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ENERGY & ENVIRONMENT
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December 1992

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Abstract

Urban areas in warm climates create summer heat islands of daily average intensity of 3-5°C, adding to discomfort and increasing air-conditioning loads. Two important factors contributing to urban heat islands are reductions in albedo (lower overall city reflectance) and loss of vegetation (less evapotranspiration). Reducing summer heat islands by planting vegetation (shade trees) and increasing surface albedos, saves cooling energy, allows down-sizing of air conditioners, lowers air-conditioning peak demand, and reduces the emission of CO_2 and other pollutants from electric power plants. The focus of this multi-year project, jointly sponsored by SMUD and the California Institute for Energy Efficiency (CIEE), was to measure the direct cooling effects of trees and white surfaces (mainly roofs) in a few buildings in Sacramento. The first-year project was to design the experiment and obtain base case data. We also obtained limited post retrofit data for some sites. This report provides an overview of the project activities during the first year at six sites. The measurement period for some of the sites was limited to September and October, which are transitional cooling months in Sacramento and hence the interpretation of results only apply to this period. In one house, recoating the dark roof with a high-albedo coating rendered air conditioning unnecessary for the month of September (possible savings of up to 10 kWh per day and 2 kW of non-coincidental peak power). Savings of 50% relative to an identical base case bungalow were achieved when a school bungalow's roof and southeast wall were coated with a high-albedo coating during the same period. DOE-2 simulations of these two buildings indicated savings of significantly lower magnitude than those measured. Given these results, the large measured savings may in part be attributed to generally lower insolation during the post-monitoring period. Our measured data for the vegetation sites do not indicate conclusive results because shade trees were small and the cooling period was almost over. We need to collect more data over a longer cooling season in order to demonstrate savings conclusively. The DOE-2 simulations of these buildings appear to indicate very small or no savings from trees. The issue of comparing DOE-2 simulations with measured data will be addressed in further detail during the second year of the project.

Acknowledgement

This work was jointly supported by the California Institute for Energy Efficiency (CIEE) and the Sacramento Municipal Utility District (SMUD) through the U.S. Department of Energy, under contract DE-AC0376SF00098. We wish to acknowledge Bruce Vincent of SMUD and Tony Fung of SCE for their helpful suggestions and comments in preparing this final report. The initial DOE-2 inputs for the monitored buildings were prepared by Joe Huang. Di Ann Fager's support was crucial to timely completion of the report.

Disclaimer

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Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces

Executive Summary

Urban areas in warm climates create summer heat islands of daily average intensity of 3-5°C, adding to discomfort and increasing air-conditioning loads. Two important factors contributing to urban heat islands are reductions in albedo (lower overall city reflectance) and loss of vegetation (less evapotranspiration). The lower concentration of vegetation in urban areas results in channeling a higher portion of the net solar gains into sensible heat rather than into latent heat, thus enhancing the heat island effect. Vegetation has a large impact on microclimate. In desert cities, for example, evapotranspiration (from trees in urban areas) is greater than of surrounding rural areas (treeless desert lands), actually lowering temperatures in the city; in climatological terms, this is referred to as the ''oasis effect.''

In response to the adverse effects of the urban "summer heat island" (SHI) of Sacramento, the Sacramento Municipal Utility District (SMUD) has embarked on a program to plant 1/2 million shade trees over the next 10 years to reduce the SHI by shading homes, schools, and places of business. Reducing summer heat islands saves cooling energy, allows down-sizing of air-conditioners, lowers air conditioning peak demand, and reduces the emission of CO_2 and other pollutants from electric power plants.

Preliminary analysis indicates that an extensive implementation program of tree planting and white surfaces in Sacramento (reaching 250,000 unshaded houses) would yield residential cooling savings of about 600 peak MW. These energy savings can be delivered with little cost. White surfaces incur no incremental costs; whereas young trees cost about $10 each. Including purchase, planting, and watering costs, the present-valued cost per saved peak kW from vegetation would be under $150 per kW in Sacramento (ignoring the many other benefits of more trees, in terms of urban amenity, aesthetics, and outdoor comfort).

The simulations of heat island mitigation measures provide a common basis for comparison of the measures and their potential energy and power savings. However, some important elements, related to actual building operation and both macro- and microclimate variations, are not easy to evaluate using simulations alone. In order to understand the realistic savings potential for SHI mitigation measures, before starting large-scale implementation, it is necessary to carry out field experiments to identify unforeseen problems, and to measure and document actual savings.

The focus of this project, jointly sponsored by SMUD and the California Institute for Energy Efficiency (CIEE), was to measure the direct cooling effects of trees and white surfaces (mainly roofs) in a few buildings in Sacramento.

The specific goals of the first year project were:

- to assess and document the albedo performance characteristics of various building and paving materials,
- to document the air-conditioning energy savings of shade trees and high-albedo surfaces by instrumenting and monitoring microclimate attributes and air-conditioning energy use in a few homes and a school in Sacramento,
- to compare simulation results with monitored data, and
- to provide an analysis of impacts of trees and white surfaces to assist SMUD in their program.

The project was designed as a collaborative effort between LBL and SMUD. The LBL participation involved project design, equipment installation, and data analysis. SMUD supplied the monitoring equipment and instrumentation. Other in kind contribution by SMUD included an engineer to instrument the selected buildings, collect data, and transfer them to LBL for analysis.

Major tasks in this project included:

Task 1: Performance Data for White Surfaces. This task included making contact with the industry and performing a review of the manufacturers products and literature, collecting data for white surfaces, documenting and comparing the data, performing cost-benefit analysis, and assessing of various strategies for encouraging a wide implementation of this measure. The purpose of this task was to provide information for creating an implementation scheme for SMUD and other utilities (see Bretz and Rosenfeld, 1992)

Task 2: Demonstration, Validation, and Documentation. The elements of this task included identification of monitoring sites, audits of the buildings, development of an experimental plan, specification and procurement of monitoring equipment, calibration of sensors, installation and testing of equipment, collection and review of test results, base case and retrofit monitoring (data collection), and data analysis to assess savings from experimental measures.

Task 3: Simulations of Energy and Peak Saving. This task included DOE-2 simulations of the buildings and a comparison of the simulated results with measured data. These results were then used to calibrate the model. The calibrated model was used to extrapolate results for different combinations of tree shading and albedo strategies in four differents climates.

This final report is prepared in seven chapters and two attachments.* Chapter I provides an overview of the project. Chapter II discusses the process of site selection, provides information on site characteristics, and discusses the albedo and tree modification experiment performed on each site. For each site, we developed a monitoring protocol for data measurement and provided guidelines for building operation. Monitoring protocols for all sites are presented in Attachment B, and the overall monitoring protocol is discussed in Chapter III. Chapter III also presents a general description of the installed equipment, instrumentation of the sites, and calibration of the equipment. Chapter IV is a summary of our field experience in performing this monitoring project. Chapter V, the data analysis chapter, is the heart of this report. In Chapter V, we present a review of the data analysis and simulation methodologies, discuss the measured and simulated energy impacts of white surfaces and shade trees for each site, compare simulation results with measured data, and discuss the differences. Chapter VI extrapolates our calibrated DOE-2 simulations to four climate regions in California, i.e., Sacramento, Riverside, Fresno, and Pasadena.

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* Three other attachments which were included in the draft report have been omitted here. The first one is LBL-31721, High Albedo Materials for Reducing Building Cooling Energy Use, H. Taha, D. Salior, and H. Akbari. The second omitted attachment is LBL-32467, Implementation of Solar Reflective Surfaces: Materials and Utility Programs, S. Bretz, H. Akbari, A. Rosenfeld, and H. Taha. Also for the sake of brevity, the detailed workplan attachment has been omitted.

Chapter VII provides a summary of the project and suggests tasks to be completed in the second year project.

This project was implemented over two years. The first year project was to design the experiment and obtain base case data. We also obtained limited post retrofit data for some sites. Hence the first year report is preliminary in nature, and all conclusions are subject to further verification during the next year.

The measurement period for some of the sites were limited to September and October. These are transitional cooling months in Sacramento, and the measured results presented here are limited to these measurement periods. During the second year project we will measure the impacts of shade trees and white roofs during the peak of the cooling season. However, for the 1991 report, with the help of simulations, we estimate the impact of high-albedo roofs and shade trees on cooling energy use for the hot summer months of June, July, and August.

For each site, pre- and post-retrofit cooling electricity use data are examined as a function of outdoor temperature (means and maxima), indoor temperatures, indoor/outdoor temperature differences, and solar radiation, as appropriate to each particular case. A discussion of solar radiation and its change over time (during the monitoring period) is provided in order to demonstrate the decrease in solar radiation during the monitoring period and it's effect on cooling energy use. Finally, hourly time-series of cooling electricity usage are shown and compared with simulated results.

A major objective of this project was to quantify the *potential* of high-albedo materials and vegetation for reducing cooling energy use in buildings. The first year measured data indicated that albedo modifications had significant impacts on cooling energy use. We did not gather sufficient data to conclusively demonstrate the impact of vegetation modifications.

In one house, recoating the dark roof with a high-albedo coating rendered air conditioning unnecessary for the month of September. Savings of 50% compared with the identical base case bungalow were achieved when a school bungalow's roof and south-east wall were coated with a high-albedo coating during the same period. DOE-2 simulations of these two buildings indicated savings of significantly lower magnitude than those measured. Given these results the large measured savings may in part be attributed to generally lower insolation during the post-monitoring period.

For the vegetation sites, savings were generally lower than those for the albedo cases. In one house, the addition of two trees on the west and one tree on the south sides resulted in a reduction of ~40% in cooling energy use, whereas the addition of two southwest trees to another home reduced its cooling energy by ~30%. The other two other cases showed smaller savings. The addition of two trees on the east side of a well-shaded house reduced its cooling energy use by ~10%, and the addition of six trees on the south side of a completely unshaded home reduced its energy use by only ~10%. However, these savings will be smaller once corrected for solar intensity and so, should be regarded as possible overestimates.

The DOE-2 simulations of these buildings appear to indicate very small or no savings from trees. The issue of comparing DOE-2 simulations with measured data will be addressed in further detail during the second year of this project. Ways of improving the simulations to reflect actual conditions are suggested in this report.

In addition to differences in internal loads, schedules, and envelope characteristics, one reason that some sites had larger percent savings than others might be the fact that the local microclimate was different from one location to another. For example, Site 2 was in a cooler environment, heavily shaded, and therefore, this might have helped save 100% of cooling energy use in September when the roof was recoated with a high-albedo coating. Site 8, on the other hand, was in a warmer part of Sacramento, and that might explain why only 10% or less of cooling energy was saved by planting six trees on its south side. Microclimate variations are briefly discussed in this report.

In general, the DOE-2 simulations confirmed our measured data. Simulations indicated that the albedo modifications made to Sites 2 and B could produce significant changes in cooling energy use. On the other hand, the simulated direct shading effect of trees used in the study led to almost imperceptible changes in cooling use, most likely because of their small size.

Note that the simulations only calculate the direct effect of trees on building surfaces and windows. Any indirect cooling effects of these trees cannot be evaluated in the DOE-2 model.

Other effects, such as increased cooling system performance from direct shading of the air-conditioning condenser unit or indirect/microclimate effects of evapotranspiration were not modeled. The DOE-2 simulation results suggest that the direct shading effects on cooling demand are not significant in these cases because the trees were small.

The impact of the modifications on cooling energy use are summarized in **Table EX-1** for both measured and simulated data. We present average daily cooling energy consumption during the pre- and post-periods from the measured data and from the model. We also present simulated daily cooling energy use during the pre-period, but using the modified case building input. The models were used to evaluate cooling usage over the specific periods of monitoring for comparison.

In **Table EX-2**, we present monthly and annual estimates of cooling energy use from the simulation models. Note that in this case we use the Sacramento TMY (Typical Meteorological Year) weather tape, and thus do not account for microclimates specific to each site.

We used the calibrated simulation models for the six houses and the school bungalow to estimate cooling energy savings for other combinations of tree and albedo strategies and in four climates regions in California. In this parametric study, we modeled the direct shading impact of varying amounts of tree cover as well as the effects of changes in roof and wall albedos.

The average annual energy and peak power savings potentials are summarized in **Table EX-3**. The savings are averaged using the basecase consumption for each building as a weighting factor. The average energy saving potentials is about 33% in Fresno and about 42% in other climate regions. The average peak power saving potentials is about 17% to 20%. Note that, since the air-conditioning systems are designed for Sacramento climate, the peak power savings for other climates, particularly Fresno, may be underestimated.

Table EX-1. Measured and Simulated Daily Energy Use and Peak Demand

		Period		Measured Average Daily		Simulated Average Daily	
Site	Building Modification	start day	stop day	Energy (kWh)	Peak (kW)	Energy (kWh)	Peak (kW)
Site 1	Control	236	293	5.17	1.40	7.00	1.41
Site 2	Base	235	253	2.95	0.90	3.26	0.67
	Albedo	260	293	0.39	0.18	0.34	0.11
	Albedo	235	253			0.93	0.24
Site 5	Base	254	258	10.33	1.91	7.55	1.49
	Trees	268	293	9.75	2.03	8.90	1.68
	Trees	254	258			7.22	1.47
Site 6	Base	234	266	5.51	1.72	7.49	1.51
	Trees	268	294	3.60	1.27	5.03	1.20
	Trees	234	266			7.46	1.50
Site 7	Base	247	266	7.95	1.51	13.15	2.12
	Trees	268	291	6.81	1.65	11.49	2.00
	Trees	247	266			13.09	2.10
Site 8	Base	235	248	20.68	2.69	20.10	2.45
	Trees	268	294	14.79	2.23	17.09	2.43
	Trees	235	248			19.93	2.43
Site B*	White (78°F Tset)			6.93	1.30	7.92	1.22
	Metal (70°F Tset)			17.35	2.70	15.78	1.70
	Metal (78°F Tset)					9.36	1.39

* Thermostat settings at Site B were changed during the monitoring period. Monitoring took place for thermostat setting of 70°F and 78°F as indicated above.

Table EX-2. Annual Cooling Energy Use and Peak Energy Demand (including Fan) (Sacramento TMY Weather)

		kWh	kW
Site 1	Control	1166	3.99
Site 2	Base	793	2.93
Site 2	Albedo	466	2.47
Site 5	Base	1865	4.46
Site 5	Trees	1822	4.44
Site 6	Base	1250	4.24
Site 6	Trees	1244	4.24
Site 7	Base	2285	4.23
Site 7	Trees	2276	4.23
Site 8	Base	2804	3.73
Site 8	Trees	2746	3.73
Site B*	Base	1099	3.48
Site B*	Albedo	863	2.80

* School occupancy schedule is 1/1-5/31 and 9/3-12/31 with appropriate holidays.

Table EX-3. Average Annual Cooling Energy and Peak Power Saving Potentials of Shade Trees and White Surfaces. The savings are averaged using the basecase consumption for each building as a weighting factor.

	Base Case		Savings	
Climate	Energy (kWh)	Peak (kW)	Energy (%)	Peak (%)
Fresno	3306	4.28	33	17
Riverside	2056	3.69	42	19
Sacramento	1399	3.78	43	19
Pasadena	1427	3.30	42	20

I. INTRODUCTION

Urban areas in warm climates create summer heat islands that increase daily average temperatures by 3-5°C, add to discomfort, and increase air-conditioning loads. Two important factors contributing to urban heat islands are reductions in albedo (lower overall city reflectance) and loss of vegetation (less evapotranspiration). A typical urban surface has an albedo of ~ 15% and is lower than the albedo of rural areas (~ 25%), which results in an increase (~ 10%) in urban solar absorption. The lower concentration of vegetation in urban areas results in channeling a higher portion of the net solar gains into sensible heat rather than into latent heat, thus enhancing the heat island effect. Vegetation has a large impact on microclimate. For example, evapotranspiration (from trees in urban areas) in desert cities, is greater than that of surrounding rural areas (treeless desert lands), actually lowering temperatures in the city, in climatological terms, this is referred to as the ''oasis effect.''

We have been studying how to mitigate the heat island effect in U.S. cities by increasing urban vegetation and albedo. Preliminary estimates of potential summer peak and energy savings from summer heat island (SHI) mitigation have been made for single-family residences in Sacramento, California, using the DOE-2 building simulation model. The results indicate that shading homes (windows, walls, and roofs) with trees can save as much as 34% of their peak cooling demand on a hot summer day (Akbari *et al.* 1990, Huang *et al.* 1990). Even more promising results were obtained by simulating a change in the overall albedo of the city, from an existing ~15-20% to a ''whitewashed'' 40% (Akbari *et al.* 1990, Taha *et al.* 1988). Under such conditions, the simulated peak cooling demand dropped by ~40-50% in Sacramento. The overall combined effects of trees and white surfaces may yield savings of as much as 50% in residential cooling peak demand in Sacramento.

An extensive implementation program in Sacramento (reaching 250,000 unshaded houses) could yield residential cooling savings of about 600 peak MW. These energy savings can be delivered with little cost. White surfaces incur no incremental costs; whereas young trees initially cost about $10 each. Including purchase, planting, and watering costs, the present-valued cost per saved peak kW, in Sacramento, would be less than $150 (ignoring the many other benefits of more trees, in terms of urban amenity, aesthetics, and outdoor comfort) (SMUD 1990).

The simulations of heat island mitigation measures provide a common basis for comparison of the measures and their potential energy and power savings. However, some important elements, related to actual building operations and both macro- and microclimatic variations, are not easy to evaluate using simulations alone. In order to understand the realistic savings potential for each SHI mitigation measure, before starting large-scale implementation, it is appropriate to carry out field experiments to identify unforeseen problems and measure and document actual savings.

Measured energy savings from urban trees and white surfaces are scarce. The only previous experimental case study, related to the impact of vegetation, is that of Parker (1981) in Florida. In that experiment, Parker measured the cooling energy consumption of a mobile building before and after adding trees and shrubs, and found savings of up to 50%. On the other hand, no significant data are available on the effects of white surfaces. It is the objective of this project to monitor both of these effects in several buildings in Sacramento.

Trees and white surfaces affect the cooling energy consumption of a building in two ways:

1. **Direct Effect:** Trees shade buildings, blocking solar gain. White roofs and walls reflect most incident solar energy. Both of these factors decrease buildings cooling loads,
2. **Indirect Effect:** Microclimatic variations resulting from changes in the surface heat balance caused by evapotranspiration and lower solar heating of the light-colored buildings and surfaces.

A. Project Objectives

This project is a collaborative effort with The Sacramento Utility District (SMUD) to assess, monitor, and document the **direct effects** of shade trees and white surfaces. The project was implemented in two phases. The focus of the first phase was to measure the direct cooling effects of trees and white surfaces (mainly roofs) with particular emphasis on trees.

The specific goals of the first year project were:

- to document the air-conditioning energy savings of shade trees and albedo changes by instrumenting and monitoring microclimate attributes and air-conditioning energy use in a few selected homes and a school in Sacramento,

- to compare simulation results with monitored data,
- to provide analysis of the impacts of trees and white surfaces to assist SMUD in its program, and
- to assess and document the albedo performance characteristics of various building and paving materials and specify/recommend how they should be used in an incentive program.

B. Project Scope

As we discussed above, the objective of this project was limited to measuring the direct impact of shade trees and white surfaces on cooling energy use of several buildings in Sacramento. There are several other impacts that trees and white surfaces may have on building energy use and the local environment that may need to be addressed in follow-up studies. Some of these other energy and environmental factors are discussed below.

Sample Selection

Only seven buildings participated in this study. The sample included only those buildings, out of approximately 100, whose occupants/owners responded positively and agreed to participate in this project. Hence, the sample of monitored buildings, by no means, is representative of the population. Furthermore, we do not account for the effects of the possible changes in occupants' behaviors as a result of participation in the monitoring study. Care must be taken in extrapolating the results to other climates and building types. With the help of calibrated simulations, we present some extrapolated savings for other climate regions, for the buildings types studied.

Impacts on Heating Energy Use

Trees and white surfaces affect the heating energy use of a building. In several earlier studies, with the help of simulations, we addressed the heating energy use of buildings (Akbari and Taha 1991, Taha and Akbari 1988, Huang and Akbari 1990). Trees have a negative effect on heating energy consumption by shading a building and a positive effect by shielding the building from cold winter wind. Although these effects are not fully understood for all different climate regions and all building types, earlier studies indicate that trees may also save energy in winter, particularly in cold climates. The impact of white surfaces is even less understood. Our simulations for two California cities indicated that about 10-20% of the summertime cooling energy savings are taken back through increased wintertime heating. Future studies should address, in detail, the heating impacts of trees and white surfaces.

The Impact of Reflected Radiation on the Cooling Energy Use of Adjacent Buildings

The impact of the reflected radiation from a building on the adjacent buildings is another issue for further consideration. Simple calculations, however, show that the total (sum of long- and short-wave radiation) incident on a neighboring building is independent of the albedo of the test building; simply, under equilibrium conditions, the solar radiation incident on a surface is either reflected back as short-wave radiation or absorbed by the surface and re-emitted as long-wave radiation. The proportion of the long-wave and short-wave radiation, however, is important on the cooling energy load of a zone. If the reflected radiation is incident on a opaque wall, the higher the fraction of the short-wave radiation, the lower the cooling energy load of the zone. If the reflected radiation is incident on windows, it is obviously better to have a lower fraction of short-wave radiation. A study should be designed to address this issue in further detail.

Experimental Protocols

A practical issue of serious concern in a field experiment is normalization of data for cross-comparison with other building types and across different climates. Issues such as operation of the air conditioners, windows, and curtains are typical of such complexities. For instance, some people may have a higher tolerance for elevated indoor temperatures than others. Some may open the windows as soon as the outdoor conditions are favorable and some may not. In this project, we have not addressed these variations in the actual operations of the experimental buildings. We have developed a set of guidelines for building operations that would make the data analysis less cumbersome. These guidelines are discussed in this report. A separate study is needed to compare these guidelines with a statistically representative assessment of prevailing practices in the operation of buildings.

Trees and Air Quality

Although trees are known for their shading and neighborhood-cooling effects, some trees are also known for their impacts on other environmental issues such as air quality. Some trees emit reactive organic gases (ROG) that contribute to air pollution; some trees improve the air quality by collecting the dust and larger particles from the air. The California Institute for Energy Efficiency (CIEE) has sponsored a project to study the impact of trees and white surfaces on the air quality of the Los Angeles Basin (Ritschard *et al.* 1992).

Practical Implementation Issues

There may be some legal issues related to trees. In a letter to the Principal Investigator, Tony Fung of Southern California Edison Company states that, "Trees create more disputes among neighbors than any other subject matter. Practical issues such as driveway breakups, foundation cracking, sewage/pipe blockage and breakage, view reduction, as well as potential hazards (fire, storm, etc.), should be addressed" and studied in detail. Before embarking on a major implementation program, the utilities should address and study all implementation issues that need to be considered in a program. Pilot studies are usually good vehicles to gather field experience for program implementation.

Of equal importance is the long-term change of the surface albedo and shading of trees. The short-term focus of this monitoring project did not provide an opportunity to address the long-term changes in albedo and tree shading. These issues need to be studied over longer periods.

C. Project Tasks

The project focused on collecting performance data for white surfaces, demonstrating and validating energy savings of shade trees and white surfaces in several buildings in Sacramento. The project also includes a performance assessment of different products and treatments for white surfaces to specify/recommend how to use white surfaces in buildings to achieve capacity and energy savings. As stated earlier, the project was designed as a collaborative effort between Lawrence Berkeley Laboratories (LBL) and SMUD. The LBL participation involved project design, equipment installation, and data analysis. SMUD supplied the monitoring equipment and instrumentation. Other in-kind contributions by SMUD included an engineer to instrument the selected buildings, collect data, and transfer them to LBL for analysis.

Major tasks in this project included:

Task 0: Detailed Workplan. In collaboration with SMUD, we developed a workplan outlining the details of the project's scope and tasks. The workplan focused on the details of the monitoring experiment, where a significant coordination between SMUD and LBL was needed. This task was completed and delivered to SMUD and CIEE in March 1991.

Task 1: Performance Data for White Surfaces. We assessed the albedo performance characteristics of various building and paving materials and specified/recommended how they should be used to achieve peak power and energy savings. This task included reviewing the manufacturers' products and literature, collecting data for white surfaces, contacting the paint industry for data, documenting and comparing data, performing a cost-benefit analysis, and assessing various strategies to encourage a wide implementation of this measure. Our findings regarding this task are summarized in two earlier reports prepared for CIEE and SMUD (Taha *et al.* 1992 and Bretz *et al.* 1992).

Task 2: Demonstration, Validation, and Documentation. In this task we studied and documented the air-conditioning energy savings of shade trees and albedo changes by instrumenting and monitoring microclimate attributes and air-conditioning energy use at seven sites in Sacramento. The elements of this task included identification of monitoring sites, audits of the buildings, development of a plan for the experiment, specification and procurement of monitoring equipment, installation and testing of equipment, collection and review of test results, base case and retrofit monitoring (data collection), data analysis, and preparation of reports. All the major elements of this task were performed jointly by LBL and SMUD.

Task 3: Simulations of Energy and Peak Savings. We performed DOE-2 simulations of the buildings, compared the simulated results with monitored data, and refined and validated prediction algorithms. Based on the results of Task 2, we performed an analysis for white surfaces and shade trees for four representative climates in California.

Our preliminary findings regarding Tasks 2 and 3 were reported in an interim report to CIEE and SMUD (Akbari *et al.* 1992). In the interim report, we discussed the project design, specification and procurement of the monitoring equipment, calibration, installation, and validation of the data-logging systems, and the preliminary analysis of the collected data for three sites. This final report updates the work presented in the interim report and completes the analysis of the measured data collected during the first year of the project.

D. Organization of Report

This report was prepared to document the first year efforts of the monitoring task and to provide preliminary savings results. In addition to this introductory chapter (Chapter I), the report is organized into six other chapters.

Chapter II discusses the process of site selection and provides an overview of the characteristics of each site. The chapter also describes the albedo and tree modification experiments performed on each site.

For each site, we developed a distinct monitoring protocol for data measurement and provided guidelines for the operation of the site. Each protocol discusses the overall characteristics of the site, the data points, data monitoring intervals, and a guideline for the operation of the building. Monitoring protocols for all sites are presented in Attachment B, and the overall monitoring protocol is also discussed in Chapter II.

Chapter III presents a general description of the installed equipment, instrumentation of the sites, and calibration of the equipment. In this chapter we first discuss the characteristics of sensors and data loggers used in the project. Then we discuss the installation of the instruments on each site. Finally, we briefly review both the bench calibration and the pre- and post-dynamic calibration of the monitoring systems.

Chapter IV is a summary of our field experience in performing this monitoring project. We first discuss our experience and problems encountered in selecting, purchasing, installing, and programming the monitoring equipment. Bringing shade trees to the sites and changing the albedo of the roofs and walls, at times, provided serious challenges to this project. This chapter also discusses our practical experience regarding tree-planting and white-surfacing of the sites.

Chapter V is the data analysis chapter. We first present an overall review of the data analysis and simulation methodologies. Then we present the measured and simulated energy impacts of white surfaces and shade trees for each site, compare simulation results with measured data, and discuss the differences. This chapter concludes by providing a summary of the simulated and measured savings for all sites and by providing a brief review of microclimate variations on each site.

In Chapter VI we use the calibrated simulation models for the six houses and the school bungalows to estimate cooling energy savings for other combinations of tree and albedo strategies and in four climates regions in California. In this parametric study, we model the direct shading impact of varying amounts of tree cover as well as the effects of changes in roof and wall albedos.

Chapter VII is the summary and conclusion chapter. This chapter provides an overview of the results and recomendations for the 1992 monitoring project.

References

Akbari, H., Huang, J., Sailor, D., Taha, H; and Bos, W. 1991. "Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMUD) Service Area," An Interim Report prepared for California Institute for Energy Efficiency and SMUD, Lawrence Berkeley Laboratory, Berkeley, CA.

Akbari, H. and Taha, H. 1991. "The Impact of Trees and White Surfaces on Residential Heating and Cooling Energy Use in Four Canadian Cities," *Energy, the International Journal,* 17(2), pp. 141-149, 1992, *also* Lawrence Berkeley Laboratory Report No. LBL-30131, 1991, *also* published as "The Impact of Trees and White Surfaces on Residential Heating and Cooling Energy Use in Four Canadian Cities," Friends of the Earth, Ottawa, Canada, 1991.

Akbari, H., Rosenfeld, A., and Taha, H. 1990. "Summer Heat Islands, Urban Trees, and White Surfaces," *Proceedings of American Society of Heating, Refrigeration, and Air conditioning Engineers, Atlanta, Georgia, (February),* also Lawrence Berkeley Laboratory Report No. LBL-28308.

Akbari, H., Huang, J., Martien, P., Rainer, L., Rosenfeld, A., and Taha, H. 1988. "The Impact of Summer Heat Islands on Cooling Energy Consumption and Global CO_2 Concentration," *Proceeding of ACEEE 1988 Summer Study on Energy Efficiency in Buildings,* Vol 5, pp. 11-23, Asilomar, CA (August).

Akbari, H., Taha, H., Huang, J., and Rosenfeld, A. 1986. "Undoing Summer Heat Islands can save Giga Watts of Power," *Proceeding of ACEEE 1986 Summer Study on Energy Efficiency in Buildings,* Vol. 2, pp. 7-22, Santa Cruz, August 17-23, 1986, also Lawrence Berkeley Laboratory Report No. LBL-21893 (July).

Huang, Y. J., Akbari, H.; Taha, H. 1990. "The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements," *Proceedings of American Society of Heating, Refrigeration, and Air conditioning Engineers,* Atlanta, Georgia (February), also Lawrence Berkeley Laboratory Report No. LBL-24131.

Huang, J., Akbari, H., Taha, H., and Rosenfeld, A. 1987. "The Potential of Vegetation in Reducing Summer Cooling Load in Residential Buildings," *J. of Climate and Applied Meteorology,* Vol. 26, No. 9, pp. 1103-1116. also Lawrence Berkeley Laboratory Report No. LBL-21291, July 1986.

SMUD 1990. "A Program to Plant 500,000 Trees in Sacramento over the Next 10 Years," Sacramento Municipal Utility District, August.

Ritschard, R., *et al.* 1993. "Analysis of Energy Efficiency and Air Quality," Lawrence Berkeley Laboratory Report No. LBL-33051.

Taha, H., Sailor, D., and Akbari, H. 1992. "High-albedo Materials for Reducing Building Cooling Energy Use," Lawrence Berkeley Laboratory Report No. 31721.

Taha, H., Akbari, H., Rosenfeld, A., and Huang, J. 1988. "Residential Cooling Loads and the Urban Heat Island: The Effect of Albedo," *Energy and Environment,* Vol. 23, No. 4, pp. 271-283. Lawrence Berkeley Laboratory Report No. LBL-24008.

II. SITE SELECTION, DESCRIPTIONS, MODIFICATIONS, AND MONITORING PROTOCOLS

A. Sites Selection

During the early stages of this project, we sent questionnaires and inquiry forms to homeowners in the Sacramento area. The forms were sent to recipients from a list of people who had previously participated in other monitoring projects conducted by this and other groups. In addition, some of the forms were sent to SMUD employees. Each questionnaire/form requested information on building characteristics, occupancy schedules, and system characteristics/operations, as well as general information on the site and the surrounding albedo and vegetation density. The questionnaires also contained a request for consent to instrument the buildings. Appendix A shows an example of the questionnaire.

The initial number of respondents was not large (~15), and additional factors further reduced this number. Many of those who initially expressed interest in participating did not respond in the final screening stages. We were left with 6 buildings,† which we decided to monitor. In addition to these buildings, two bungalows at a nearby school were made available for the monitoring project.

Therefore, we did not actually select these buildings, rather, they were opportunity sites. We had no control over the selection, and the only choice we had was to decide which would be vegetation cases and which would be assigned to albedo modifications. In the following sections, we describe each site and explain how it was monitored.*

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† Initially we had recruited eight sites for monitoring: Site 1 through Site 8. However, Sites 3 and 4 withdrew at a latter stage and did not participate in the project. To keep our records straight, we kept the initial numbers of the sites throughout the project.

* Due to the very process of site selection, and the limited responses that we received, the sites are by no means representative of the entire area. Also, due to these limitations, the results of this project will not have statistical significance.

B. Site Description

Six of the seven sites formed an arc about 32 km long, stretching from northeast Sacramento to its southeastern newer areas. The seventh site was a school, where we monitored two classroom bungalows. **Figure II-1** shows the relative locations of these sites. **Table II-1** summarizes the characteristics of the participant buildings.

Site 1 was the northernmost site of the arc. It was located in a relatively new residential area and was typical of new construction. Since it was shaded and located next to a similar but unshaded building (site 8), we decided to use site 1 as a control station. Site 2, located in the older area of Carmichael, was selected as an albedo case because all the exterior walls (and portions of the roof) were heavily shaded by dense vegetation, and also because the owner gave us permission to permanently re-coat his roof with a white elastomeric coating.

Site 5 was well shaded on the south side but could accommodate two small trees on the unshaded east side. Site 6, the southernmost of all, was located in a new residential area that had a low tree cover. The house itself had little vegetation, particularly on the west side. We decided to position two trees to shade the west windows and partially shade the condenser unit. Also, the roof was highly insulated, thus establishing another reason for monitoring this site as a vegetation, not albedo, case. Thus sites 5 and 6 were monitored for vegetation effects.

Site 8 was a mirror image of site 1 and adjacent to it. It had no vegetation cover and accordingly, we decided to use it as a vegetation case. Finally, at the school site, we monitored two classrooms for the impacts of albedo modification. The units were adjacent to each other (~0.5 m gap between them) and had similar exposure, dimensions, occupancy, cooling systems, and other characteristics.

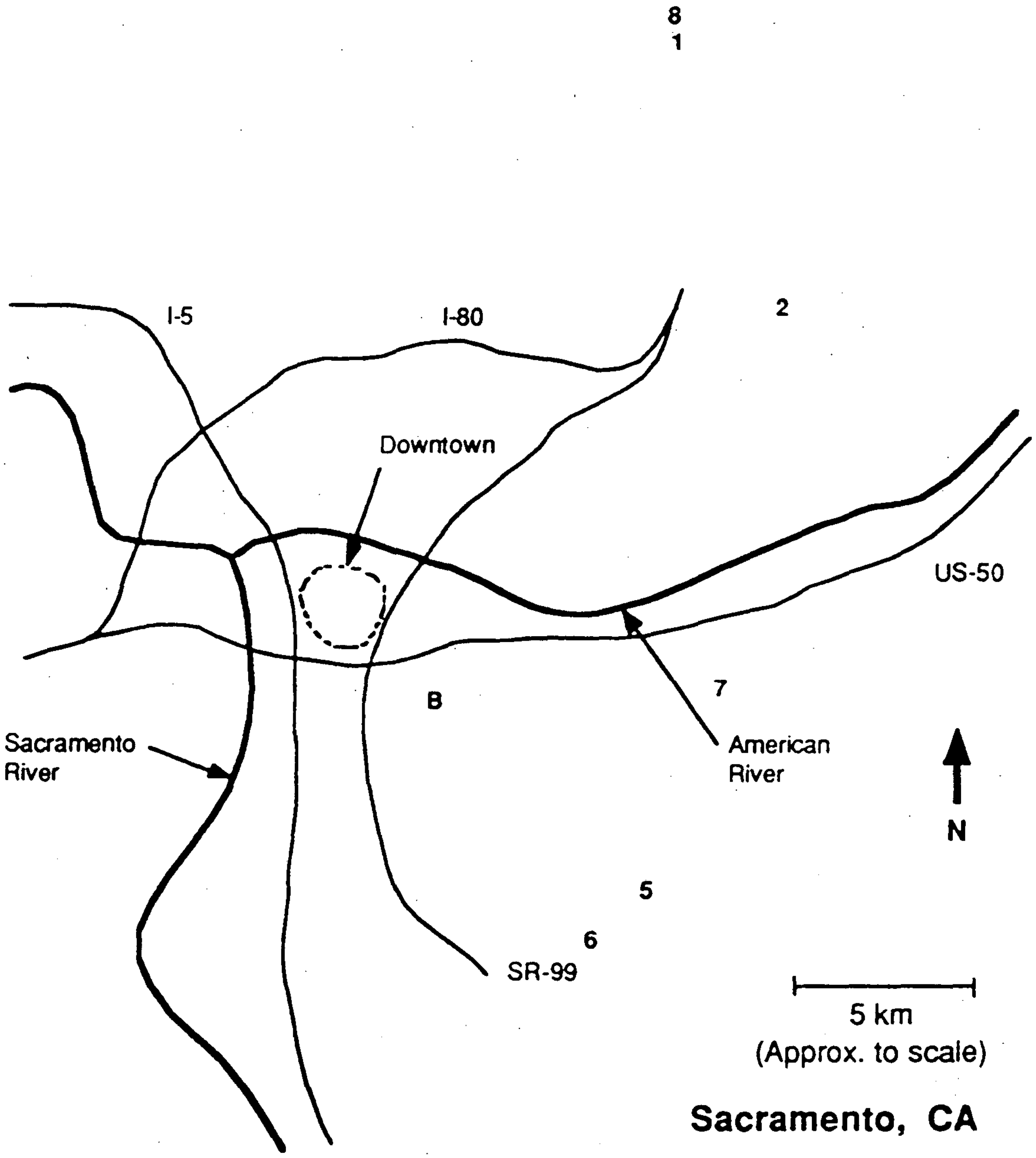


FIGURE II-1. Monitoring sites in Sacramento

Table II-1 Site and Building characteristics.
Building description, schedules, thermostat settings,
and other vital information is listed below for all sites.
Unknown characteristics and those determined by qualitative inspection
are marked with symbols (see footnotes).

Site→ Case→	Site 1 (control)	Site 2 (albedo)	Site 5 (vegetation)	Site 6 (vegetation)	Site 7 (vegetation)	Site 8 (vegetation)	Site B (albedo)
Building Type→	house	house	house	house	house	house	school
Site vegetation*	moderate	heavy	moderate	low	moderate-low	low	low
Neighborhood vegetation‡	moderate-low	moderate-heavy	moderate-low	low	moderate	moderate-low	low
Albedo*	low	low	low	moderate-low	low	low	moderate-low
Neighborhood albedo‡	moderate	moderate-high	moderate-high	moderate	moderate-low	moderate	moderate
Building description							
ft^2 †	1000	1825	1500	1200	1450	900	960
Building age	8	29	5	4	10	8	2
No. of stories	1	1	1	1	1	1	1
Roof material	comp. shingles	rolled comp.	comp. shingles	asph. shingles	comp. shake	comp. shingle	corrug. metal
Wall material	stucco/brick	plywood	wood siding	stucco/siding	stucco	stucco	plywood siding
Roof insulation	R-19	R-11	R-19	R-30	R-19	R-19	R-19
Wall insulation	R-11	R-8	R-11	R-11	R-11	R-11	R-11
Windows	2-pane	1-pane	2-pane	2-pane	2-pane	2-pane	2-pane
Foundation	slab	crawl	slab	slab	slab	slab	crawl
Air conditioner	central	central 3.5T	central 3T	central 3T	central	central	HP 34600
Heater	central	gas 90000 Btu	HP	Furnace	gas 42000 Btu	central	HP
Duct	ceiling	crawl	ceiling	ceiling	ceiling	ceiling	ceiling
Schedules							
No. of occupants	1	2	2	4	6	1	0 summer,~20 school
Weekday schedule	0 (700-1830)	0 (700-1830)	0 (530-2000)	0 (800-1700)	§	0 (800-1700)	~20 (800-1700)
Weekend schedule	0 (1/2 wknd)	2 (all)	1 (all)	vary	§	vary	0 (all)
Thermostat setting							
Heating (°F)	68	68	70	68	68	70	§
Cooling (°F)	72	80	80	80	not used	82	78

* *Pre-monitoring conditions*
† *Excluding garage*
‡ *Determined by visual inspection*
§ *Information not available at this time*
Abbreviations: comp. = composition, asph. = asphalt, corrug. = corrugated, wknd. = week end

C. Modifications

Albedo Modifications

Site B

One of the two school bungalows was painted twice (with different colors) to test the effects of albedo modification on surface temperature and air conditioner energy use. On 8-9-91, we started logging data for the "basecase" configuration, that is, the school as it was. Based on our measurements, the metallic roof had an albedo of 0.34 (and an estimated emissivity of about 0.3). On 8-21-91, we started logging data again, after the roof and the southeast wall were painted dark brown (the actual painting took place on 8-19). Our measurements indicated an albedo of 0.08 (and an estimated emissivity of 0.95) for the brown paint. Finally, on 8-30-91, we began logging data after the roof and the southeast wall were painted white (actual painting took place on 8-28), with a version of the Enerchron® white elastomeric coating. Our albedo readings indicated a value of 0.68 (we assumed a similar emissivity as that of the brown paint, i.e., 0.95).

Site 2

We started to download data from this site on 8-22-91. The basecase albedo for the black-painted rolled composition roof was 0.18 over the living area and 0.30 over the garage (not conditioned). After painting with a reflective version of Enerchron®, our measurements indicated albedos of 0.77 over the living area and 0.81 over the garage. A yellowish hue over the living areas (resulting from fallen leaves) was the reason behind the lower albedo values. Data logging with the white roof started on 9-13-91.

Tree Modifications

Tree modifications were performed mainly with trees in movable containers placed adjacent to walls and windows. At the time of positioning (9-24-91), these trees had a leaf cover of about 50% based on our estimates. The following information is available to characterize the small trees that were placed on the vegetation sites:

- Leaf-Area Index (LAI): the cumulative leaf area integrated over a specified height range (usually from stem height to crown height) divided by the site area (ground surface) the tree is occupying: We estimate the LAI to be around 2.

- Stem height: the height above ground of the lowest stem branchings: ~1.5 m.
- Crown height: the height above ground of the highest stem of the tree: ~2.4 m.
- Canopy diameter: the diameter of the canopy as seen from above the tree: ~1-1.5 m.
- Silhouette area: the projected area of the tree's canopy (such as that seen by the sun or the wind): ~2 m^2.
- Porosity: the amount of unobstructed area seen through the canopy by an observer at a specified direction (such as from a wall or underneath the tree): ~ 50%.

Although these trees can grow to 9 m tall by about 9 m abreast, their sizes at the time of monitoring were small. Their impacts on energy use will be much larger once they grow to full size.

Site 5

This house was well shaded on the south and north sides. On the west side there was only one small window, but on the east side there were two bedroom windows that we shaded with two of the trees described above. These trees were removed at the end of the data collection period, as they blocked the narrow walkway on the east side of the building.

Site 6

This site had no trees on the west-facing side. We shaded two west-facing windows and partially shaded the condenser unit (also located on the west side of the house). An additional tree was placed to shade one bedroom window on the south.

Site 7

This site had a relatively low amount of trees. The windows facing south west, north west, and north east were all unshaded. There was a tall tree on the south side of the building, but it was too far removed to cast any shadows on these windows. We positioned two small trees so that the south west windows were shaded.

Site 8

This site had a very low tree cover (the lowest among all others considered in this study). It had a translucent patio cover on the south west corner that did not block solar radiation. A large tree (6 m across, 8 m tall) was planted on the south west corner of the building on 9-17-91. Because the truck could not get close enough, the tree was planted relatively far (~5 m) from the southwest corner. This tree would thus cast a shadow on the wall starting at about 4 P.M.. In addition to this permanent tree, 7 other small trees (as described above) were placed along the south wall to shade the windows and portions of the wall as well as the condenser unit.

D. Monitoring Protocols

Prior to the start of monitoring, we developed detailed experiment design protocols for each site. These protocols, which act as stand-alone documents, are contained in Attachment B. While the specifics of each site dictated variations in the experiment protocols, the essential features are the same, and are described below.

Measurement Goals

Each site was identified as either the control site (site 1), a vegetation site (sites 5, 6, 7, and 8), or an albedo site (sites 2 and B). Regardless of whether a test site was to be used as an albedo case or a vegetation case, certain indoor and outdoor variables needed to be measured. The equipment used for these measurements and the instrumentation methods are described Chapter III (Equipment, Instrumentation, and Calibration).

Data Product and Output

There are two types of products to be expected from each site. First, environmental characteristic data such as building albedo, vegetation type/tree cover, and view factors were evaluated. Second, microclimate and energy use data for the air-conditioning unit were recorded. Data analysis included initial examination of the data for outliers, missing data, and signal-saturated output. The next phase of data analysis consists of two categories: intercomparison among all sites within the pre-modification period, and intercomparison with concurrent data from other sites and prior data from the same site after modification.

Experimental Design Approach

A schedule was proposed for modifying each site. The goal was to monitor each building in each phase of modification for at least two weeks. Unfortunately, this was not possible in all cases. Initially, it was planned that certain sites would be returned to the base configuration near the end of the monitoring period. This was not done. It was also necessary to specify *standard* operating procedures for the buildings, so that the data analysis could proceed with as few variables as possible. It was therefore requested that: windows remain closed at all times; thermostat settings be identical and constant; and lights be turned on and off in a consistent, similar, and predictable fashion. During the course of the monitoring period, some anomalous data were recorded and later explained to be a result of a deviation from the standard operating procedures.

Data Analysis

Data analysis proceeded under the assumption that changes in air-conditioning energy use were resulting from albedo and vegetation modifications. As has been pointed out elsewhere in this report, this assumption may not be valid in some cases. Each protocol document contains a table that gives the sampling/averaging and logging intervals for each sensor.

Data Accuracy, Quality Control/Verification, and Format

During the monitoring period, data were downloaded by SMUD and sent to LBL on 3 1/2 " IBM-formatted disks. Initial data analysis had proceeded without benefit of pre- and post-calibration analysis but was later adjusted accordingly. The data-reduction procedure was also refined to account for sensor error/drift. A post-calibration of the equipment was performed to aid in defining data accuracy and correcting for sensor error.

At the end of each protocol document is a site drawing depicting the orientation and layout of the building. This drawing also specifies the locations of each sensor, including the weather station. The locations of the condenser and air handler, potential locations for trees (at vegetation sites), and the locations and sizes of windows are shown.

III. EQUIPMENT, INSTRUMENTATION, AND CALIBRATION

The study required the measurement of numerous variables at each site. To facilitate an orderly procedure for these measurements and to ensure data quality, we developed methods for using and interfacing sensors. The following three sections are devoted to the tasks of: (a) describing the sensors used, how they work, and how accurate they are; (b) discussing in general how we used these sensors to perform the measurements we required; and (c) explaining how we calibrated and/or verified the performance of the sensors. In addition, we also discuss our technique for measuring roof albedo.

A. Equipment Description

Depending upon the requirements at a given site, we employed a variety of sensors to measure the necessary variables: air temperature, surface temperature, relative humidity, wind speed, wind direction, solar radiation, air conditioner energy use, and sub-surface soil temperature and moisture. Sensors were used to monitor these variables for either a 10 minute time step (for those variables that change quickly), or 20 minute time step (for those that do not change rapidly). A brief description of these sensors follows.

Temperature: Indoor, outdoor, surface, soil, and supply and return air temperatures were measured using 24-gauge type-T thermocouples from Omega. These thermocouples have a quick response and are generally accurate to within a degree Celsius. In all uses of these thermocouples, it was necessary to extend the length of the wire by using 24-gauge type-T thermocouple wire, also from Omega.

