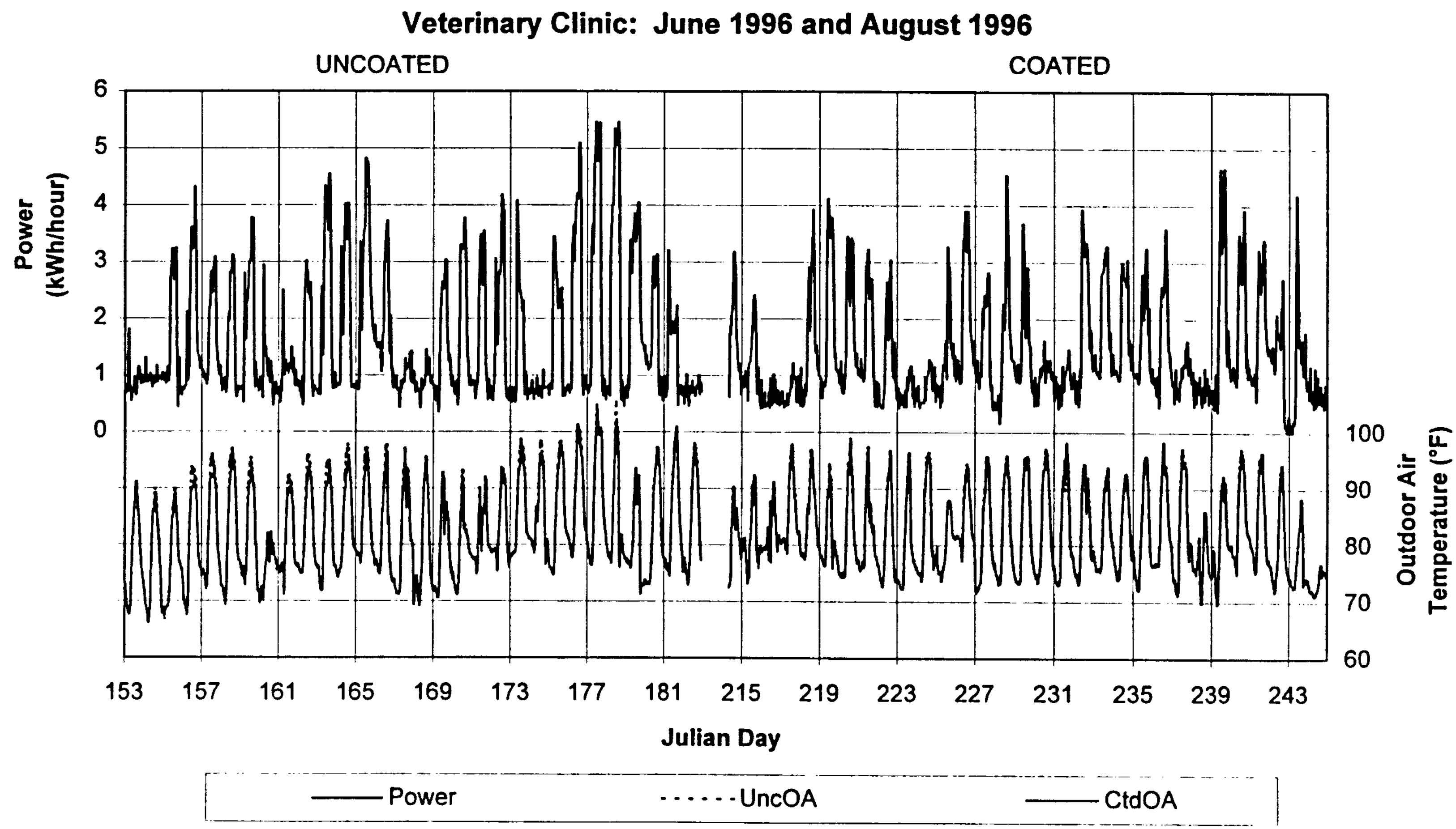

Fig. 15. Power demand for the Veterinary Clinic before and after coating of the roof.