Relative Humidity and Air Temperature: The Hygrometrix Inc. Model P-20-HT combined humidity and air temperature probe (and associated electronics conditioning box) was used to measure ambient indoor and outdoor relative humidity and air temperature. The humidity sensor is a composite of organic and inorganic crystals that sense moisture by the hygromechanical stress of crystallite structures acting on a metal beam. The resulting strain of the beam is measured by silicon strain gauges bonded to the beam. This sensor is mounted in a 1/2-inch diameter probe (roughly 4 inches in length). This probe is connected to a signal-processing electronics box through standard six-wire phone cable. The signal-processing box generates two voltage signals that represent relative humidity and air temperature. Hygrometrix claims a full-range linear response to relative humidity from 0 to 100 %.

Wind Speed and Direction: The Model 038 Sentinel wind speed and direction probe from Met One was used to characterize the local wind. The wind speed sensor is a cup anemometer that has a range of 0 to 100 mph with a starting threshold of 1 mph, and a stated accuracy of ± 0.25 mph. The anemometer utilizes a sealed magnetic switch that produces two pulses per revolution at a rate proportional to wind speed. The wind direction sensor position is transmitted by a 10 K Ω potentiometer. The range of wind direction measurement is 0 to 360 ° with a starting threshold of 1 mph and an accuracy of ± 3 °.

Solar Radiation: A Licor Pyranometer Sensor, model LI-200SA, was used to measure incoming solar radiation. This instrument uses a silicon photovoltaic detector mounted in a fully cosine-corrected head. The pyranometer spectral in response (0.1 - 1.2 μm) does not cover the full range of the solar spectrum. Licor claims, however, that under natural daylight conditions, the LI-200SA is accurate to within 5%. The sensors we acquired had sensitivity ranging from 90 to 98 $\mu A/1000 Wm^{-2}$.

Soil Moisture: Delmhorst Inc. gypsum block soil moisture sensors were used to measure soil moisture tension. These blocks are made of gypsum cast around two concentric electrodes. When a block is connected to a voltage source and allowed to come into equilibrium with moist soil, current flows between the electrodes. By measuring the electrical resistance of these blocks, available soil moisture can be inferred using an empirical look-up table provided by Delmhorst.

Air-conditioning Energy Use: The PM-1000 power monitor from Rochester Instrument Systems (RIS) was used to measure air-conditioning energy usage. The PM-1000 works by measuring line voltage and current, electronically computing the energy being used, and reporting a pulse output which is proportional to Watt-hours.

Data Logger: In order to record and store data continuously over the course of the investigation, Zi-Tech Instrument Corporation Dataloggers, model DT100F, were used. These data loggers allow 23 differential analog channels of input and 9 channels for digital input. They come equipped with thermocouple linearization and cold junction compensation circuitry.

Albedo: To measure albedo, we used an Eppley PSP (Precision Spectral Pyranometer), a high-precision radiometer that is sensitive to radiant energy in the 0.28-2.8μm band. That PSP yielded an output of 9.98 μV per W/m^2, had a linearity of ±0.5% between 0 and 1400 W/m^2, and a response time of 1 second. These characteristics were obtained based on calibration at the EPPLEY Laboratory, in Newport, R.I.

The double-dome design of the PSP minimizes the effects of convection (on read-out) resulting from tilting the pyranometer at different angles. For this reason, the PSP was especially suitable for the type of albedo measurements we performed in this project, since the measurements required the apparatus to alternatively face up and down.

The PSP was mounted at the end of a stand we designed for this purpose in another project. For each roof, we took several measurements to detect any spatial variation in albedo (which we did in some cases, e.g., Site 2). The albedo values we obtained in this field project compared well with the values obtained from roof albedo measurement tests on other sites that we performed in another project.

B. Site Instrumentation

Air Temperatures: Air-conditioning supply and return air temperatures were typically measured by feeding the end of a thermocouple through the ducting so that the tip of the thermocouple was roughly one inch from the outlet vent of the ducting. This provided representative supply and return temperatures. Indoor and outdoor ambient air temperatures were measured using the temperature output from the Hygrometrix sensor mounted as discussed below.

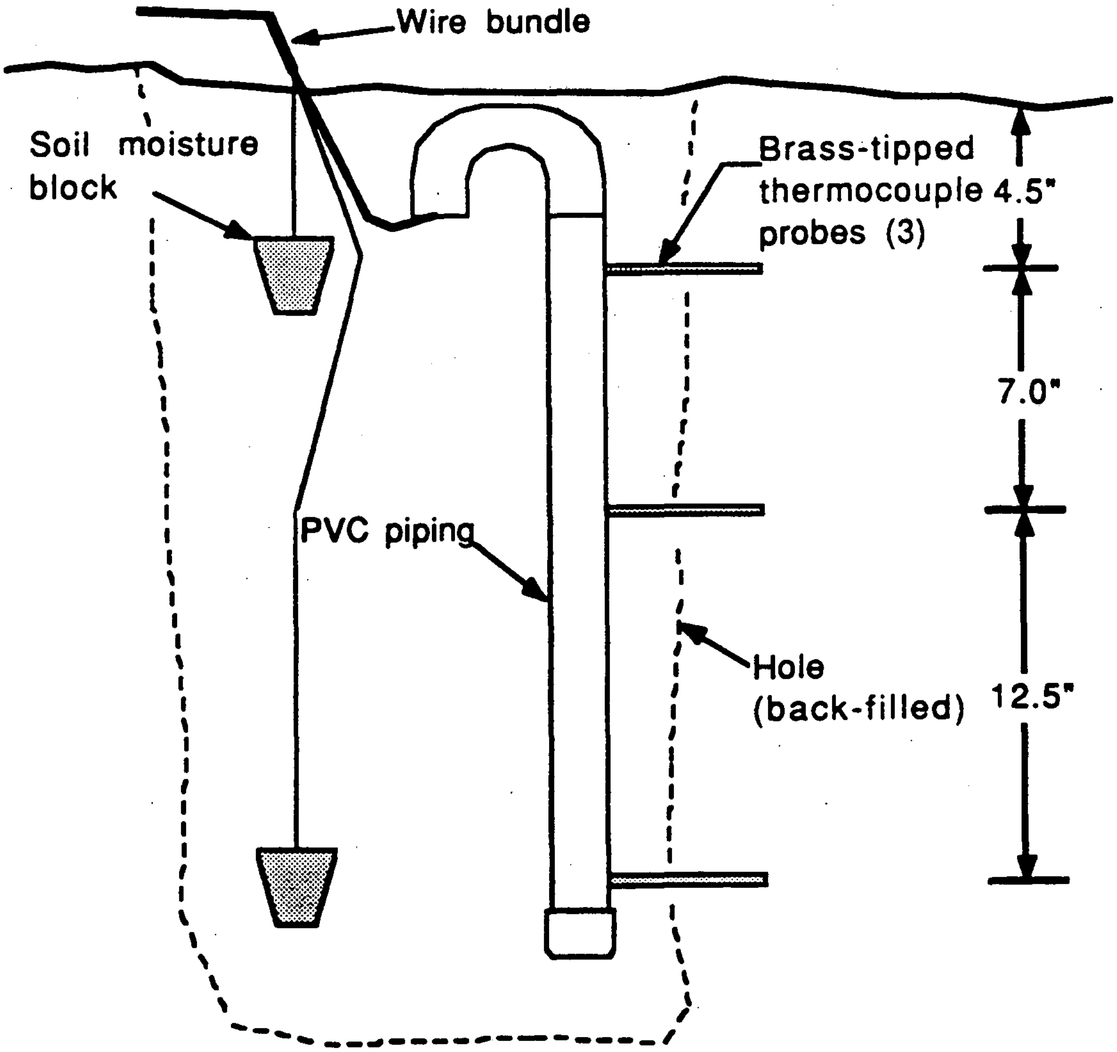
Relative Humidity and Air Temperature: The indoor relative humidity/air temperature sensor was typically placed at least 2 feet below ceiling level with the tip of the probe roughly 6 inches away from the wall. In order to measure typical indoor ambient conditions, these sensors were located so that they were not influenced by the impingement of cool air from air conditioner supply vents. The outdoor humidity/temperature sensor was usually placed underneath a deck overhang or eave so that it was not subject to direct insolation. Furthermore, to ensure that representative ambient outdoor conditions were being measured, this sensor was located so that it was well ventilated.

Wind Speed and Direction: The Met One wind sensors were mounted on a section (3 to 5 feet long) of PVC pipe. This piping was, in turn, secured to either the rooftop or a corner of the building so that the sensors themselves were roughly 3 - 5 feet above roof level and about 20-25 feet above ground.

Soil Temperature and Moisture: Sub-surface soil temperatures were measured using type-T thermocouples mounted in a sealed probe, as depicted in **Figure III-1.** This probe was installed in the soil by digging a 6 inch diameter, 24 inch deep hole with a standard post-hole digger. The soil temperature probe was then positioned in the hole so that the first brass tube was 4-1/2 inches from the surface. The three brass probes were then pushed into the side of the hole in order to cause minimal disturbance to the soil. The hole was then backfilled with dirt, installing the moisture sensors at two depths. The resulting soil measurement system is depicted in **Figure III-1.**

Data Loggers: In order to simplify the connection of the many sensors at each site to the data logger, we prepared each data logger in advance by internally wire-wrapping certain circuitry connections. This resulted in the ability to connect sensors quickly and easily at a test site and program the data logger to average, record, and save data. Data were typically saved at 10 minute intervals and down-loaded by phone modems every 3 days. Data loggers were placed in the garage (at residential sites) and inside classrooms (at the school site).

Figure III-1. Moisture and temperature probe



C. Calibration

Bench Calibration and Conversion Constants

Prior to the dynamic (field) calibration that we performed, bench calibration was carried out. When interpreting the output, conversion from analog to digital and to meaningful physical units was necessary. For wind speed, wind direction, and solar radiation, the following conversions were used:

1. The cup anemometers were calibrated to give two pulses per revolution. An rpm (revolution per minute) count is obtained by dividing the pulses in a minute by a factor of 2. Then, equation 1 is used to convert to m s^{-1}:

$$\bar{V}_{(m/s)} = \frac{\omega}{37.5067} + 0.44704 \tag{1}$$

where ω is rpm. The wind speed data we present in this report are 10-minute averages.

2. The wind vanes circuitry was supplied with 5 volts DC, and wind direction was found as a linear function of voltage output (V) by:

$$\theta = 72V \tag{2}$$

where V is the output voltage and θ is degrees clockwise from north. The wind direction data we present in this report are instantaneous values at the end of each 10 minute interval.

3. Each photometer (pyranometer) was supplied with a calibration constant taken from bench tests. At the monitoring sites, each photometer was connected to a millivolt adapter with a resistance of 147 Ω. Conversion to W m^{-2} units was obtained from **Table III-1.**

Pre- and Post-Retrofit Dynamic Calibration

Before installation at the residential and school sites, the sensors and data-loggers were dynamically calibrated side by side in a large open yard at SMUD. After the end of the project, the sensors were recalibrated to make sure no drift had occurred. Data from post-calibration are discussed in this section since some sensors were not available when we performed pre-calibration. We should note that for available sensors, both pre- and post-calibration indicate the same performance. Each combination of sensors, wires, connections, and a data-logger formed a "set" of components that we kept together at the

TABLE III-1. Photometers calibration constants (W m^{-2}/μA) based on bench calibration at manufacturer site. Individual photometers were connected to a millivolt adapter with a resistance of 147Ω.

PHOTOMETER	Multiplier W m^{-2}/μA
Site 8 (photometer A)	11.05
Site 8 (photometer B)	10.75
Site 2	10.55
Site 6 (photometer A)	10.17
Site 6 (photometer B)	10.99
Site B	91.1

calibration site and after we moved the equipment to the monitoring sites. The components of each set were identified by their serial numbers. Each of the pre- and post-calibration periods lasted for one week. Pre-calibration was performed in August 1991, whereas post-calibration was performed in December 1991.

In the dynamic calibration configuration, sets of sensors and data-loggers were positioned side by side in an open yard. Similar sensors, e.g., wind vanes, cup anemometers, photometers, etc., were grouped together and placed very close to each other. The purpose of dynamic calibration was to detect potential deviations in readings of similar sensors, as well as to test the correlation in readings of the same variable as measured by different sensors, e.g., air temperature measured by thermocouples vs air temperature measured by RTDs (Resistance Temperature Detectors). A week of post calibration yielded the formulas and correlations given in **Tables III-2** through **III-4**.

These tables provide correlations among variables between a specific site (set) and the control site (set). In addition to these correlations, other relationships within each set (each site) were developed involving indoor air temperature sensors and thermocouples. These

TABLE III-2. Air temperature sensors calibration. "c" means corrected temperature, and the numbers refer to corresponding sites. Control air temperature is at Site B, and α is significance of F-Test.

Correction	Adj. R^2	α
$T5c = 0.9545\ T5 + 0.5189$	0.9934	0.0001
$T2c = 0.9641\ T2 + 0.5420$	0.9941	0.0001
$T1c = 0.9533\ T1 + 0.5392$	0.9967	0.0001
$T7c = 0.9456\ T7 + 0.3092$	0.9889	0.0001
$T6c = 0.9555\ T6 + 0.4318$	0.9975	0.0001

TABLE III-3. Solar radiation sensors calibration. "c" means corrected solar radiation, and the numbers refer to corresponding sites. Control solar radiation is at Site B, and α is significance of F-Test.

Correction	Adj. R^2	α
$K6c = 0.9563\ K6 + 3.4239$	0.9463	0.0001
$K2c = 0.9753\ K2 + 2.0229$	0.9390	0.0001
$K8c = 1.0397\ K8 + 10.821$	0.8812	0.0001

correlations are given in **Table III-5**. In each case, except for Site 8, the control temperature was the outdoor air temperature at that particular site. In Site 8, the control temperature was that of the indoor air, since Site 8 was not equipped with an outdoor air temperature sensor. In this table, Tai is indoor air temperature, TT means thermocouple temperature, "c" indicates corrected temperature, and α is significance of F-test.

After subjecting the raw data-files to the criteria and conversions set forth in these sections, data from each site were manipulated to handle format problems, missing/wrong date

TABLE III-4. Wind speed sensors calibration. "c" means corrected wind speed, and the numbers refer to corresponding sites. Control wind speed temperature is at Site 1, and α is significance of F-Test.

Correlation	Adj. R^2	α
$U5c = 0.9603\ U5 + 0.0036$	0.9918	0.0001
$U2c = 0.9200\ U2 + 0.1747$	0.8412	0.0001
$U6c = 1.0717\ U6 - 0.0754$	0.9760	0.0001
$U7c = 0.9731\ U7 + 0.0186$	0.9442	0.0001
$UBc = 0.9859\ UB + 0.0084$	0.9766	0.0001

and time stamps, and missing/erroneous data.

IV. EXPERIENCE WITH MONITORING EQUIPMENT AND BUILDING MODIFICATIONS

A. Monitoring Equipment

Selection

Criteria for equipment selection were simple and straightforward. We obtained the highest quality and most accurate equipment available within budget constraints.

- The Zi Tech datalogger was selected from a list of five manufactures for many reasons. Zi Tech's equipment has a sufficient amount of input channels: 23 differential or 46 single-ended analog inputs, 8 digital inputs, and 8 digital outputs. It had the lowest cost for the required features and no hidden costs for additional required accessories. Programming, including communication with the equipment both on a local and remote level, was relatively simple. Previous experience with other monitoring projects using this equipment also factored in the decision.
- Sensors selected were typical of equipment commonly used in the field. Besides keeping cost in mind, we decided to obtain high quality and accurate sensors. Also, delivery time was utmost in importance due to time constraints of this project.

Purchasing Equipment

Purchase orders were sent to vendors in the first week of June after all monitoring equipment was finalized and approved. Equipment was ordered at this late date due to increased time involved with site selection. All equipment was scheduled to and did arrive within a 30 day period except for the dataloggers and temperature/humidity sensors. The large cost associated with the dataloggers and temperature/humidity sensors required that they be sent out for bids. This process delayed equipment arrival by an additional 30 days on top the thirty days required for delivery from Australia. Though a 60 day period for delivery of monitoring equipment is not unusual, installation was delayed until the first week of August. To ensure arrival of equipment in time for future installations, a minimum of 90 days must be allowed for delivery.

Programming and Data Retrieval

Programming the Zi Tech dataloggers was fairly simple and straightforward. This is due to pre-wire-wrapping of each datalogger (substituting hardware configuration in lieu of software programming) allowing the user to assign specific terminals to specific input channels, output channels, and signal conditioners.

Some problems were encountered with programming the datalogger's clock to record in the desired HH:MM:SS (hour:minute:seconds) format. Time format was continuously returned in the seconds only format. This problem persisted even after confirming the proper programming of the clock from the manufacturer. We found by chance that the problem occurred when we were downloading data using the software program supplied with the datalogger. When we downloaded data using our modem's communications program (Bitcom), time was returned in the desired HH:MM:SS format. This condition only occurred using a direct (local) connection and was never encountered with a remote (modem) connection.

Another obstacle we confronted at the beginning of the data-collection period was a loss of recorded data. This occurred several times before a solution was found. The condition causing data not be to recorded was a program flag (/L) to enable data recording being reset to the disable (/l) position. After trial and error and many consultations with the manufacturer's representatives, we found the culprit to be the datalogger's communications program. Once this was known, a simple solution simple was to not connect the serial cable to the datalogger until the communication program had fully initialized.

Our data were recorded in 10 and 20 minute intervals. The 10 minute interval was recording 7 to 9 channels whereas the twenty minute interval was recording 8 to 13 channels. So when the data was downloaded, records of the two separate time intervals were uneven, making it difficult to align similar channels in the same columns, thus incurring time-intensive data manipulation. To eliminate this condition, all channels should be recorded at the same time interval wherever possible to simplify data analysis.

Problems Encountered

As expected with a monitoring project of this size, we encountered problems, primarily related to equipment installed in the field. We were able to identify some of these problems and remedy them on-line. Other conditions, concerning site control, were not so easily remedied. All site control conditions, including thermostat settings and window shades schedules, depended on the occupants' cooperation.

Initial problems with the remote communication with dataloggers in the field occurred between the phone modem and datalogger. Through numerous discussions with both the representatives of the modem and datalogger manufacturers, plus our own trial and error we were able to solve this problem, which was identified as the serial cable between the phone modem and datalogger. After many combinations of pin configurations were tried, we found the correct configuration for SMUD's particular modem pool arrangement.

Sensor problems were minimal (3.5%); only 4 sensors out of 115 sensors had problems. There were two surface thermocouples and also a pyranometer that had fallen down. All three sensors were mounted on a stucco wall with duct tape. Heat from the wall and its dryness would not allow the tape to remain adhered for a long time. This condition was easily solved by applying a small amount of silicon sealant on the thermocouple and wall and then applying duct tape over. The pyranometer's problem was solved by screw-mounting it to the wall. The last sensor to have a problem was an air-conditioning supply temperature thermocouple that had a bad connection, which we repaired. There were three occasions when the temperature and humidity sensors and watt-hour recordings were incorrect. These were not hardware problems but software problems caused by power outages and resetting the program incorrectly. These power outages also caused some of the modems to malfunction, which required site visits to induce a power reset and then complete reprogramming of both the datalogger and phone modem.

The site control problems concerned the thermostat settings and window operation/shading. At the school site, all of the thermostats were controlled by a separate timer that we set to identical schedules. Unbeknown to us, after a series of power outages, these timers were offset by approximately seven hours until data were retrieved and reviewed. The timers were reset and their off flags removed to prevent future problems. Once school was in session we experienced another set of thermostat control problems. The temperature setting was frequently lowered from 78°F to 72°F in the unmodified (control) classroom. At each data retrieval the thermostat would usually have to be reset even though it was in a locked cover. There were no similar problems experienced at the residential sites. What was experienced, however, was a reluctance to leave all window coverings open as requested. Site 6 would always completely shut window coverings on the weekend and Site 8 would halfway close the mini-blinds throughout the entire test period.

These site control problems affected measured cooling energy use in several ways. At the school site, the irregularity in the thermostat setpoint affected our cooling energy savings estimates. The air-conditioning system uses more energy when set at a lower indoor temperature. Removing window coverings increases the heat gain to the house and thus raises cooling energy use and lowers savings estimates. Problems with power outages, equipment problems, and faulty sensors limited the amount of data available and lessened the statistical reliability of our conclusions.

When the majority of data had been collected and some data analysis had begun, the kilowatt-hour usage of the air-conditioners seemed to be noticeably lower than expected. Even though we did not monitor the air-handler's power usage, adding this additional load to the monitored load still did not seem to correct the problem. To verify if the datalogging equipment was correctly measuring watt-hours, an independent source of measurement was needed. This was done using a Esterline Angus "Power Master IIIB ac multimeter" and directly comparing its instantaneous readings with the dataloggers' in 5 minute intervals. We found that the dataloggers' readings were exactly one half of the Esterline's measurement. The reason was the installation of the power monitor's current transformer, i.e., two passes through the current transformer instead of the single pass that was implemented. In either case, doubling the datalogger's recorded power measurements provided the correct energy usage for the condensing units at all sites.

B. Trees

Four of the six residential sites were chosen to be modified with shade trees. Our objective was to directly shade all south- and west-facing walls and windows and also the air conditioner's condenser unit. Although large mature trees were preferred for shade modification, yard access conditions, existing landscaping, and site owner's objections reduced our expectations down to planting one large red oak tree at only one site. Even this large tree could not be planted as close to the house as desired because of the size of the tree planting equipment and the yard and patio constraints. Smaller, more portable (hand carried) trees were needed, but the largest portable tree that could be located in Sacramento were 24 inch box trees.

Limited by the amount of trees available to us for shading, we decided to concentrate on three sites, Sites 8, 6, and 7, in respective order of importance. At site 8, which had the large oak tree brought in, we also located seven small trees to shade the south wall. At Site 6, we brought in three small trees to shade one west-facing bedroom window and the condenser unit and one tree to shade one south-facing bedroom window. At Site 7, two trees were brought in to shade two southwest-facing bedroom windows. After initial placement of these trees, one of the project staff returned the next day to relocate them to maximize shading at approximately two to three o'clock in the afternoon.

Attempting to heavily shade residential sites that previously lacked shade proved to be a difficult task. First, the number of sites should be kept to a minimum in order to concentrate available vegetation resources and to reduce the time involved in implementing these modifications. Second, effort is needed to locate trees of sufficient size and shading. Third, the logistics of delivering, locating and planting all vegetation (including heavy equipment such as trucks and forklifts) must be considered. Not to be overlooked are a site owner's objections and concerns to be address thoroughly and completely before including them on a final list of sites.

C. White Coatings

SMUD contacted three manufacturers of reflective white coatings to ask if they would like to have their product tested in this monitoring project. The manufacturers were

1. National Coatings
2. Thermo Materials
3. Helios

Only two of the three manufacturer's contractors in the Sacramento area returned our call and expressed interest in participating. Of these two only one contractor considered doing all of the work involved in modifying the two chosen albedo sites and within our time schedule. Through this process of elimination we decided by default to use Helios's Enerchron coating product at both albedo test sites.

V. ANALYSIS OF MEASURED DATA AND COMPARISON WITH SIMULATIONS

A. Introduction and Approach

This chapter presents and discusses the results of our analysis of the measured and simulated data for the seven buildings that participated in this monitoring project. The chapter includes a detailed analysis of the measured data, a comparison with the DOE-2 simulated results, and use of the measured data for calibration of the DOE-2 model. Finally, the chapter presents the results of our DOE-2 simulations and describes the use of the DOE-2 model to estimate cooling energy impacts over the entire cooling season.

The measurement period for some of the sites was limited to September and October 1991. These months typically are transitional cooling months in Sacramento, and the measured results presented here are limited to these measurement periods. With the help of simulations, we estimate the impact of high-albedo roofs and shade trees on cooling energy use for the hot summer months of June, July, and August.

Although it was clear that we would need to continue the experiment for a second cooling period, the collection and analysis of the data for the first year provided invaluable insight at a minimum marginal cost of data collection and analysis. Hence, the data presented in this report mainly characterizes the base case conditions for the experiment.

Our approach for data analysis includes a presentation and discussion of the measured data followed by DOE-2 simulation model development to estimate the energy use of the buildings. We calibrate our simulation results with the measured data and use the calibrated models to gain insight into interdependencies among variables.

An important component of this project was to model the monitored buildings using the DOE-2.1D building energy program and perform computer simulations to better understand and assess the measured data. The approach for the modeling component of the project included (1) initial model development using data from site surveys, (2) comparison of the models with measured data at an hourly time scale, (3) modifications of some of the inputs based on perceived problems with the original simulations, and (4) comparison of the results from the measured data with model predictions.

Once the computer models are calibrated against the monitored data, i.e., adjusted to correspond as closely as possible to the measured data during the monitoring period, they are then used to analyze the potential savings for the same strategies under different climate and building conditions, such as during peak summer conditions, and to extrapolate from the limited monitoring period to longer time spans, such as over an entire year. In addition, the computer models can be used to study variations and combinations of tree-planting and albedo strategies beyond those that were directly measured. The danger of relying solely on simulations is that the cumulative effects of input errors, simplifying assumptions about building operations, and deficiencies in the modeling techniques can often produce computer results that may differ from real measured energy use by as much as 50-100%. This project allowed us to combine the veracity of the measured data with the flexibility of computer simulations to extrapolate the results.

In the sections to follow, we first discuss the data analysis approach and simulation methodology. Next we present data and discuss results for the buildings that participated in high-albedo and shade-tree experiments, respectively. The chapter concludes with a summary of the measured and simulated data followed by a discussion of microclimate variations around the monitored buildings and a comparison with airport weather.

B. Data Analysis Methodology

Our data analysis approach has two major components: graphical presentation of the measured data and regression analysis. The collected data have been gathered in different time intervals. We first integrate the 10-minute interval data and produce hourly files. For each building, we show plots of cooling energy use against drybulb temperature. The plots include hourly kWh vs hourly outdoor air temperature, daily kWh vs average daytime outdoor air temperature, and daily kWh vs daily maximum outdoor air temperature. We also present cooling electricity use plotted against the difference between outdoor and indoor air temperatures. This tends to suppress the data variations and normalize for the changes in inside temperature. Our plots also include time series of total daily solar radiation on the building roofs and walls as appropriate.

We have only analyzed the most reliable data from the first year of data collection. Since some of our measurements, particularly outside surface temperature measurements, are questionable, we only briefly present and discuss them in this first year report.

C. Simulation Methodology

The intent of the computer modeling is to mirror as accurately as possible the actual situations encountered in the field during the monitoring period. Therefore, care has been taken to model the buildings as realistically as possible, including the materials, construction, insulation levels, geometry, and surface properties of the buildings, the location of windows, and the shading effects of overhangs, trees, and adjoining buildings. Similarly, we attempted to duplicate the internal conditions of the buildings, including the indoor temperature and internal heat gain from occupants, lights, and equipment. We have also tried to estimate the cooling system characteristics from available data and to accurately model the system performance. In order to reproduce the actual weather of the monitoring period, we used hourly weather data for August 1 through October 31 acquired from the National Climatic Data Center (NCDC) for the Sacramento Executive airport, supplemented with on-site weather data gathered during the monitoring effort.

We first developed models based on data collected for each site by the LBL and SMUD project teams. These models were the basis for initial comparisons with the measured data. The data we used in the comparisons consisted of cooling energy consumption and interior temperature.

We refined the models to the point where we felt that the disagreements between the measured and simulated data were not significant, or where disagreements, which we could not explain based on survey characteristics, still existed. We then used the models to assess the daily energy savings identified in the analysis of the measured data. Finally, we used the models to estimate savings for an entire year instead of the 2-3 months during which the measurements took place. In the next chapter, we discuss how the models were used to estimate potential energy savings from shade trees and high-albedo building surfaces in other climates.

In this section, we describe the model inputs and how they were derived, as well as some of the primary findings from the calibration task.

Building Geometry and Adjoining Surfaces

Computer models were generated for each of the seven buildings that were monitored in this project. For simplicity, these buildings will be referred to throughout this section as either Site 1 through 8 (residential sites), or as Site B (school site). The geometry of the buildings was based on measurements made by SMUD, complemented by measurements and photographs taken by the LBL project team. Although care has been taken to model the buildings as realistically as possible, there are inherent limitations in the DOE-2 program, modeling approaches, or data used to develop DOE-2 input that limit the accuracy of the simulations.

A graphics program was created to read the DOE-2 input files and produce three-dimensional drawings of all surfaces being modeled, including walls and roofs, shading devices such as eaves and overhead patio shades, neighboring buildings that may shade the modeled buildings, and vegetation. These computer drawings were used to debug the DOE-2 input files. **Figures V-1A** and **VI-1B** are sample drawings of the DOE-2 input files for Sites 6 and 8, viewing the buildings from the southwest. Note that the DOE-2 program models only flat rectangular surfaces, so that three-dimensional objects such as trees are approximated by a set of flat surfaces and end up looking like boxes. In the figures shown here, trees added as part of the experiment are marked in the plan by X's. The tree surfaces are given a transmissivity value that approximates the amount of solar radiation passing through the leaves and the canopy. These figures also show neighboring buildings, represented by the freestanding surfaces to the north and west. Shading elements that are above ground level are reflected in the plan by dotted lines. Garages are modeled as unconditioned spaces attached to the houses. **Table V-1** gives the general dimensions and internal loads of the houses obtained by reconciling the survey results with the building geometries derived from the modeling effort.

The internal loads shown on Table V-1 are based on (1) site survey results, (2) electricity billing data for each site, and (3) standard engineering assumptions. For the residential sites, the magnitude of the internal loads from appliances and lighting are estimated from the minimum monthly electricity consumption over the previous 16 months. Previous LBL work has shown that approximately 75% of typical residential electricity usage is input to the conditioned space as sensible heat gains and 10% is input as latent gains (Huang et al., 1987), with the remaining 15% occurring outside of the conditioned space. Occupant internal gains are based on the number of occupants per house as reported in the site surveys as well as previous work (Ritschard et al., 1992, ASHRAE, 1989). Two different internal gains schedules were developed: one for occupants and one for appliances. For each of these, we developed schedules for occupied and unoccupied days to account for typical occupancy patterns identified by each building owner in the original site surveys. The appliance heat gain schedule was taken from the ASHRAE 90.2 Standard model input (ASHRAE, 1990), and a modified version was used to

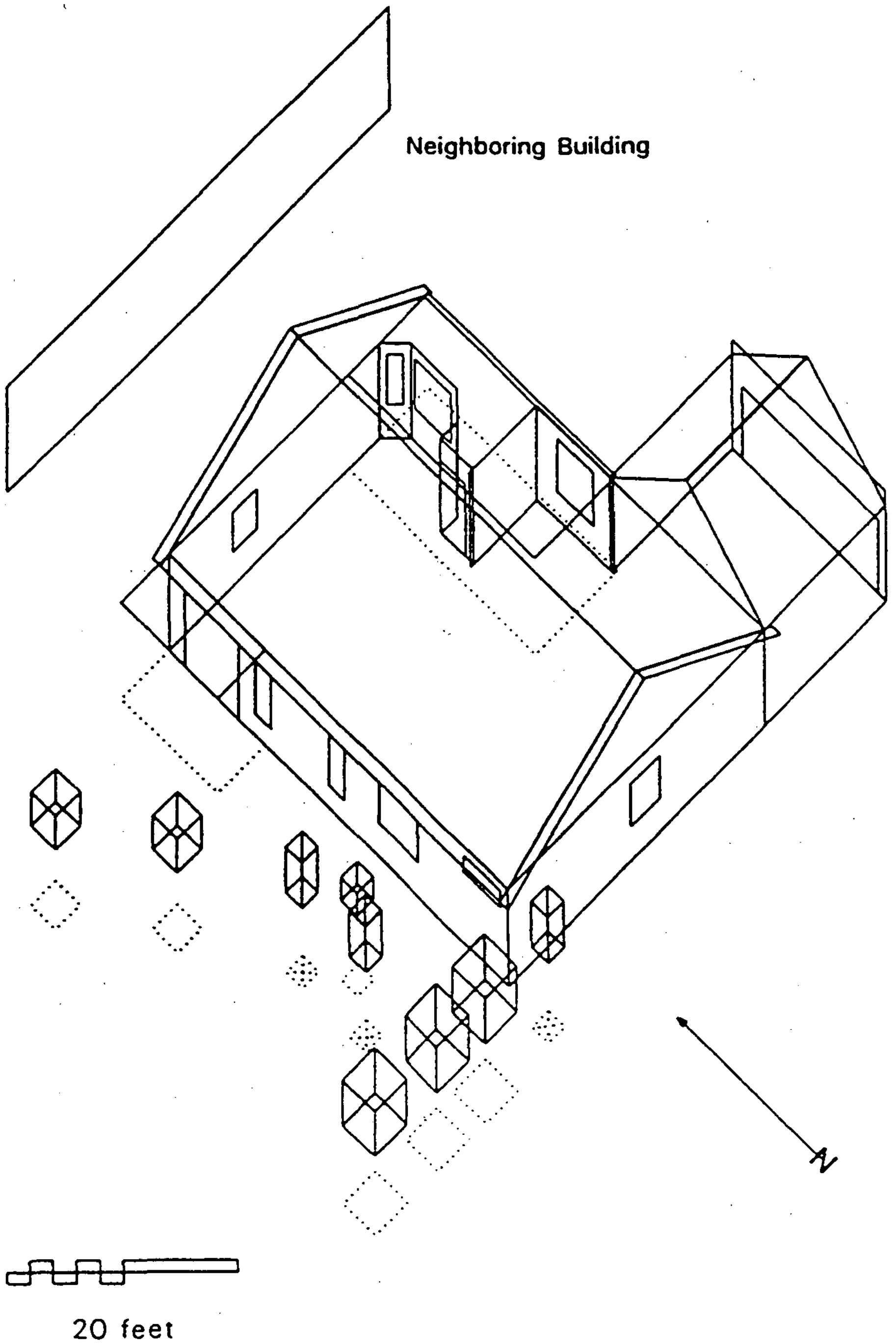


Figure V-1A House 6, tree case, viewed from the southwest: Boxes represent trees, boxes with x's represent trees added for the monitoring project. Neighboring buildings and trees are modeled as building shades in DOE-2. Dotted lines show the ground projection of building shades.

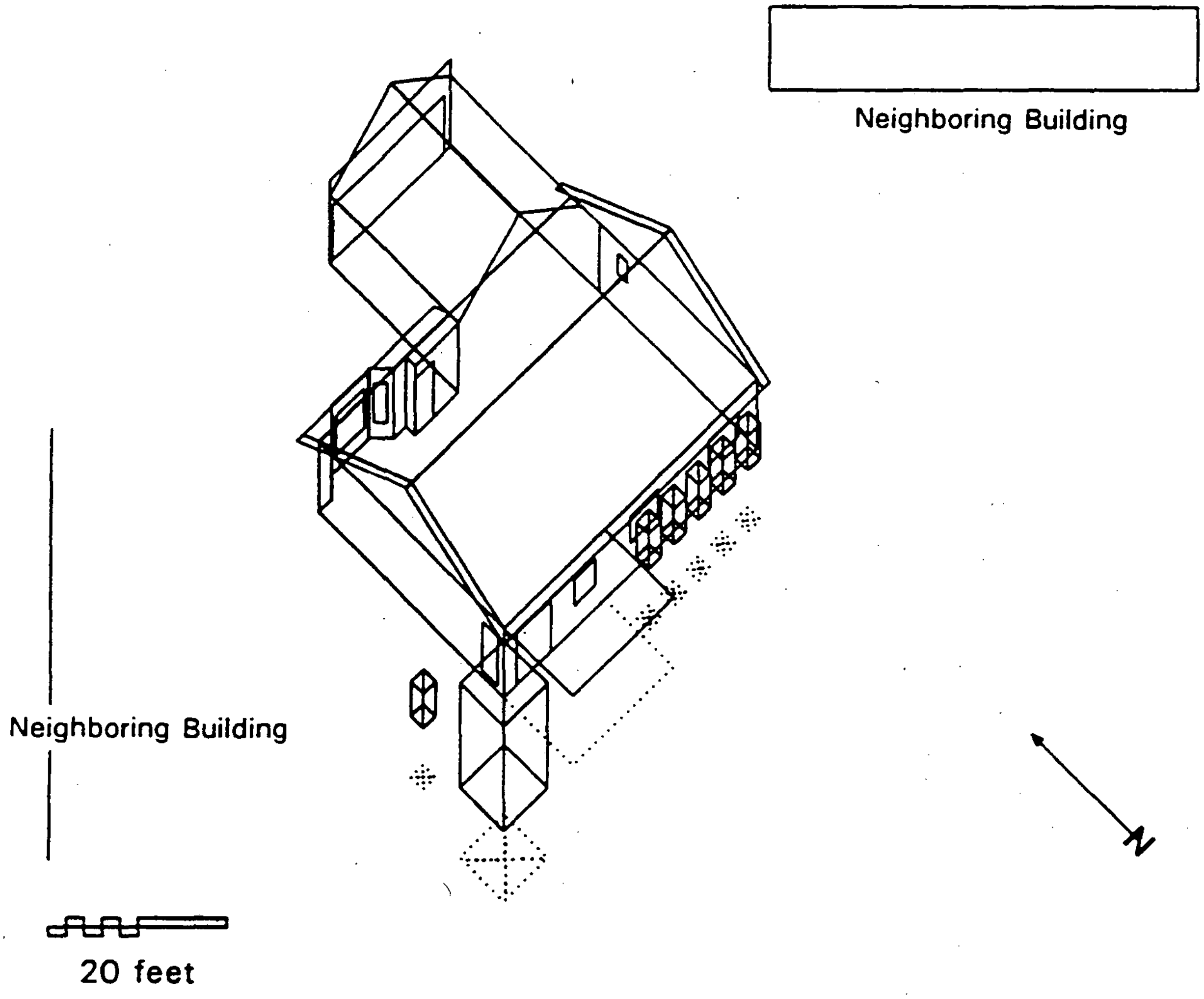


Figure V-1B House 8, tree case, viewed from the southwest: Boxes represent trees, boxes with x's represent trees added for the monitoring project. Neighboring buildings and trees are modeled as building shades in DOE-2. Dotted lines show the ground projection of building shades.

describe the unoccupied condition. The occupancy schedule was taken from previous California Energy Commission work (Muira, J. and Horn, M., 1980), and was also modified to describe the unoccupied condition. For the School, a simple 9 A.M. to 4 P.M. weekday schedule was used with a 1.5 watts/ft^2 lighting load and occupancy of 25 children.

Table V-1. Building Geometry and Internal Loads Used in the DOE-2 Simulations

	Cond. floor area (ft^2)	Cond. volume (ft^3)	Perimeter length (ft)	Exterior wall height (ft)	Internal wall area (ft^2)	Internal loads Sensible (Btu/day)	Internal loads Latent ratio*
Site 1	1122	10098	143	8	800	30000	0.22
Site 2	1701	15309	201	8	1436	31000	0.22
Site 5	1544	13896	192	8	1480	42000	0.20
Site 6	1291	11619	156	8.5	990	47000	0.20
Site 7	1165	10485	189	8.5	1000	66000	0.18
Site 8	1122	10098	143	8	800	47000	0.19
School †	960	9600	128	10	0	68000	0.40

* Latent load (Btu/day) = Sensible Load × Latent Ratio

† Lighting 1.5 watts/ft^2 plus 25 per students × 350 Btu/hr (ASHRAE 1989) from 9 am to 4 pm.

Thermal Integrity

The insulation characteristics of each house are based on information reported in the surveys, or, for the school bungalows, on the building's engineering drawings and specifications. The existing roof and wall albedos were estimated based on the material and color shown in the photographs taken by the LBL project team. In Sites 2 and B, the roof albedo was obtained from on-site measurements by the LBL staff. The window characteristics are also taken from the survey results, while an average effective-leakage-fraction of 0.0005 (leakage area/floor area), corresponding to an infiltration rate of around 0.5 air change/hour, was assumed for all buildings. **Table V-2** summarizes the conservation levels used in the DOE-2 simulations.

Table V-2. Building Conservation Levels and Base Case Surface Characteristics Assumed in the DOE-2 Simulations

	Roof/Ceiling			Wall			Infiltration (approx. ACH)	Num. of window panes
Site	R-value	Albedo	Color/ material	R-value	Albedo	Color/ material		
Site 1	19	0.40	tan shingles	11	0.30	tan stucco	0.5	2
Site 2	11	0.18	silver composition	7*	0.30	khaki wood	0.5	1
Site 5	30	0.16	med brown shingle	11	0.50	lt tan wood	0.5	2
Site 6	30	0.35	lt brown shingle	11	0.40	lt blue stucco	0.5	2
Site 7	19	0.16	med brown shingle	11	0.45	off-white stucco	0.5	2
Site 8	19	0.16	med brown shingle	11	0.30	tan stucco	0.5	2
School	19	0.34	dull white metal	11	0.30	tan wood	0.5	1

* Wall between house and garage is uninsulated.

HVAC System Characteristics

System types, capacities, and air flowrates are based on site reports, supplemented by cooling equipment product literature for some sites, and are listed in **Table V-3**. For air-conditioner efficiencies, Site 2 had the most complete and reliable data because it was a newer, high-efficiency unit. Sites 5 (with a heat pump), 6, and 7 had enough information to make reasonable estimates. No information was available for the heat pumps at Sites 1 and 8. The same cooling efficiency was used at these sites as at Site 5, the other heat pump site. The cooling efficiency at the school site is an estimate.

With the product data for sites 2 and 7, a comparison of cooling performance at part-load and at non-rated outdoor drybulb and indoor wetbulb conditions was made to assess the reliability of the DOE-2 cooling system default curves. The differences for these sites were considered not significant enough to develop specific equipment efficiency and capacity curves for each site. Heat pump heating efficiencies are taken from the product literature.

The thermostat settings were originally based on the experimental design control, calling for constant 78 °F (25.5 °C) setpoints in all houses and the school. However, schedules and setpoints were developed for each building to closely match the measured data. Those presented in Table V-3 are the final input values used. For Site 1, we developed a thermostat setpoint schedule to best mimic the measured interior temperature data. The thermostat in the school control building, once occupied, was frequently readjusted downward. For the final DOE-2 simulations, the thermostat was set at 70 °F (21.1 °C) to best match the metered data. Other observations relating to the thermostat operation are discussed later in this chapter. In addition, we modeled the buildings with windows closed. The occupants were asked to keep the windows closed at all times so that cooling provided by window venting would not be a factor in the results.

Supply fan wattages, while not directly measured and not included in the measured data except for at Site B, were estimated to have an air flow of 0.333 W/CFM for the house sites and 0.417 W/CFM (733 Watts) at Site B.

Distribution System Location and Efficiency

Initial comparisons between simulated and measured cooling energy consumption data showed that the simulation models were underpredicting peak cooling use by 100% or more. This suggested that there may be substantial inefficiencies in the cooling systems at most sites. This may be due to (1) air conditioner inefficiencies, or (2) duct system inefficiencies. Without adequate testing of all the HVAC equipment, we cannot definitively determine the source of this inefficiency, but previous work has shown there are significant losses in residential duct systems in California due to air leakage and conduction. Moreover, there is a large variation in the amount of duct leakage across different buildings (Modera et al., 1991, Proctor and Pernick, 1992).

Table V-3. System Characteristics Assumed in the DOE-2 Simulations

	Heat	Cool	Heating Equip			Cooling Equip			Air flow
	Temp.	Temp.		Cap.	Eff.		Cap.	Eff.	Rate
Site	(F)	(F)	Type	(Btu/hr)	(%/COP)	Type	(Btu/hr)	(COP)	(CFM)
House 1	68	78†	HP	21000	2.1	HP	24000	2.1	800
House 2	68	80	Furn	90000	70	A/C	40000	3.57	1060
House 5	70	78	HP	29000	2.1	HP	29000	2.1	1060
House 6	68	82	Furn	60000	70	A/C	38000	2.35	1200
House 7	68	78	Furn	47000	70	A/C	36000	2.77	1200
House 8	70	76	HP	21000	2.1	HP	24000	2.1	800
School	68	78•	HP	50000	2.7	HP	34600	2.7	1760

Note: Heating setbacks were used at Site 2 and the School.

† Schedule used, with cooling enabled at 3 p.m.

• School control building modeled with 70°F thermostat setpoint.

In cooling mode, supply ducts leak conditioned air and conduct heat from the zones they pass through, while return ducts pick up unconditioned air from these zones. Thus, the location of the duct system is also important in determining the efficiency of the system. At all houses except for Site 2, the supply and return duct systems are located in the attic. At Site 2, the supply ducts are in the crawlspace while the return is located fully within the conditioned space, since the air handler and coils are in an interior closet. In fact, in this building there are virtually no return ducts. Thus, it is not surprising that early simulations of the buildings showed a substantial under-prediction of measured cooling energy use at all sites except for Site 2. The duct locations are summarized in **Table V-4.**

Based on measured data and simulations performed by Modera et al. (1991), a simple duct efficiency model was incorporated into the DOE-2 simulations. Results from a series of detailed building and duct system simulations performed on typical houses with attic supply and return

Table V-4. Ceiling and Foundation Construction and Duct Locations for House Sites in the SMUD Project

Site	Year Built	Ceiling Construction	Foundation Construction	Supply Duct	Return Duct	Duct Insulation*	Duct Condition*
Site 1	1984	Attic and Vaulted	Slab	Attic	Attic and Garage		
Site 2	1963	Low-Pitch Vaulted	Crawl	Crawl	Indoor Closet	Yes	Good
Site 5	1987	Attic	Slab	Attic	Attic and Garage	Yes	OK-flexduct
Site 6	1988	Attic and Vaulted	Slab	Attic	Attic and Garage		
Site 7	1982	Attic	Slab	Attic	Attic and Garage		
Site 8	1984	Attic and Vaulted	Slab	Attic	Attic and Garage		
Site B	1989	Dropped Ceiling	Crawl	Dropped Ceiling	None		

* From previous house audits by Modera et al. 1991.

ducts were used to correlate duct efficiencies with (1) outdoor drybulb temperatures, (2) attic temperatures, and (3) solar gain. The fit of the efficiency data to attic temperature was good. Two different duct conditions were modeled; one for *typical* California duct systems and one for *improved* ducts with one-half the leakage of typical ducts. The ducts in both cases are insulated with R-4 duct insulation.

We have complete data on the duct systems for Sites 2 and 5 from an earlier study (Modera et al., 1991). Both of these sites have ducts that are closer to the *typical* levels of leakage than the *improved* level. We have no data on the duct conditions in the other homes. Thus, we modeled all sites with the *typical* duct efficiency model except for Site 2 and Site B. At Site 2, the supply ducts are in a crawl space and there are essentially no return ducts, and we have not yet characterized the performance of this type of duct system. In addition, cooling performance of these ducts will not be as degraded, since there is no return duct and the supply ducts are in the crawlspace, which will not be as warm as the attic. At Site B, all of the ducts are in the conditioned space of the buildings. The duct efficiency regression lines are as follows:

New: duct.eff = 1.346 - 0.00656 × attic.temp ($R^2 = .84$)
Old: duct.eff = 1.379 - 0.00766 × attic.temp ($R^2 = .85$)

In the DOE-2 model, the efficiency of the air conditioner is recalculated each hour based on the previous hour's attic temperature. In addition, the cooling capacity of the air-conditioning system is scaled downwards by the same duct efficiency value. While this is a great simplification of the complex interactions between the attic space conditions, the duct system, and the air-conditioner itself, it appears to capture most important effects of duct performance on air-conditioner electricity use reliably. However, we have found that under peak conditions, i.e. when the AC unit runs at peak capacity for the entire hour, this model becomes unstable, and cannot accurately predict peak cooling energy use.

Since the duct efficiency is calculated based on attic temperature, correctly modeling the attic becomes important for estimating both the heat flow into the conditioned space and the attic temperatures that the duct system sees. In initial simulations of the monitored buildings, we did not model the attic space. Instead, the attic was modeled as a simple R-value in the roof construction. There are several reasons for not modeling the attic as a zone in DOE-2.

1. Attics are typically gabled, while DOE-2 computes space temperatures based on an assumed rectangular space.
2. DOE-2 does not model the radiation exchange component of heat transfer, which may be a large effect in cooling mode where surfaces are typically quite warm.

3. Attic ventilation rates, which are important for determining attic temperature, are typically unknown and vary a great deal from house to house (Huang et al., 1987).

However, to accurately simulate the duct efficiency, we needed to know the attic temperature where the ducts are located. Thus, attics are modeled as unconditioned zones so that attic temperatures can be calculated. From the simulated duct efficiencies, it was also possible to correlate duct efficiency with outdoor temperature (as a proxy for attic temperature), but the regression R-squared is only about 0.50.

Since attic temperatures are extremely sensitive to the inputs used, primarily ventilation rates, we performed sensitivity analysis. Initial simulations with attic ventilation at 1 $ft^2/150\ ft^2$ produced lower than expected attic temperatures. Thus, attics are modeled with 1 $ft^2/450\ ft^2$ of ventilation area. Peak attic temperatures in August thus range from 109°F at Site 1 to 131°F at Site 7.

Given the importance of the duct system in the cooling energy use of a building, the impact of a high-albedo roof on cooling energy will be more than just for the change in conductive loads. With ducts in the attic space, the higher albedo roof will both reduce the cooling load on the conditioned space and increase the cooling system efficiency. However, in this study no attic duct buildings were included as albedo test cases. Site 2, the only albedo test site among the houses, does not have ducts in the attic. In fact, it has no attic. However, with the calibrated models for the other sites, we can estimate the effect of a high albedo roof on duct efficiencies and overall cooling energy use. These are discussed in the following chapter.

Climate Data

Data for August 1 through October 31, 1991, covering the period of monitoring, was obtained from the National Climatic Data Center (NCDC) in Asheville, NC. These data served as the primary climatic input for the DOE-2 simulations. These data were measured at the Sacramento Executive Airport and include hourly dry bulb and wet bulb temperatures, wind speed and direction, cloud cover, and cloud type. The last two items are used with a modified DOE-2 algorithm, based on Fresno solar and cloud cover data, to calculate the amount of solar gain.†

Ideally, the simulations would use data collected from each site as inputs. However, there were significant data gaps, making it difficult to construct complete microclimatic databases. In addition, the solar data collected was not readily transferable into the required DOE-2 input format. Thus, the Airport data was used for all sites except for Site 2, which will be discussed later in more detail. At Site 2, actual data for drybulb temperature, relative humidity (used together to calculate wet bulb temperatures) and windspeed were used as model inputs.

Normally, building simulations use climatic inputs from weather data describing "typical" conditions, such as TMY (Typical Meteorological Year) weather tapes. This project greatly benefited from using climate data taken from the actual period of monitoring at the Airport, a nearby location. A comparison of the NCDC Airport weather data for August through October with the TMY data illustrates the degree to which these three months were "typical." This comparison is shown in **Table V-5**. Compared to the TMY data, the monitored period was cooler (fewer cooling degree days and degree hours) in August, but warmer in September and October. In addition, the monitored period had less solar radiation than the TMY data in August, but in September and October, had more direct normal solar radiation but less total horizontal solar.

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† The algorithm was supplied by Fred Buhl, Building Technologies Program, Lawrence Berkeley Laboratory.

Table V-5. Comparison of 1991 Airport Weather Data with Sacramento TMY

	Sacramento TMY			1991 NCDC Airport Data		
	Aug	Sep	Oct	Aug	Sep	Oct
Daily Averages (°F)						
Dry Bulb	73	70	63	71	72	67
Wet Bulb	61	59	55	61	60	55
Maximum	101	100	94	89	92	85
Minimum	53	49	41	58	57	53
Wind(mph)	9.0	7.7	6.6	9.3	6.6	6.7
Degree Days (base 65°F)						
Heating	5	5	86	1	1	83
Cooling	324	207	72	249	289	204
Cooling Degree Hours/24 (base75°F)						
	144	78	26	105	134	91
Average Daily Solar (Btu/ft^2)						
Dir. Normal	2694	2311	1745	2358	2423	1917
Tot. Horiz.	2391	1928	1297	2091	1791	1239

Site model calibration overview

To calibrate the models for each building, we compared model outputs for cooling compressor energy consumption and interior temperatures to corresponding measured data at the hourly level. At most monitoring sites, the measured data had significant gaps, which precluded the possibility of comparing the models with the measured data over long-term periods. On the other hand, the DOE-2 model works on an hourly time-step. Thus, comparisons with the measured data at its original 10-minute time step were difficult. Based on the limitations of the data and the model, we chose one week of continuous hourly data from the pre- and post-modification data sets to compare with corresponding simulation results. At Site 5, there was no complete week of measured data in the pre-period, so we compare the results for a five-day period. At the school site (B), we compare simulated and measured data for the test building and for the control building, but over the same time period, when the school was occupied.

Initially, the comparisons were made for cooling compressor energy consumption and outdoor temperature. These comparisons also identified sites with significantly different ambient temperature regimes than the NCDC airport site and suggested that the simulations for Site 2 would be greatly improved by using the actual weather data collected for that site. A summary of the differences in outdoor temperatures between all sites is presented at the end of this chapter.

Indoor temperature data gave clues to occupant behavior and thermostat management that helped explain some of the differences between simulated and measured cooling data. The calibration results presented here show simulated and measured data for interior temperature and cooling compressor energy use. It should be noted that the DOE-2 model treats the building (not including the garage) as one zone; that is, the entire indoor space is conditioned to the same temperature. Indoor temperature was measured at a single point in each building, typically a bedroom or living room. While this single point may not be representative of the whole house or the thermal conditions at the thermostat, it gives us some indication as to how the house is cooled.

The project participants were asked to keep their thermostats consistently set at 78 °F (25.5 °C), a setting that was also used in the simulations. The graphics that follow, however, suggest that on some days the thermostats were reset, while at some sites the thermostat may be functioning incorrectly. The simulated indoor temperature is consistent and smooth, whereas the data suggest this was not necessarily true in all rooms of the houses studied. It must also be noted that the primary method of determining the impact of the modifications on these buildings is the change in cooling energy use.

D. Measured Energy Savings Results and Comparison with Simulations

In this section, we discuss the analysis of measured and simulated data from all seven sites monitored in Sacramento, CA, between August and October 1991. The results are presented on a site-by-site basis and some analysis for all sites collectively is also given.

The measured data are discussed in terms of environmental, microclimate, indoor, and outdoor monitored conditions, as appropriate. In addition, cooling electricity use is discussed to quantify the impacts of albedo and vegetation modifications.

In each site, the cooling electricity use is examined as a function of outdoor temperature (means and maxima), indoor temperatures, indoor/outdoor temperature differences, and solar radiation, as appropriate to each particular case. The analysis is carried out for pre-retrofit (basecase) and post-retrofit (albedo or vegetation modifications) conditions. The results are presented at both daily and hourly time scales. A discussion of solar radiation and its change over time (during the monitoring period) is also given. This is to account for the lower solar heating of the building envelopes during the latter parts of the monitoring period. Finally, hourly time-series of cooling electricity usage are also shown when comparisons with simulated results are performed.

In this study, we used Julian dates to keep track of measured data. In **Table V-6**, Julian days are tabulated with their corresponding 1991 calendar dates for quick reference.

Table V-6. 1991 Julian Days / Dates Within the Field Measurements' Time Frame

Calendar day	JD	Calendar day	JD	Calendar day	JD
08-01-91	213	09-01-91	244	10-01-91	274
08-05-91	217	09-05-91	248	10-05-91	278
08-10-91	222	09-10-91	253	10-10-91	283
08-15-91	227	09-15-91	258	10-15-91	288
08-20-91	232	09-20-91	263	10-20-91	293
08-25-91	237	09-25-91	268		
08-30-91	242	09-30-91	273		

We discuss energy or electricity use in terms of condenser electricity consumption, i.e., air-handler fan energy use in split systems is not accounted for. About 0.2 to 0.3 kW should be added to the results to account for that component. This applies to all residential sites we monitored. In the school bungalows, cooling was achieved with heat pumps and the reported electricity use is that of the entire packaged unit.

Following the presentation of the measured data for each site, we present the comparisons of simulated and measured hourly cooling energy use and indoor temperature using the final model inputs. These show the degree to which the models correctly predict the actual conditions on an hourly basis at each site. On each figure, we also show the measured and predicted average daily energy use for the days during the period where cooling energy use is consistent.

Finally, the use of simulation models to estimate energy savings from the vegetation and albedo modifications is presented. Simulated daily cooling energy estimates are plotted against daily maximum outdoor temperatures. On each graph are three sets of data. One set reproduces the measured data from the base case period; that is, the base case building over the time period of measurement in the base condition. In some cases more data points may appear in the simulation results because of missing measured data between the start and stop days. Likewise, a second data set reproduces the measured data from the modified condition over the period of measurement in the modified condition. The third data set is the model estimates for the modified case (high albedo or trees) simulated during the base case period condition. This adjusts for differences in climate not accounted for by the kWh versus temperature relationship, primarily solar insolation. Each set of data is described by a simple linear regression line drawn through the points. The difference between the lines drawn through the modified case/base period set and the base case/base period set represent the actual savings from the modifications as predicted by the simulation models.

Control site (Site 1)

Site 1 was instrumented and monitored as a control site where no albedo or vegetation modifications were performed. Data from this site were available for 60 days [Julian day (JD) 235 through JD 294], but there were 18 days of missing data (JD 240 - 247, 263 - 266, and 269 - 274). The data from this site were used to get reference weather and energy use sets when needed.

Site 1 was located far northeast of Sacramento and was in a relatively newer area. Neighborhood vegetation was medium to low and the site vegetation was low except that the walls were lined with shrubs. **Figure V-2A** shows daily data from this site, where cooling electricity use in kWh/day is plotted against the maximum daily temperature (°C) at Site 1. One can see that mechanical cooling started after the outdoor maximum temperature went over 30°C. A linear regression line was fitted to the data to show the general trend in cooling energy use as a function of daily maximum temperature. The slope of this line is about 1.2 kWh/day per °C of maximum daily temperature. This means that the cooling electricity use at Site 1 could be decreased by ~6 kWh/day if the maximum outside air temperature were decreased by ~5°C. Based on computer simulations of microclimates, a reduction of this magnitude in maximum daytime heat island appears to be feasible [Taha et al., 1991, Taha et al., 1992].

In terms of hourly data, **Figure V-2B** describes the conditions at Site 1. In this figure, the cooling energy use in Wh h^{-1} is plotted versus mean hourly outdoor air temperature (°C). Recall that outdoor air temperature was read every 10 minutes and in this figure, we present the mean of 6 readings per hour.[1] The data in Figure V-2B indicate that there was cooling energy use within the outdoor temperature range of 17-40°C. We should be cautious when interpreting the data at the lower end of the range (temperatures 17-23°C) as some of that energy may be heating energy use (since Site 1 had a heat pump unit).

In **Figure V-2C**, the same energy use data are plotted against the hourly outdoor-indoor temperature difference (To-Ti). The sloping of the scatter is obvious and indicates that there was need for cooling when the outdoor temperature was in the range of -7 to 12°K higher than the indoor temperature.

The comparison of hourly measured and simulated data for Site 1 are presented in **Figures V-2D** and **VI-2E**. The measured interior temperature data shows a distinct morning peak followed by a more thermostatically controlled period, as if a threshold temperature must be reached before the cooling system is activated. This produces a delayed spike in cooling energy use. We mimic this observed behavior by adding a thermostat setpoint schedule that allows cooling starting at 3 P.M. However, the simulated indoor temperature is consistently lower in the morning and the peak cooling load is not well matched in the pre-period. The measured

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[1] A similar procedure was applied to indoor air temperature, temperature differences, and relative humidity.

interior temperature data also suggests that the building cools down at night slower than the simulated building.

In general, however, the daily cooling electricity totals match well over the period for which there exists consistent data. The lack of cooling energy use on days 280 and 281 suggests that cooling may have been turned off on those days.

Daily kWh from the simulation model is plotted against the peak outdoor temperature in **Figure V-2F.** The regression line through the points meets the 0 kWh axis at 29 °C in the measured data and 27 °C in the simulated data. At 40 °C daily maximum temperature, the measured data regression line gives 13 kWh/day while the line for the simulated data gives 14 kWh/day.

Figure V-2A. Site 1: Daily cooling electricity use (kWh/day) vs daily maximum outdoor air temperature (°C). The monitoring period at this site was August 23 through October 21, 1991, and there were no albedo or vegetation modifications at this control site.

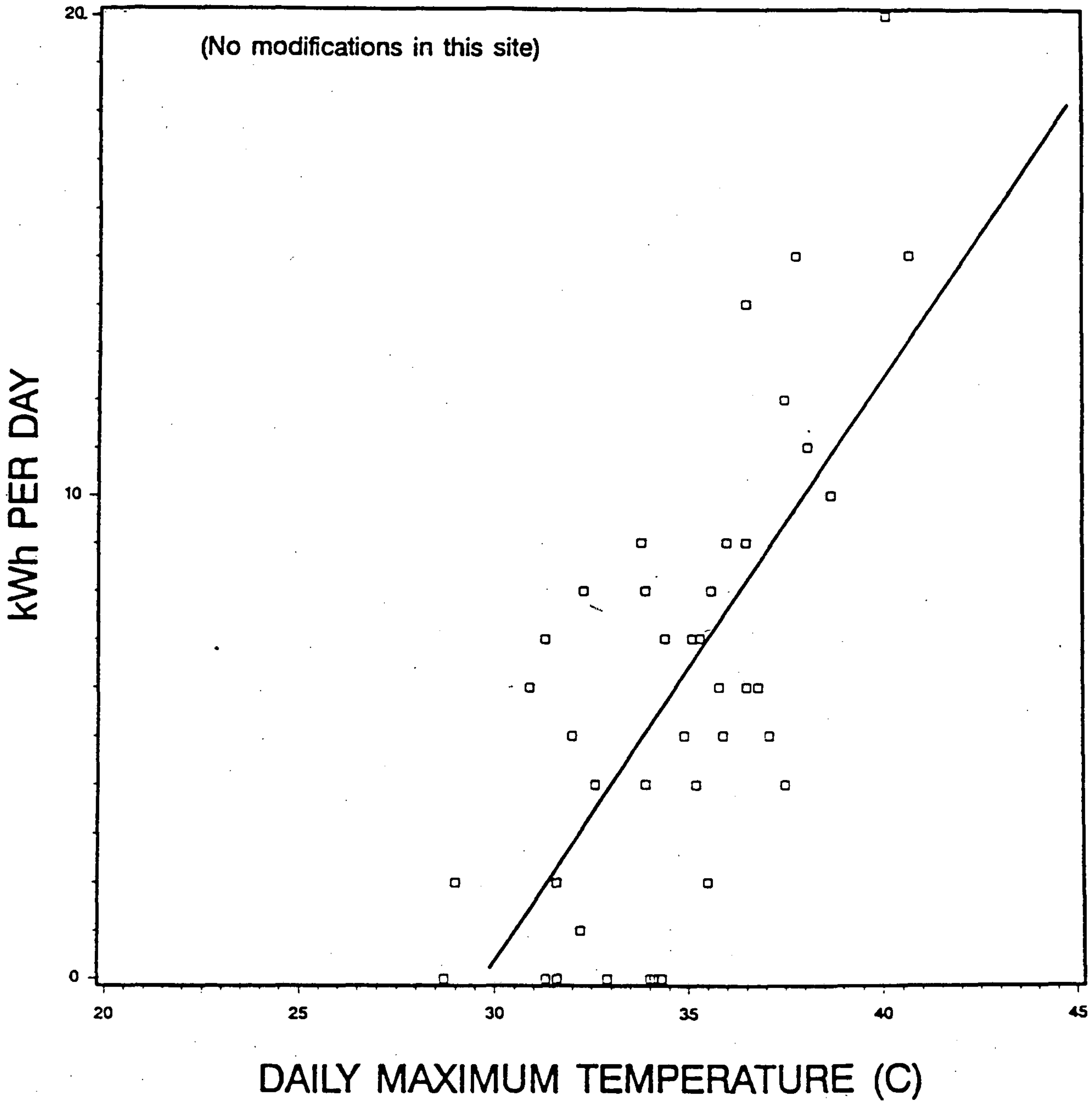


Figure V-2B. Site 1: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor air temperature (°C). The monitoring period at this site was August 23 through October 21, 1991, and there were no albedo or vegetation modifications at this control site.

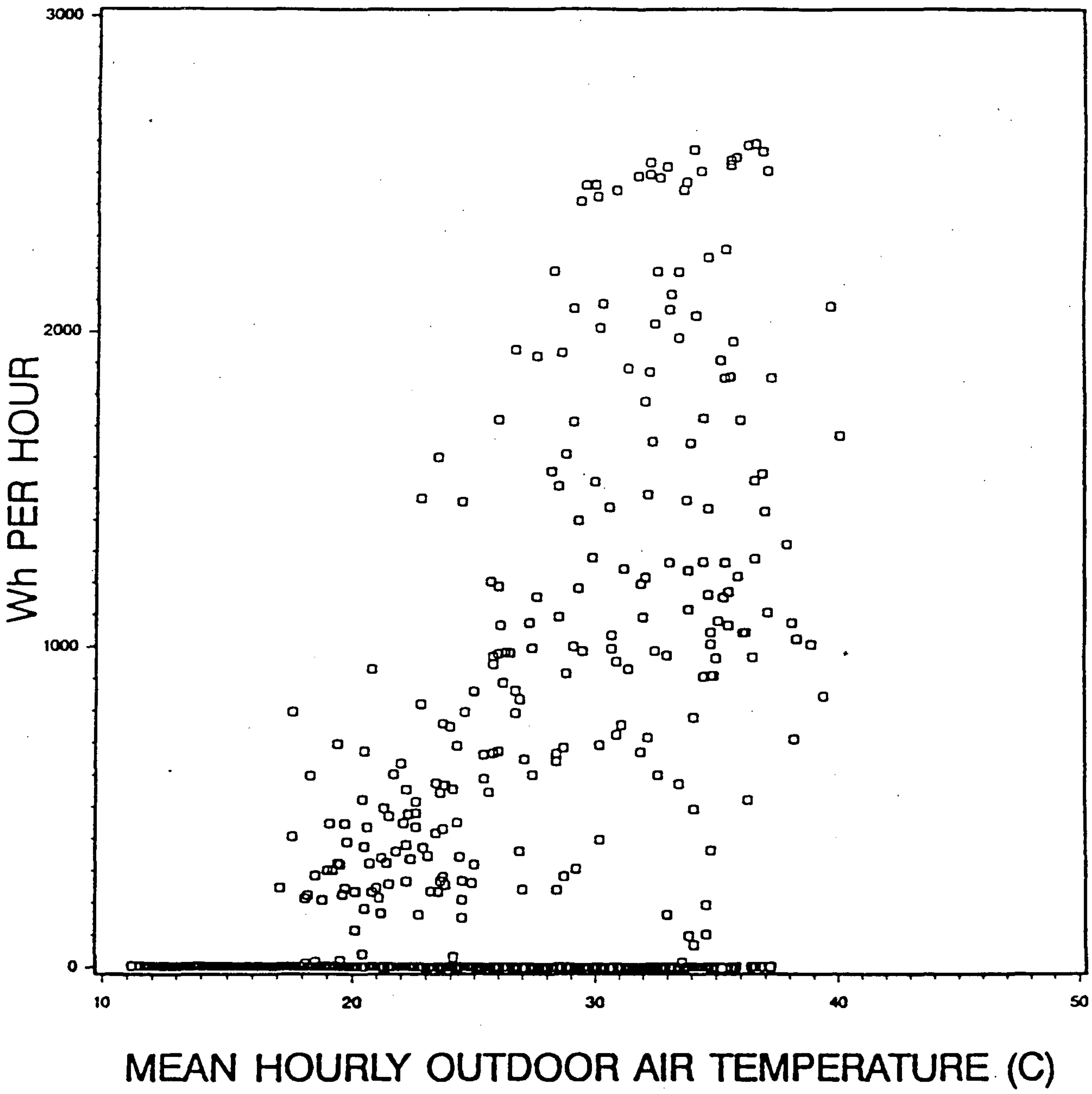


Figure V-2C. Site 1: Hourly cooling electricity use (Wh/h) vs hourly difference between outdoor and indoor air temperatures (°C). The monitoring period at this site was August 23 through October 21, 1991, and there were no albedo or vegetation modifications at this control site.

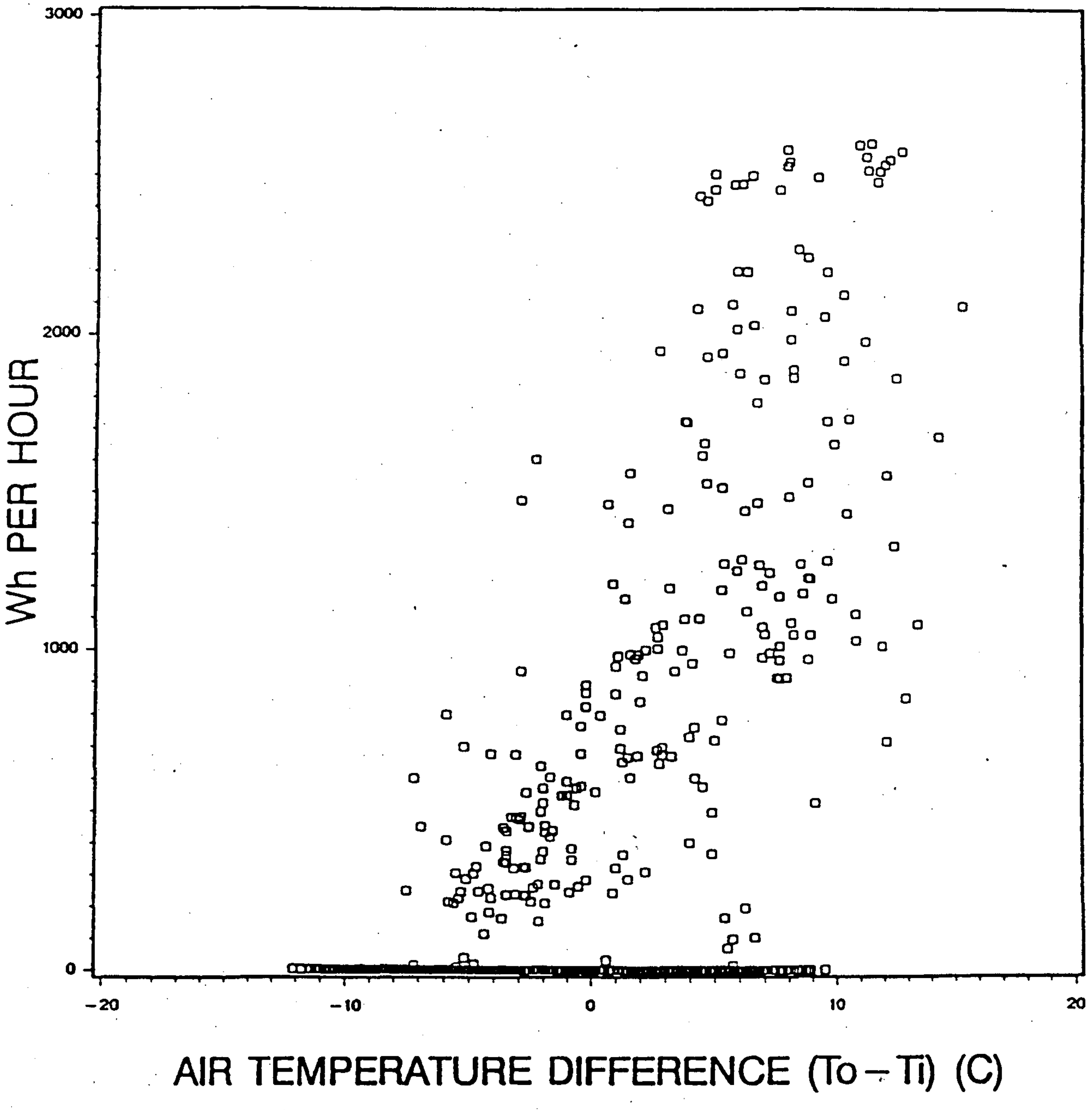


Figure V-2D. Compressor watt hours and building interior temperature for 9/13 to 9/19 at Site 1. Comparison of measured and simulated data during late summer.

Days 258 to 260 Measured: 10.0 kWh/day DOE-2: 10.7 kWh/day.

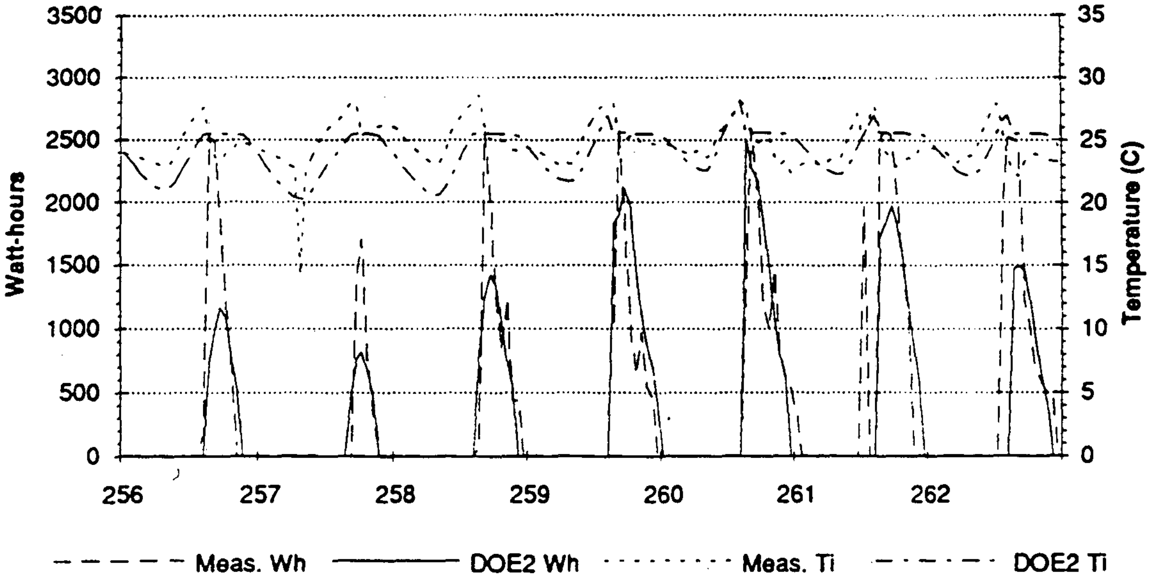


Figure V-2E. Compressor watt hours and building interior temperature for 10/7 to 10/13 at Site 1. Comparison of measured and simulated data during late summer.

Days 284 to 286 Measured: 7.4 kWh/day DOE-2: 7.7 kWh/day.

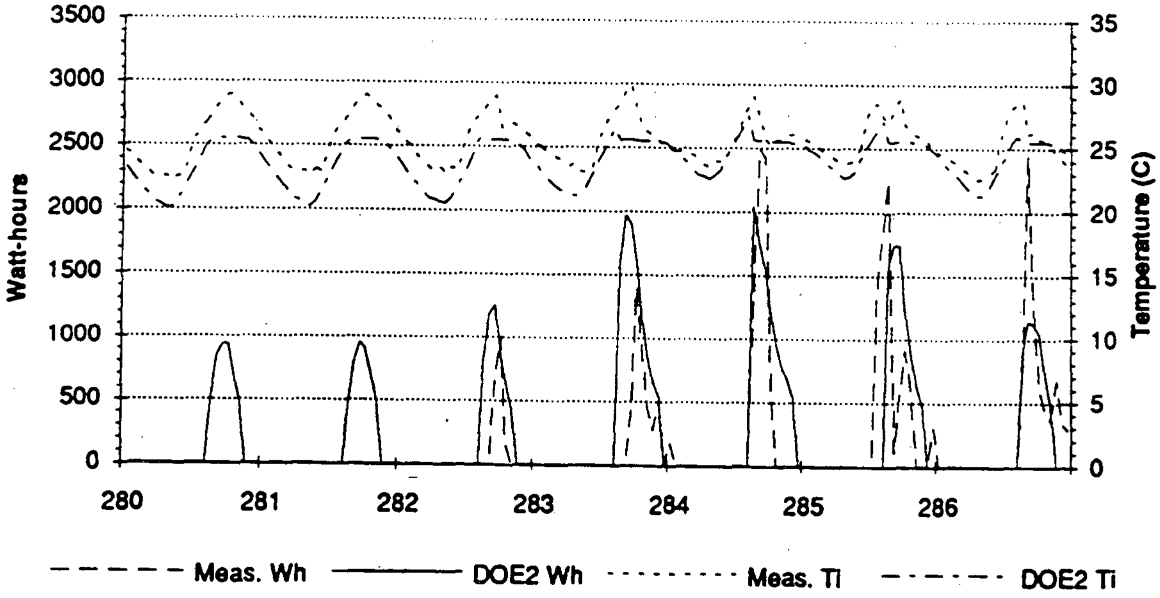
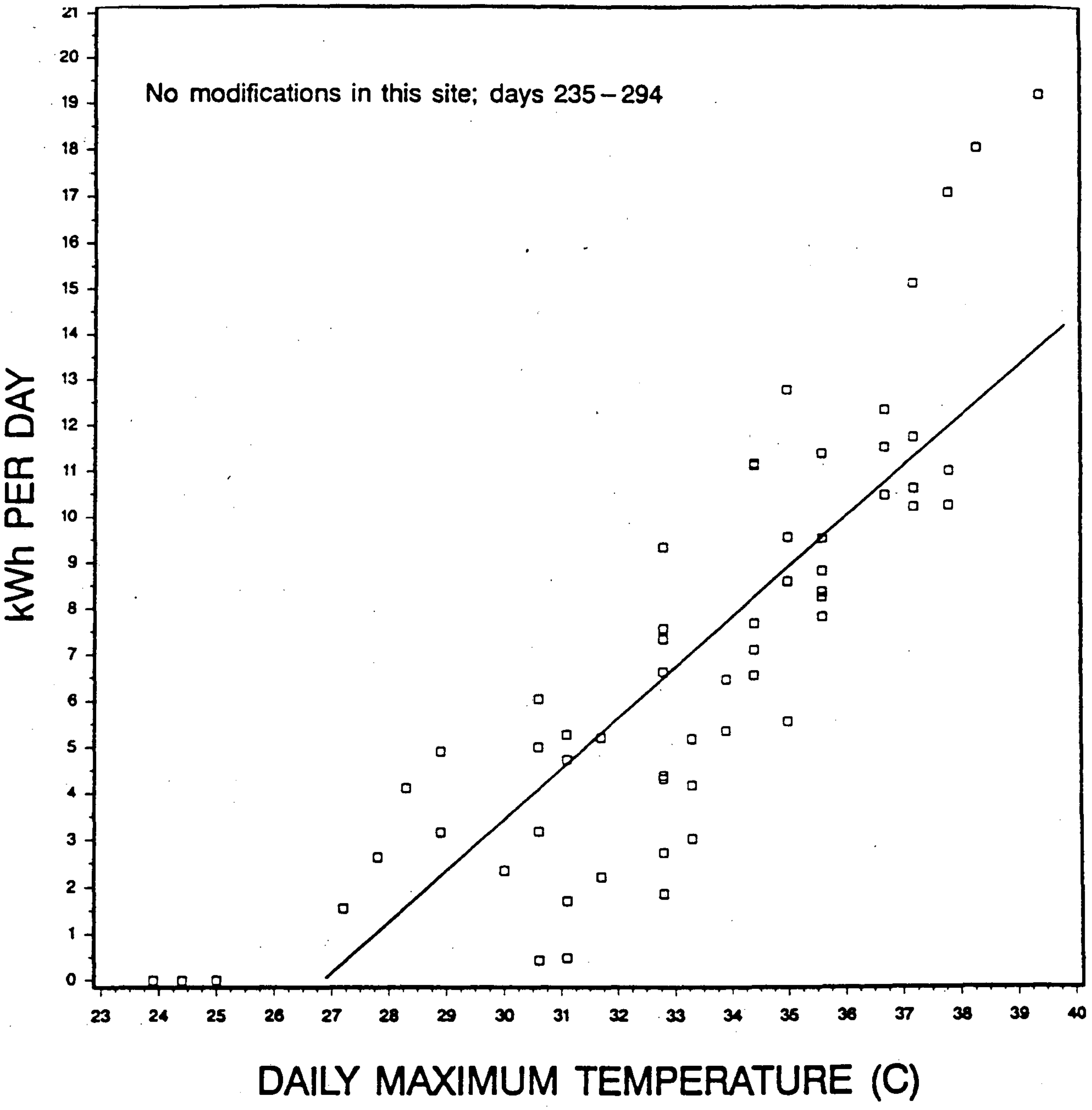


Figure V-2F. Site 1: Simulation Results Daily data for period of monitoring. No modifications in this site; days 235-294.



Albedo Modification Sites

Site 2

Site 2 was monitored to examine the effects of a roof's albedo modifications on cooling energy use. Twenty days of data for pre-modification conditions (JD 234 - 253) and 35 days of data for post-modification conditions (JD 259 - 293) were available for this site. There were missing data for 4 days in the "pre" period and one day in the "post" period.

Site 2 was located in a heavily vegetated area of Carmichael (northeast of Sacramento) and both neighborhood and site vegetation were high. Since the major path for heat gain into this house was the roof, coating it with a high-albedo coating was perhaps the most significant modification that could affect its energy performance.

Figure V-3A shows daily data from this site. Cooling electricity use in kWh/day is plotted against the maximum daily temperature (°C) at Site 2. The squares represent daily cooling energy use for the case with a dark roof (albedo = 0.18), whereas the triangles represent the energy use for the case with a whitened roof (albedo = 0.77). In effect, increasing the albedo of the roof canceled all the cooling energy use in that building. The reason why there appears to be cooling energy use even after whitening the roof (shown with arrows) is that the thermostat setting was lowered from 25.5°C down to ~23.5°C in a few post-retrofit days. The downward-pointing arrows suggest that these points should actually be lying on the x-axis. But practically speaking, the cooling load disappeared after the application of a high-albedo coating on the roof (to a maximum outdoor air temperature of 34°C). However, these results may overestimate the savings since they were obtained in late summer when ambient temperature and solar gains are lower, i.e., higher maximum daily temperatures for pre-retrofit period were not observed during the post-retrofit period.

In Figure V-3A, a linear regression fit is also shown. The solid line corresponds to the dark roof situation, and has a slope of 0.86 kWh/day per °C of maximum air temperature. The owner of this house reported that heat gain through the garage wall was significantly reduced after the roof was coated white, and that had a large impact on cooling needs in the building.

It is also worth noting that solar intensity was generally lower during the "post" period, as shown in **Figure V-3B**. In this figure, we can see that across a period of 45 days, the daily total solar radiation received at Site 2 decreased from 7.2 kWh/day to 4 kWh/day (squares correspond to the "pre" interval, whereas diamonds correspond to the "post" interval). How much of an effect this decrease had on the reduction in cooling energy use cannot be determined

Figure V-3A. Site 2: Daily cooling electricity use (kWh/day) vs daily maximum outdoor air temperature (°C) for pre- and post-retrofit periods. Pre-retrofit monitoring period at this site was August 22 through September 11 and the post-retrofit period was September 16 through October 21, 1991. Pre-retrofit albedo = 0.18, post retrofit albedo = 0.77. The arrows indicate points that would have otherwise been on the zero energy use line were it not for the thermostat resetting from 78°F down to 74°F. Line is a regression fit through the pre-retrofit data points.

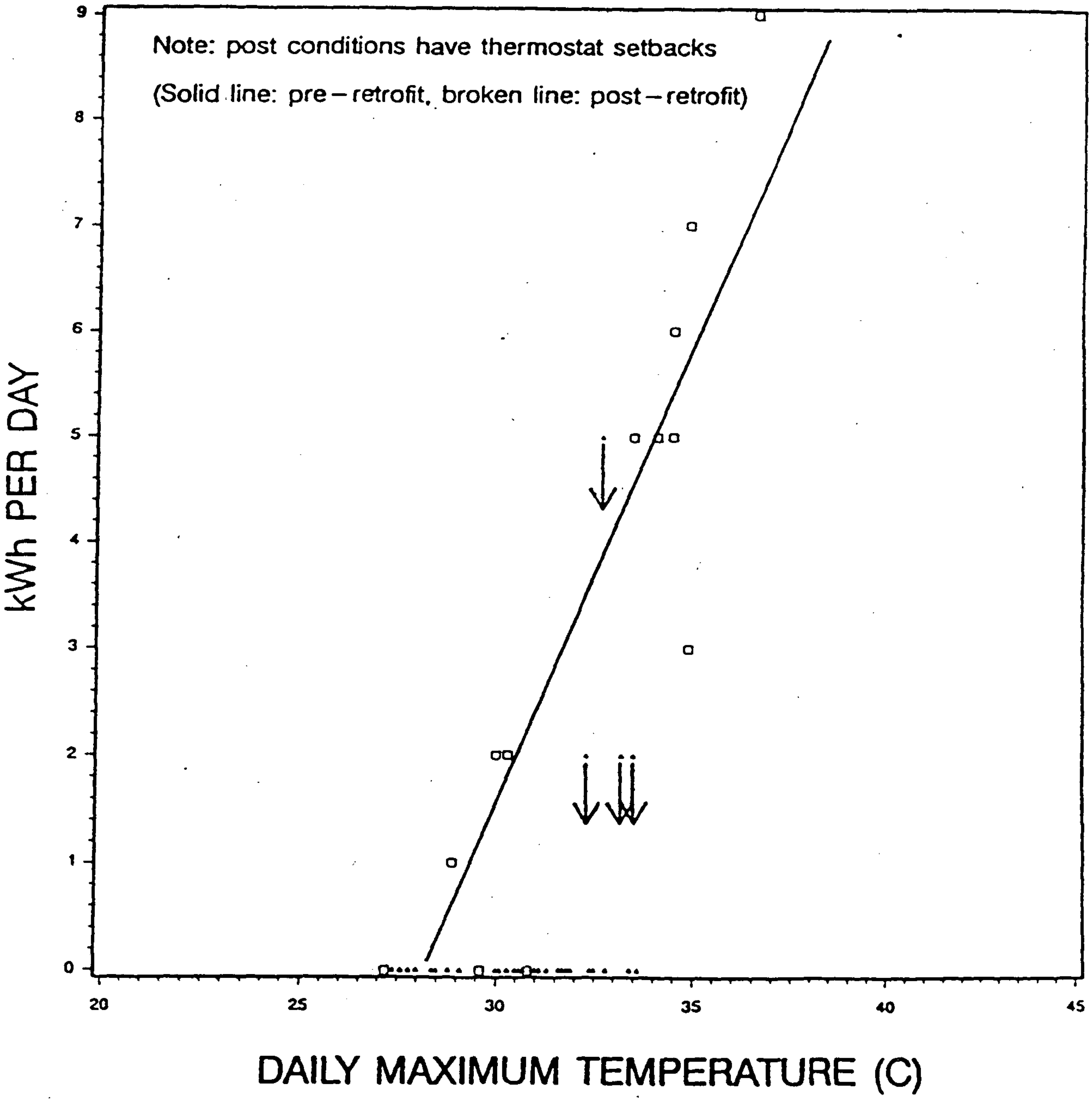
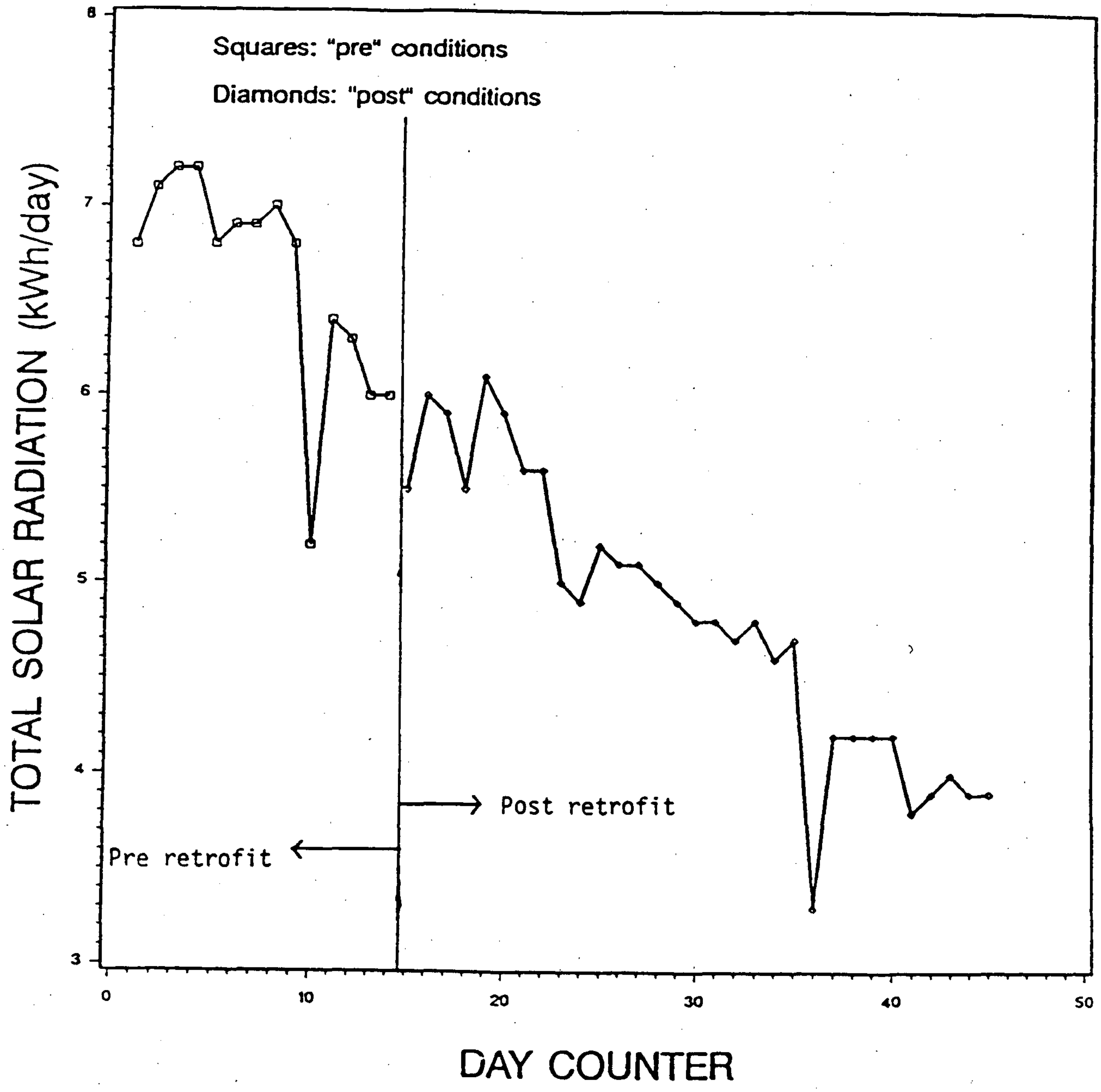


Figure V-3B. Site 2: Variation in total daily horizontal solar radiation (kWh/day) over 45 days of monitoring. The left portion of the graph represents solar radiation during the pre-retrofit period whereas the right portion represents radiation during the post-retrofit period. Pre-retrofit monitoring period at this site was August 22 through September 11 and the post-retrofit period was September 16 through October 21, 1991.



from measured data alone because most of the points corresponding to the "post" period lie on the x-axis (see the triangle symbols in Figure V-3A). DOE-2.1D simulations of this site were performed for corresponding periods and appear to indicate that about 20% of the measured savings may be caused by the effect of lower insolation during the post-monitoring period.

In **Figure** V-3C, hourly data are shown, where cooling energy use in Wh h^{-1} is plotted versus the mean hourly outdoor air temperature (°C) at Site 2. The solid line is a fit to "pre" conditions and the broken line is a fit to "post" conditions. The large amount of energy savings is clear. In **Figure V-3D**, the same energy use data are plotted against the hourly outdoor-indoor temperature difference (To-Ti). The sloping of the scatter is now more obvious, and indicates that there was need for cooling when the outdoor temperature was in the range of 0-9°C higher than the indoor temperature. Because of thermostat reset during the "post" period, we did not perform regressions to estimate savings (as we did with the daily data), as savings could reach 100% were it not for the setpoint lowering. As in the case with daily data, correction for solar intensity is necessary at the hourly level, too (~20% of measured savings are not caused by albedo modifications).

Analysis of the 20-minute data reveals some other aspects of the impact of albedo modification. In **Figures V-3E** and **V-3F**, for instance, the roof surface temperature is plotted versus solar radiation for the cases before and after modification, respectively *(note that the surface temperature data are questionable)*. Each is fitted with a regression line, and from these we can see that the surface temperature of the roof is lower in the high-albedo case. The regression lines indicate that the surface temperature at high albedo was about 5°C lower in the afternoon than the one with the low albedo. Recall, however, that this depression underestimates the the impact of the albedo on surface temperature, because of the improper contact of the thermocouple with the surface. That is, the decrease in surface temperature should be larger than reported here, but short of reliable surface temperature data, we cannot find the actual temperature of the roof. Note that this problem does not exist in the cases where roofs are made of shingles, because the thermocouple is fully embedded in the material. But with this roof, which is flat and solid, the thermocouple cannot be embedded. In the second year of monitoring, we will attempt to correct this problem. We will analyze surface temperature data once more reliable data are collected.

The hourly comparisons of simulated and measured data for Site 2 are presented in **Figures V-3G** and **V-3H**. The thermostat operates as expected at this site, and the simulated interior

Figure V-3C Site 2: Hourly cooling electricity use (Wh/h) vs mean outdoor temperature (°C) for pre- and post retrofit conditions. Pre-retrofit albedo = 0.18, post-retrofit albedo = 0.77. The solid line represents the low albedo case (pre-retrofit). Pre-retrofit monitoring period at this site was August 22 through September 11 and the post-retrofit period was September 16 through October 21, 1991.