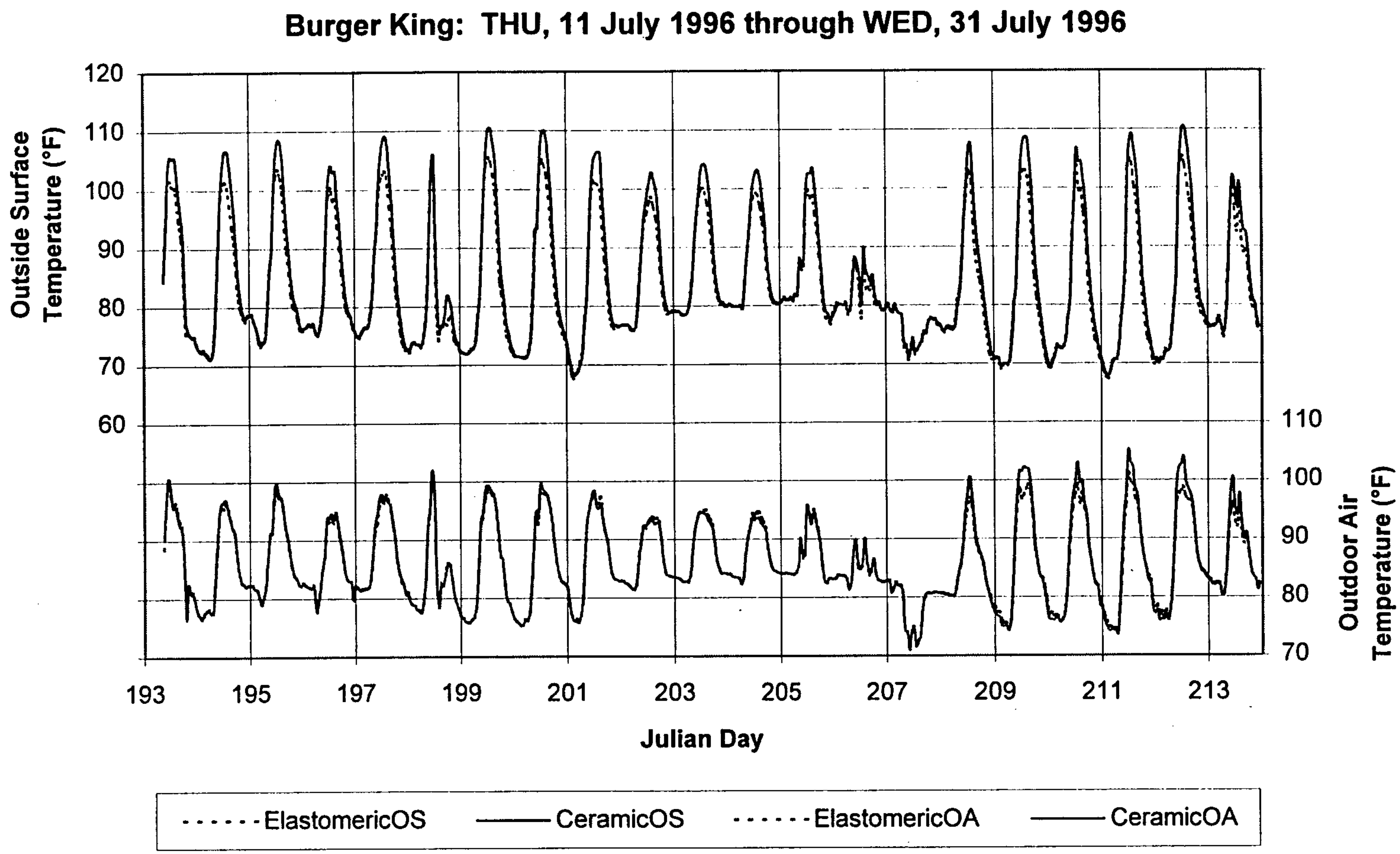

Fig. 16. Comparison of temperatures for freshly coated patches on the Burger King roof.