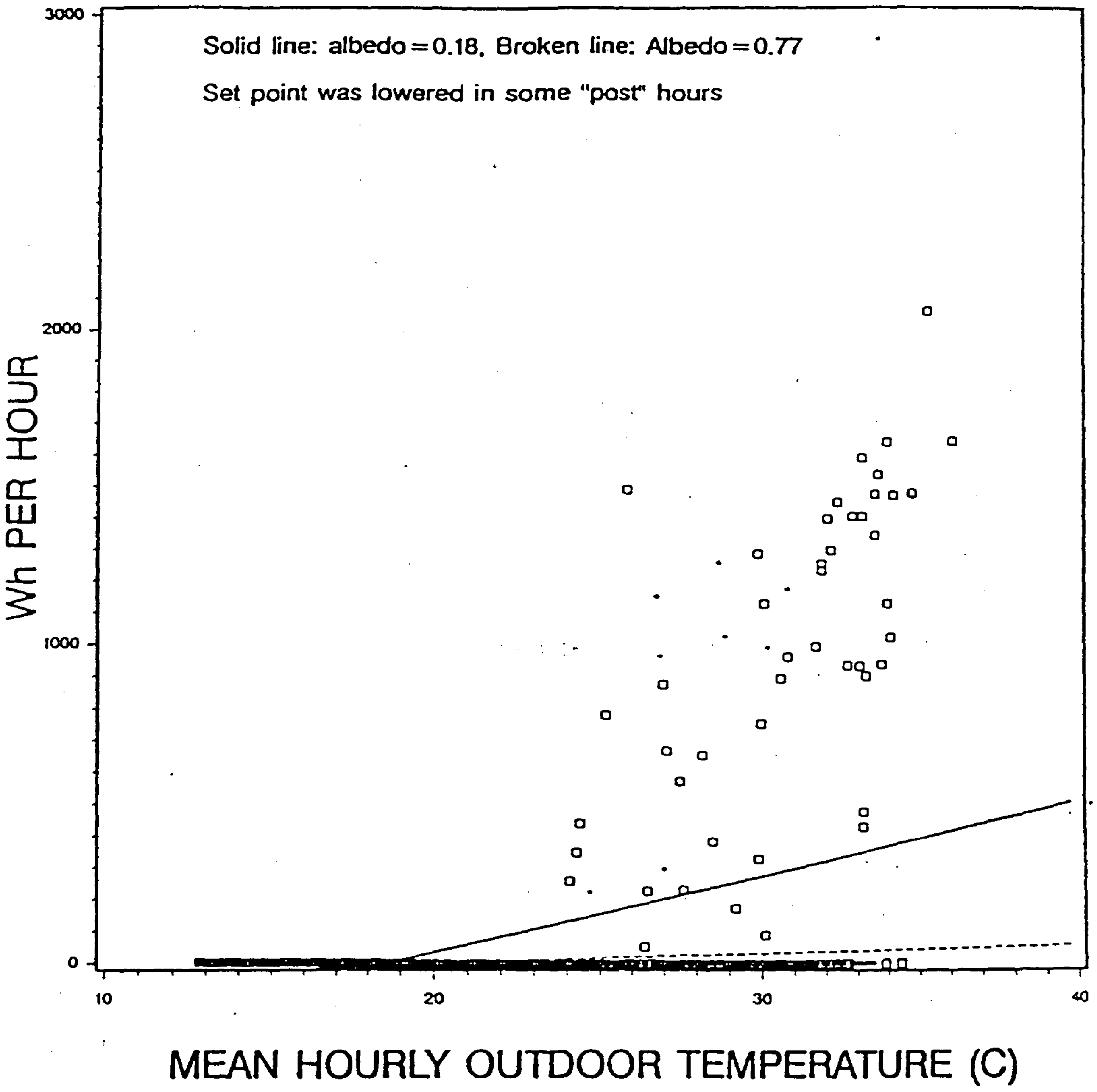


Figure V-3D. Site 2: Hourly cooling electricity use (Wh/h) vs difference between outdoor and indoor temperatures (°C). Squares represent low-albedo case and diamonds represent the high-albedo case. Pre-retrofit monitoring period at this site was August 22 through September 11 and the post-retrofit period was September 16 through October 21, 1991.

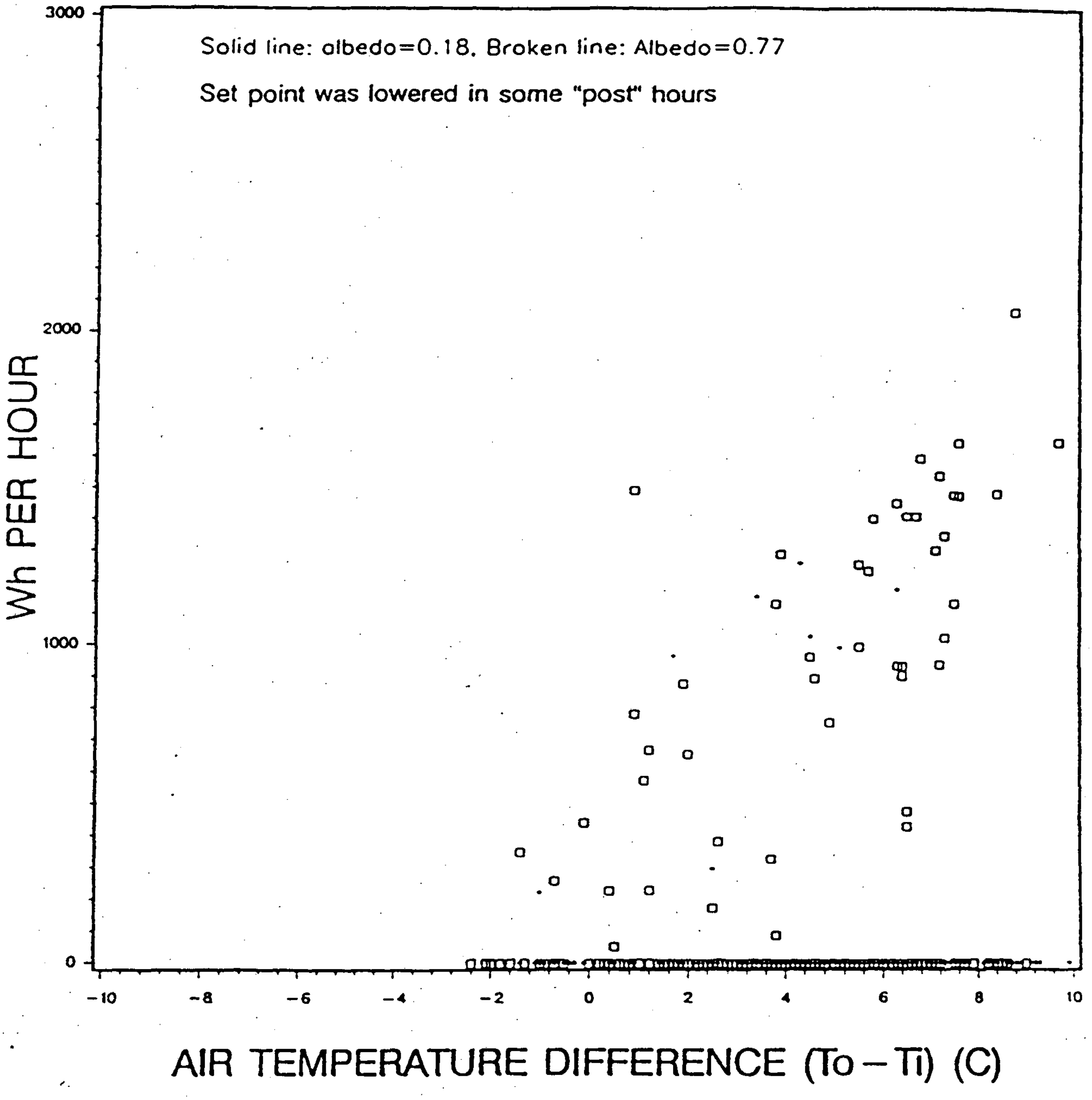


Figure V-3E. Site 2: Roof surface temperature (°C) vs solar radiation (W/m^2) at 20 minute intervals for the low-albedo case. Line is a regression fit. Note that the data seem questionable; the thermocouple reading may be influenced by solar radiation and ambient air temperature.

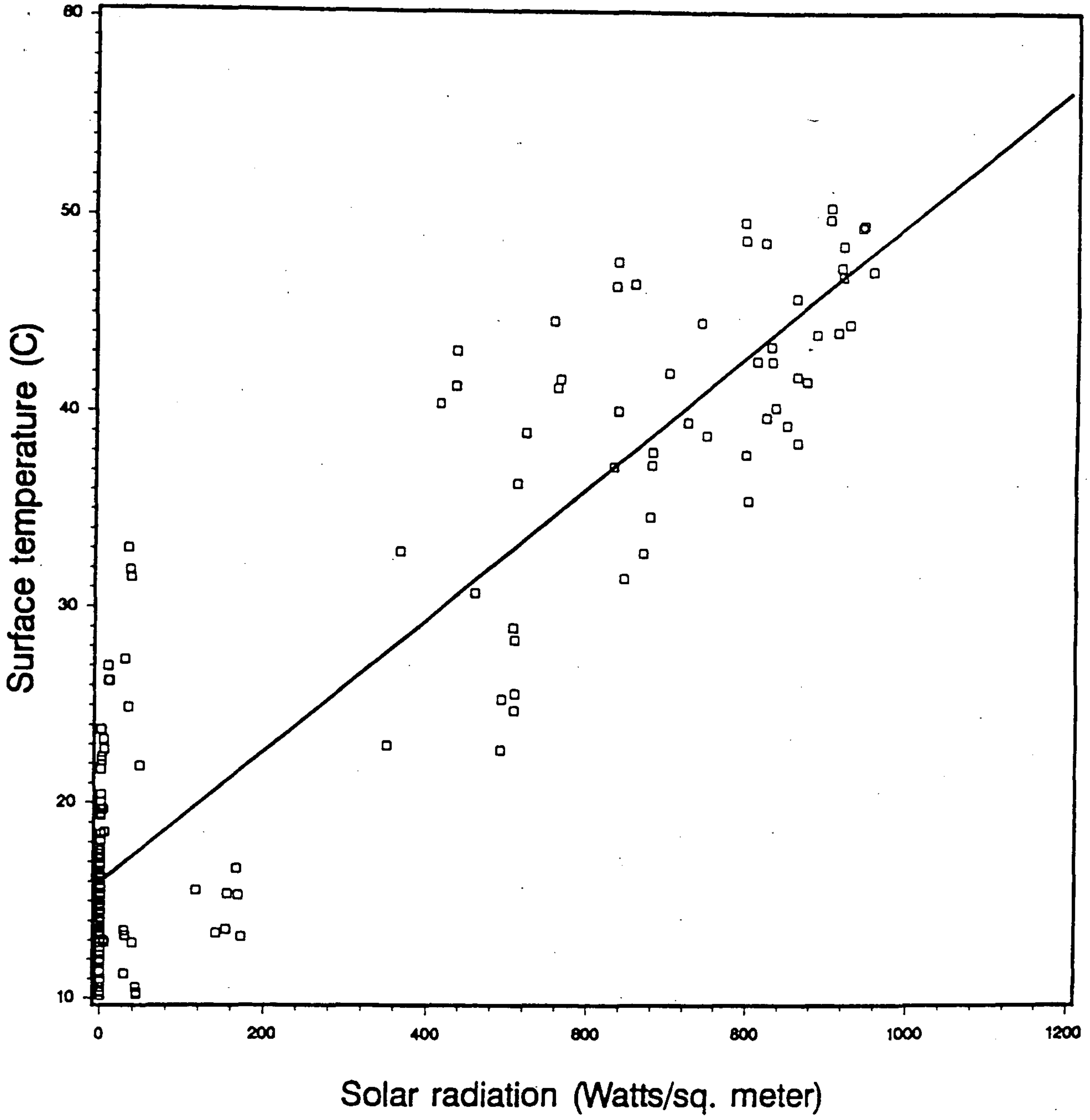


Figure V-3F. Site 2: Roof surface temperature (°C) vs solar radiation (W/m^2) at 20 minute intervals for the high-albedo case. Line is a regression fit. Note that the data seem questionable; the thermocouple reading may be influenced by solar radiation and ambient air temperature.

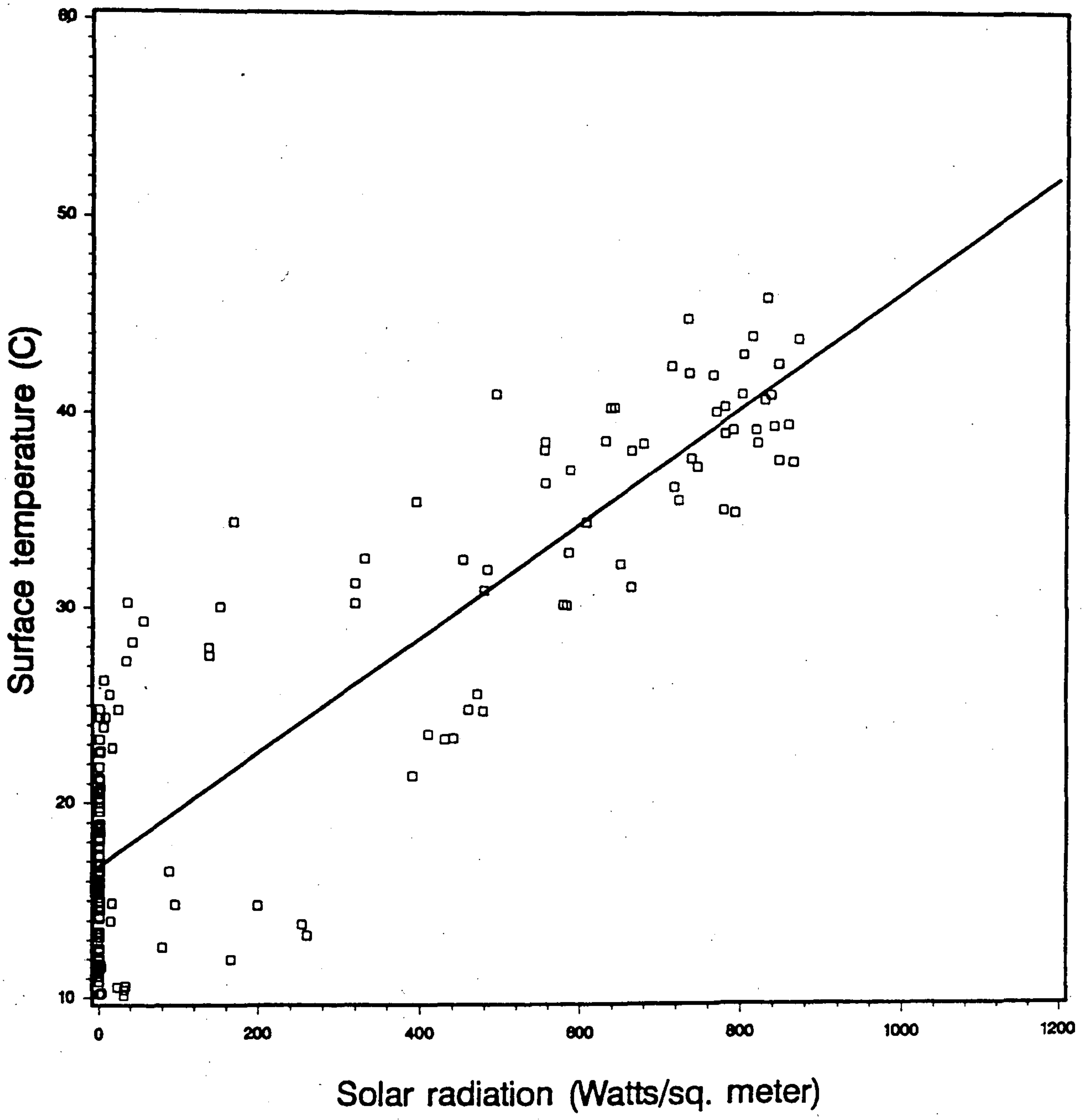


Figure V-3G. Compressor watt hours and building interior temperature for 9/1 to 9/7 at Site 2. Comparison before albedo modification using ACTUAL SITE temperature and windspeed. Days 245 to 248 Measured: 5.5 kWh/day DOE-2: 7.0 kWh/day.

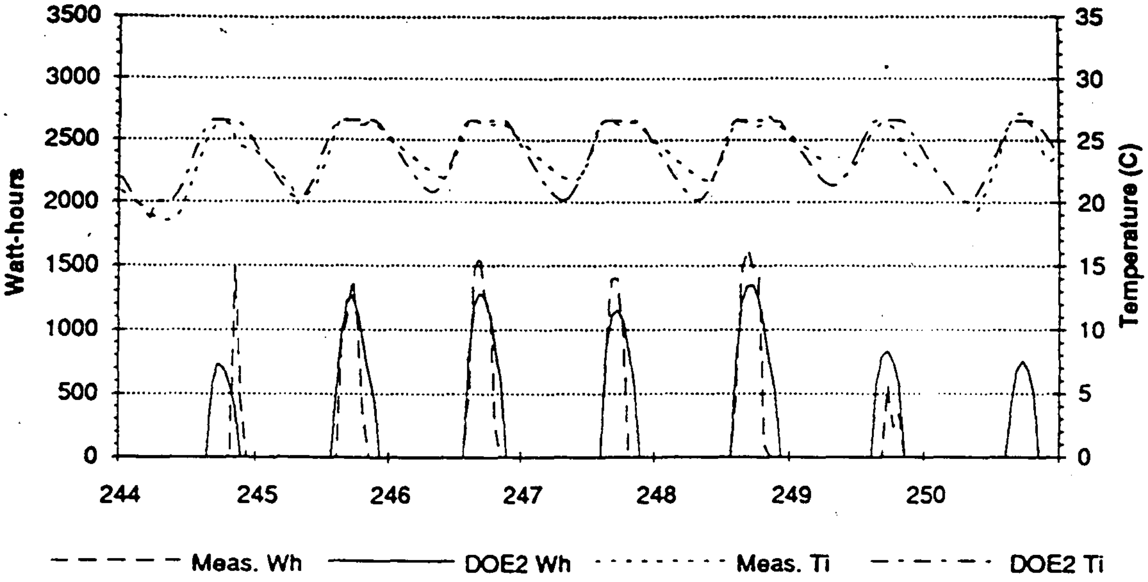
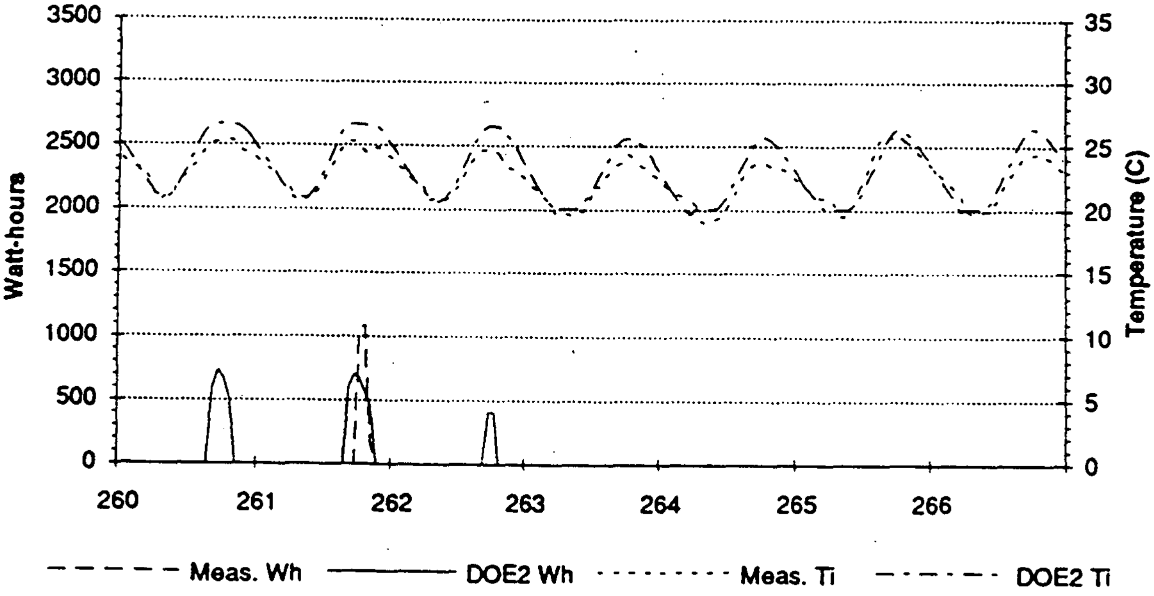


Figure V-3H. Compressor watt hours and building interior temperature for 9/17 to 9/23 at Site 2. Comparison after albedo modification using ACTUAL SITE temperature and windspeed. Days 260 to 266 Measured: 0.3 kWh/day DOE-2: 0.9 kWh/day.



temperatures match the measured data extremely well except that the simulated building appears to cool faster at night than the measured data suggests. In addition, the cooling energy use is relatively well simulated. In the pre-period, the simulated peaks are slightly lower than the measured peaks, but the simulated total daily usage is 20% too high. The simulations capture the effect seen earlier, where after painting the roof of the building white, cooling use dropped virtually to zero. The measured data in Figure V-3H show that the interior temperature hovered just below the thermostat setpoint during that week. The simulation model reaches the setpoint and on a few days during this period, and a small amount of cooling is used.

As previously mentioned, a site-specific weather data set was produced for Site 2 from the site-measured temperature, humidity, and windspeed data. A study of the sensitivity of this model to climatic inputs is shown in **Figures V-3I** and **V-3J**. The impact of changing from airport temperature and windspeed data to site data was to decrease the simulated peak cooling load on very hot days by 40% or 1.0 kW, and on more typical days by 0.5 kW. The microclimate surrounding Site 2 has a large impact on its cooling energy use.

In **Figure V-3K** we present simulated daily cooling energy use versus daily maximum temperature from the Site 2 model. As shown in the calibration charts, the simulations overpredict daily cooling energy use. At an outdoor temperature of 35 °C, the model predicts about 7.5 kWh/day, while the measured data regression line predicts about 6.0 kWh/day, a difference of 25%. The simulation model also allows us to account for changing climatic conditions over the period of measurement. The model shows that when simulating the dark roof and white roof cases over the base case time period, the savings are approximately 60%.

Figure V-3I. Simulated compressor watt hours for 9/1 to 9/7 at Site 2 using different weather inputs. Comparison before albedo modification showing effects of temperature and windspeed. Days 244 to 250 AP data: 8.5 kWh/day Site Data: 5.3 kWh/day.

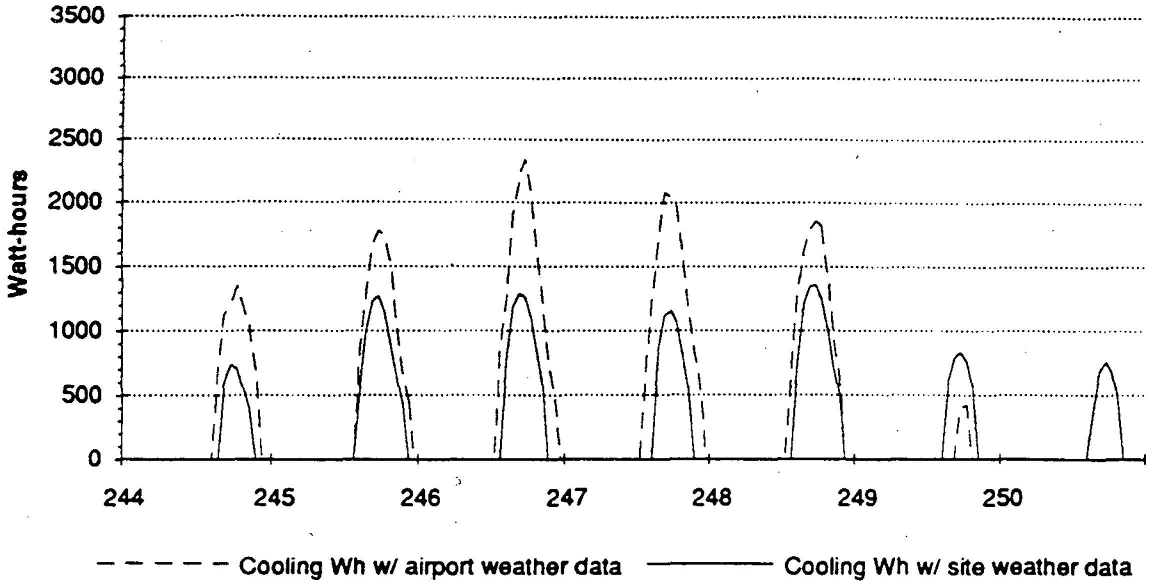


Figure V-3J. Compressor watt hours and building interior temperature for 9/17 to 9/23 at Site 2 using different weather inputs. Comparison after albedo modification showing effects of temperature and windspeed.

Davs 260 to 266 AP data: 2.6 kWh/day Site Data: 0.9 kWh/day.

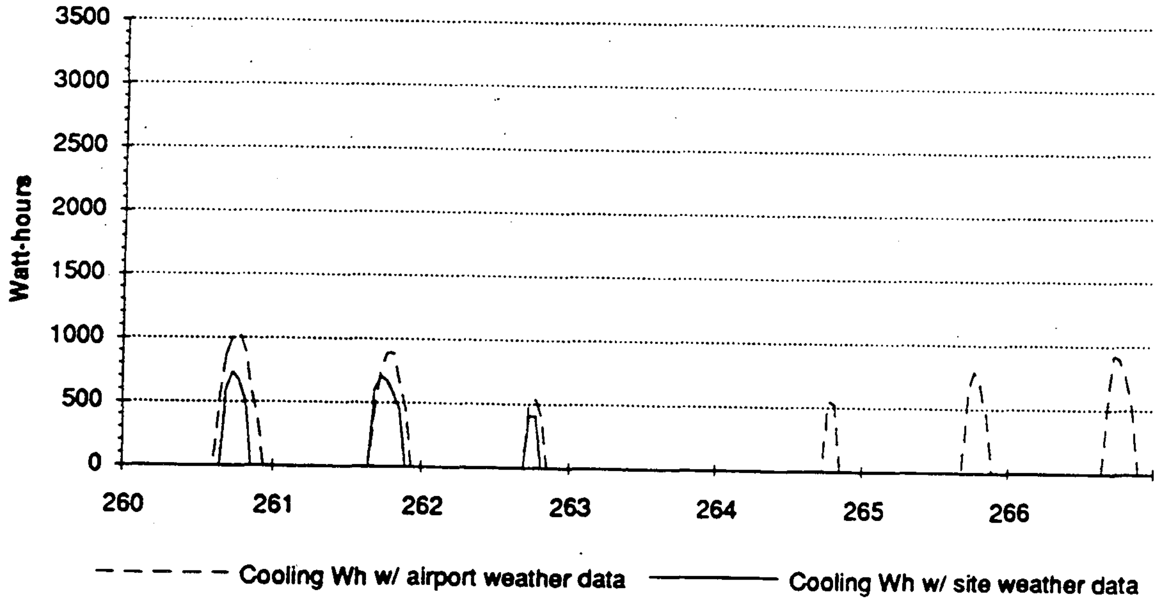
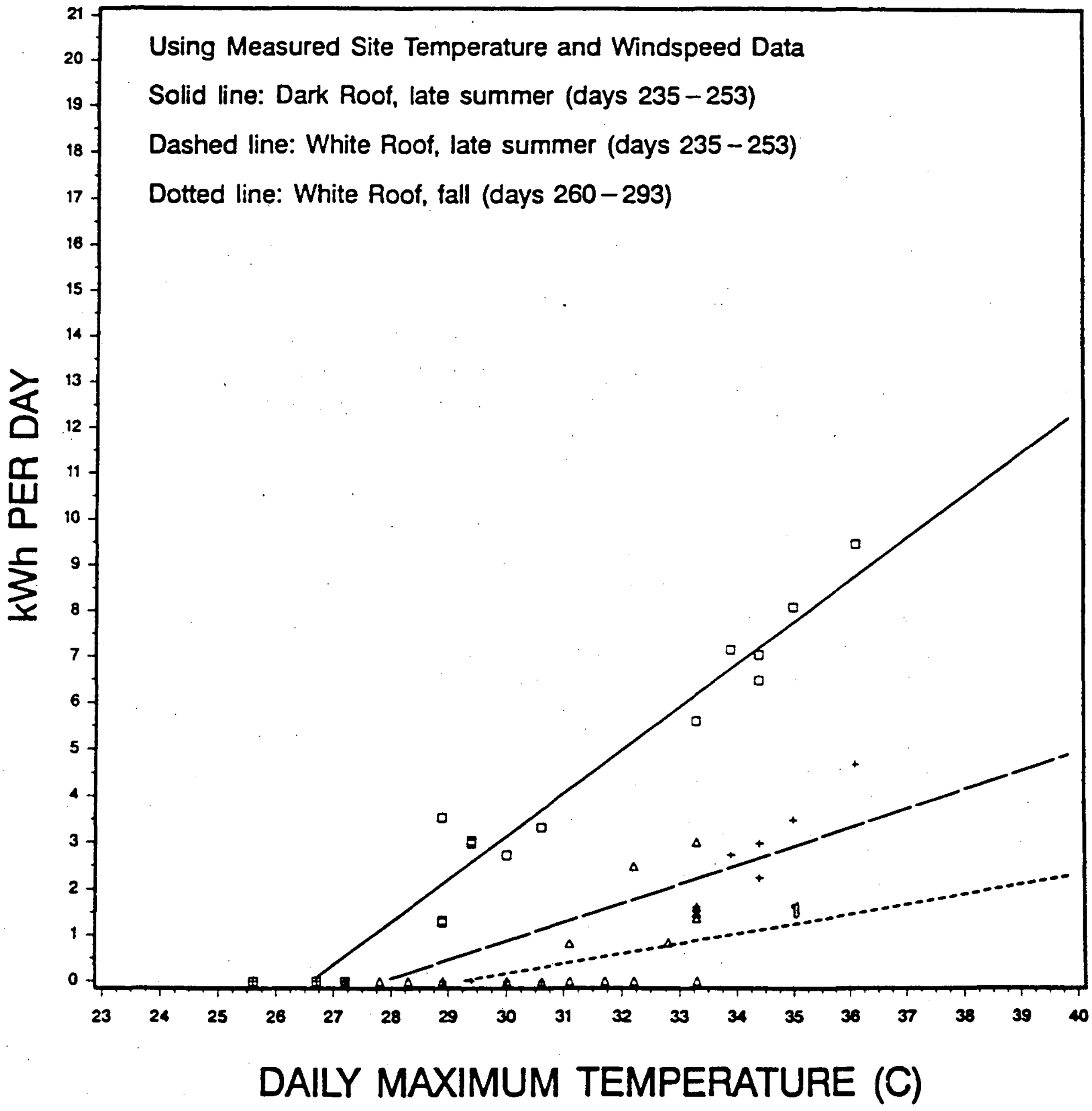


Figure V-3K Site 2 Simulation Results: Daily data Simulations were performed using Site temperature and windspeed data. The square and solid line represent the dark roof in late summer (day 235-253). Crosses and dashed line represents the white roof in late summer (days 235-253). Triangles and dotted line represent a white roof during fall (days 260 - 293).



Site B

Site B is a school in which two classroom bungalows (one test and one control) were monitored. The test unit was fully instrumented, whereas the control unit was provided only with a kWh-meter. The test unit underwent two modifications during the monitoring period. First its roof and southeast wall were coated with a brown paint and the unit was monitored in that state for about one week. Then, the roof and the southeast wall of the test unit were coated white and monitored for 35 days. **Table V-7** gives values for albedo (α) and emissivity (ε) of walls and roofs of both test and control units throughout the monitoring period.

TABLE V-7

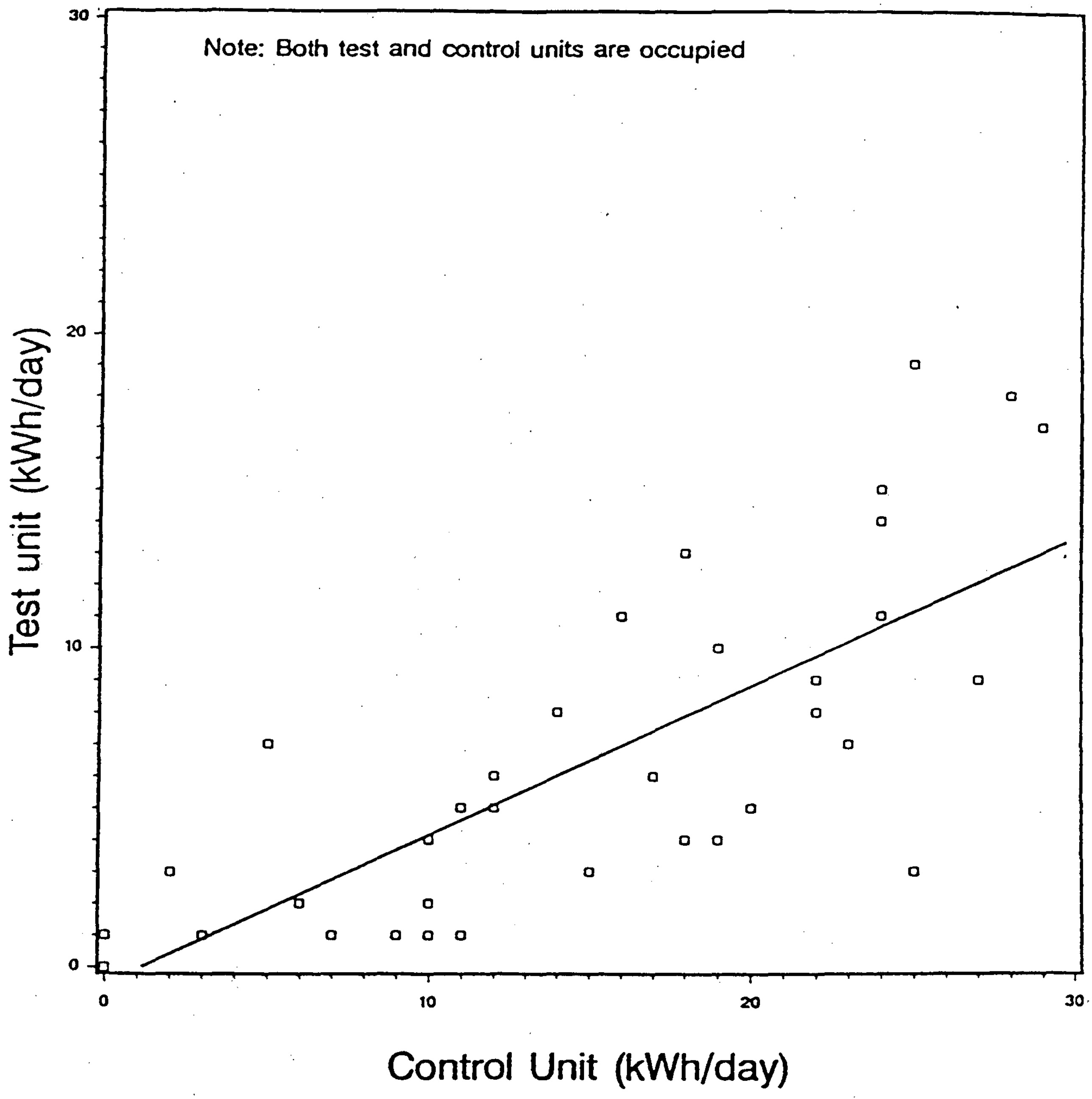
Monitoring periods, albedo, and emissivity of control and test units coatings.

	Control unit				Test unit					
	Roof		All walls		Roof		SE wall		Other walls	
Monitoring	α	ε	α	ε	α	ε	α	ε	α	ε
Period A (Aug 11 to Aug 18)	0.34	0.30	0.30	0.95	0.34	0.30	0.30	0.95	0.30	0.95
Period B (Aug 20 to Aug 27)	0.34	0.30	0.30	0.95	0.08	0.95	0.08	0.95	0.30	0.95
Period C (Aug 28 to Sep 2)	0.34	0.30	0.30	0.95	0.68	0.95	0.68	0.95	0.30	0.95
Period D (Sep 3 to Oct 21)	0.34	0.30	0.30	0.95	0.68	0.95	0.68	0.95	0.30	0.95

Period A corresponds to the basecase configuration, Period B corresponds to the time interval during which the test unit had a brown roof and brown southeast wall. Period C corresponds to the time interval during which the roof and the wall of the test unit were coated white. During all three periods, both test and control units were unoccupied. Finally, Period D corresponds to the interval during which the test unit was coated white and both units were occupied after school started.

Figure V-4A shows daily cooling energy use data for both test and control units for Period D, i.e., when both test and control units were occupied. There are 35 days of data (points) in this figure, and the regression line indicates that the cooling energy use in the white-coated test unit was about 50% of the amount of cooling energy used in the control unit (with yellow walls and metallic roof) under identical climate conditions. One should keep in mind, however, that in addition to the effect of higher albedo coatings on the roof and southeast wall of the test unit, other factors that might have contributed to the higher energy usage in the control unit include:

Figure V-4A. Site B: Daily cooling electricity use (kWh/day) at the test unit vs daily cooling electricity use (kWh/day) at the control unit. The control unit has a metallic roof and yellow walls, whereas the test unit has a white roof, white southeast wall, and yellow northwest wall. Both units are occupied. Monitoring period is from September 3 through October 21, 1991.



1. Thermostat reset in the control classroom. The thermostat in that unit was frequently reset to ~22.5°C, during the monitoring period (compared to 25.5°C in the test unit).
2. Lower emissivity (~0.30) of the metallic roof compared to the emissivity of the painted roof (~0.95) in either brown or white configurations.

The DOE-2 simulations appear to indicate that only 15-20% of the measured savings are resulted from the high albedo coating. The rest is a result of thermostat setting and emissivity differences and will be covered in the following discussion.

At the hourly level, **Figures V-4B** and **V-4C** show data for the test unit during Periods B and C (brown and white, both unoccupied cases). Because the amount of data available is small, no regression was performed. But we can still see that moving from an albedo of 0.08 (brown) to 0.68 (white) had a significant impact on cooling energy use. Figure V-4B indicates that while cooling with the low albedo case started at an outdoor air temperature of 22°C and went all the way up to 2.4 kWh/h, cooling energy use in the case with white coating started at an outdoor air temperature of 31°C and went up to about 1.7 kWh/h.

Figure V-4C shows that while cooling needs in the low albedo case encompass a To-Ti range from -3°C to +11°C, the cooling needs in the case with high albedo were confined to a To-Ti range of +4°C to +12°C. Note that, in these correlations, there was no need to adjust for solar radiation as Periods B and C were short and Period C immediately followed Period B, so that there was no significant decrease in solar radiation over these intervals (total daily irradiance during Period B was ~7 kWh/day and during Period C ~6.9 kWh/day. Also, there are no concerns regarding emissivity or thermostat settings since this is the same unoccupied (test) unit.

In **Figures V-4D** and **V-4E**, the roof surface temperature for the cases before and after albedo modifications is shown. From the regression lines, one can see that, on the average, the afternoon surface temperature in the white roof was 10°C lower than with the brown roof. Note that this surface temperature depression is probably an underestimate since we had the same problem as discussed in Site 2, namely, that the thermocouple could not be embedded in the roofing material.

The comparison of hourly simulated and measured data for Site B (the school) are presented in **Figures V-4F** and **V-4G.** The top graphic, Figure V-4F, compares data from the test building, while the bottom graphic compares data from the control building over the same

Figure V-4B. Site B: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor air temperature (°C) for pre- and post-retrofit conditions at the test unit. The squares represent the pre-conditions (albedo = 0.08, brown), whereas the diamonds represent the post-conditions (albedo = 0.68, white). Monitoring period is from August 20 through September 2, 1991.

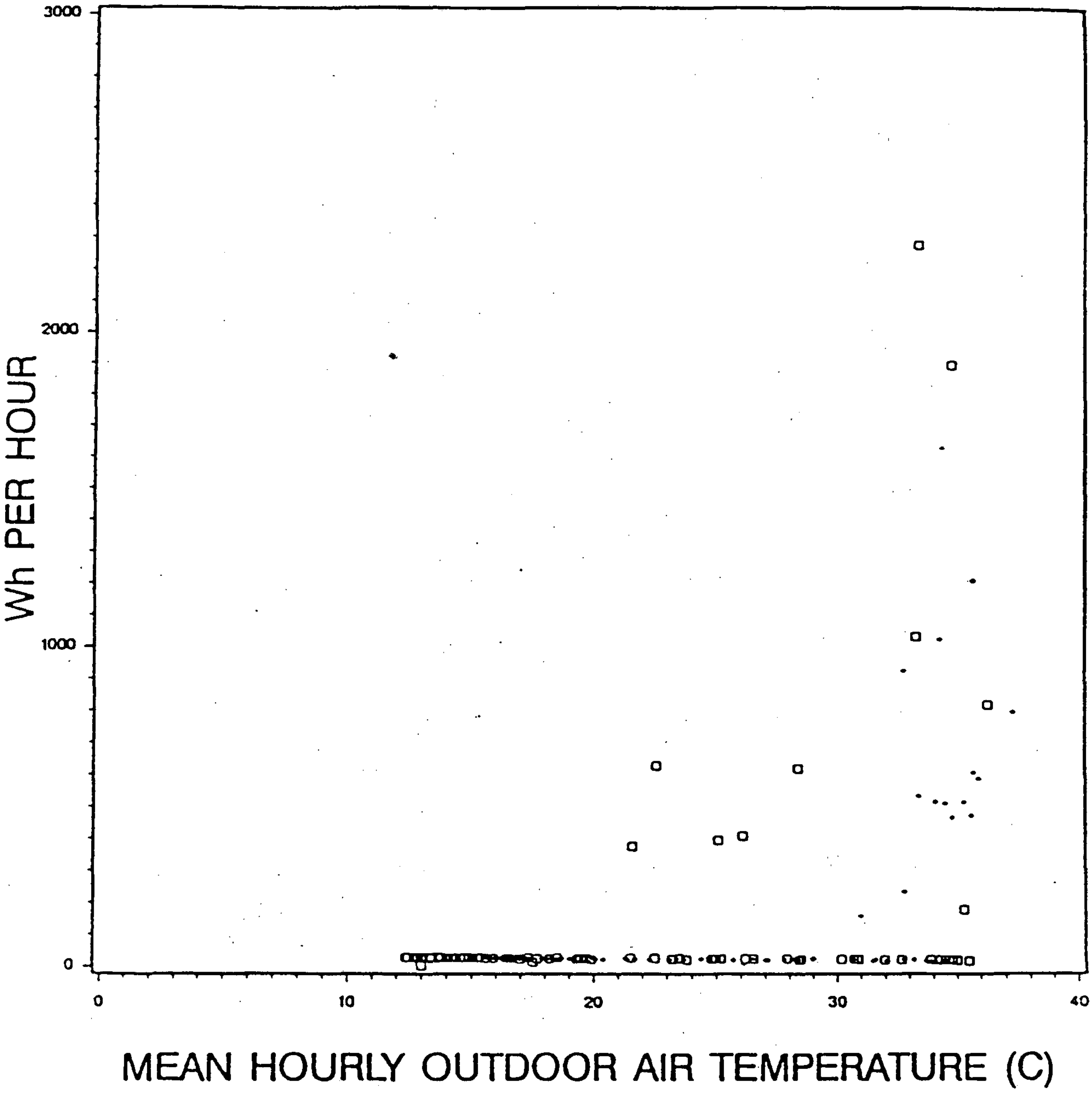


Figure V-4C. Site B: Hourly cooling electricity use (Wh/h) vs mean hourly air temperature difference, outdoor minus indoor (°C) at the test unit. The squares represent the pre-conditions (albedo = 0.08, brown), whereas the diamonds represent the post-conditions (albedo = 0.68, white). Monitoring period is from August 20 through September 2, 1991.

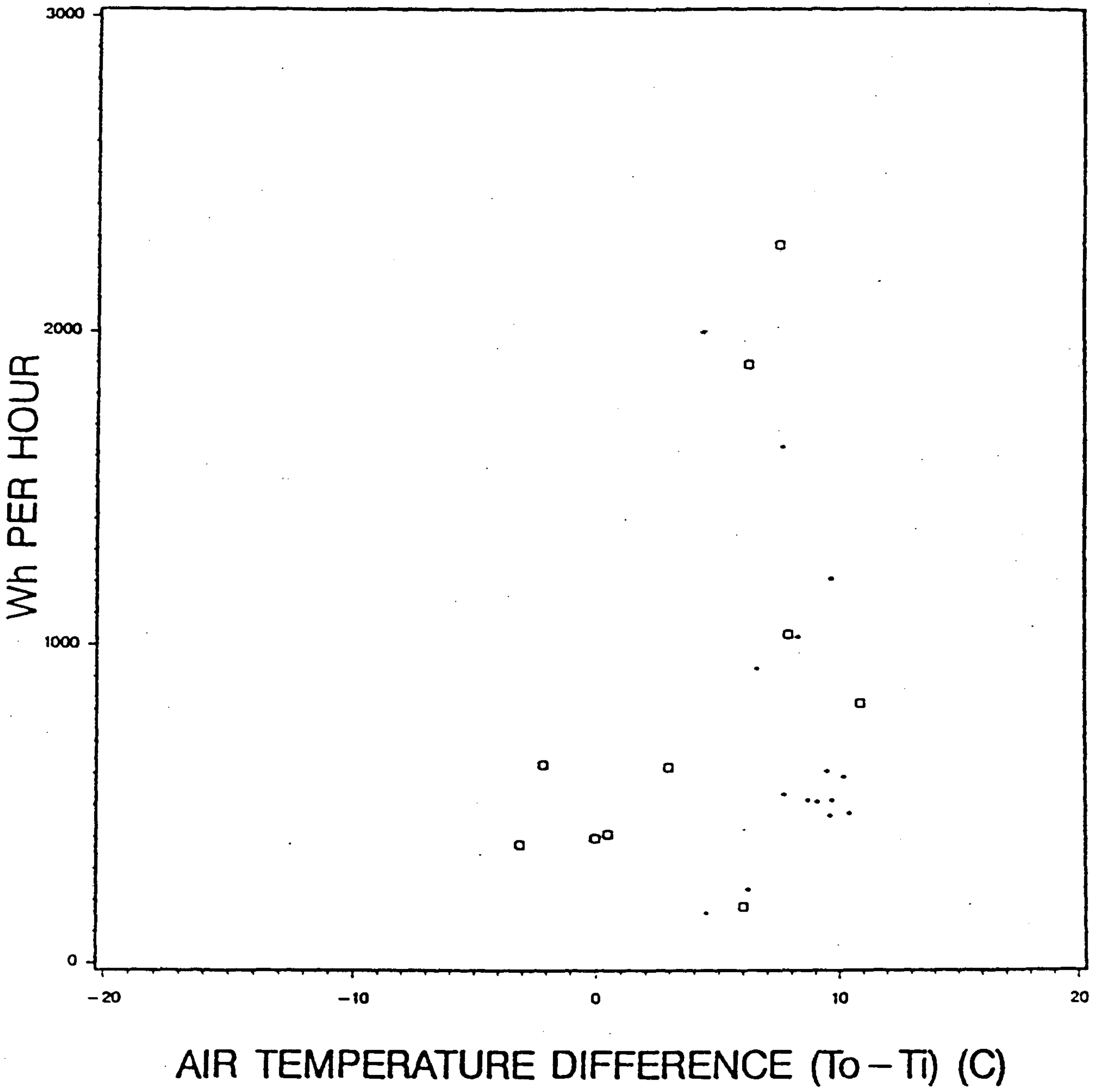


Figure V-4D. Site B: Roof surface temperature (°C) vs horizontal solar radiation (W/m^2) for the pre-retrofit case. Albedo is 0.08. Line is a regression fit. This is monitoring period August 20 through August 27, 1991.

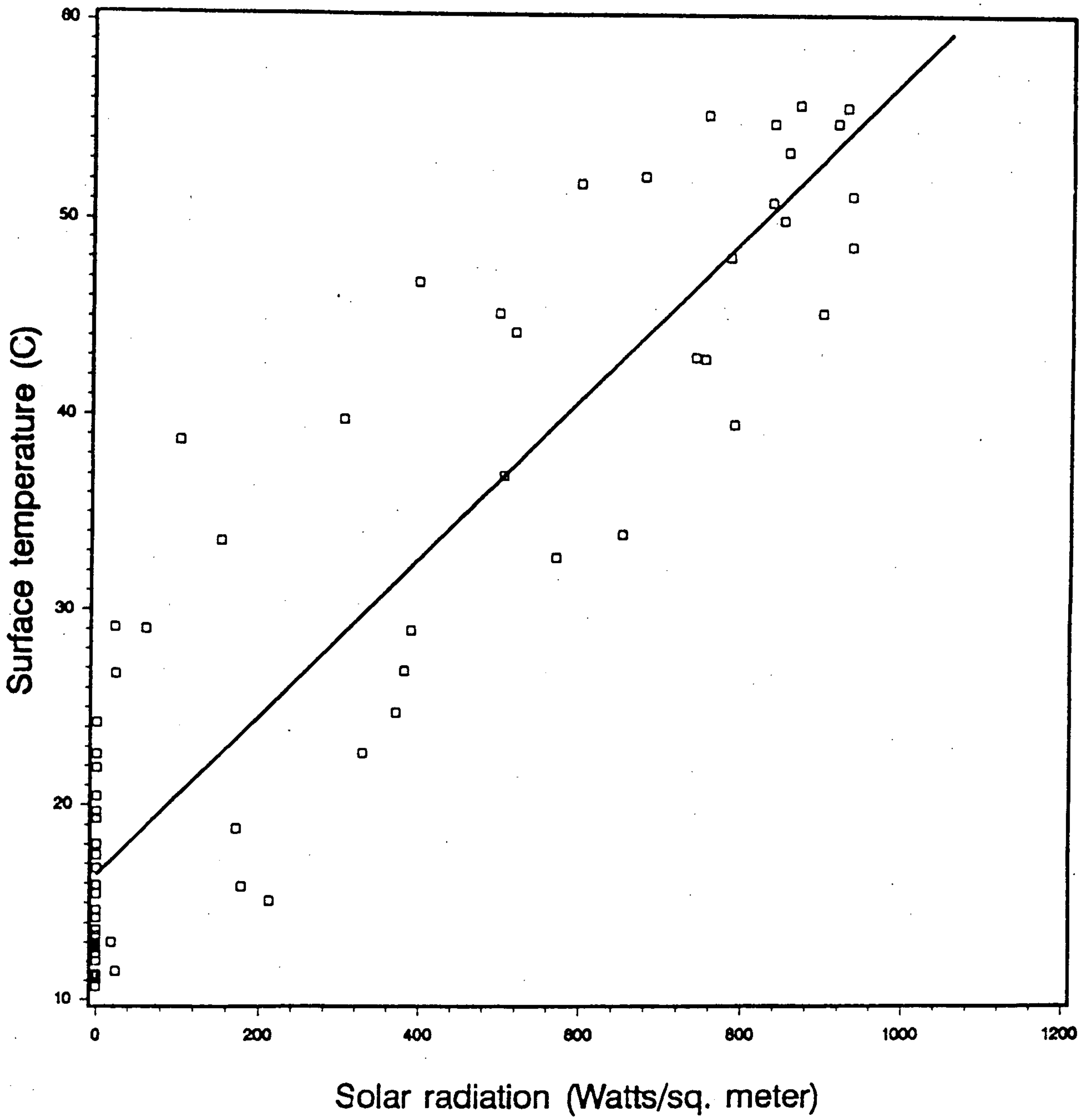


Figure V-4E. Site B: Roof surface temperature (°C) vs horizontal solar radiation (W/m^2) for the post-retrofit case. Albedo is 0.68. Line is a regression fit. This is monitoring period August 30 through September 2, 1991.

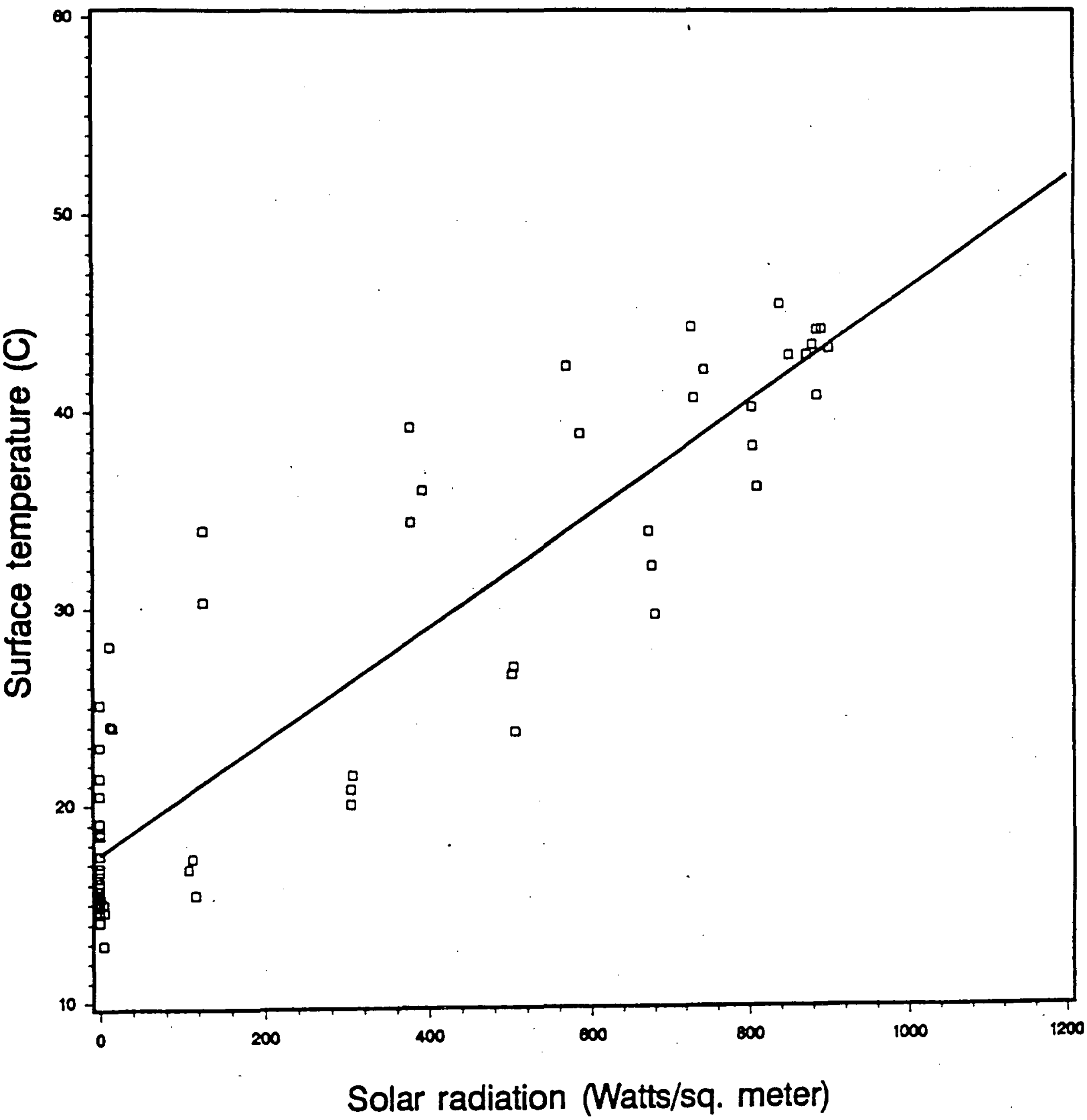


Figure V-4F. Package AC unit watt hours and building interior temperature for 10/5 to 10/11 at Site B. Comparison of measured and simulated data for TEST building (at 78°F setpoint). Days 280 to 282 Measured: 9.6 kWh/day DOE-2: 10.8 kWh/day.

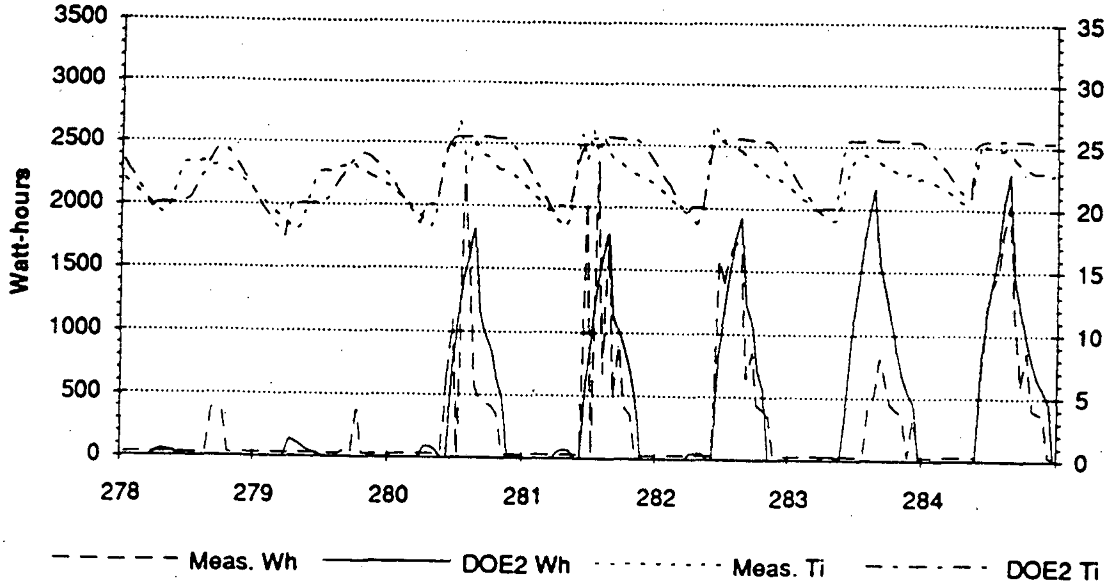
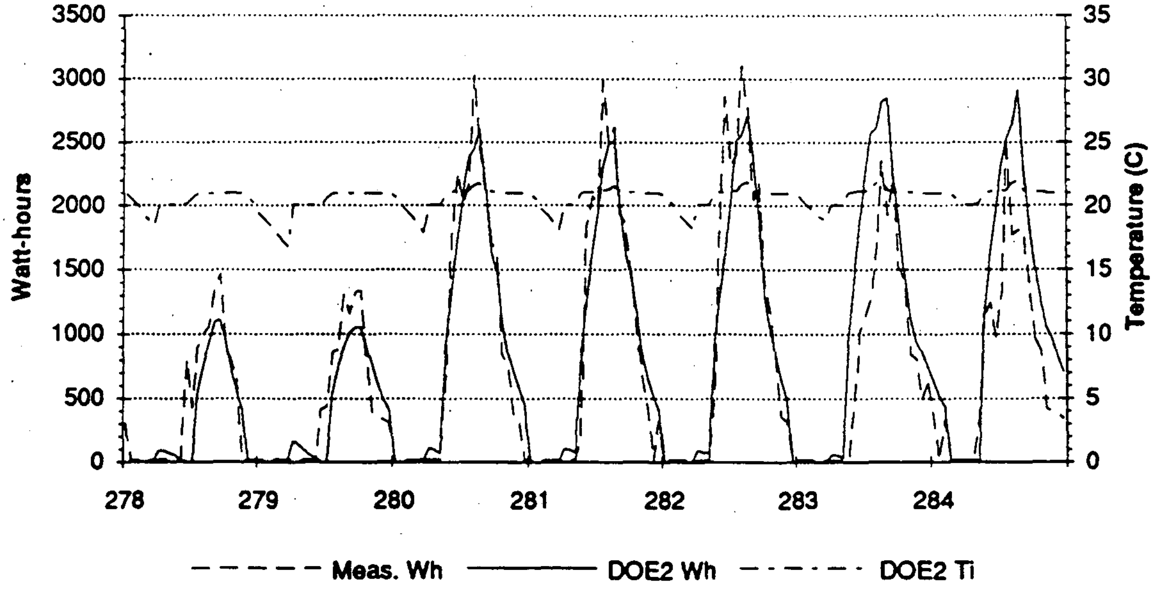


Figure V-4G. Package AC unit watt hours and building interior temperature for 10/5 to 10/11 at Site B. Comparison of measured and simulated data for CONTROL building (at 70°F set-point). Days 280 to 282 Measured: 22.8 kWh/day DOE-2: 22.3 kWh/day.



time period. Because the control building did not have an indoor temperature sensor installed, no comparison is made here. However, visits to the site during the monitoring period suggest that the thermostat in this building was frequently reset to a lower temperature than the prescribed 26°C, with typical settings of 21, 22, or 23. The best fit to the measured data occurs with simulations at a thermostat setting of 21°C, so that value is used in the remainder of the analysis. The agreement in energy consumption for the test building is slightly high, but the peak cooling load matches well. Note that cooling energy consumption on days 280 and 281 is extremely variable from hour to hour. The agreement in energy consumption with the test building is quite good.

Note that the data shown here are for the period after school began for the fall term, which is the period with the greatest amount of data. Days 278 and 279 are a weekend with no occupancy, and the difference in the cooling loads between weekdays and weekends suggests that cooling in these buildings is driven by internal gains from occupants and lights. In fact, the DOE-2 simulations show that 65% (in September) to 85% (in October) of the cooling load is due to internal heat gains. Day 283 also appears to be slightly abnormal in the case of both buildings.

Parametric simulations were performed to study the impacts of painting the roof and wall white, thereby increasing the albedo of those surfaces and increasing the emissivity of the metallic roof. The cooling impact of these changes is compared with the potential error from assuming a thermostat setting of 21°C in the control building in **Figures V-4H** and **V-4I**. The model estimates of the albedo and emissivity impacts are relatively small, particularly in comparison to the impacts of the thermostat setpoints. Without real knowledge of the thermostat setpoint or the interior temperature in the control building, therefore, no concrete conclusions can be made about the discrepancy between the simulated and measured data.

The simulations for the school site suggest that there are significant reductions in the cooling load resulting from albedo modifications, although less than shown simply by the measured data. The summary of simulation results is shown in **Figure V-4J**. Daily cooling energy consumption for weekdays during the occupied period is plotted versus daily maximum temperature for three cases. The top set of data is for the metal roof condition at a 21°C interior temperature (the simulated control site). The bottom set of data is for the white roof condition at a 26°C indoor temperature. The middle set of data adjusts for the difference in thermostat setpoint, and suggests that actual savings from the white roof over this period are about 1 to 2 kWh/day, depending on the temperature. The top and bottom regression lines show similar results as the measured data, where the difference in cooling energy consumption between the test and control units is about 50%.

Figure V-4H. SIMULATED fan and compressor watt hours 10/5 to 10/11 at Site B. Simulation of bungalow in BASE and ALBEDO cases at same thermostat setpoint.

Days 278 to 284 White Roof: 9.1 kWh/day Metal: 10.6 kWh/day.

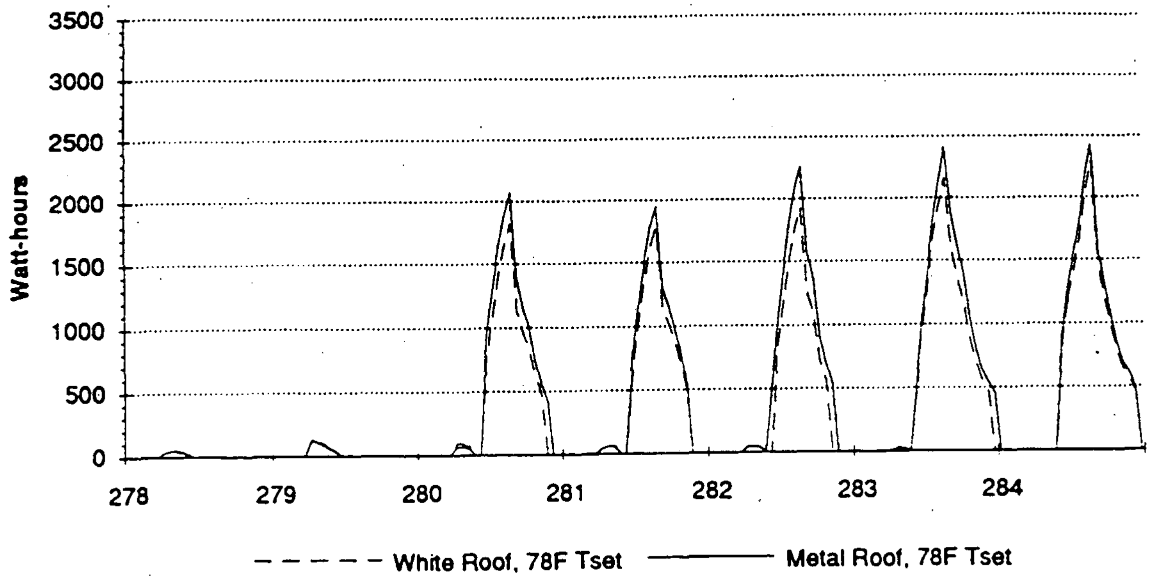


Figure V-4I. SIMULATED fan and compressor watt hours 10/5 to 10/11 at Site B. Simulation of bungalow in BASE case at two different thermostat setpoints.

Days 278 to 284 70°F Tset: 19.6 kWh/day 78°F Tset: 10.6 kWh/day.

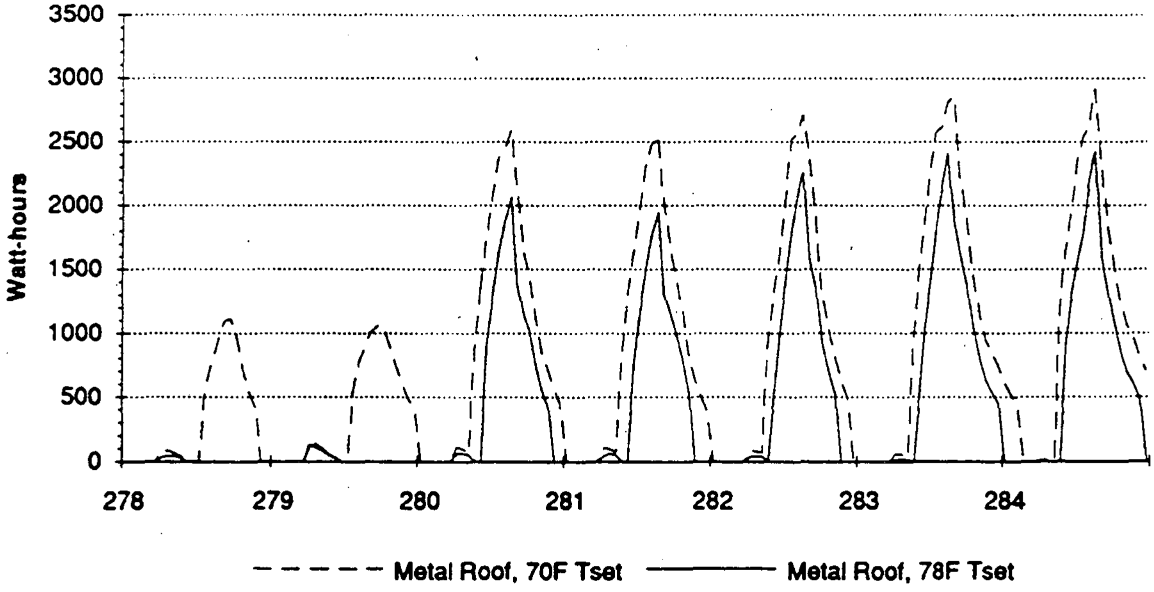
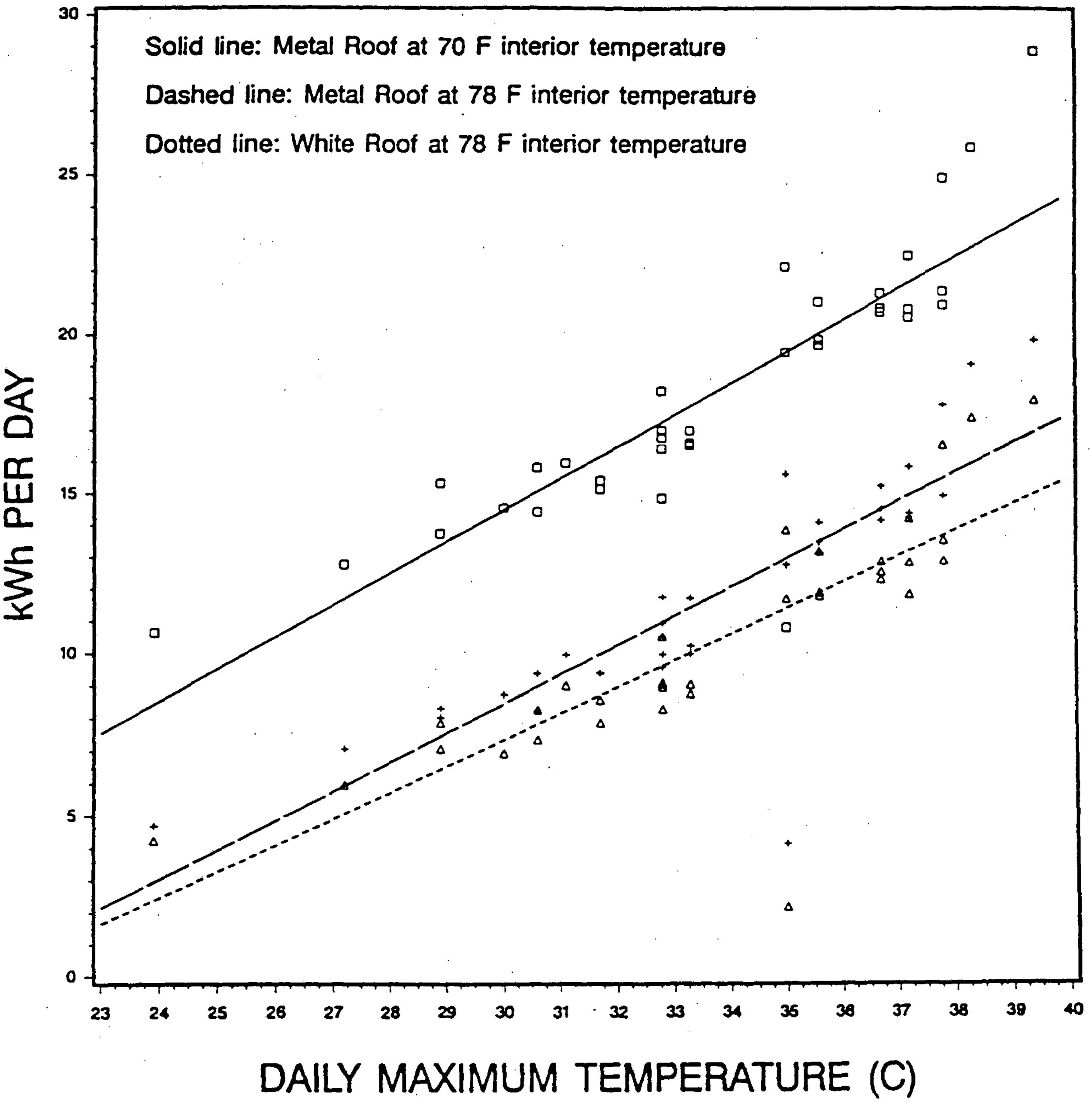


Figure V-4J. Site B: Daily data for occupied monitoring period: Square and solid line represent a metal roof at 21°C interior temperature. Crosses and Dashed lines represent a metal roof at 26°C interior temperature. Triangles and dotted line represents a white roof at 26°C interior temperature.



Vegetation Modification Sites

Site 5

This site is located far southeast of Sacramento. The neighborhood is relatively new and vegetation is generally low. This particular house, however, was well vegetated on the north and south sides, and was additionally well shaded by means of a large overhang running the entire length of the south side. It had minimal exposure (windows) on the west side. The only potential locations for placing trees were two small windows on the east side. The house was first monitored for 11 days (JD 249 - 259), and then two small trees were placed on the east side, and the building was monitored again for 26 days (JD 268 - 293).

Because of the existing heavy shading and since the trees were placed on the east side (which has a relatively small impact on heat gain), we expected little differences in energy use between the base and the modified cases. **Figure V-5A** shows that there was not much difference between the two cases on a daily basis. For example, at 38°C, there are savings of 2 kWh/day resulting from the two trees. These savings correspond to ~14% at that temperature. **Figure V-5B** shows hourly data from Site 5 in Wh/h plotted versus mean hourly outdoor air temperature (°C). At 38°C, the savings indicated by the regression lines amount to only ~7%. If a correction for solar radiation is performed, there may be minimal or no savings in cooling energy use at this site.

DOE-2 simulations of this site indicate that the savings were not caused by the small trees, but by the effects of lower insolation. The comparison of measured and simulated data for Site 5 are presented in **Figures V-5C** and **V-5D**. Only five days of complete measured data were available for the comparison during the pre- period.

If we look at the best days in each time series, for example 255 through 257 in Figure V-5C and 275 through 277 in Figure V-5D, we see that the peak cooling load predicted by the model agrees well with the measured data. However, the DOE-2 model overpredicts daily cooling energy in the pre-period and underpredicts in the post-period. We were not able to determine the cause of this discrepancy. In the post-period, the simulated cooling consumption continues much longer into the evening than the measured data show. This may be due to slightly lower outdoor temperatures at the site in the evening as compared to the airport. In the post-period, this discrepancy results in the simulated daily cooling being 25% higher than measured. In addition, days 278 and 279 in the post-period have extremely high cooling energy use which

Figure V-5A. Site 5: Daily cooling electricity use (kWh/day) vs maximum outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions with two additional trees on east. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was September 6 through September 23, and the post-retrofit period was September 25 through October 21, 1991.

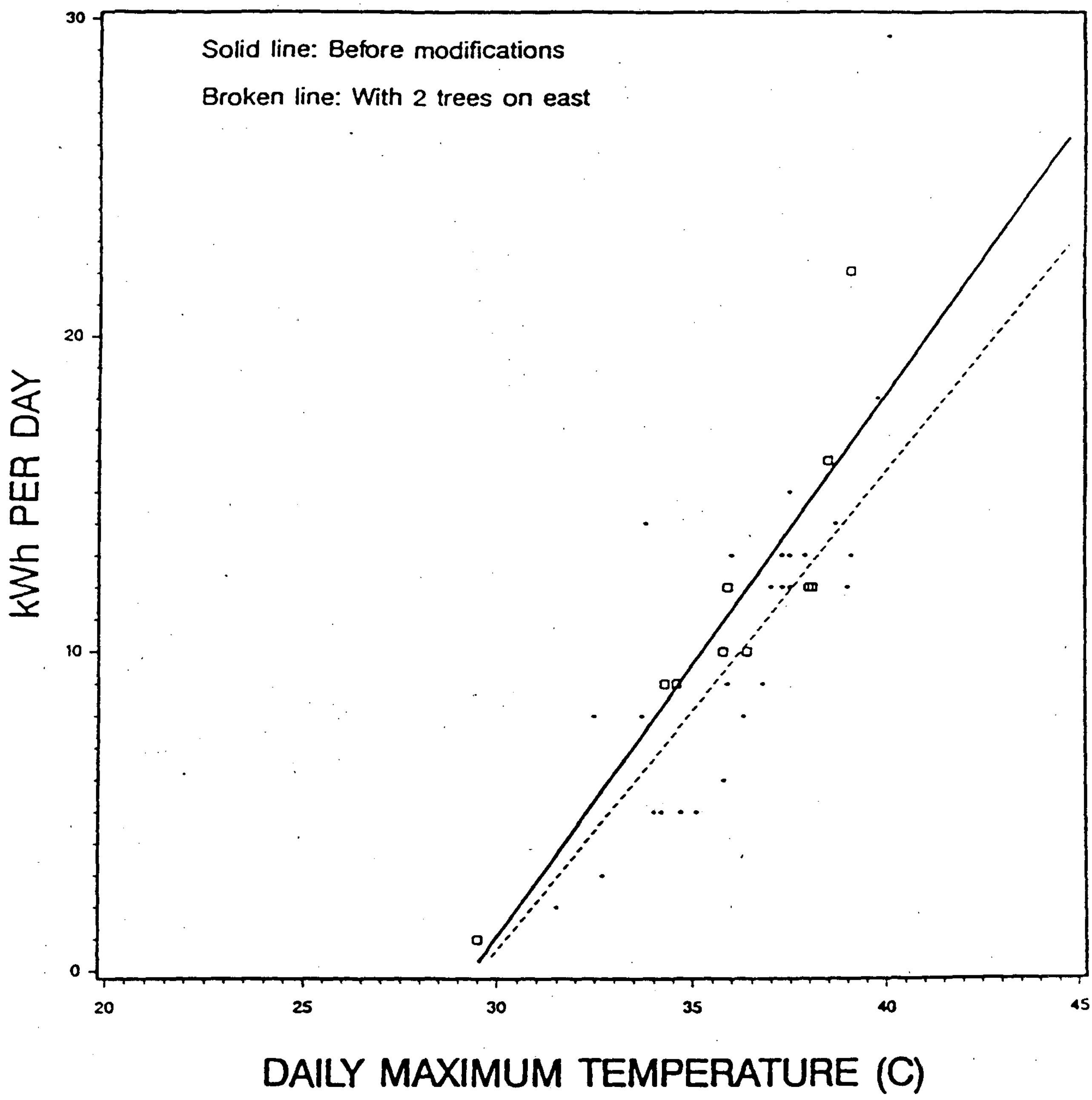


Figure V-5B. Site 5: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions with two additional trees on east. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was September 6 through September 23, and the post-retrofit period was September 25 through October 21, 1991.

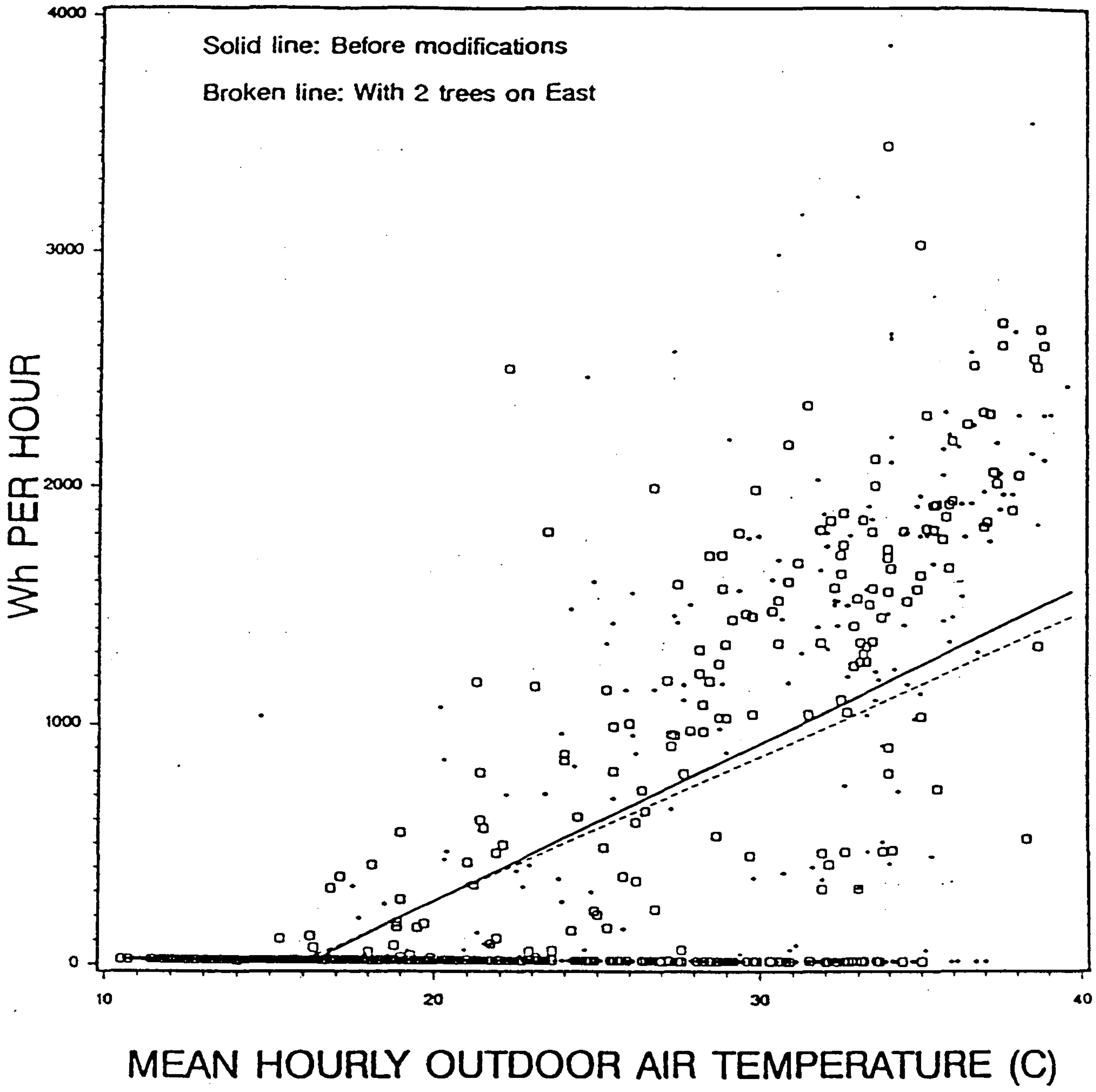


Figure V-5C. Compressor watt hours and building interior temperature for 9/11 to 9/15 at Site 5. Comparison of measured and simulated data before vegetation modification.

Days 255 to 258 Measured: 10.3 kWh/day DOE-2: 7.7 kWh/day.

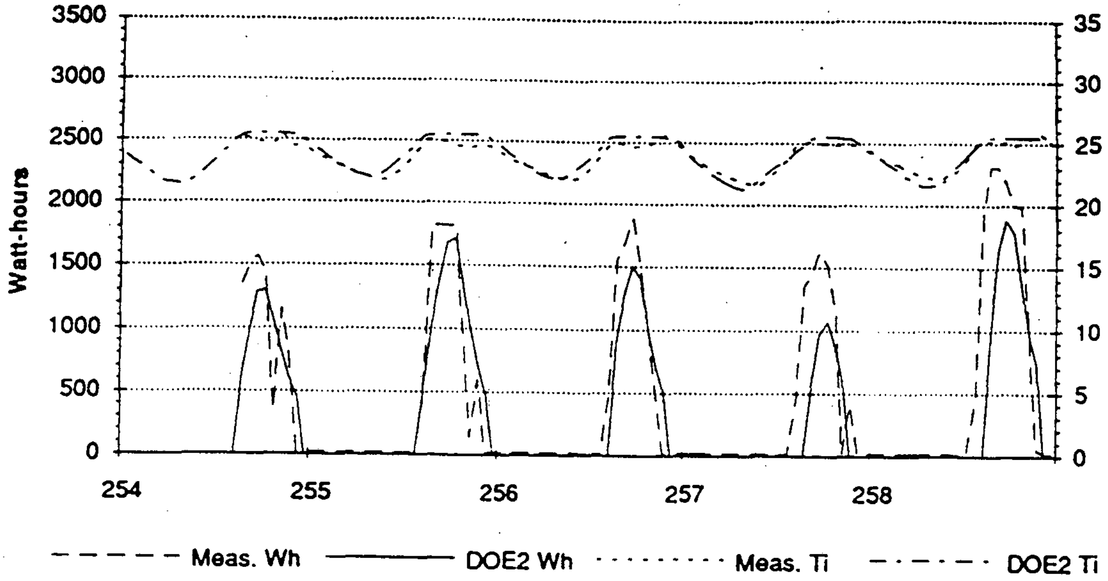
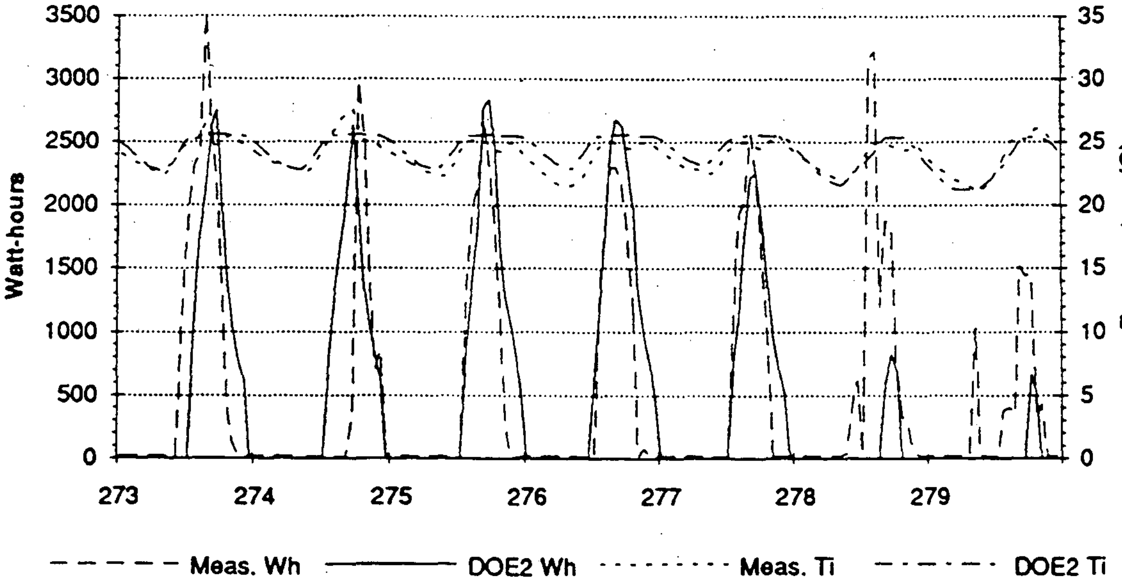


Figure V-5D. Compressor watt hours and building interior temperature for 9/30 to 10/6 at Site 5. Comparison of measured and simulated data before vegetation modification.

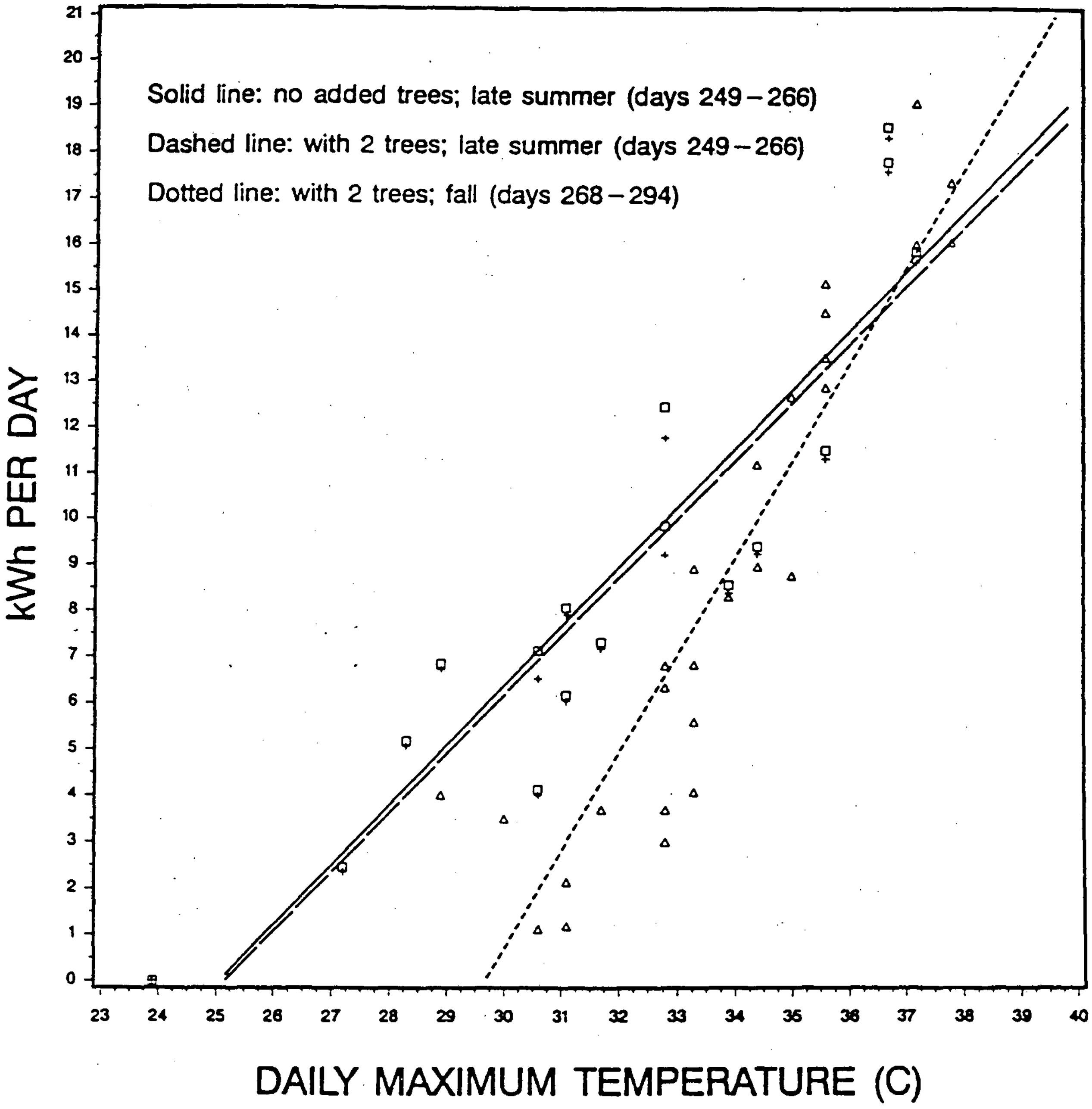
Days 275 to 277 Measured: 13.3 kWh/day DOE-2: 16.6 kWh/day.



is not explained by the climatic conditions on those days.

Daily cooling usage plotted against outdoor temperature is shown in **Figure V-5E**. The correlation with the measured data shown in Figure V-5A is not good. This may be due to the scarcity of measured data in the pre-period. However, both the simulated and the measured data show a daily usage of about 18 kWh/day at 40 °C. Figure V-5E also shows that after accounting for changes in the climatic conditions between the pre- and post-periods, there is little difference between the trees and base case. The difference in slopes for the regression lines through the points also suggests that the impact of the change in solar insolation over the project period is a more important factor in determining cooling energy consumption when the outside temperatures are relatively low.

Figure V-5E: Site 5 Simulation Results: Daily data for monitoring period Squares and solid line represent base case in late summer (days 249 - 266). Crosses and dashed line represent the addition of 2 shade trees in late summer (days 249 - 266). Triangles and dotted line represent the case of 2 shade trees in fall (days 268 - 294).



Site 6

This site is also located far southeast of Sacramento. It is in a relatively newer development, and both the house and surroundings vegetation density is low. Pre- and post-retrofit data for this site are available for 33 days (JD 233 - 265) and 26 days (JD 268 - 293), respectively. There were six missing days in the "pre" monitoring period and seven missing days in the "post" monitoring period. In the "post" monitoring period, two trees were placed on the west side and one tree on the south side. The condenser unit was also partially shaded by one of the west trees.

Figure V-6A shows daily energy use data plotted versus the maximum daily temperature at Site 6. For example, at 38°C, there is a reduction of 4.5 kWh/day (~30%) in cooling electricity use. **Figure V-6B** shows the decrease in daily total solar radiation across the entire monitoring period at Site 6. The solid line represents the conditions before vegetation modifications took place, whereas the broken line represents the conditions afterwards. The large dips represent periods with overcast skies. In general, we can see that, across 40 days of monitoring at this site, the daily total solar radiation dropped from 7 kWh/day down to ~4 kWh/day. The implications of lower insolation on "savings" are estimated with the help of DOE-2 simulations. These appear to indicate that almost all of the measured savings resulted from the effects of lower solar radiation intensity.

At the hourly scale, energy use was correlated to mean hourly outdoor air temperature and to the outdoor-indoor air temperature difference (To-Ti). **Figure V-6C** shows the first case. The squares represent the hours before vegetation modifications took place, whereas the small diamonds represent those hours after 2 trees on the west side and one tree on the south side were installed. Looking again at an outdoor air temperature of 38°C, the regression lines indicate that there were reductions of 38% in energy use. **Figure V-6D** shows the same hourly data, but in this case, it was plotted versus hourly outdoor minus indoor air temperature difference. The bulk of the cooling energy use occurred when outside air temperature was 0-10°C higher than indoor air temperature. When outdoor air temperature was 5°C higher than that indoors, the regression indicates savings in cooling energy of 44% because of the trees. However, the DOE-2 simulations of this site appear to indicate that most of the savings in cooling energy use were not caused by vegetation, but by the lower insolation.

Figure V-6A. Site 6: Daily cooling electricity use (kWh/day) vs maximum outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions include two additional trees on west and one tree on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.

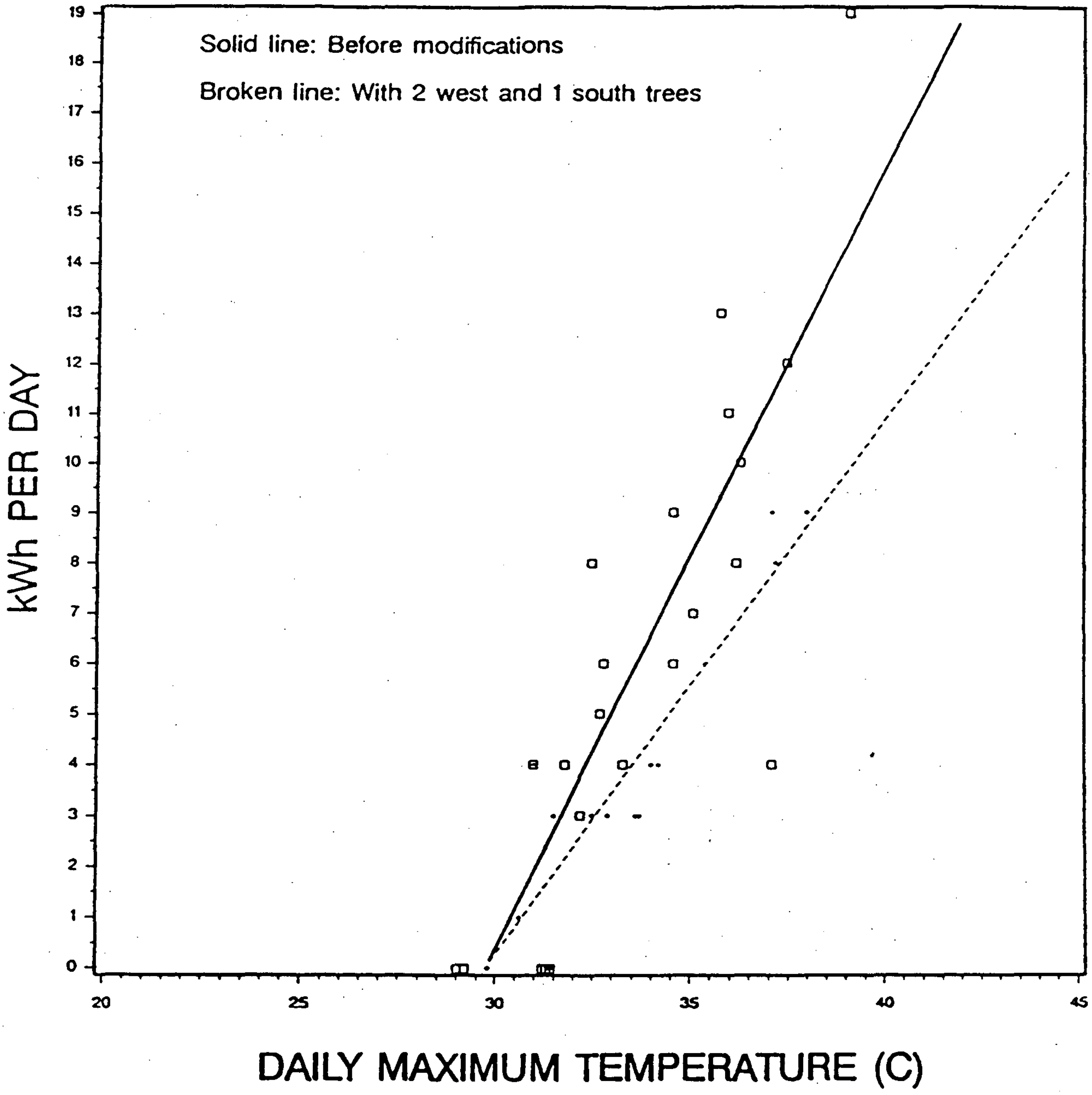


Figure V-6B. Site 6: Variation in total daily horizontal solar radiation (kWh/day) over 39 day of monitoring at Site 6. The left portion of the graph represents solar radiation during the pre-retrofit period whereas the right portion represents radiation during the post-retrofit period. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.