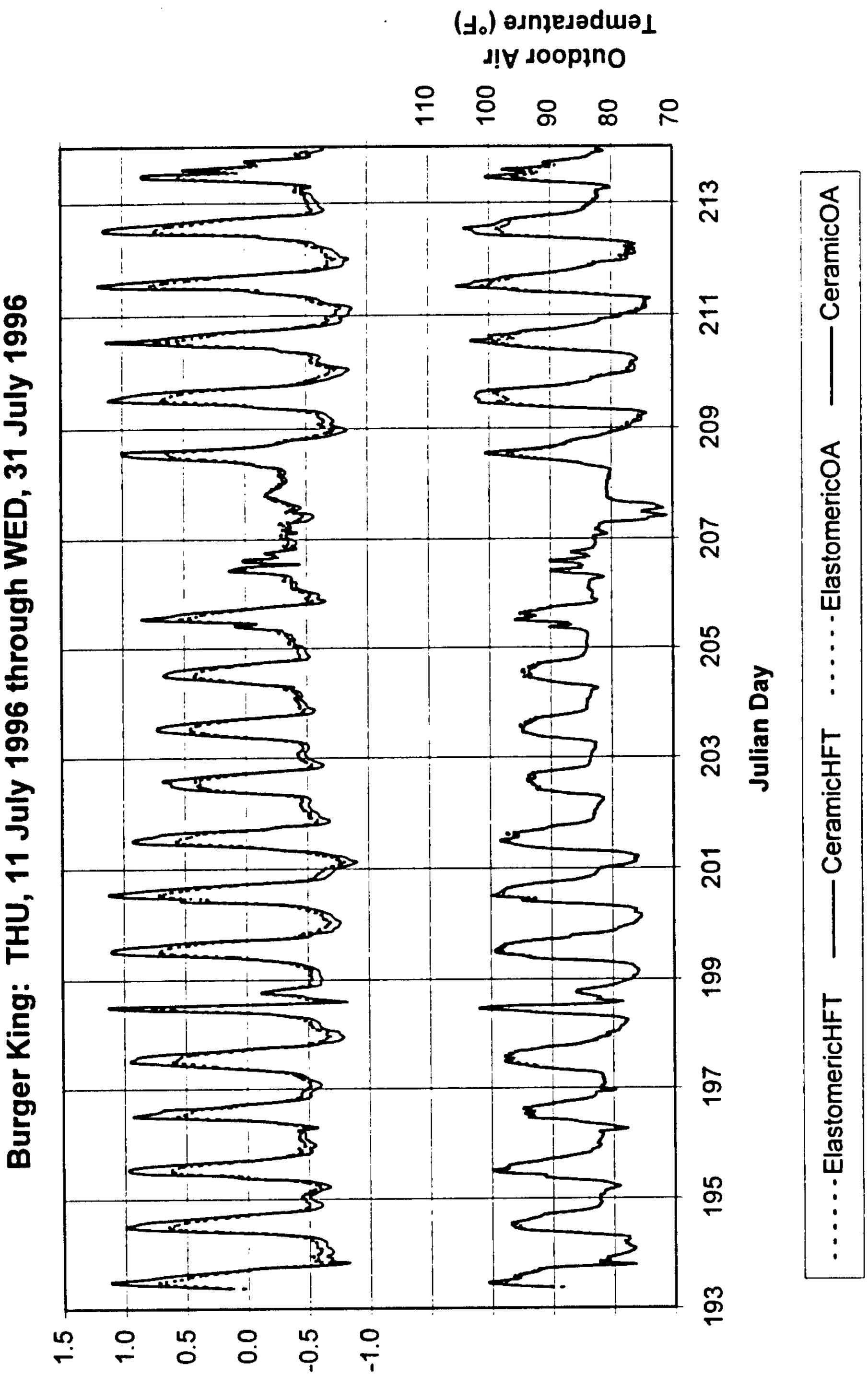

Fig. 17. Comparison of heat fluxes through freshly coated patches on the Burger King roof.

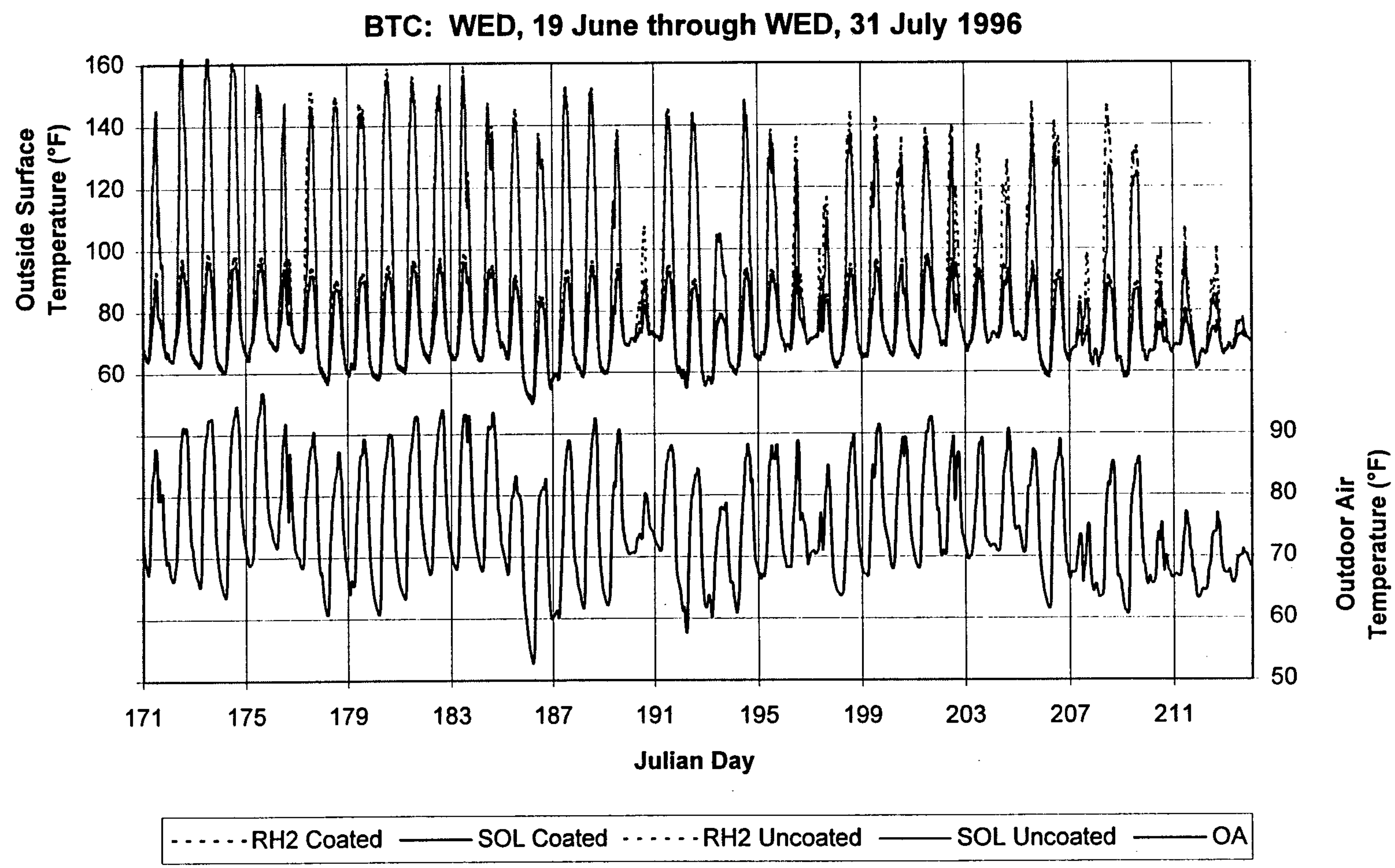

Fig. 18. Comparison of temperatures for RH2 and SOL coatings and uncoated membranes at the Buildings Technology Center.

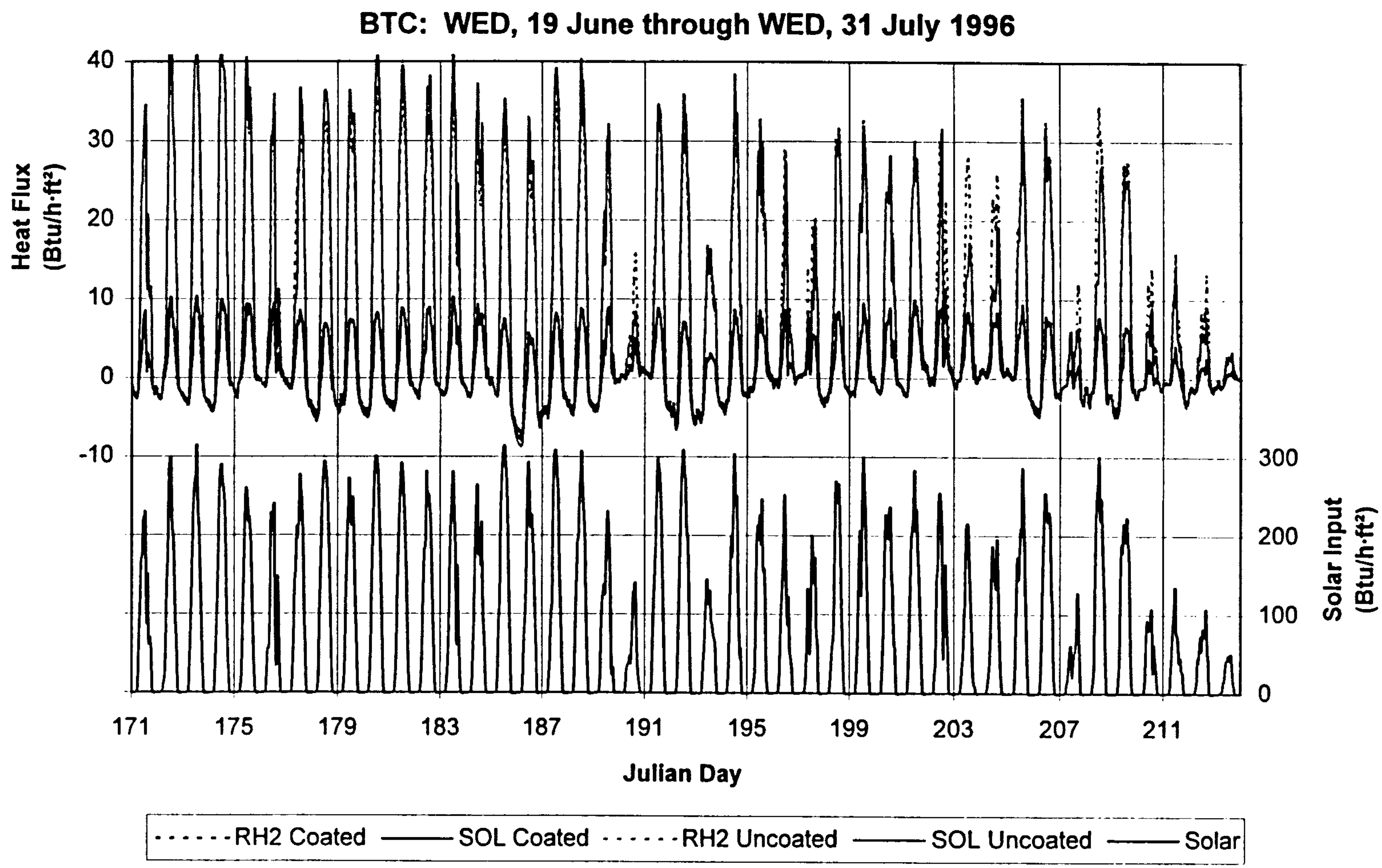

Fig. 19. Comparison of heat fluxes through RH2 and SOL coatings and uncoated membranes at the Buildings Technology Center.