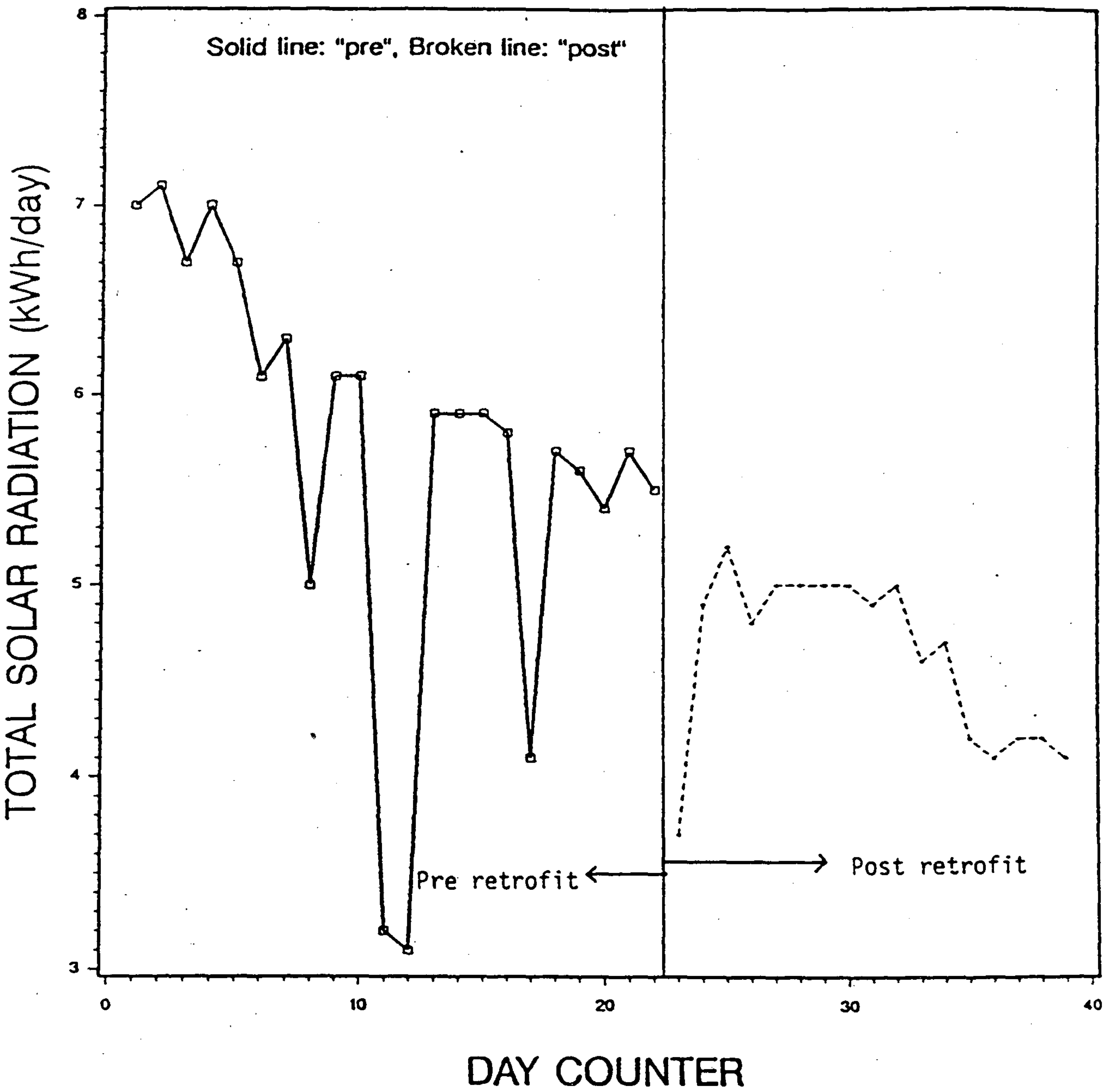


Figure V-6C. Site 6: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions include two additional trees on west and one tree on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.

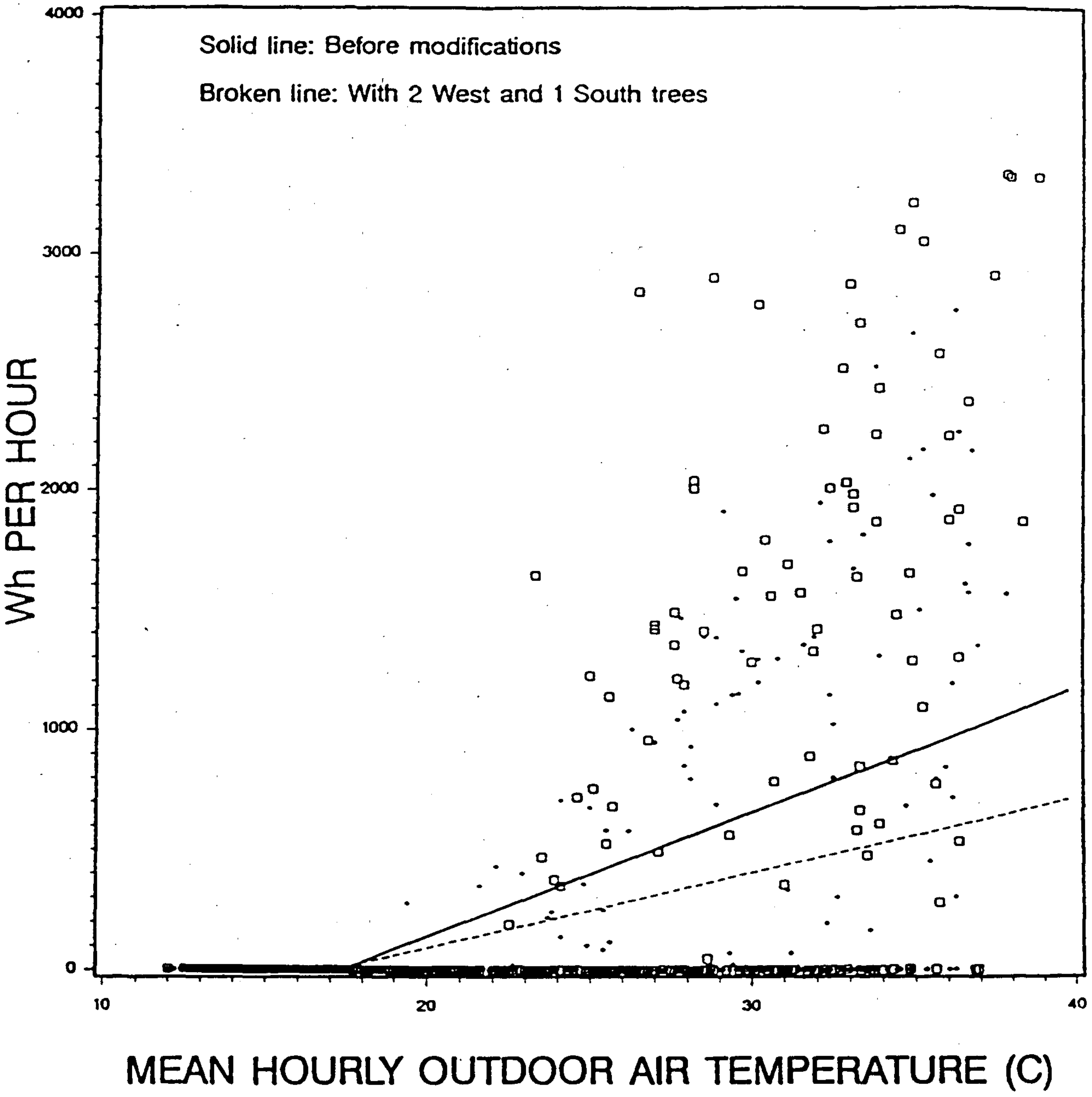
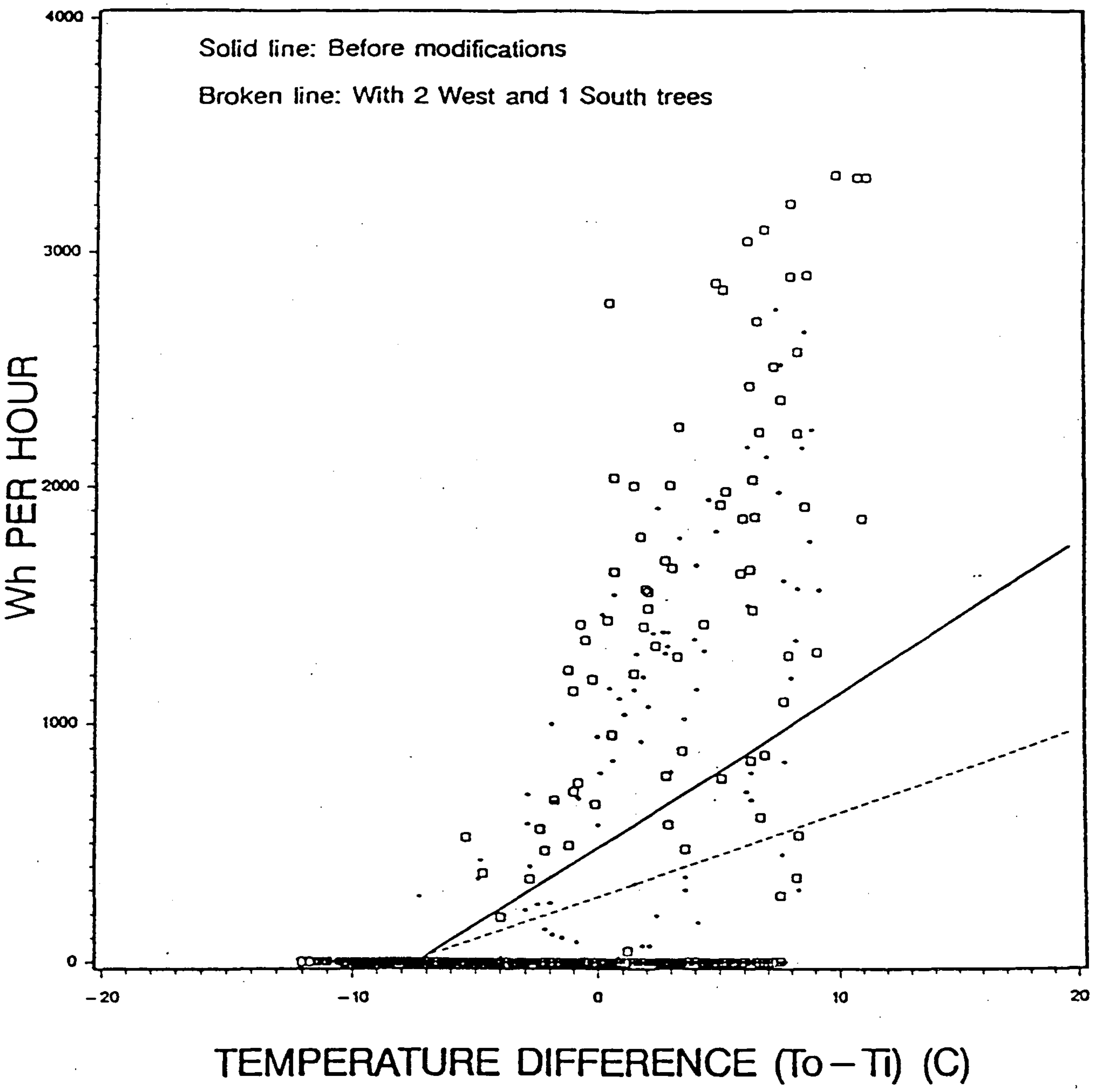


Figure V-6D. Site 6: Hourly cooling electricity use (Wh/h) vs hourly air temperature difference, outdoor minus indoor (°C). Post-conditions include two additional trees on west and one tree on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.



In **Figure V-6E** and **V-6F**, the surface temperature of the west wall is plotted versus the outdoor air temperature for both pre- and post-modification cases. In each case, a linear fit is shown, and according to these lines, we can see that in the afternoon, when outdoor air temperature is around 35°C (when the west wall is insolated), the surface temperature of the wall is on the average 4°C lower with the trees in place than the case without trees. Recall that the trees were small and that effect is small accordingly. Also, some of the effect may have been caused by lower insolation.

The comparison of measured and simulated data for Site 6 are presented in **Figures V-6G** and **V-6H**. At this site, the simulated peak load coincides with the measured peak for the post-period, but is typically 0.5 kW lower in the pre-period. The models also overpredict cooling energy use in the post-period more than in the pre-period. As at Site 5, the simulated building has cooling consumption later into the evening than the real building, which leads to the overprediction of total daily cooling use. We also see at Site 6 that the outdoor temperature drops faster in the evening than at the airport, which may explain some of the disagreements.

The simulated cooling use is plotted against outdoor temperature in **Figure V-6I**. The model and measured data shown in Figure V-6A agree well on cooling energy consumption at higher temperatures. The measured data shows 15 kWh/day at 40°C in the pre-period and 10.5 kWh/day at 40 °C in the post-period. The model predicts 16 and 13.5 kWh/day, respectively. The model also shows that when the same climatic inputs are used for the base and tree cases, there is virtually no difference in cooling energy consumption.

Figure V-6E. Site 6: West wall surface temperature (°C) vs outdoor air temperature (°C) for pre-retrofit conditions. Solid line is regression fit to the data. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.

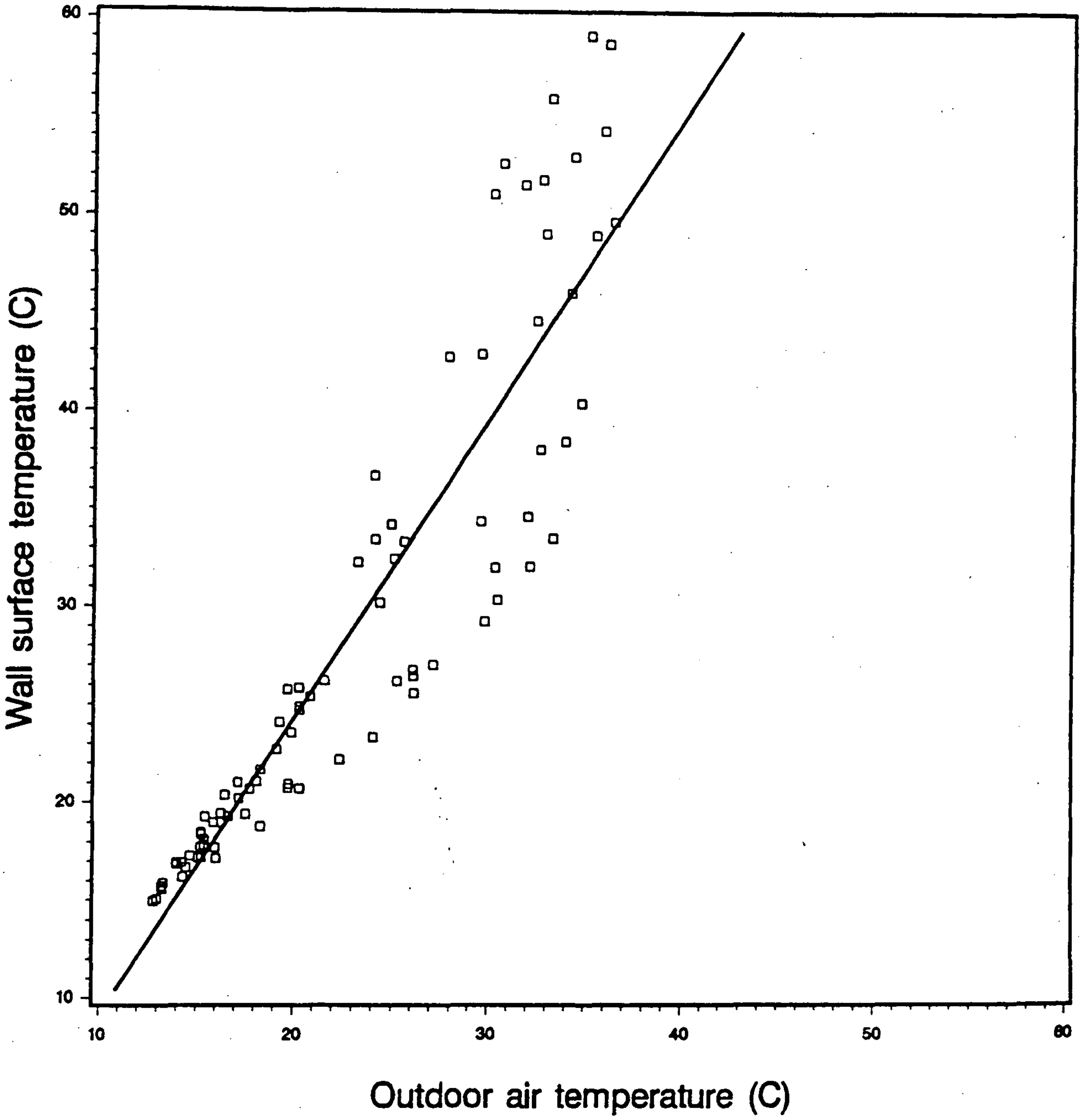


Figure V-6F. Site 6: West wall surface temperature (°C) vs outdoor air temperature (°C) for post-retrofit conditions. Solid line is regression fit to the data. Post-retrofit condition: two additional trees on west and one additional tree on south. Pre-retrofit monitoring period at this site was August 21 through September 22, and the post-retrofit period was September 25 through October 21, 1991.

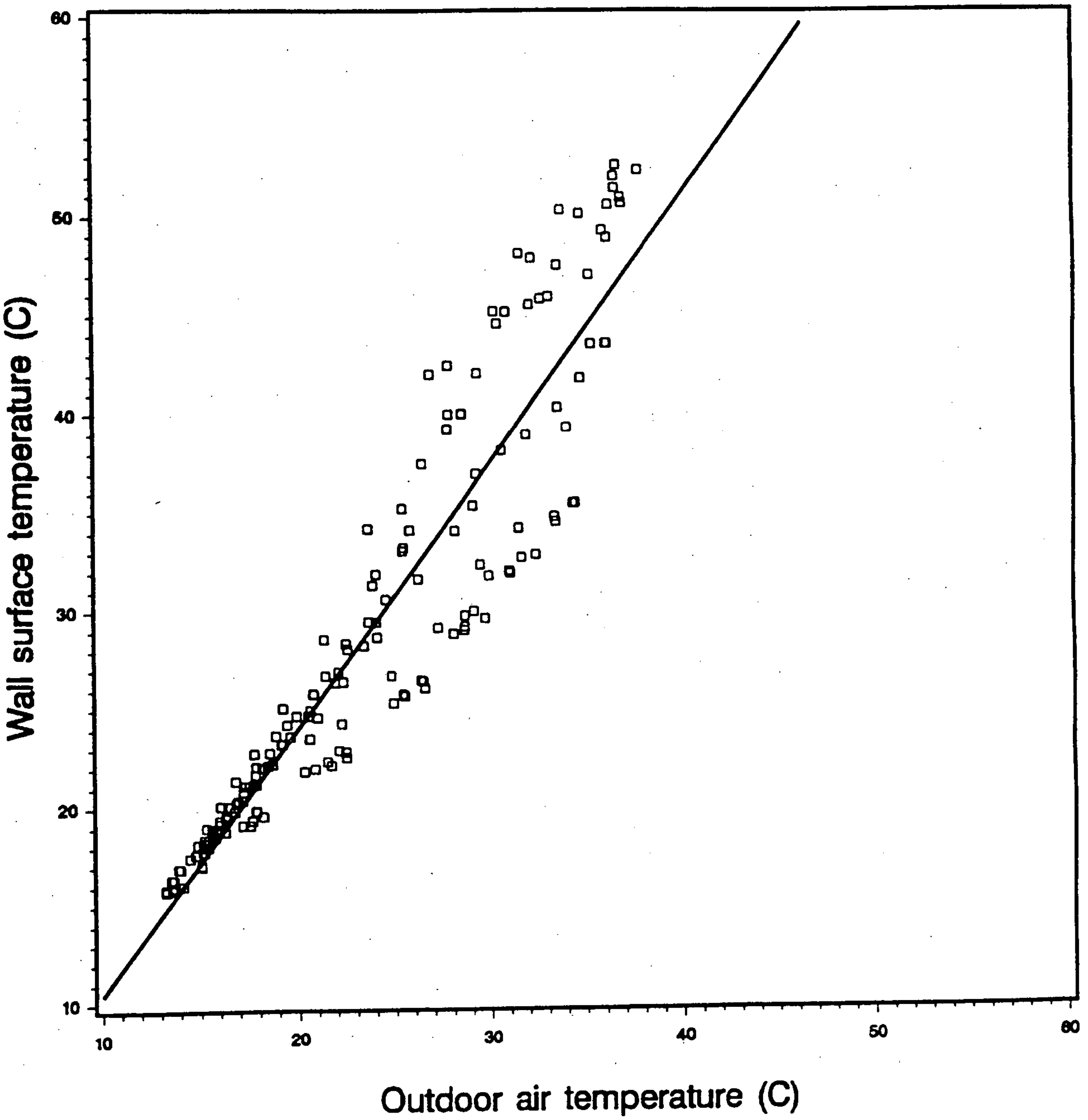


Figure V-6G. Compressor watt hours and building interior temperature for 9/17 to 9/23 at Site 6. Comparison of measured and simulated data before vegetation modification.

Days 260 to 266 Measured: 7.7 kWh/day DOE-2: 8.5 kWh/day.

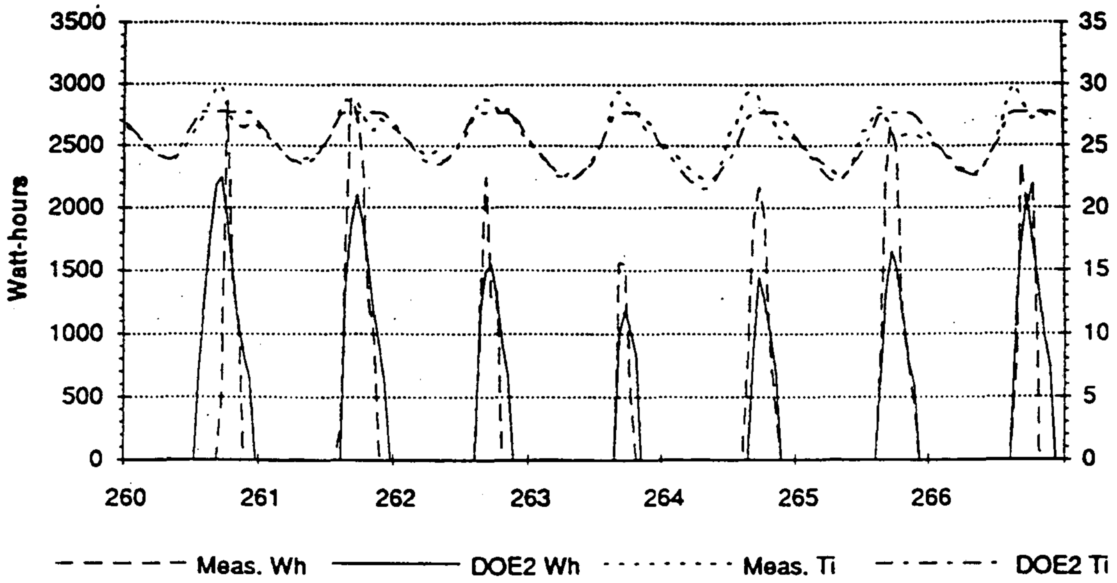


Figure V-6H. Compressor watt hours and building interior temperature for 9/30 to 10/6 at Site 6. Comparison of measured and simulated data after vegetation modification.

Days 274 to 277 Measured: 8.3 kWh/day DOE-2: 10.4 kWh/day.

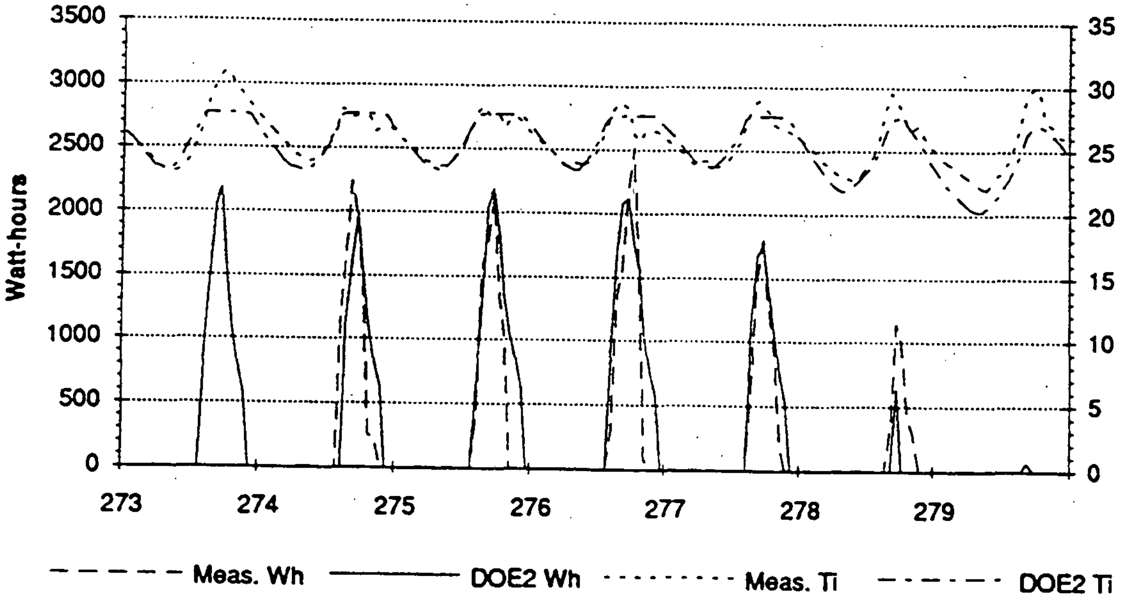
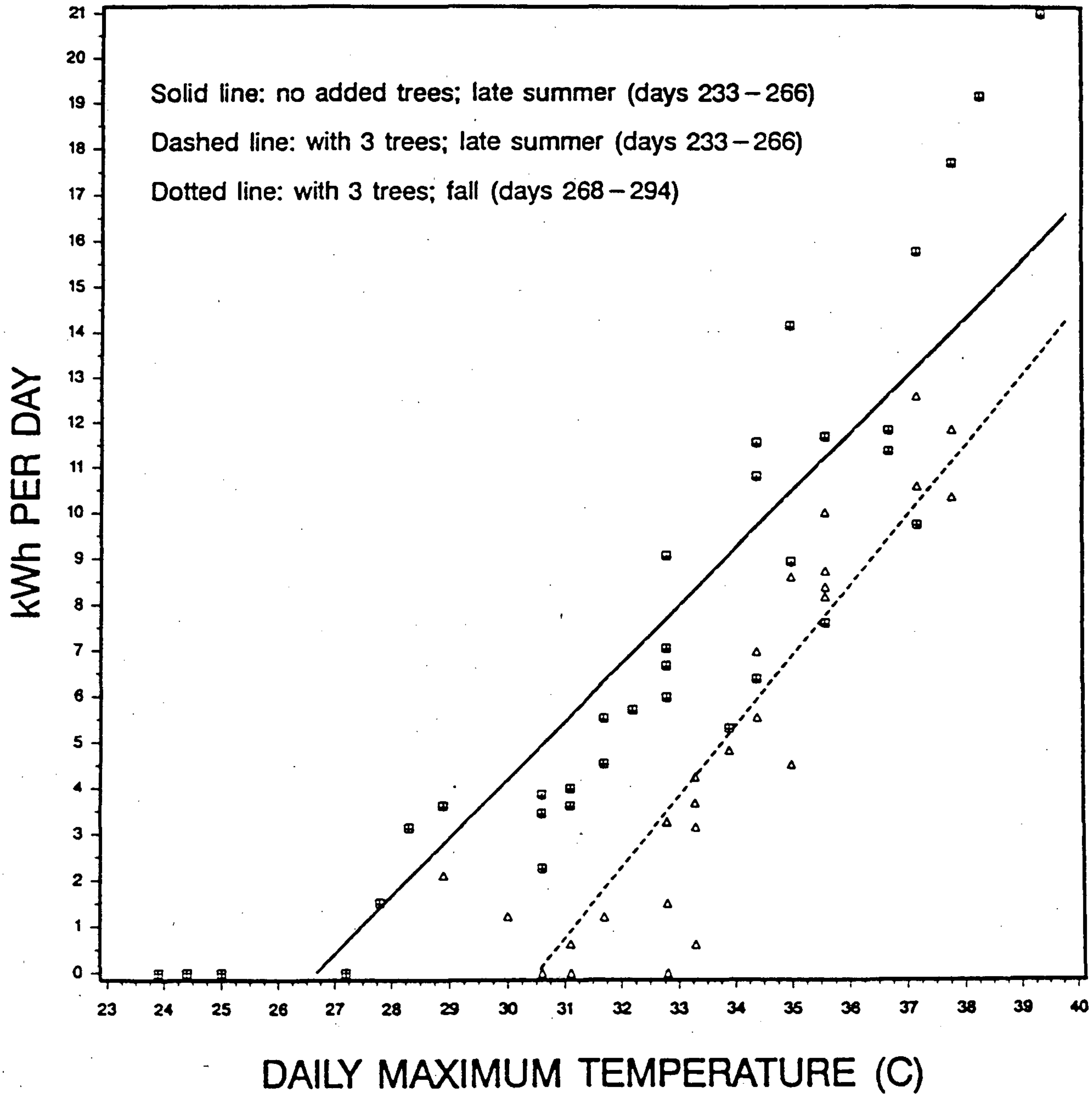


Figure V-6I. Site 6: Simulation Results: Daily Data Squares and solid line represent base case in late summer (days 249 - 266). Crosses and dashed line represent the addition of 3 shade trees in late summer (days 249 - 266). Triangles and dotted line represent the case of 3 shade trees in fall (days 268 - 294).



Site 7

Site 7 is located far southeast of Sacramento, just west of Mather AFB, in a relatively open area. Vegetation at both neighborhood and building scales was moderate. Site 7 had two unshaded southwest windows, which were subsequently shaded with two small trees. Pre- and post-retrofit data for this site were available for 20 days (JD 246 - 265) and 23 days (JD 268 - 290), respectively. There were a few hours of missing data in both "pre" and "post" monitoring periods.

Figure V-7A shows daily data for Site 7. As in the previous figures, the solid line represents pre-modification conditions whereas the broken line represents conditions after two trees were placed on the southwest side. For example, at 38°C outdoor air temperature, the positioning of 2 southwest trees resulted in a reduction of ~5 kWh/day or about 34% of cooling electricity use.

The hourly data suggest smaller changes. **Figures V-7B** and **V-7C** represent hourly energy use data plotted versus mean hourly outdoor air temperature and the hourly difference in temperature between outdoor and indoor air, respectively. Figure V-7B indicates a reduction of only 6% at 38°C, and Figure V-7C indicates that at an outdoor minus indoor air temperature difference of 5°C, the reductions amount to about 20%. The DOE-2 simulations indicate that almost all these reductions were caused by lower insolation.

Figures V-7D and **V-7E** depict the changes in the surface temperature of the southwest wall before and after trees were in place. In a fashion similar to that discussed earlier, the regression lines in those figures indicate that the change in surface temperature of the southwest wall was not significant. But that is probably because the temperature sensor was not in a shaded spot. The temperature difference in the afternoon, as indicated by the regression lines, amounts to only 0.5 °C (on the average) and is close to sensor accuracy.

The comparisons of hourly simulated and measured data for Site 7 are presented in **Figures V-7F** and **V-7G**. This site shows highly erratic behavior in both cooling energy use and interior temperatures. There are days of no cooling (248), the thermostat "threshold" (250, 270, and 272), and other unexplained noise (247 and 268). On the most controlled days, such as 251 to 253 and 269, 270, and 273, the simulated peak load is similar to the measured peak while the daily simulated totals are slightly higher.

Figure V-7A. Site 7: Daily cooling electricity use (kWh/day) vs maximum outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions with two additional trees on southwest. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was September 3 through September 23, and the post-retrofit period was September 25 through October 18, 1991.

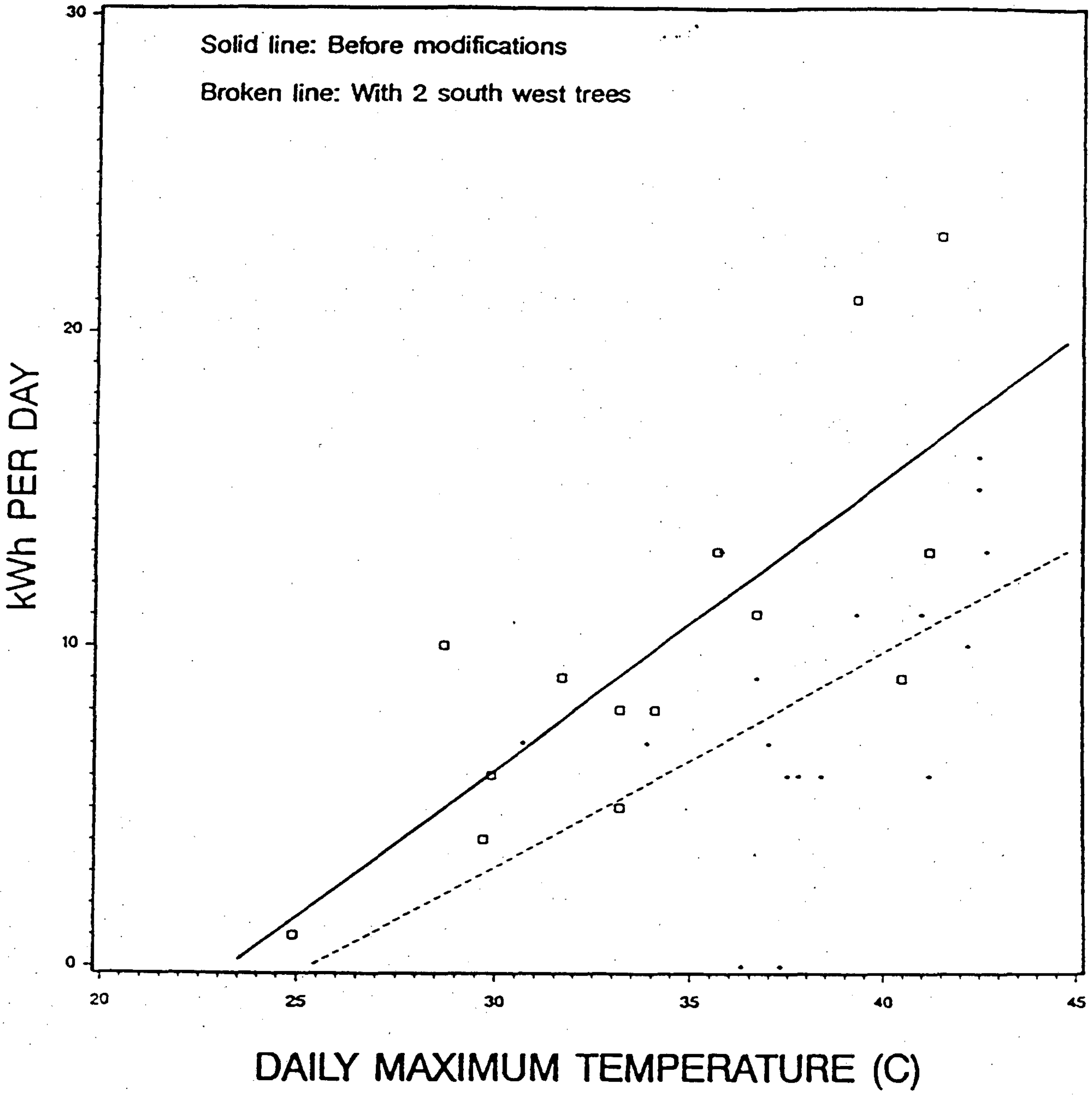


Figure V-7B. Site 7: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor temperature (°C) for pre- and post- retrofit conditions. Post-conditions with two additional trees on southwest. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was September 3 through September 23, and the post-retrofit period was September 25 through October 18, 1991.

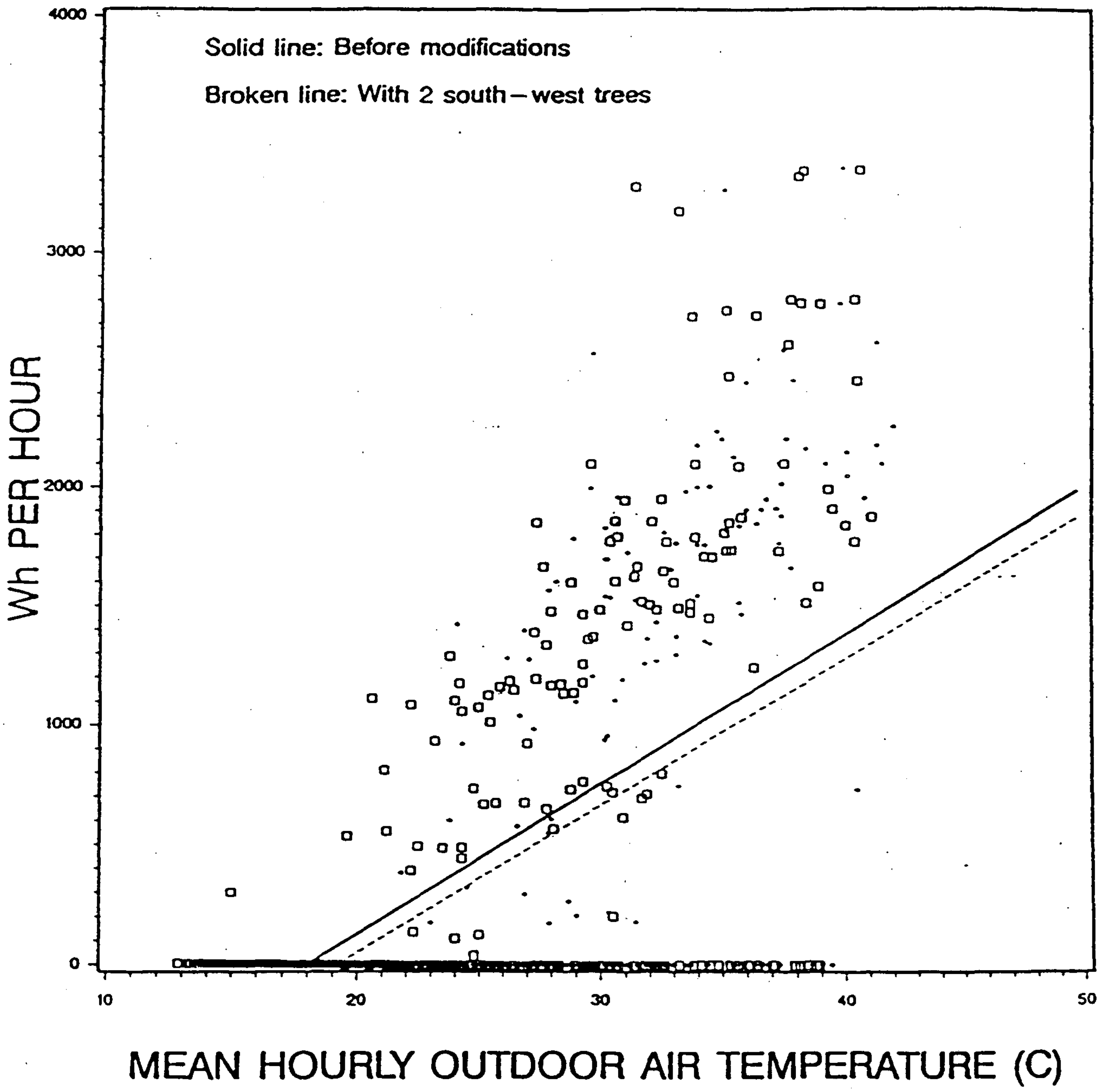


Figure V-7C. Site 7: Hourly cooling electricity use (Wh/h) vs hourly difference between outdoor and indoor air temperature (°C). Solid regression line represents pre-retrofit conditions, whereas the broken regression line represents post-retrofit conditions, i.e., with two trees on the southwest. Pre-retrofit monitoring period at this site was September 3 through September 23, and the post-retrofit period was September 25 through October 18, 1991.

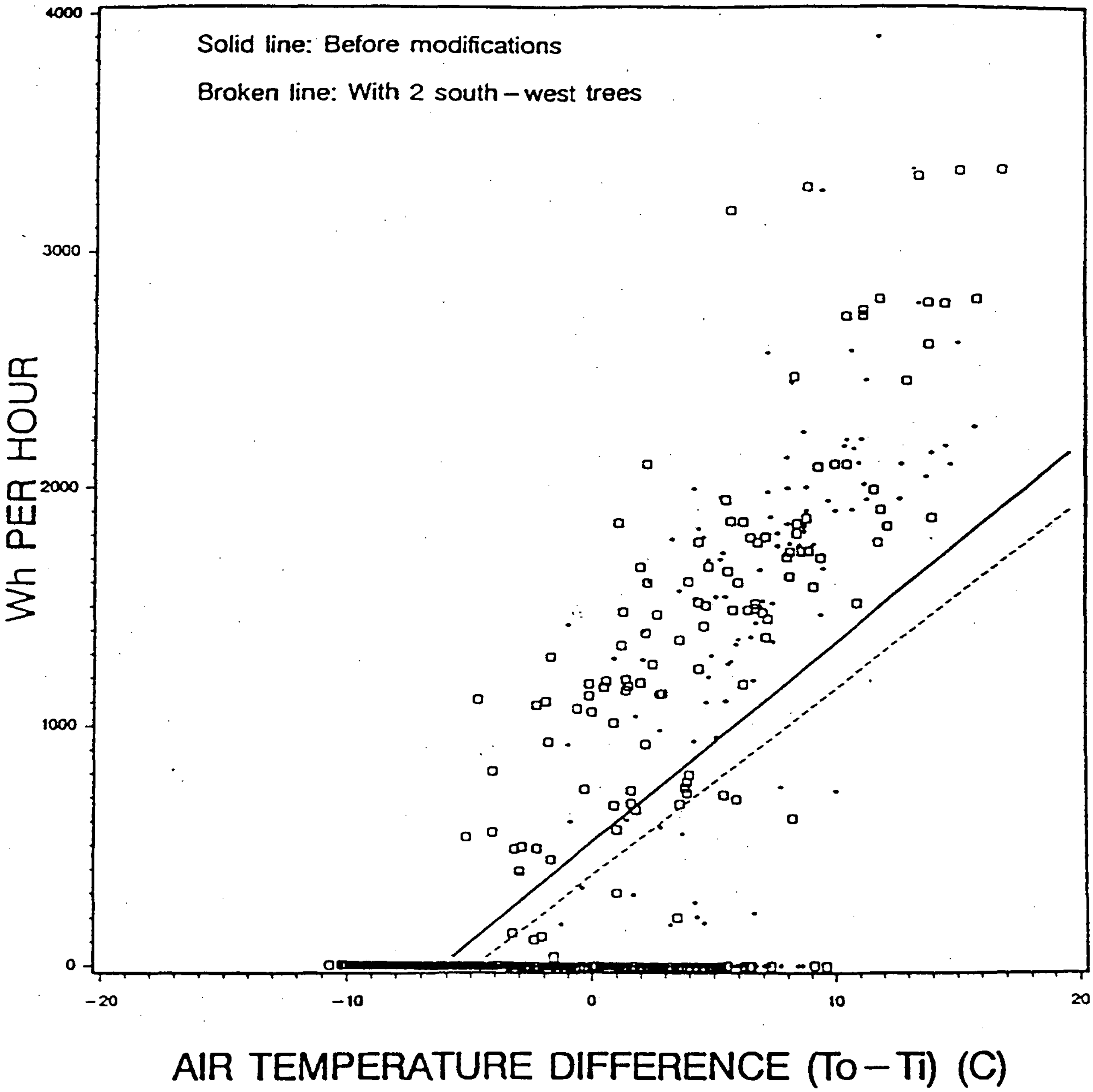


Figure V-7D. Site 7: Southwest wall surface temperature (°C) vs outdoor air temperature (°C) for pre-retrofit conditions. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was September 3 through September 23, and the post-retrofit period was September 25 through October 18, 1991.

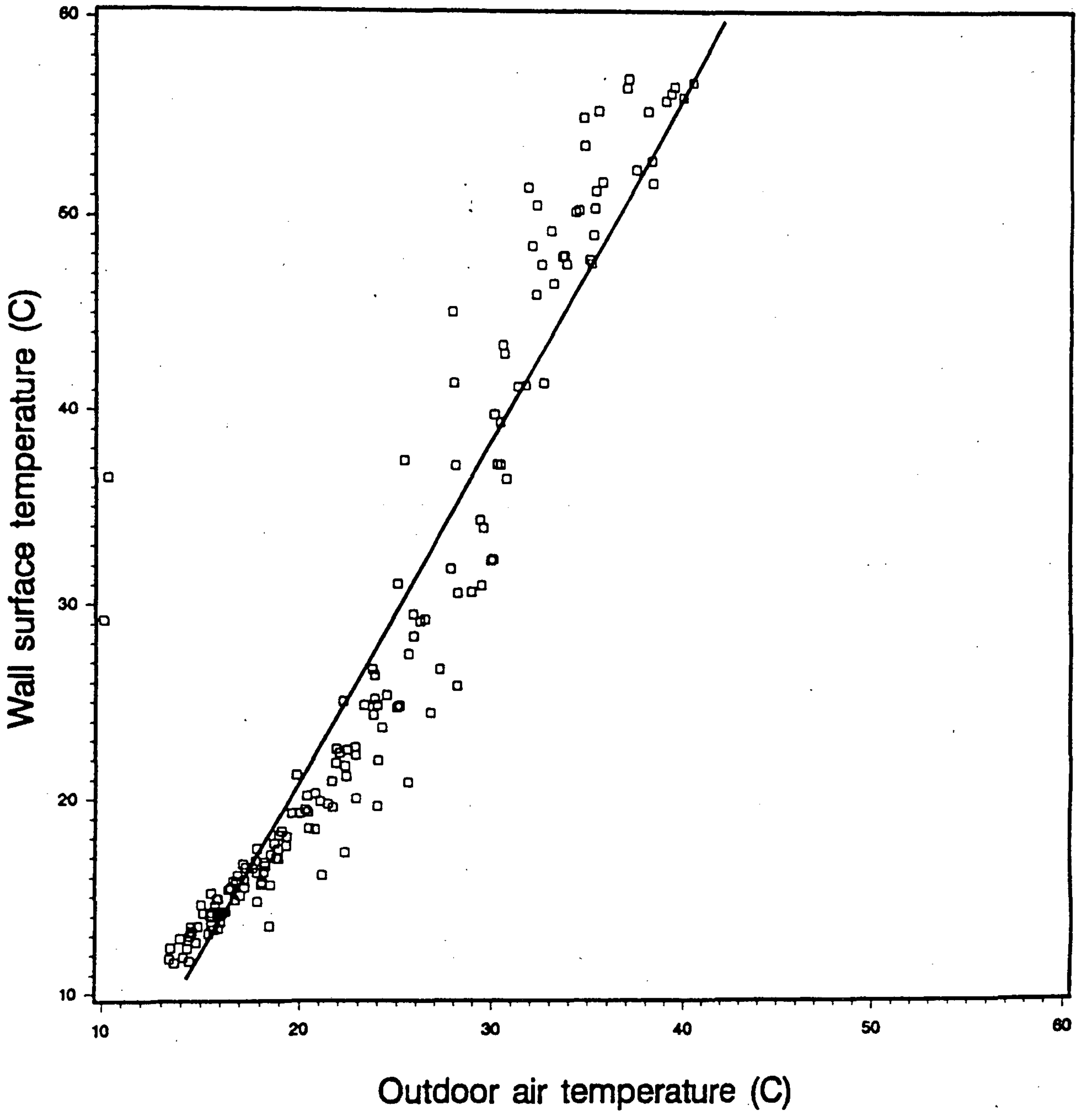


Figure V-7E. Site 7: Southwest wall surface temperature (°C) vs outdoor air temperature (°C) for post-retrofit conditions, i.e., with two additional tress on the southwest. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was September 3 through September 23, and the post-retrofit period was September 25 through October 18, 1991.