5

Decommissioning Plan

The effect of weathering on the solar reflectance of radiation control coatings is valuable information for life-cycle cost analyses comparing net savings in cooling costs to the initial investment in time and materials needed to coat a roof. The 2-year period of performance for this demonstration allows much of this information to be gathered. Experience at the BTC with small areas coated with various radiation control coatings has shown that solar reflectance continues to deteriorate beyond 2 years. Since no additional investment in monitoring technology is required, it is useful to continue gathering data at the three buildings at Tyndall Air Force Base until deterioration of solar reflectance levels off. Two more years of data acquisition are judged sufficient to observe this phenomenon and its effect on energy savings. The minimal funding needed to analyze the data should be available as part of the ongoing work at the BTC with advanced radiation control coatings. The results will be incorporated into the reports and papers from the BTC work. There is funding from the New Technology Demonstration Program to produce the report on the first 2 years of intensive data collection and analysis, including modeling to project the results to other federal buildings with various roof constructions and in other climates. Continued data acquisition will require continuing support by Tyndall Air Force Base and Burger King only for the use of their communications lines.

Upon the completion of the demonstration and additional data acquisition, the coatings will remain in place for the rest of their useful life or until the roofs on which they reside are replaced. The data loggers will be retrieved and the lead wires to them cut as close to the roof as possible so as to leave no noticeable disturbance. No attempt will be made to retrieve the thermocouples or the heat-flux transducers.

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Conclusions

A monitoring plan was designed and implemented to carry out a 2-year demonstration of radiation control coatings installed on federal buildings at Tyndall AFB in Florida. The use of instrumented patches with and without a radiation control coating on two entire roofs at Tyndall AFB allows us to obtain direct comparisons throughout the project for outside-surface temperatures and heat fluxes through R_{US}-12 (R_{SI}-2.1) insulated roofs with and without coatings. On one roof the effects of shading enhance the apparent benefit of the coating. The other has a thermally massive roof deck. Its effect on the benefit of the coating is not yet certain. Both roofs have rough-surfaced BURs, so initial solar reflectance is not as high as on smooth surfaces. Data are included from a smooth-surfaced, R_{US}-22 (R_{SI}-3.9) insulated roof at Tyndall AFB and smooth-surfaced, R_{US}-1.5 (R_{SI}-0.3) insulated test sections at ORNL's BTC. At both sites, side-by-side tests are being done on latex-based coatings, with ceramic beads added to improve solar reflectance, and on acrylic elastomeric coatings, with titanium dioxide added to improve solar reflectance. Therefore, the data cover the range of parameters of interest for assessing the benefit of radiation control coatings.

Measured solar reflectances for the ceramic coating as applied on the two rough-surfaced BURs at Tyndall AFB are 0.52 and 0.54, respectively. This is in the range of reflectances for coatings applied on smooth membranes and weathered 1–2 years at the BTC. On smooth surfaces 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 coating and a different ceramic coating on smooth surfaces 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 acrylic elastomeric coatings tested at the BTC.

The solar reflectance of a coating and the thermal characteristics of the roof to which it is applied affect the temperatures of the coated surface and the heat fluxes through the roof. The R_{US}-12 (R_{SI}-2.1) insulated roof with shading effects showed average decreases of 15, 13, and 10% in coated surface temperatures relative to uncoated surface temperatures in July, August, and September 1996, respectively. The heat fluxes through the insulation under the sunlit coated and uncoated locations yielded average decreases of 55, 54, and 51% in the same months. The heavyweight concrete decked roof with the same insulation thickness showed 11% outside-surface temperature decreases for the coated surface in August and September 1996. The average decreases in heat fluxes were 33 and 31%, respectively. On the R_{US}-1.5 (R_{SI}-0.3) insulated test sections coated with higher solar reflectance materials at the BTC, results were more dramatic. Relative to a neighboring uncoated surface, the ceramic coating with 0.85 initial solar reflectance showed a 28% decrease in outside-surface temperature and a 77% decrease in heat flux for July 1996. The acrylic elastomeric coating with 0.81 reflectance showed a 26% decrease in sunlit surface temperatures and a 78% decrease in heat fluxes.