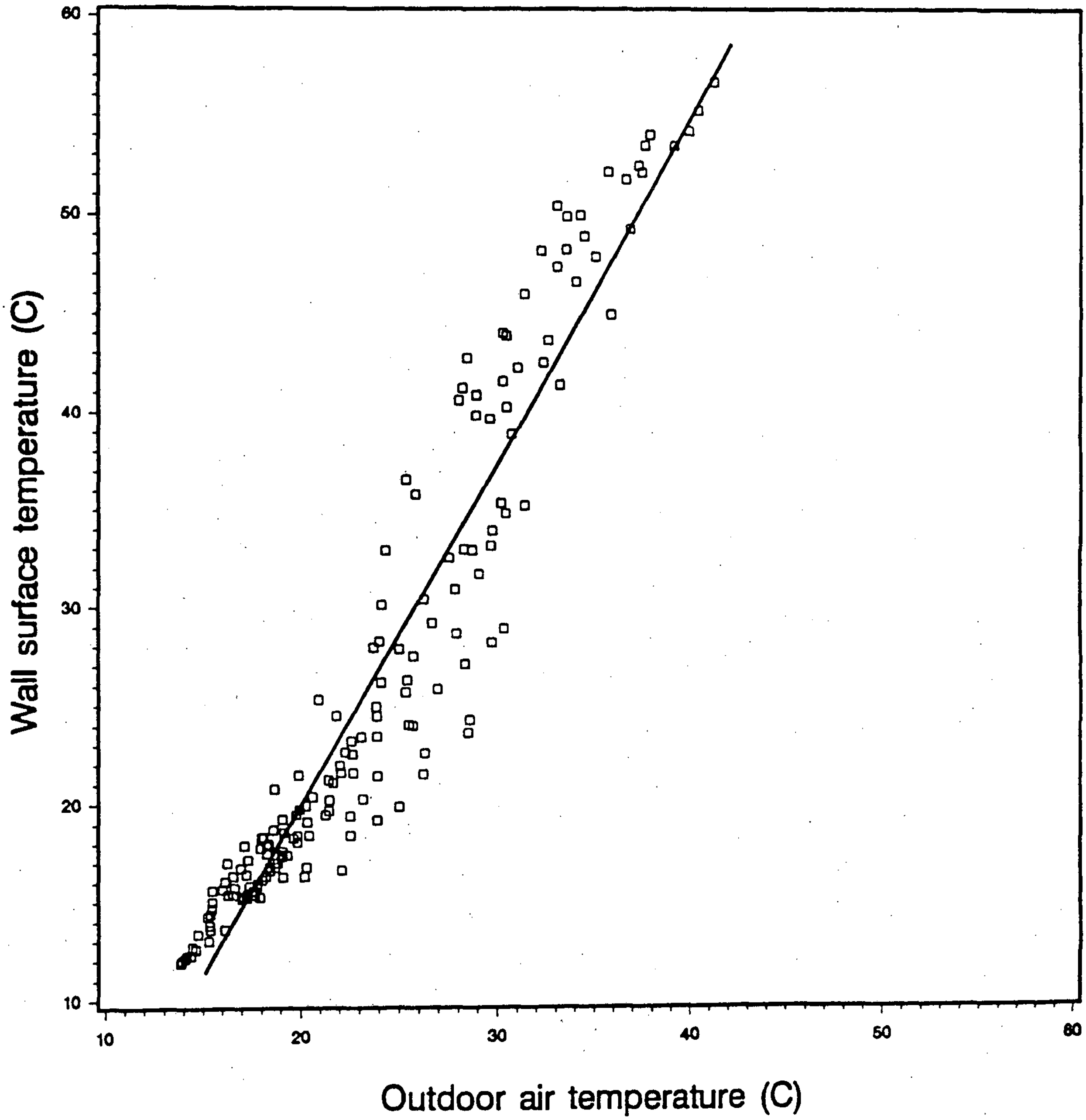


Figure V-7F. Compressor watt hours and building interior temperature for 9/4 to 9/10 at Site 7. Comparison of measured and simulated data before vegetation modification.

Days 249 to 253 Measured: 6.2 kWh/day DOE-2: 7.2 kWh/day.

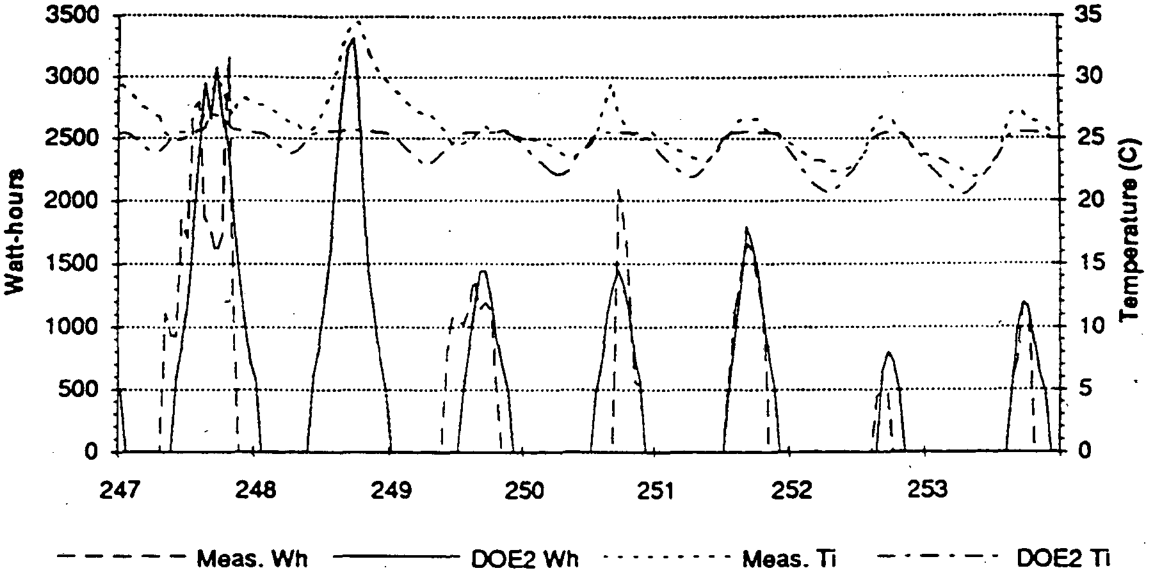
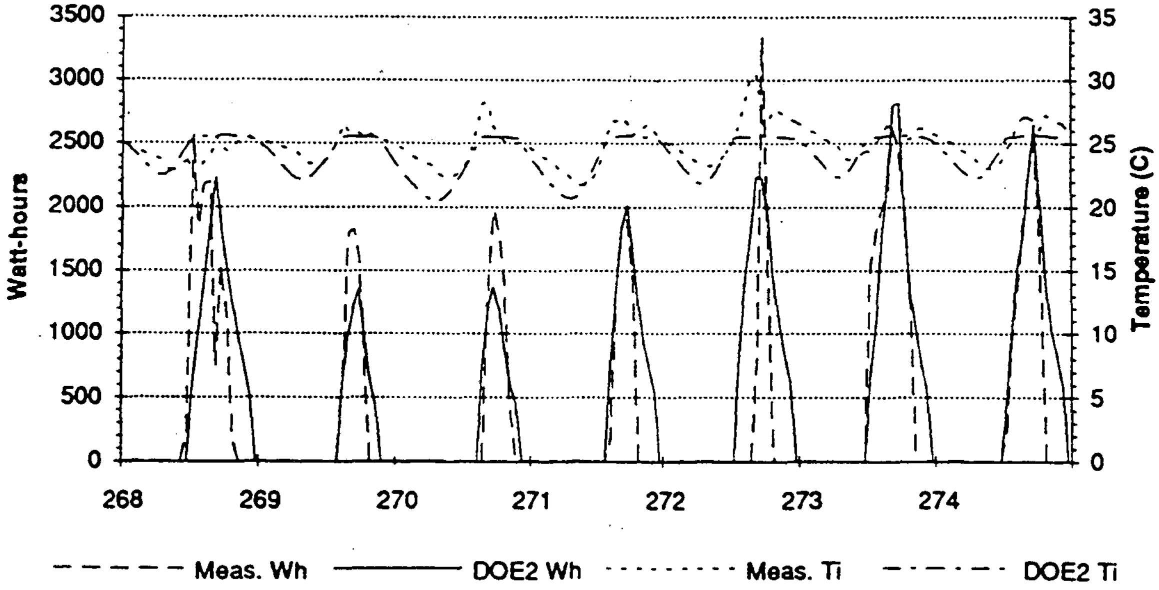


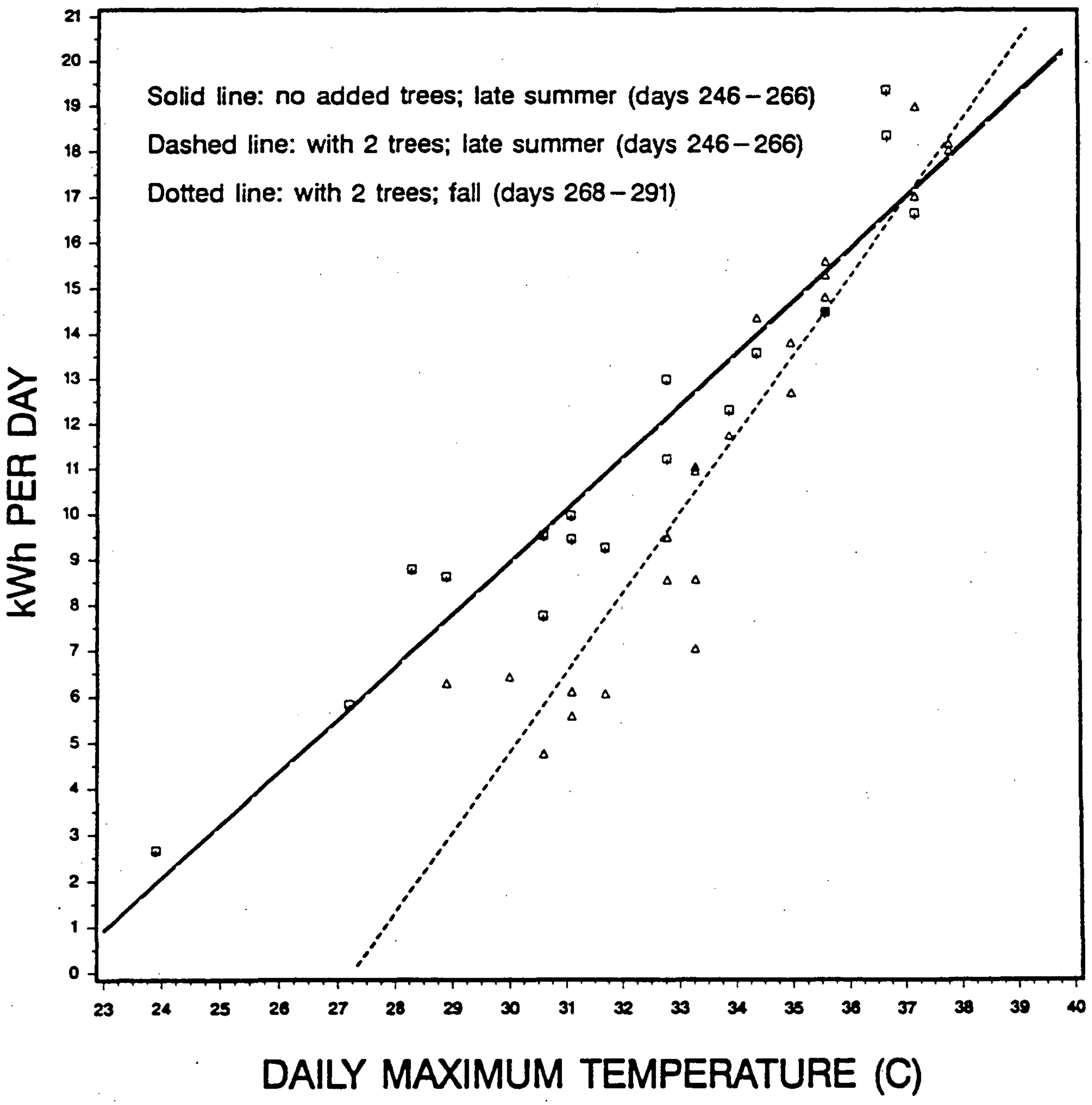
Figure V-7G. Compressor watt hours and building interior temperature for 9/25 to 10/1 at Site 7. Comparison of measured and simulated data after vegetation modification.

Days 269 to 271 Measured: 6.8 kWh/day DOE-2: 7.9 kWh/day.



The simulated daily data is plotted in **Figure V-7H**. The simulated data does not agree well with the measured data shown in Figure V-7A. This is likely because of the erratic cooling energy use shown in Figures V-7F and V-7G. The model also predicts no real difference between the base and the tree case.

Figure V-7H. Site 7: Simulation Results: Daily data. Squares and solid line represent base case in late summer (days 249 - 266). Crosses and dashed line represent the addition of 2 shade trees in late summer (days 249 - 266). Triangles and dotted line represent the case of 2 shade trees in fall (days 268 - 294).



Site 8

Site 8 is located just next to Site 1 (in northeast Sacramento) and has similar surrounds. However, Site 8 has much less vegetation than Site 1 and, in fact, the building envelope was mostly unshaded. We decided to position several trees along the south wall, so as to shade the windows and portions of the wall. **Figure V-8A** represents some of the daily data from that site. We do not show all the days because we were uncertain about some of the data. It appears that the thermostat was reset on some days (reset to lower than 25.5°C) and in the daily data we present here, these days were removed. At 38°C, there is a savings of ~2.5 kWh/day in cooling electricity use, which amounts to a reduction of 12%.

Figures V-8B and **V-8C** summarize hourly data at Site 8. At an outdoor air temperature of 38°C, for example, the regression lines in Figure V-8B indicate a reduction of 7%, and at an outdoor minus indoor air temperature difference of 5°C, the reduction also amount to 7%, according to the regressions in Figure V-8C. The DOE-2 simulations indicate that there could be no savings if the effects of lower insolation were accounted for.

However, the trees seem to have had a significant impact on the surface temperatures of the walls. **Figures V-8D** and **V-8E** show the temperature at the south wall, whereas **Figures V-8F** and **V-8G** depict the surface temperature of the west wall. For each wall, the temperature is plotted versus solar radiation. The time-sequence of the scatter is in a counter-clockwise direction.

In Figure V-8D, we can see that an increase in solar radiation in the morning (lower scatter) results in increasing surface temperature at the south wall, and, as insolation continues, the afternoon temperatures (upper scatter are higher). Figure V-8E shows that, after the trees were in place, the afternoon south-wall surface temperatures (upper scatter) are generally lower than those depicted in Figure V-8D. On the average, the afternoon surface temperature on the south wall was decreased by 7°C, due to the shading effects of trees. Recall that site 8 had more trees than other sites. The regression lines in these figures have no special usefulness aside from demarcating the lower and upper scatters (morning and afternoon hours).

In Figure V-8F the surface temperature at the west wall for the pre-conditions is shown. Examining the upper scatters show that although the maximum temperatures on the south and west walls are comparable, the timing of the maximum temperature on the west wall (Fig V-8F) is about 3 hours later than at the south wall (Fig 8D). Figure V-8G shows the large depression

Figure V-8A. Site 8: Daily cooling electricity use (kWh/day) vs maximum outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions with seven additional trees on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

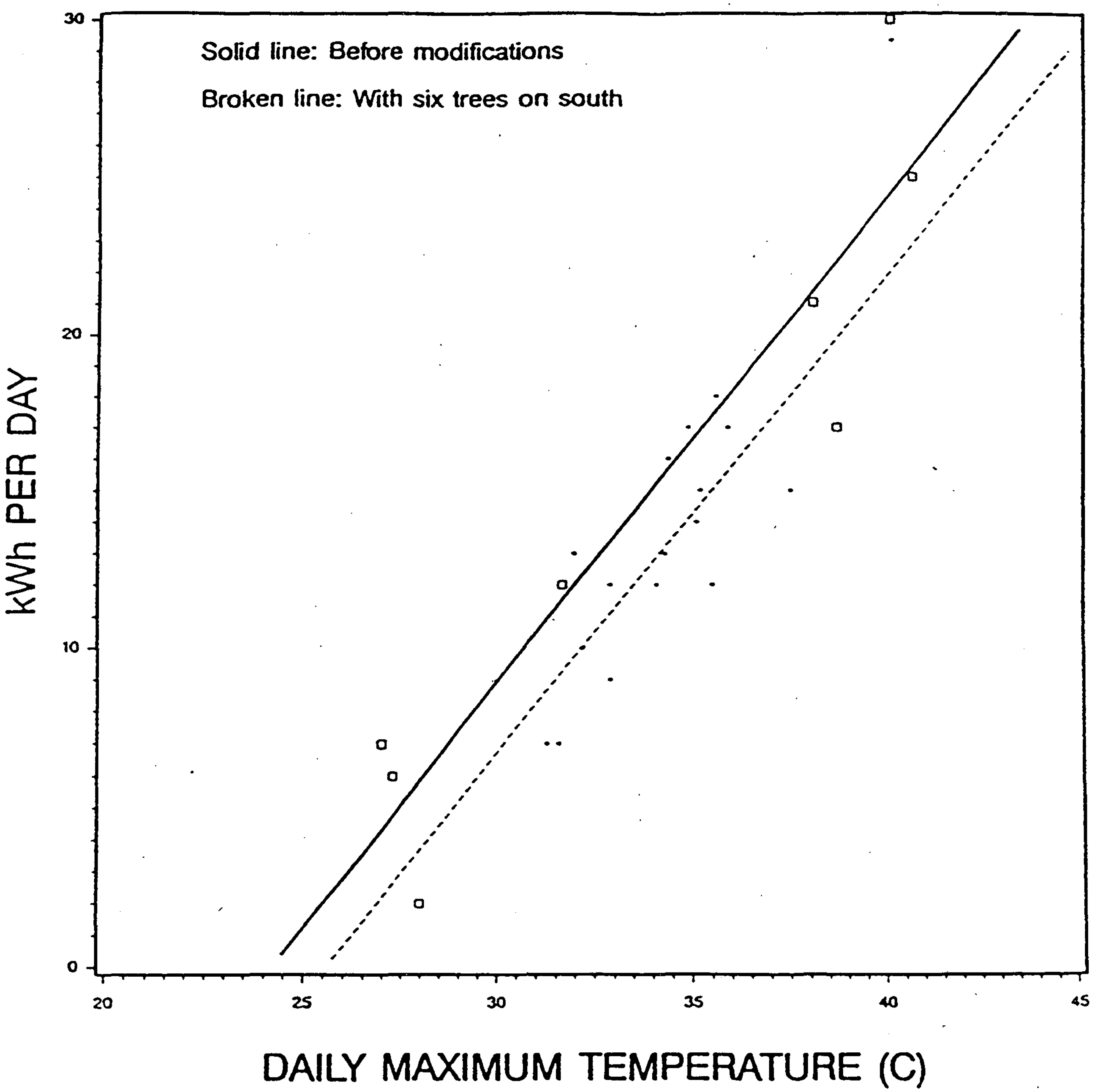


Figure V-8B. Site 8: Hourly cooling electricity use (Wh/h) vs mean hourly outdoor air temperature (°C) for pre- and post-retrofit conditions. Post-conditions with seven additional trees on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

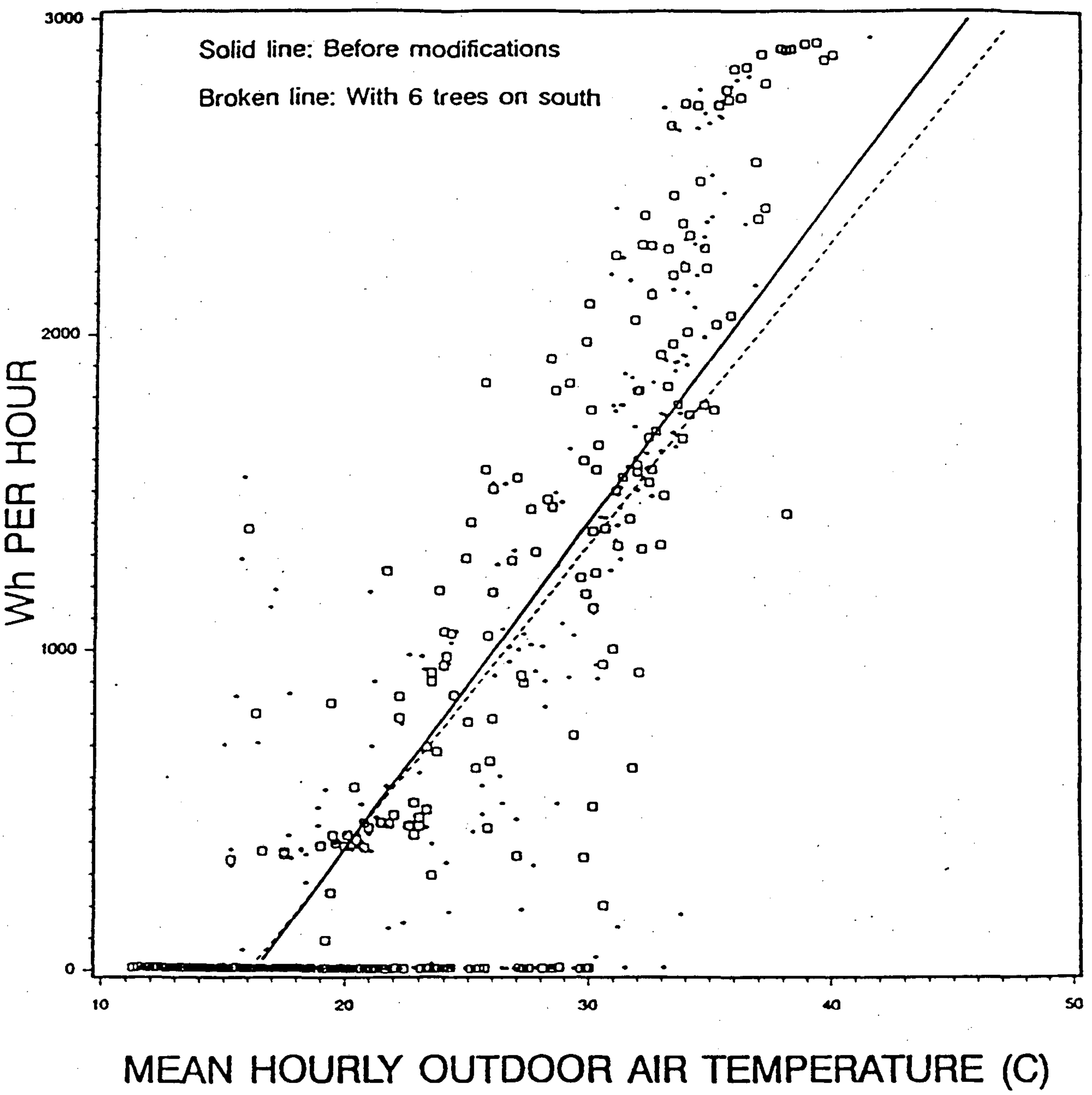


Figure V-8C. Site 8: Hourly cooling electricity use (Wh/h) vs hourly difference between outdoor and indoor air temperatures (°C). Post-conditions include seven additional trees on south. Solid regression line is for pre-retrofit conditions, broken regression line is for post-retrofit. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

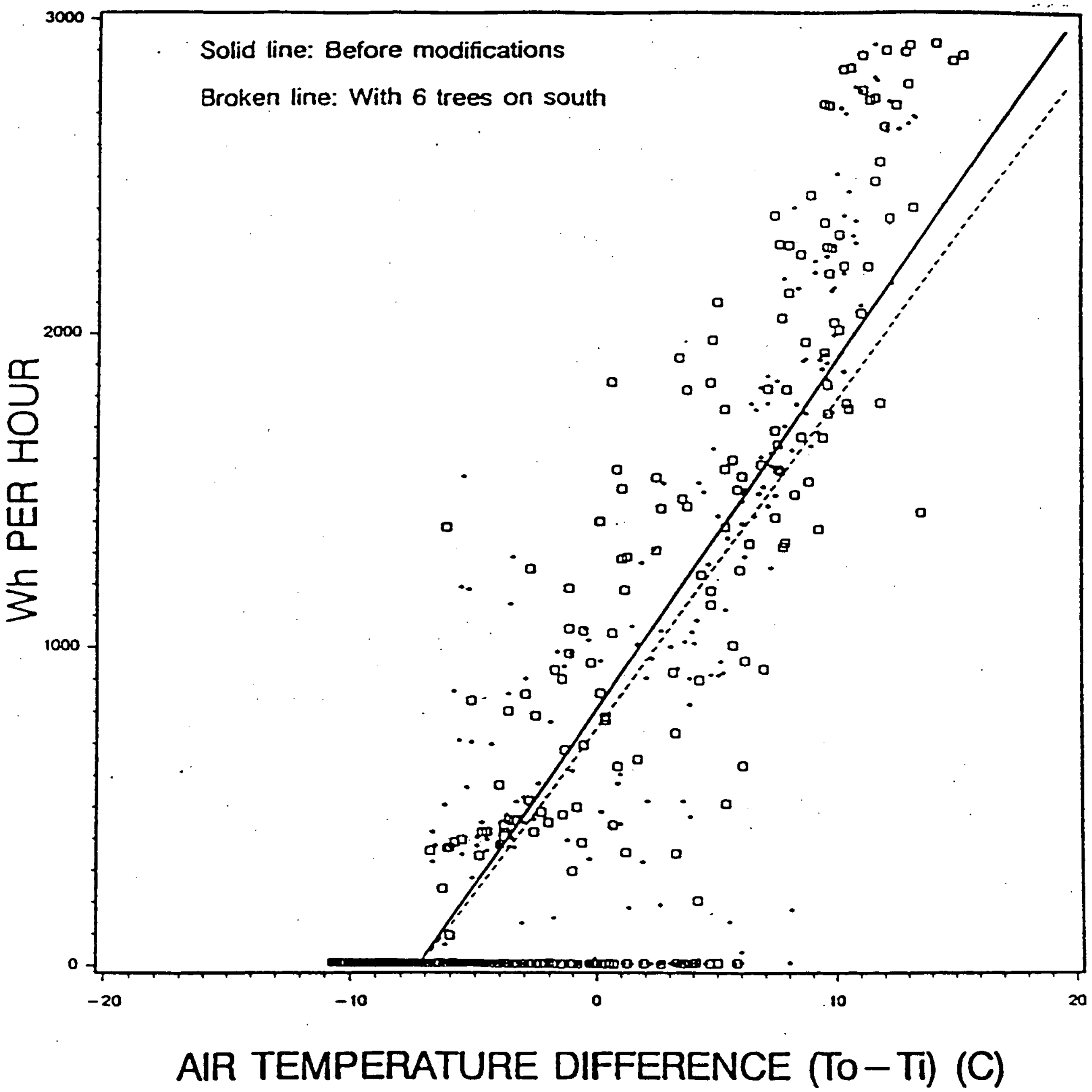


Figure V-8D. Site 8: South wall surface temperature (°C) vs horizontal solar radiation (W/m^2) for pre-retrofit conditions. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

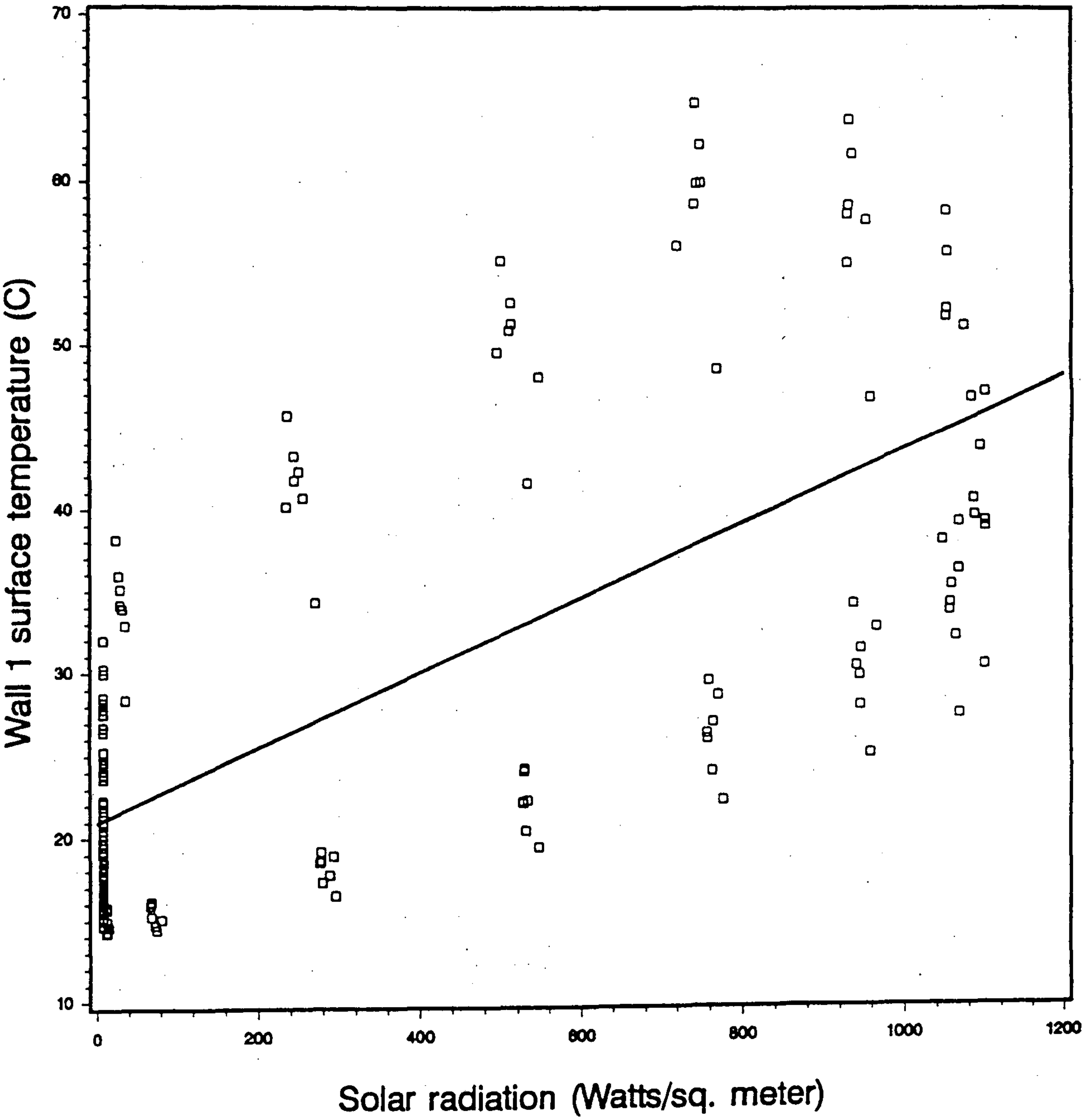


Figure V-8E. Site 8: South wall surface temperature (°C) vs horizontal solar radiation (W/m^2) for post-retrofit conditions. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

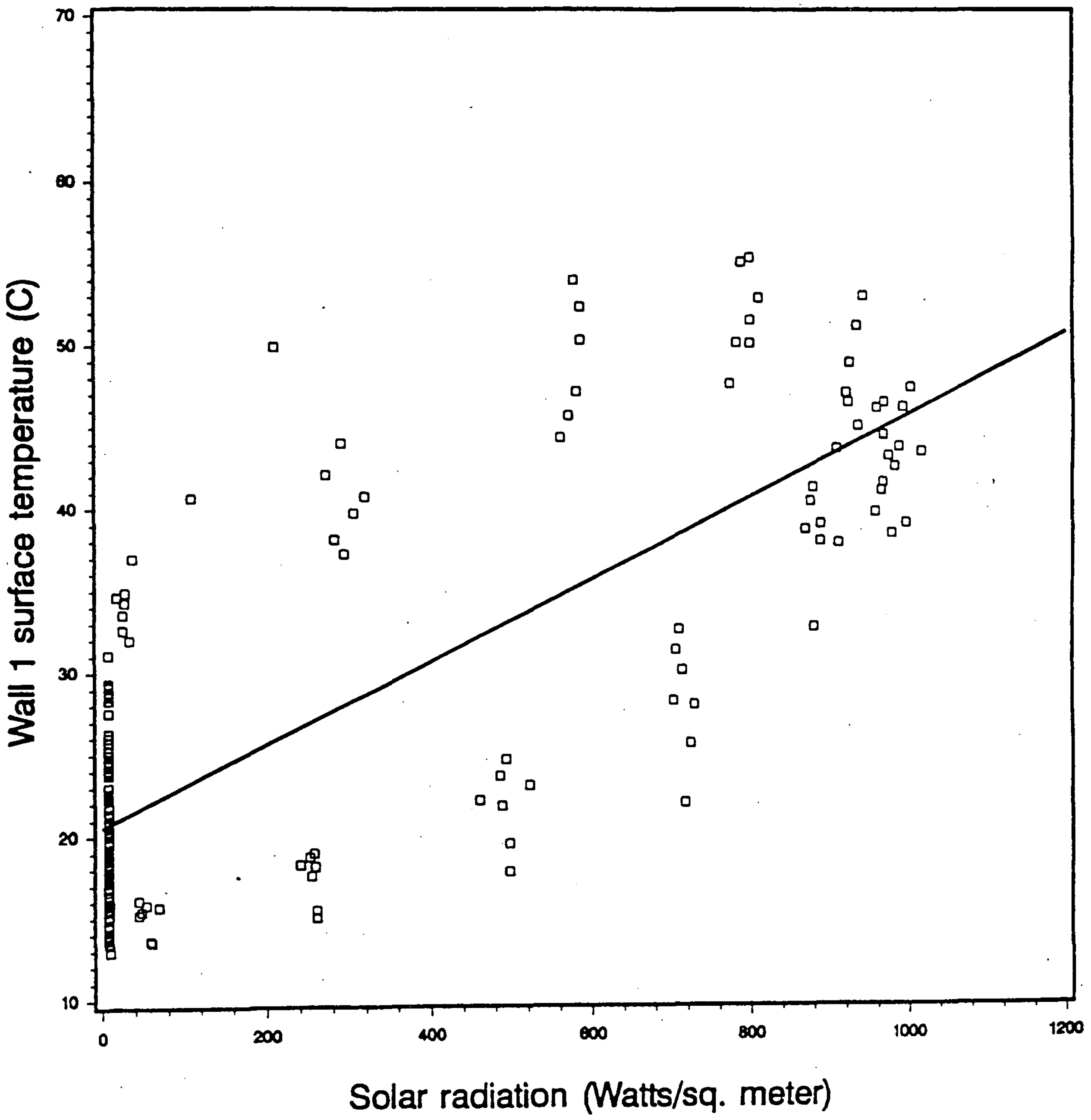


Figure V-8F. Site 8: West wall surface temperature (°C) vs horizontal solar radiation (W/m^2) for pre-retrofit conditions. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.

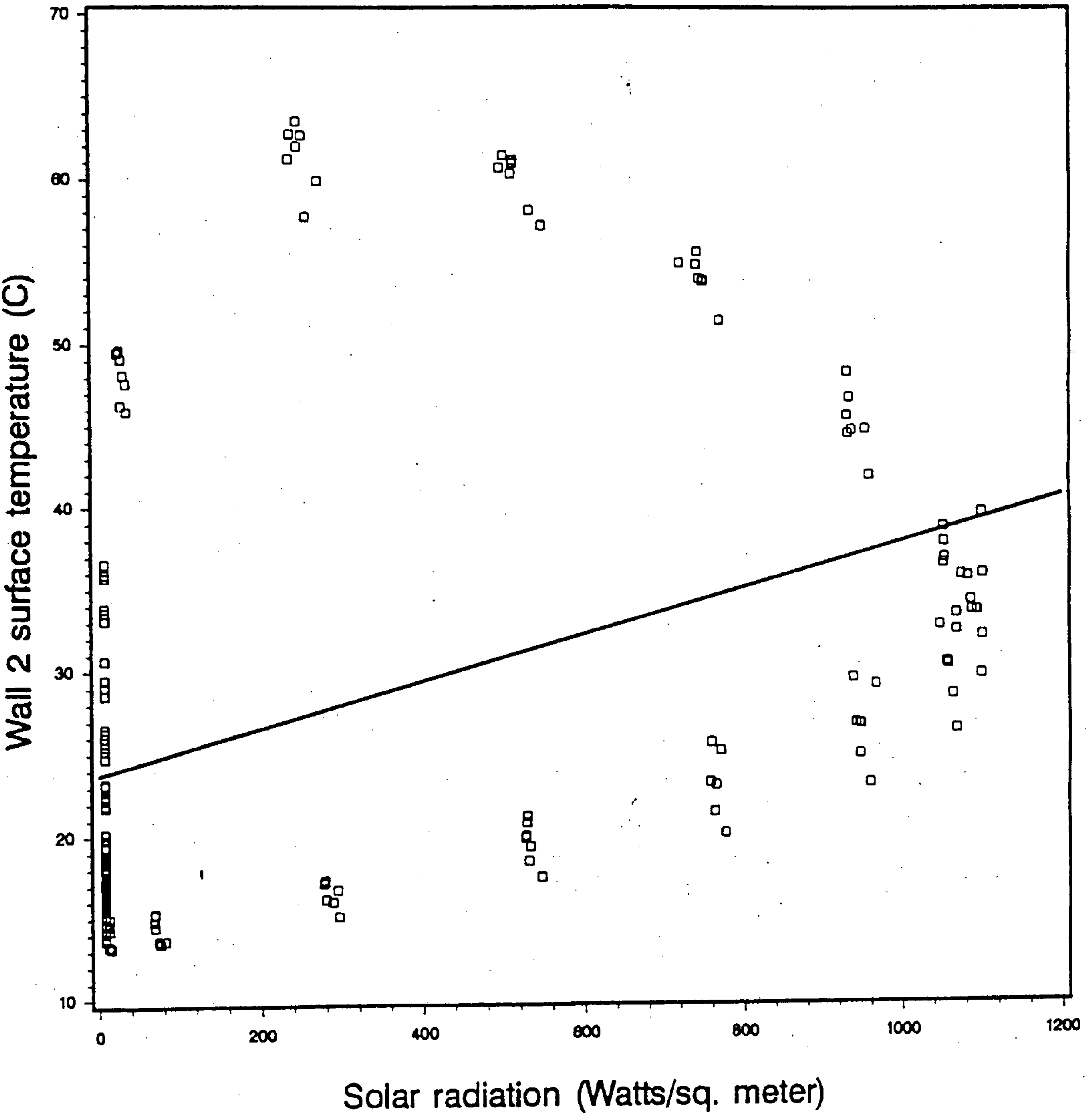
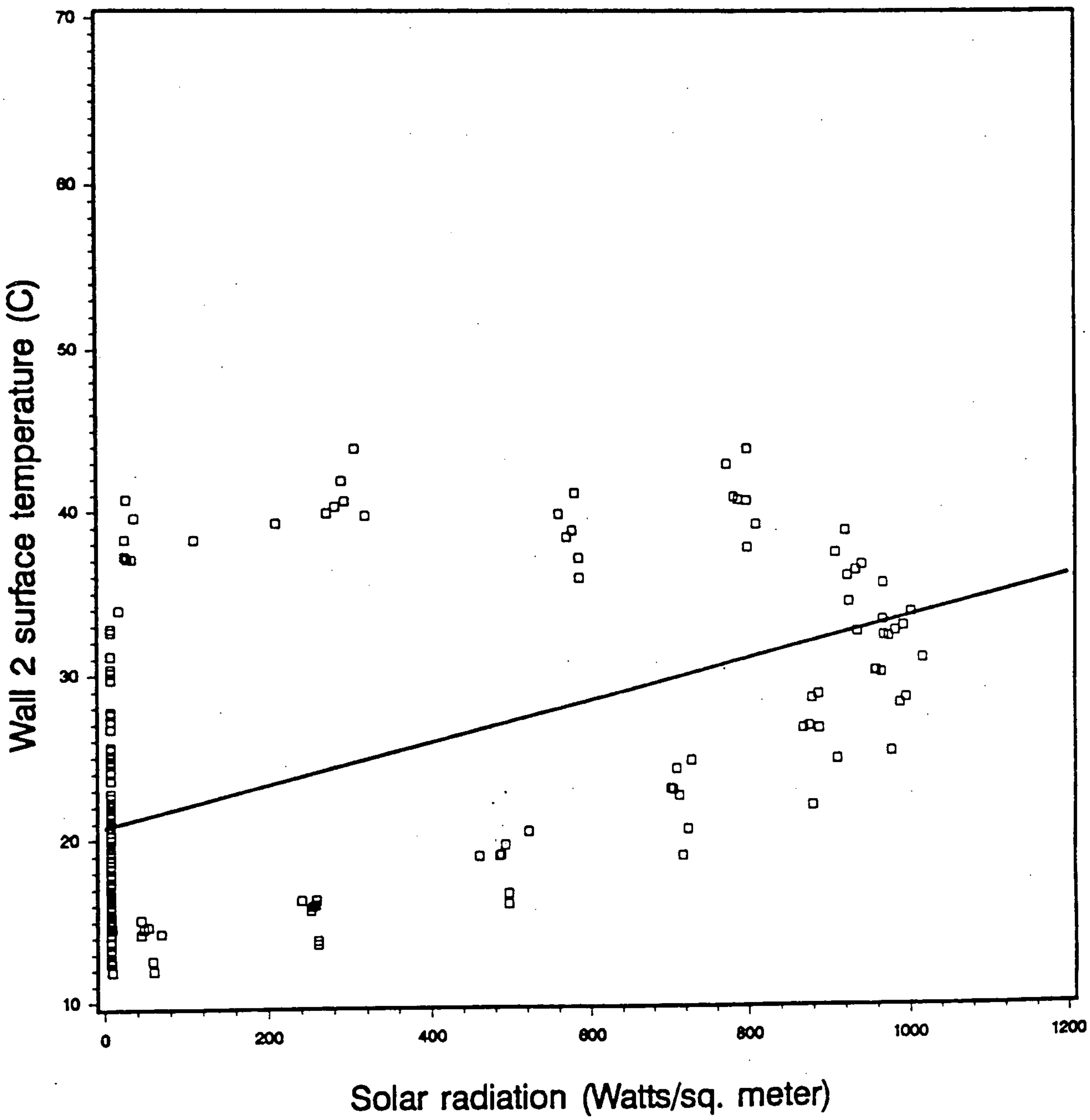


Figure V-8G. Site 8: West wall surface temperature (°C) vs horizontal solar radiation (W/m^2) for post-retrofit conditions. Solid line is a regression fit to the data. Pre-retrofit monitoring period at this site was August 23 through September 6, and the post-retrofit period was September 25 through October 21, 1991.



in the surface temperature of the west wall after the trees were in place. At the time of peak west-wall surface temperature (solar radiation = 300 Wm^{-2}), the surface temperature was on the average 20°C lower after the trees were in place (compare the upper scatter in Figures V-8F and V-8G). Note that the solar radiation given in these figures is not the normal on the surface but the total horizontal solar radiation measured at roof level.

The comparisons of simulated and measured data for Site 8 are presented in **Figures V-8H** and **V-8I**. The indoor temperature at this site is well-controlled and the simulated load and measured load agree well except for a few days when the simulated peak is much higher than the measured peak. On these days, the cooling system in the house appears to be running continuously over several hours and the simulation model does not accurately predict the peak power draw of the equipment. The model overpredicts total daily cooling by about 12% to 14% in the pre- and post-periods. The measured data for Julian days 275 and 276 also suggests that nighttime cooling or heating is being supplied by the heat pump.

The simulated daily data are plotted in **Figure V-8J**. Compared to the measured data shown in Figure V-8A, the simulated data is consistently higher by about 4 kWh/day over the pre-monitoring period, but the slope of the regression line is similar. As with the other tree sites, when accounting for the change in climatic conditions between the pre- and post-periods, the simulated cooling energy savings from the trees is minimal.

Discussion

Overall, the calibration and comparison exercises highlight the difficulty encountered in matching simulation results with measured data. The types and magnitudes of the errors are not consistent across the sites. The daily energy consumption is slightly overpredicted at Sites 2, 5 (pre-period), 6, 7, and 8, but the peaks match well. Peak loads at Sites B and 5 match well, but daily energy consumption at Site 5 does not match well.

The analysis suggests the models could benefit from further refinements. However, given the current level of characterization for each site, the models perform reasonably well. The necessary refinements would focus on details of the cooling systems, which is the primary method of assessing albedo and vegetation impacts, occupancy patterns, thermostat operations,

Figure V-8H. Compressor watt hours and building interior temperature for 8/30 to 9/5 at Site 8. Comparison of measured and simulated data before vegetation modification.

Days 242 to 248 Measured: 22.5 kWh/day DOE-2: 25.4 kWh/day.

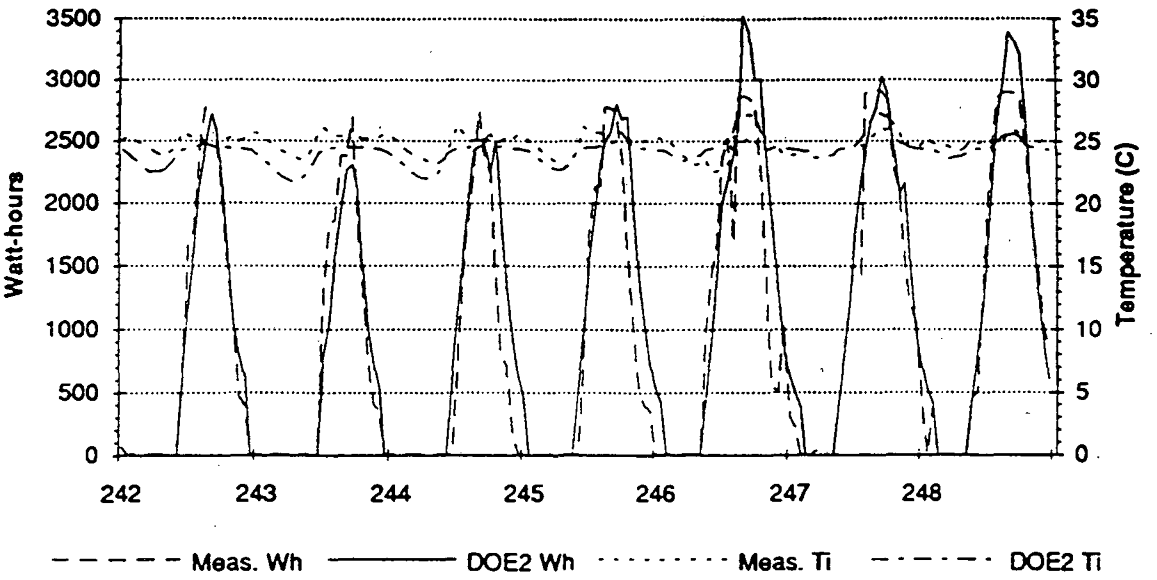


Figure V-8I. Compressor watt hours and building interior temperature for 10/2 to 10/8 at Site 8. Comparison of measured and simulated data after vegetation modification.