The effect of a radiation control coating on building electricity use is more complicated than its effect on surface temperatures or heat fluxes for the roof. The roof is only one component of the building heating or cooling load. More data and analysis beyond the scope of this first volume of the report from the project at Tyndall AFB are needed to make quantitative conclusions for the whole cooling season, although average power demand during occupied periods for the first month with the coating was 13% less than during the last month without the coating for the simpler of the two Tyndall buildings. Whole-building electricity use is being followed in the buildings to calibrate a model for the annual energy use of the buildings. By varying parameters in the model, we will sort out the effects of variations in solar reflectance, thermal characteristics of the roof and climatic differences among locations.

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Appendix

Statement of Work for CRADA No. ORNL96-0403
with ThermShield International, Ltd.
for Test Bed Demonstration Project—Radiation Control Coatings

Purpose and Background

The purpose of this Cooperative Research and Development Agreement (CRADA) between Lockheed Martin Energy Research Corp. (Contractor) and ThermShield International, Ltd., is to install, operate, monitor, evaluate and make known the results of the demonstration of radiation control coatings manufactured by ThermShield and installed on federal buildings at Tyndall Air Force Base (Tyndall AFB), Florida. The Contractor and the Participant are hereinafter referred to as the "Parties."

Radiation control coatings are a technology whose primary effect is to increase the reflectance (albedo) of existing surfaces, thereby decreasing the radiation heat exchange between the surface and its surroundings. A secondary effect is the ability to insulate the underlying surface somewhat from convective heat transfer with its surroundings. Plain elastomeric coatings accomplish this by forming a layer of the order of 40 mils thick, applied in two coats. So-called insulating coatings are about half as thick, but they have ceramic beads suspended in the latex base. Besides the secondary effect on convection, there are claims that both kinds of radiation control coating waterproof surfaces against leaks, prevent corrosion or rusting of metals, and protect surfaces from other atmospheric contamination.

A manufacturer of insulating liquid coatings has submitted its technology to the Test Bed Demonstration Program (TBDP). Its product is in use in the private sector over the entire range of climates from tropical to arctic, and has been on the market for approximately 5 years with research results dating back as far as 10 years. Use for coating pipes and other surfaces not exposed to solar radiation involves infrared radiation. The coatings may not improve the reflectance in these cases. The focus is on use for roofs because the high reflectance of these coatings for solar radiation is documented. Roofs offer the maximum benefit from coatings. The product literature from this manufacturer and others is replete with anecdotal testimonials about the noticeable decrease in temperature under roofs with the insulating coatings compared to those without it. This demonstration seeks to use this manufacturer's coating on roofs at a federal site (Tyndall AFB) and monitor its performance independently—not only the roof temperatures, but also heat fluxes and whole building energy and power use.

Technical Objectives

The technical objectives of this CRADA comprise technology deployment and energy conservation efforts with the radiation control coatings industry and the utility sector. These objectives will be met by work to be done by the Parties to the CRADA through their joint efforts. The results of this collaboration will include a high-level data reporting, analysis, and management system to support the deployment efforts associated with the technology. The technical objectives include successfully install, commission, operate, maintain, and document the performance of radiation control coatings on roofs at Tyndall AFB; determine the life cycle savings that can be achieved by using radiation control coatings, based on documented installed cost and operating/maintenance costs with and without coatings; determine if any specific improvements are required in the coatings before they can be successfully deployed in the federal sector; determine the most effective way to facilitate the widespread and rapid deployment of radiation control coatings in the federal sector; and, clearly define any barriers to deployment.

Scope of Work

The approach to achieving the objectives stated above involves collaboration between the Parties to the CRADA. Through a synergistic effort, a significant advancement in the deployment of radiation control coatings will occur. The CRADA effort will be performed under three (3) tasks and multiple subtasks over a 36-month period of performance. A description of the tasks and the responsibilities of each Party are described below.

Task 1.0 — Planning

The planning effort includes those activities necessary to design the TBDP so that the installation of the radiation control coating can be made; necessary operating data on the buildings affected can be obtained before and after installation; and the formal technology demonstration can be ended. Planning includes activities up to the point where monitored operation and data acquisition begin. For radiation control coatings, the collection of data on roof performance and building energy and power demands is necessary for several months before the coatings are installed so as to establish a basis for comparison. Historical data available in the records at Tyndall AFB will be a valuable but insufficient part of the database. The planning effort will be performed under the following five (5) subtasks:

Subtask 1.1 — Site Evaluation: The Contractor, working with Tyndall AFB, will obtain a description of the buildings, their existing energy systems and as-built construction, and available information about past operation, maintenance and control of the energy systems that will serve the building immediately before and after the radiation control coatings are installed. The detail necessary is such that a model can be constructed to predict the energy and power demands of the buildings with and without radiation control coatings by using a description of the buildings and local climatological data: dry and wet bulb temperatures, solar data, cloud cover and rainfall data, wind speed and direction. The description must include necessary schematics, energy consumption and billing information, maintenance records and photographs, as well as other information necessary to portray the buildings as they currently exist. This information must emphasize and detail the roofs of the buildings and possible changes in operating characteristics of the buildings' energy systems that may impact the validity of any tests associated with the roof coatings (e.g., going from full-load operation without satisfying thermostat setpoints to part-load operation with cycling to meet setpoint). The Contractor will provide a report detailing the "before" condition of the buildings and energy systems that focuses on the roofs and energy systems which are affected by the radiation control coating six months after the effective date of the CRADA.

Subtask 1.2 — Roof Coating Specification and Its Installation: ThermShield, based on the description of the existing buildings and roofs, will provide the necessary materials and labor for installation of the technology, including the preparation of the roof surfaces for coating and specify the required amount of coating materials and any necessary accessories (such as application tools, fixtures, and consumables) that are not available at Tyndall AFB. If the Tyndall AFB facility staff can perform periodic inspection to assure that the roof coatings are remaining intact during the demonstration, ThermShield should provide guidelines and training to do the inspections. Otherwise, ThermShield will provide for such inspections. ThermShield will assess the condition of the existing roofs and estimate the amount of coating material required three months after the effective date of the CRADA.

Subtask 1.3 — Technology Monitoring Design and Delivery: The Contractor will design a monitoring approach for the project based on the description of the buildings, the report on the "before" condition of the buildings and information that will be needed to evaluate the effect of the technology. This will include defining what is to be measured and logged, the method of measurement, the increment at which measurements should be taken, the method of data acquisition and reporting, and the necessary report formats. In addition, the Contractor will provide the monitoring equipment and necessary installation, operation, and maintenance instructions, as well as develop and define the quality assurance program for the acquisition of the performance data for the roof coatings and the operational data for the energy systems of the buildings on which they are installed. The Contractor will provide a plan that addresses the monitoring of the building; delivery and installation of data acquisition equipment needed to accomplish the monitoring; and operating and maintenance instructions for the equipment 3 months after the effective date of the CRADA.

Subtask 1.4 — Reflective Roof Coatings and Monitoring Installation: The Parties will install the data acquisition equipment on the roofs and in the buildings, then apply the roof coating in accordance with the instructions and plans prepared pursuant to subtasks 1.2 and 1.3 above. The Parties will then conduct testing and field verification work to establish both the "before" conditions for the demonstration and the baseline upon which the radiation control coatings will be evaluated. Plans are to measure the reflectance at a remote laboratory. A separate piece of roof membrane will be coated along with the roof and aged with it. Samples cut from this separate piece of roof membrane will be sent to the remote laboratory. Subsequent to installation of the data acquisition equipment, the Parties will conduct a test to verify that it is functioning properly, that is, that all necessary data are being obtained and secured to permanent storage on appropriate computer media according to the technology monitoring plan described in subtask 1.5 below. The Parties will deliver a report verifying that the documenting plans have been implemented, that the installation is functioning properly, and that it is being properly monitored 3 months after the effective date of the CRADA.

Subtask 1.5 — Monitoring Decommissioning: The radiation control coatings for this project are expected to remain in place beyond the 2-year demonstration period, and no attempt will be made to remove them or deliberately end their usefulness on the building after the end of the 2-year demonstration. It is further assumed that the separate pieces of roof membranes will remain in place on the roof and both will be available for twice-a-year measurements of solar reflectance by remote testing for at least 3 more years to establish aging and weathering effects on reflectance. To provide for the orderly completion of the demonstration and removal of instruments or continuation beyond the 2-year demonstration of some monitoring, the Contractor will develop a plan for responsibilities under removal and continuation scenarios. This plan will also include a contingency plan to address an early end to the demonstration due to failure of the roof coatings or catastrophic events which adversely impact the Tyndall AFB site. The plan for unscheduled and scheduled ending of the demonstration as well as possible continuation of some monitoring will be completed 18 months after the effective date of the CRADA.

Task 2.0 — Execution

The execution effort includes those activities necessary to operate, maintain, monitor, and document the performance of the roof coatings throughout the project (including the baseline data on the buildings for comparison to data after installation) and to ensure that information on the progress and results associated with the project are made available to those associated with the project. The execution effort will be performed under the following three (3) subtasks:

Subtask 2.1 — Performance Monitoring and Data Acquisition: Pursuant to the design delivered for subtask 1.3 above, the Contractor will monitor the temperatures above and below the roofs and the heat fluxes through them at selected locations before and after the installation of the radiation control coatings. Also, the Contractor will monitor the energy and power demands of the buildings as well as local weather conditions over the same time period. This includes the acquisition of all data at the specified intervals that are defined as critical to evaluating the performance of the roof coatings and conduct of data validation tests to ensure that accurate data are being obtained. The Contractor will carry out calibration of automated data acquisition equipment throughout the test as required and implement all assurance program tasks associated with performance of the coatings and the data acquisitions systems. The Contractor will provide seasonal reports on the status of the demonstration overall and the data acquisition systems starting 6 months after the effective date of the CRADA.

Subtask 2.2 —Operations and Maintenance (O&M): The Parties will operate the building with and without the radiation control coatings in place according to normal schedules and procedures defined by current O&M manuals at the Tyndall AFB site. Weekly inspections are expected and should include inspection of data acquired to verify that they fall with the range of feasible values. The Parties will keep a log of activities directed toward O&M of the buildings with sufficient accuracy to permit detailed cost analysis to be carried out for the effects of the roof coatings. At a minimum, this log need only include O&M activity, parts and material usage, labor and downtime costs and comments for those activities connected to the use of the radiation control coatings. The Parties will provide seasonal reports on the log entries that are related to the analysis of the effects of the radiation control coatings starting 5 months after the effective date of the CRADA.

Subtask 2.3 — Data Analysis: The Contractor will analyze the performance and O&M data to determine the performance, energy and power use, operating costs, and life cycle costs with and without the radiation control coatings, as well as the reliability and serviceability aspects of the installation. The Contractor will provide an interim report after the first year of demonstration and a final report at the end of the demonstration, both containing results of the data analysis to date. The reports will be delivered 15 months and 27 months after the effective date of CRADA.

Task 3.0 — Documentation

Documentation includes those efforts necessary to record the project activities, evaluate the project, determine the level of success of the project, and present the results. The documentation effort of this CRADA will be performed under the following three (3) subtasks as described below:

Subtask 3.1 — Preparation of Test Bed Report: The data acquired pursuant to subtasks 2.1 and 2.2 and the analysis conducted on the data pursuant to subtask 2.3 above, will make it possible for the Contractor to report on the results of the installation of radiation control coatings and monitoring for 2 years. The Contractor will prepare a report detailing if and to what degree the new technology will benefit the federal sector. The information about the "before" conditions of the buildings and the data acquired after installation of the radiation control coatings will be used. The data will show energy use, power demand, O&M costs associated with the coatings, reliability of the coatings, and other factors considered important for evaluation. The Contractor will provide a detailed report that contains the results of the data acquisition and analysis effort, the expected benefits of the technology in the federal sector, a description of any necessary improvements in the technology before its widespread deployment in the federal sector, and a description of any limiting factors. This report will be due 30 months after the effective date of the CRADA.

Subtask 3.2 — Development of TBDP Presentation and Media: Commensurate with the success of the TBDP, the Parties will develop the necessary materials to communicate the results of the TBDP and identify those policy makers, utilities, and others involved in impacting use of radiation control coatings in the federal sector. In addition, the Parties will identify the most effective media for making these materials and results of the project available. This could include a press release, video, multimedia CD, printed matter, promulgation to the World Wide Web on the Internet, and conferences or workshops. The Contractor will provide a communications package on the results of the TBDP targeted to different key audiences 33 months after the effective date of the CRADA.

Subtask 3.3 — Implementation of Presentation: The Parties will implement the most beneficial presentation through the most effective media based on the efforts described in subtask 3.2 above. The purpose of this presentation will be to communicate the results of the project to those in the federal sector who could specify increased use of radiation control coatings in the federal sector and who would support the test bed concept. In addition, communication must also focus on those in the private sector who would advocate the use of radiation control coatings and the test bed concept. The Parties will work through various trade associations, research institutes, and/or other organizations broadly representing manufacturers of radiation control coatings. The Parties will provide a copy of the presentation and a brief report on its implementation, distribution, and reception 36 months after the effective date of the CRADA.

Property Considerations

The following tangible property will be exchanged: None.

Deliverables

The following reports and abstracts are required to be delivered under Article XI of the CRADA:

A. The Parties agree to produce the following deliverables:
   1. an initial nonproprietary abstract suitable for public release;
   2. other abstracts (final when work is complete, and others as substantial changes in scope and dollars occur.);
   3. a final report; to include a list of Subject Inventions;
   4. other topical/periodic reports where the nature of the research and magnitude of the dollars justify; and
   5. computer software in source and object code format as defined within the Statement of Work.

B. It is understood that the Contractor has the responsibility to provide the above information at the time of its completion to the DOE Office of Scientific and Technical Information.

In addition to the minimum deliverables listed above, the following will be delivered: None.

Schedule

The duration of this project is 36 months.

Program Management

The principal investigators for this CRADA are Thomas W. Petrie (Contractor) and Ron Kaba (ThermShield).

The principal investigators for the Parties will communicate or meet as needed to review the program and to ensure that the project continues on schedule. Brief seasonal status reports will be jointly issued every 3 months after the first winter by the 15th day of the month. A more detailed interim report after the first year and a final report for the project will be prepared for wider distribution after full review by the Parties.

INTERNAL DISTRIBUTION

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EXTERNAL DISTRIBUTION

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Report Number (14) ORNL/CON--439/V1

Publ. Date (11) 199702

Sponsor Code (18) DOE/EE , XF

UC Category (19) UC-1600 , DOE/ER