Days 277 to 281 Measured: 12.7 kWh/day DOE-2: 14.5 kWh/day.

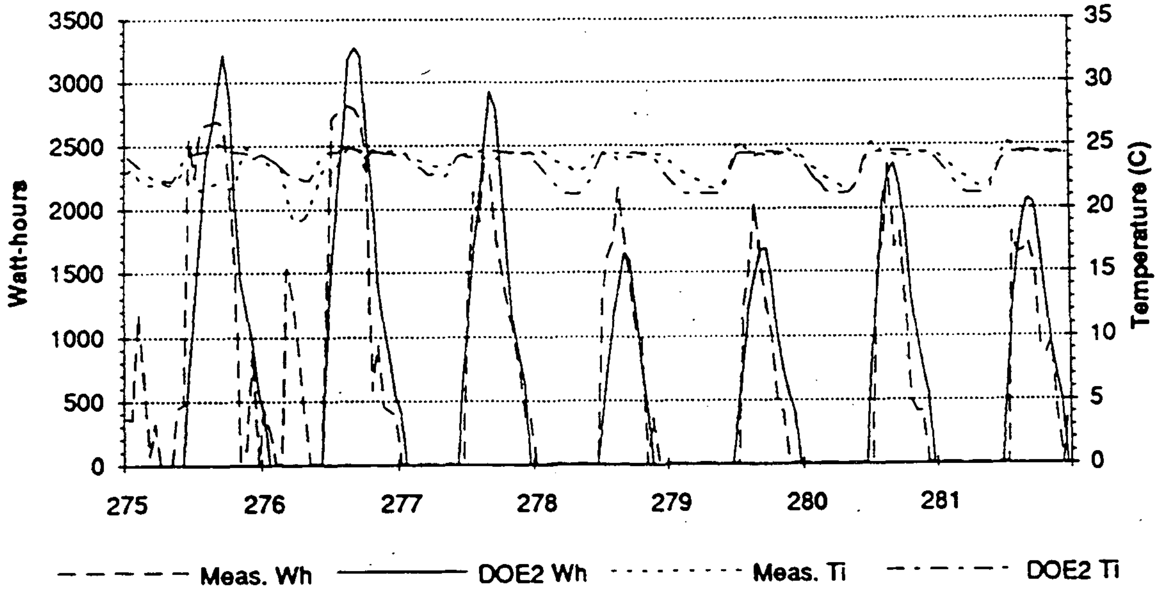
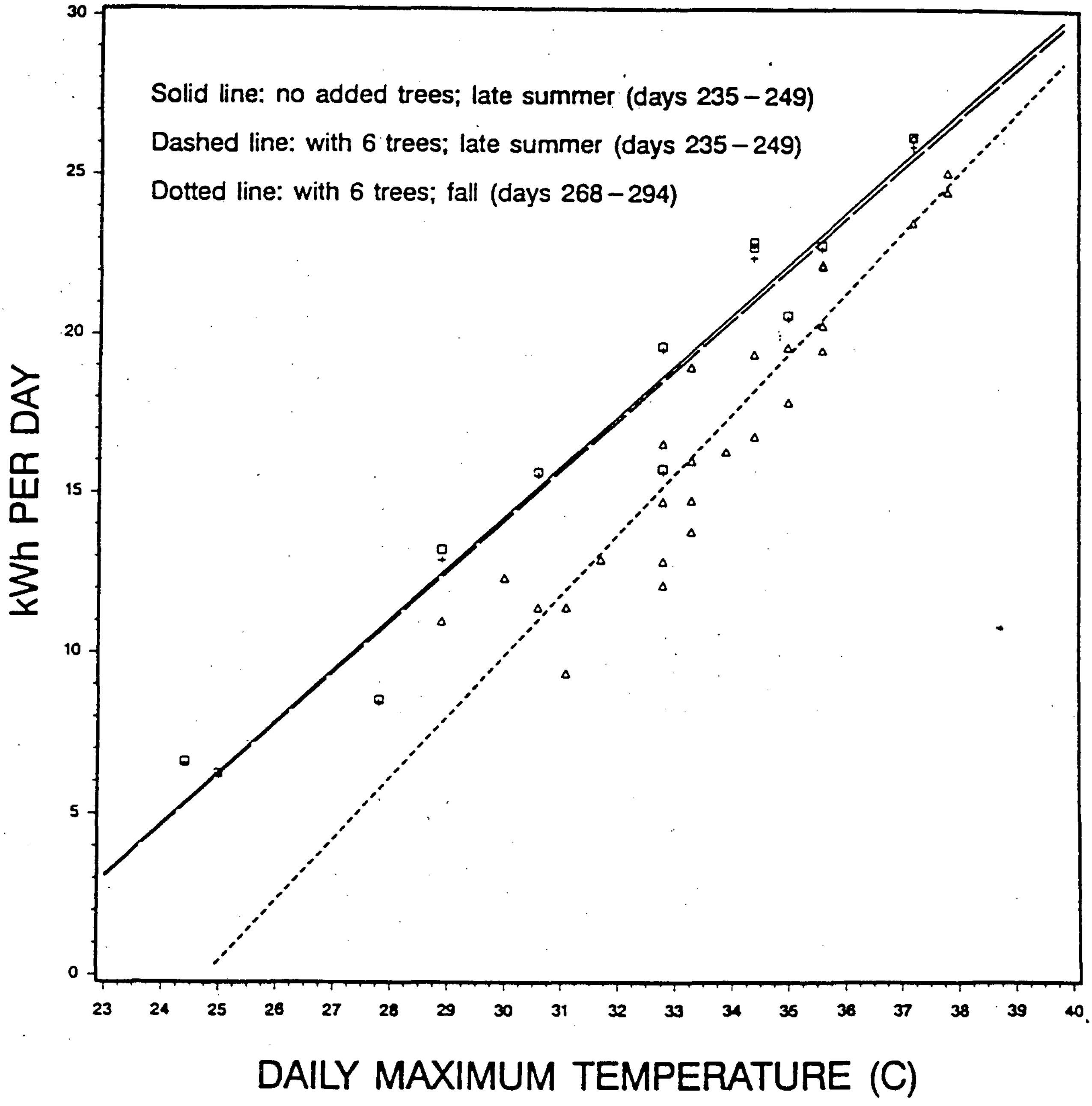


Figure V-8J. Site 8: Simulation Results: Daily data Squares and solid line represent base case in late summer (days 235 - 249). Crosses and dashed line represent the addition of 6 shade trees in late summer (days 235 - 249). Triangles and dotted line represent the case of 6 shade trees in fall (days 268 - 294).



building thermal mass, and the local climate characteristics. The first-order refinements listed below include data that could be gathered to refine the model estimates in addition to existing data.

1. At a minimum, the ducting systems in each house should be tested for air leakage and conduction losses. These parameters could then be incorporated into the models to more accurately characterize duct performance at different climatic conditions.
2. The cooling equipment efficiency should also be tested. This testing could be one of several techniques ranging from simple spot testing to more complete monitoring of air flows and temperatures and electricity consumption.
3. More information about occupancy patterns and appliance usage schedules would improve the inputs for hourly internal gains inputs. The effect of improved characterization of internal gains is unclear, however.
4. Some of the interior temperature data shows the buildings have a slower thermal response to diurnal temperature swings than the model predicts. Better model inputs for thermal mass may improve the models in this area.
5. More complete climatic data for each site would allow us to develop model inputs that are more specific to a site's microclimate. The primary reason that site temperature data were not used with simulations was because of the amount of gaps in the measured data. In addition, the site solar data was not useful to the DOE-2 models because of the method of measurement. These problems will be solved in future work.

In future data-collection studies, the model calibration would also benefit from several indoor temperature sensors, which would help to understand the conditions throughout the building. In particular, a sensor located next to the thermostat would help explain and verify apparent thermostat abnormalities.

Summary

The purpose of this study was to quantify the potential of high-albedo materials and vegetation for reducing cooling energy use in buildings. The analysis of measured data indicates that albedo modifications had significant impacts on cooling energy use, whereas vegetation modifications had only small measurable impacts in two sites and negligible effects in others.

In one house, recoating the dark roof with a high-albedo coating indicated almost 100% savings in cooling energy use during September (uncorrected for insolation changes). Savings of 50% were achieved when a school bungalow's roof and southeast wall were coated with a high-albedo coating. The original roof of the bungalow was metallic and its original southeast wall was painted yellow. DOE-2 simulations of the house also showed significant savings, but attributed some savings to generally lower insolation during the post-monitoring period. For the school bungalow, the simulations show only about 15% savings from the high albedo roof, and attribute some of the apparent savings to the different reported thermostat setpoints in the two buildings.

In the vegetation sites, savings were generally much lower than in the albedo cases. In one house, the addition of two trees on the west and one tree on the south sides resulted in saving ~40% in cooling energy use, whereas the addition of two southwest trees to another home reduced its cooling energy by ~30%. The other two other cases showed smaller savings. The addition of two trees on the east side of a well-shaded house reduced its cooling energy use by ~10%, and the addition of six trees on the south side of a completely unshaded home reduced its energy use by only ~10%. However, these savings will be significantly smaller once corrected for solar intensity and so, should be regarded as possible overestimates.

The DOE-2 simulations of these buildings appear to indicate very small or no savings from trees. The issue of comparing DOE-2 simulations with measured data will be addressed in further detail during the second year of this project. Ways of improving the simulations to reflect actual conditions were suggested in this report.

In addition to internal loads, schedules, and envelope characteristics, the reason why some sites had larger savings than others might be the fact that the local microclimate was different from one location to another. For example, Site 2 was in a cooler environment, heavily shaded, and therefore, this might have helped save 100% of cooling energy use when the roof was recoated with a high-albedo coating. Site 8, on the other hand, was in a warmer part of Sacramento, and that might explain why only 10% or less of cooling energy was saved by planting six trees on its south side. Microclimate variations are briefly discussed in Section E.

The major conclusion of the simulation work is that the albedo modifications made to Sites 2 and B produced significant changes in cooling energy use. On the other hand, the direct shading effect of the trees used in the study led to almost imperceptible changes in cooling use, most likely because of their small size. Any indirect cooling effects of these trees cannot be evaluated in the DOE-2 model.

An issue to keep in mind in the following year of this project is the start of monitoring. Preferably, this should start earlier in summer to avoid the concerns of seasonal cooling. An ideal time to start would be the month of June. Also, plenty of time should be allowed for equipment acquisition, testing, calibrating, and installing in the field. These tasks are the most crucial and demanding of all project phases. Finally, since some of the savings (in the vegetation sites) were larger than expected, we recommend repeating the entire experiment with more controlled vegetation tests. Also, in the second year of this project, larger and more mature trees should be used instead of the small ones.

The previous figures have shown that models seem to be reasonably calibrated against the measured given the level of detail gathered in the measured data and the difficulties of simulating real buildings under real conditions. A quantitative assessment of the model calibration is given in **Table V-8**. In this comparison we show the measured energy data and the simulated estimates on a daily basis for each site. We also show the results from a linear fit of the measured data to the simulated data. Note that we only include days with full data, and delete some of the days with abnormal cooling usage due to either extremely high peak usage or to days when the air-conditioning was essentially turned off.

For most sites, the correlation between the measured and the simulated data is above 70% (as given by the R^2), although there are specific cases where this is not true. For example, at Site 2 the modified case period only has a few days with any cooling usage and the comparison is thus almost meaningless. The errors in the fit are typically between 1 and 3 kWh/day. The peak cooling (kW) is more difficult to model than the daily total (kWh), most likely because of the many unknowns in cooling system performance and occupant behavior. However, for the school bungalow, the correlation between simulated and measured energy is better for the peak than for the daily total, and in general these two buildings are not modeled well.

The model estimates of the savings in cooling energy use are summarized in **Table V-9**. These are calculated by simulating the Base and Modified cases over the period of monitoring in the Base case. Note that the simulations only calculate the direct effect of building surface and window shading from the trees. Other effects, such as increased cooling system performance

Table V-8. Comparison of Measured and Simulated Data on Daily Basis

					Measured		Simulated†		Regression Model Results			
					Average Daily		Average Daily		Measured = a + b × Simulated			
		start	stop	N*	Energy	Load	Energy	Load	Energy (kWh)		Load (kW)	
Site	Case	day	day	days	(kWh)	(kW)	(kWh)	(kW)	StdErr	R^2	StdErr	R^2
Site 1	Control	236	293	36	4.84	1.37	5.74	1.22	2.97	0.51	0.80	0.39
Site 2	Base	235	253	13	2.95	0.90	4.33	0.85	1.16	0.85	0.40	0.74
Site 2	White‡	260	293	30	0.23	0.11	0.39	0.13	0.63	0.21	0.32	0.15
Site 2	All	235	293	43	1.06	0.35	1.58	0.35	0.85	0.84	0.35	0.67
Site 5	Base§	255	258	4	10.33	1.91	7.66	1.54	2.76	0.37	0.19	0.72
Site 5	Trees	268	293	23	9.20	1.91	8.64	1.63	2.63	0.56	0.36	0.47
Site 5	All	255	293	27	9.37	1.91	8.50	1.62	2.61	0.53	0.34	0.48
Site 6	Base	234	265	17	5.55	1.68	5.44	1.30	2.24	0.78	0.74	0.65
Site 6	Trees	268	292	13	4.42	1.56	4.58	1.06	1.42	0.78	0.36	0.75
Site 6	All	234	292	30	5.06	1.63	5.07	1.19	2.33	0.66	0.69	0.54
Site 7	Base	247	265	14	10.21	1.93	12.26	1.97	3.36	0.71	0.51	0.57
Site 7	Trees	268	290	20	7.83	1.89	11.34	2.01	2.81	0.71	0.85	0.39
Site 7	All	247	290	34	8.81	1.91	11.72	1.99	3.06	0.70	0.71	0.43
Site 8	Base	236	248	8	20.68	2.69	22.35	2.72	2.30	0.87	0.15	0.80
Site 8	Trees	268	293	25	14.79	2.23	17.15	2.42	3.31	0.64	0.28	0.56
Site 8	All	236	293	33	16.22	2.34	18.41	2.49	3.16	0.73	0.29	0.58
Site B1	White	246	293	25	6.93	1.30	8.66	1.38	3.80	0.51	0.51	0.65
Site B2	Metal**	246	293	25	17.35	2.70	19.59	2.16	6.06	0.37	0.67	0.42

* Days with 100% data capture only (selected days removed at each site with erratic cooling usage).

† Average of simulated data only for days with complete measured data

‡ R^2 for Site 2 post period is low because almost all values are 0.

§ Site 5 "pre" period data contains only four days for the comparison.

** Thermostat setpoint for Site B1 is 78°F and for B2 is 70°F.

from direct shading of the air-conditioning condenser unit or indirect/microclimate effects of evapotranspiration were not modeled directly. The DOE-2 simulation results suggest only that the direct shading effects on cooling demand are not significant in these cases because the trees were small.

Table V-9. Model Estimates of Experimental Savings over Base Case Period

		Base Case Average Daily Usage		Modified Case Average Daily Savings			
Site	Case	(kWh)	(kW)	(kWh)	(%)	(kW)	(%)
Site 2	Albedo	3.26	0.67	2.33	71	0.43	64
Site 5	Trees	7.55	1.49	0.33	4	0.02	1
Site 6	Trees	7.49	1.51	0.03	1	0.01	1
Site 7	Trees	13.15	2.12	0.06	1	0.02	1
Site 8	Trees	20.10	2.45	0.17	1	0.02	1
Site B†	Albedo	9.36	1.39	1.44	15	0.17	12

† Base case is occupied building with metal roof simulated with 78°F setpoint.

In **Table V-10**, we present monthly and annual estimates of cooling energy use from the simulation models. Note that in this case we use the Sacramento TMY weather tape, and thus do not account for microclimates specific to each site.

Table V-10. Simulated Annual Cooling Energy Use and Peak Energy Demand (including Fan) (Sacramento TMY Weather)

			Month						Total
			May	Jun	Jul	Aug	Sep	Oct	Year
Site 1	Control	kWh	74	170	377	355	161	29	1166
		kW	3.66	3.86	3.99	3.93	3.77	1.92	3.99
Site 2	Base	kWh	79	121	278	223	79	13	793
		kW	2.27	2.15	2.93	2.43	2.02	1.11	2.93
Site 2	Albedo	kWh	32	60	188	140	41	5	466
		kW	1.90	1.78	2.47	2.10	1.53	0.83	2.47
Site 5	Base	kWh	122	271	607	564	255	46	1865
		kW	3.68	3.64	4.46	4.34	3.97	2.18	4.46
Site 5	Trees	kWh	115	264	597	554	246	46	1822
		kW	3.66	3.62	4.44	4.33	3.95	2.16	4.44
Site 6	Base	kWh	164	159	396	363	143	25	1250
		kW	4.14	2.93	4.24	3.54	3.01	1.68	4.24
Site 6	Trees	kWh	162	158	395	362	142	25	1244
		kW	4.11	2.92	4.24	3.54	3.01	1.66	4.24
Site 7	Base	kWh	223	364	657	608	342	91	2285
		kW	3.65	3.84	4.19	4.23	3.61	2.50	4.23
Site 7	Trees	kWh	222	363	657	606	340	88	2276
		kW	3.65	3.84	4.19	4.23	3.61	2.42	4.23
Site 8	Base	kWh	283	404	692	685	499	241	2804
		kW	3.28	3.52	3.73	3.66	3.58	3.05	3.73
Site 8	Trees	kWh	277	401	689	682	487	210	2746
		kW	3.26	3.52	3.73	3.66	3.58	2.97	3.73
Site B*	Base	kWh	194	101	217	171	265	151	1099
		kW	2.70	1.51	1.91	3.48	2.73	2.27	3.48
Site B*	Albedo	kWh	153	67	167	123	225	128	863
		kW	2.53	1.37	1.67	2.80	2.47	2.07	2.80

* School occupancy schedule is 1/1-5/31 and 9/3-12/31 with appropriate holidays.

E. Microclimate Variations

The sites we monitored are scattered over the greater Sacramento area, with typical distances of 4-10 miles from one to another. The distance between the northernmost and southernmost sites is about 20 miles. Due to this, and to local factors, the microclimates at these sites were different. Although microclimate variations from one site to another may have an impact on the absolute amount of energy used at one particular site, they have no impact on the differences in energy use between the pre- and post-retrofit conditions at a particular site. In this section, we discuss some aspects of these variations.

In addition to weather stations' data from each of the seven sites we monitored, data from the Sacramento Executive Airport weather station were also obtained for the 1991 monitoring period. Sites 5 and 6 were the closest to the airport, and Sites 5, 6, 1, and 8 had microclimate/landscape conditions similar to that of the airport. We discuss Site 1 as a representative of the new areas in north Sacramento, Site 2 as a representative of the Carmichael, older and well-vegetated areas, Site 7 to represent the eastern Sacramento parts, and finally, Site 6 to represent the newer, southern Sacramento areas. The temperatures at Sacramento Executive Airport are used as a basis for intercomparison among these sites.

In **Figure V-9A**, the maximum daily temperatures at Site 1 are plotted along with the maximum daily temperatures at the airport site for Julian days 213 through 305. The diamonds represent Site 1 whereas the squares represent the airport. The bold vertical lines, linking the diamonds and the squares, represent days when data from both sites are available. Examining these lines, we can see that Site 1 is consistently warmer than the airport except when there is no significant temperature difference.

In **Figure V-9B**, some hourly data from these two sites are examined. The figure shows the range, standard deviation, and mean of the data at each hour during the period under consideration. The solid line joins all the means. The vertical axis represents the difference in air temperature between Site 1 and the airport. We can see that, the mean of this difference fluctuates around 1°C (meaning that Site 1 is generally warmer than the airport by ~1°C). However, between hours 13 and 20, Site 1 is clearly warmer than the airport. And, at the time of maximum difference (18:00), Site 1 is generally 2°C warmer than the airport. On the other hand, Site 1 is cooler than the airport between 6 and 9 A.M.. These variations are caused by local factors, which give rise to different microclimates. But in general, the difference in temperature (except for the afternoon peak) is not very large, and that was expected since both Site 1 and the airport are in outlying areas with little vegetation and no particular topographic effects (water bodies, hills, etc.).

In **Figure V-9C**, daily maxima at Site 2 and the airport are shown. We can see that the bold lines are longer than those shown in Figure V-9A, indicating that the temperature difference between Site 2 and the airport is greater than that between Site 1 and the airport. Also, in this case, Site 2 is cooler than the airport all the times during the maximum temperature of the day.

This indicates that Site 2 is cooler than the airport during late morning and afternoon hours. Hourly data from these sites are shown in **Figure V-9D**. It is clear that Site 2 is cooler during daylight hours and warmer during night hours than the airport. This is a typical behavior of well-vegetated areas, such as Carmichael, where Site 2 is located. Figure V-9D indicates that, on the average, Site 2 is 2°C cooler than the airport during daylight hours, and about 1.5°C warmer at night.

In **Figure V-9E**, the daily maxima at Site 6 and the airport are shown. One can see that the

Figure V-9A. A comparison of daily maximum air temperatures (°C) at Site 1 and the Sacramento Executive Airport. Bold vertical lines join points when data from both locations are available.

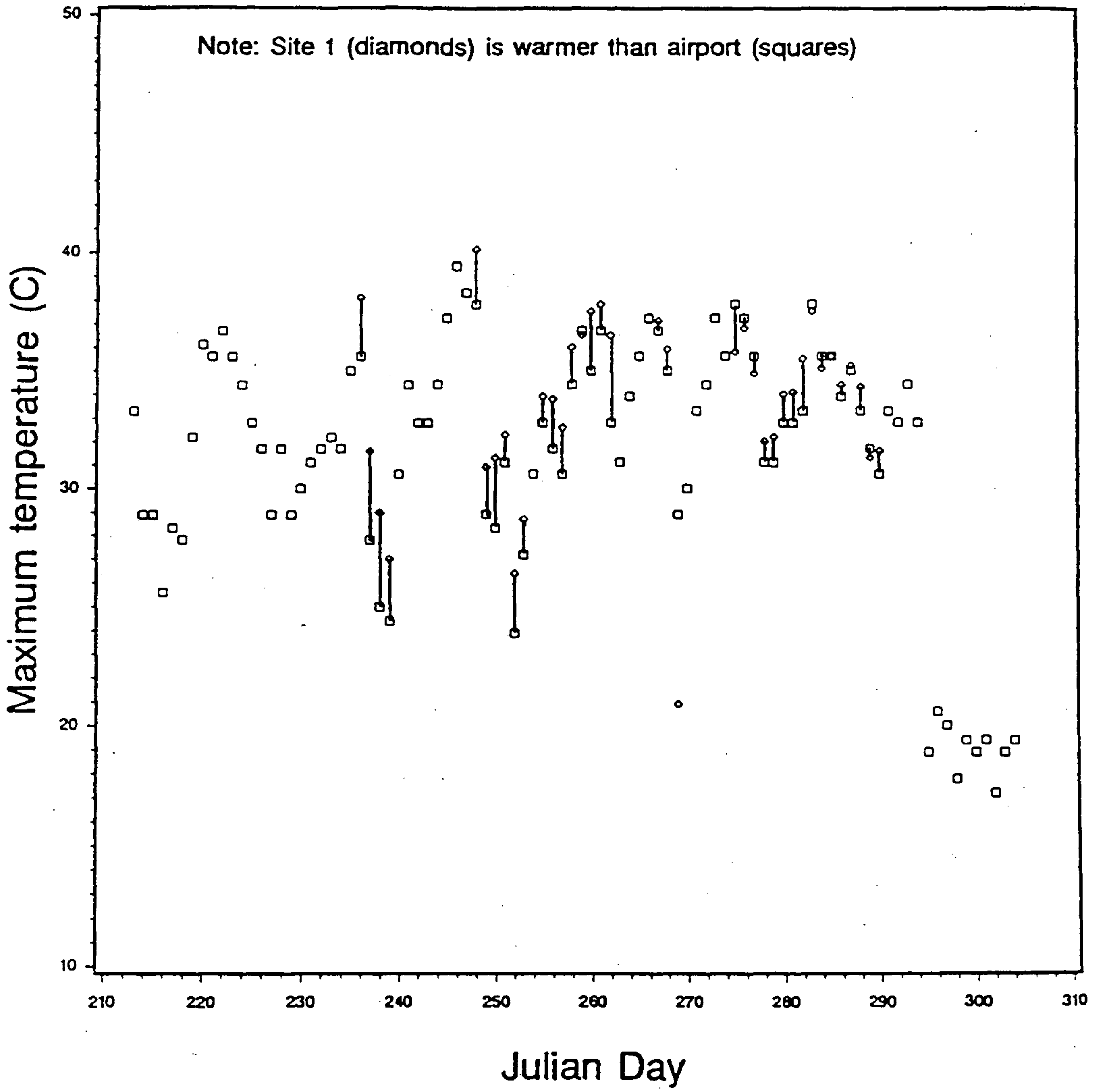


Figure V-9B. Difference in hourly air temperatures (°C) between Site 1 and at the Sacramento Executive Airport, during the monitoring period of 1991. Shown are the maximum and minimum deviations, standard deviations, and mean (joined by the solid line).

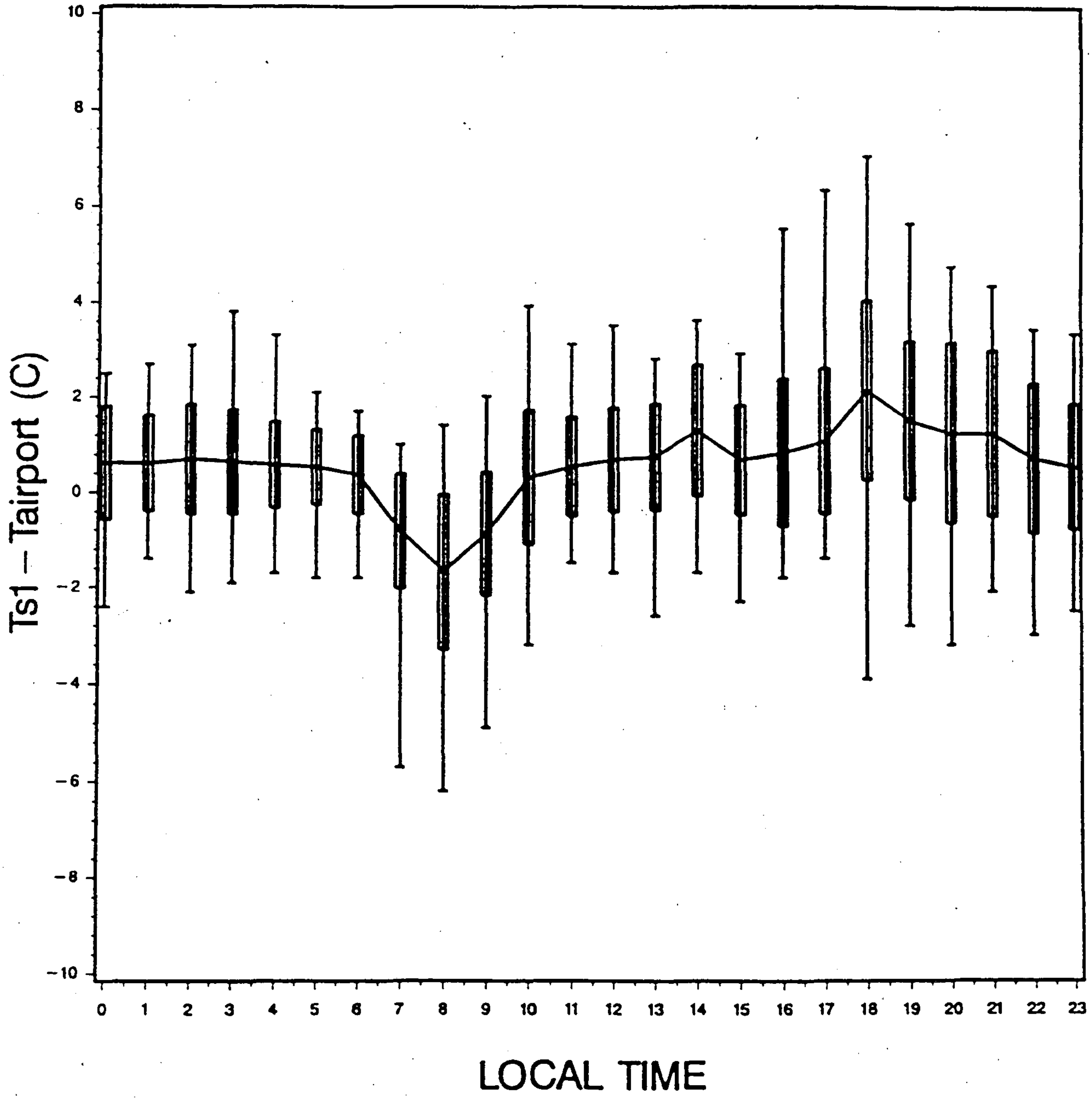


Figure V-9C. A comparison of maximum daily air temperatures (°C) at Site 2 and at the Sacramento Executive Airport. Bold vertical lines join points when data from both locations are available.

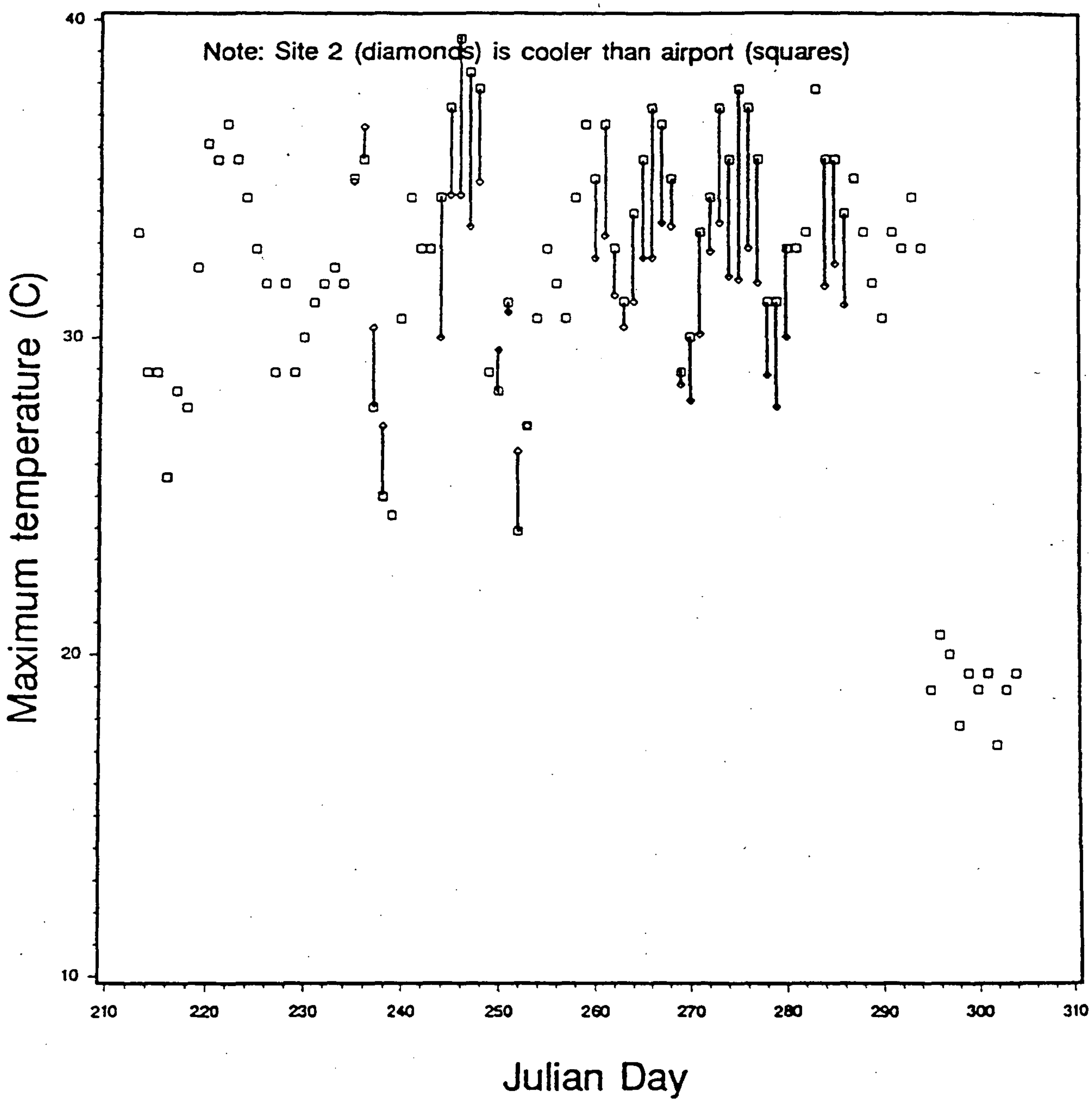


Figure V-9D. Difference in hourly air temperatures (°C) between Site 2 and the Sacramento Executive Airport, during the monitoring period of 1991. Shown are the maximum and minimum deviations, standard deviations, and mean (joined by the solid line).

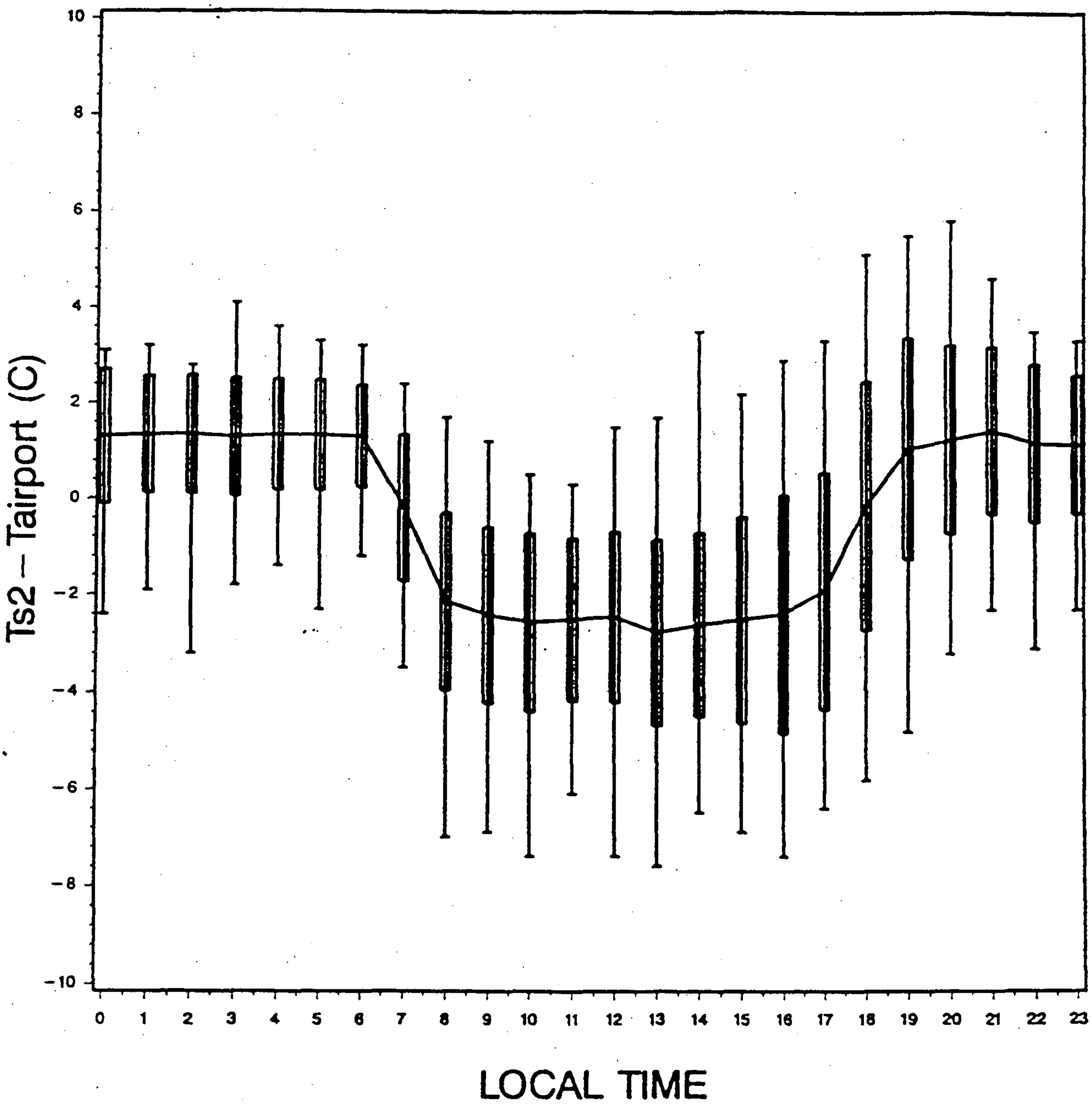
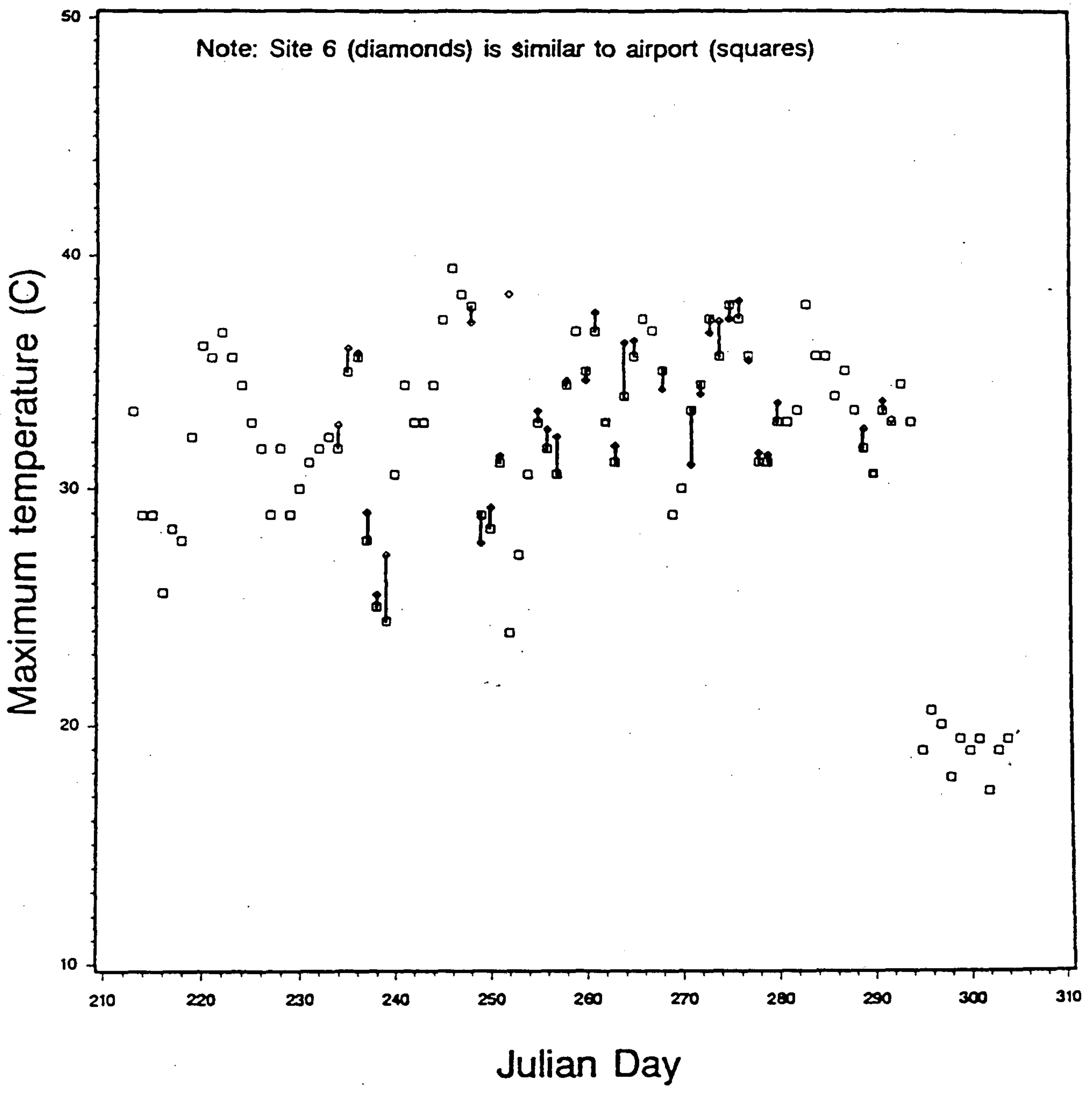


Figure V-9E. A comparison of maximum daily air temperatures (°C) at Site 6 and at the Sacramento Executive Airport. Bold vertical lines join points when data from both locations are available.

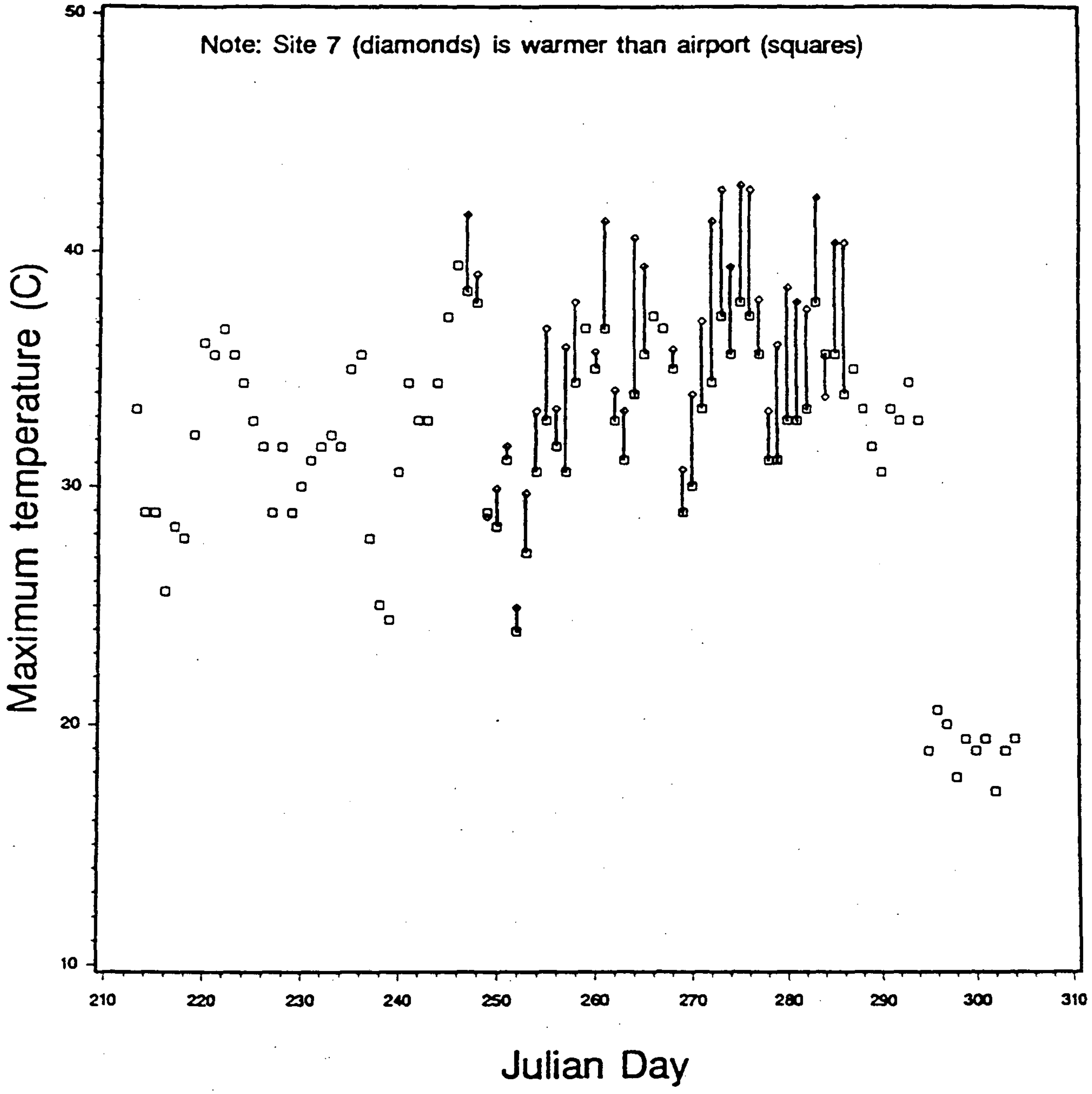


differences in temperatures are small, indicating that the afternoon microclimate at both locations is similar. This is expected, since Site 6 is the closest to the airport, in a newer area devoid of vegetation, and with a terrain type similar to that of the airport's surrounds.

Finally, **Figure V-9F** depcits data at the airport and Site 7. The maxima at Site 7 are consistently higher than the airport, and the difference is large in general. Site 7 is in a relatively open area, close to Mather AFB. Little vegetation is another factor in this site's microclimate.

In summary, the data we obtained from the 1991 monitoring of these sites indicated that, during the late summer months, afternoon temperatures are highest at Site 7 (East Sacramento), and lowest at Site 2 (Carmichael). In the other parts (North and South of Sacramento) conditions were in between and similar to the conditions at the Sacramento Executive Airport.

Figure V-9F. A comparison of maximum daily air temperatures (°C) at Site 7 and at the Sacramento Executive Airport. Bold vertical lines join points when data from both locations are available.



REFERENCES

American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). 1989. *ASHRAE Handbook of Fundamentals*, Atlanta, GA.

American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). 1990. "ASHREA Standard: Energy Efficient Design of New Low-rise Residential Buildings. (BSR/ASHRAE 90.2p), Public Review Draft". Altanta, GA.

Huang, Y.J., R. Ritschard, J. Bull, S. Byrne, I. Turiel, D. Wilson, C. Hsui and D. Foley. 1987. "Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings," Technical Support Document for the PEAR Microcomputer Program. Lawrence Berkeley Laboratory Report No. LBL-19128, Berkeley, CA.

Modera, M., D. Dickerhoff, R. Jansky, and B. Smith. 1991. "Improving the Energy Efficiency of Residential Air Distribution Systems in California: Final Report, Phase I," prepared for the California Institute of Energy Efficiency and U.S. Department of Energy, Lawrence Berkeley Laboratory Report No. LBL-30886, Berkeley, CA.

Muira, J. and M. Horn. 1980."Base Case Buildings," California Energy Commission and The Building and Appliance Standards Office. Sacramento, Ca., Item No. P400-80-021, Report No. 2, June 1980.

Proctor, J. and R. Pernick, 1992. "Getting It Right the Second Time: Measured Savings and Peak Reduction from Duct and Appliance Repairs," in *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, DC.

Ritschard, R. L., J. W. Hanford, and A. O. Sezgen. 1992. "Single-Family Heating and Cooling Requirements: Assumptions, Methods, and Summary Report," Gas Research Institute. Report No. GRI-91/0236, Chicago, IL.

Taha, H., H. Akbari, and A. Rosenfeld. 1991. "Heat Island and Oasis Effects of Vegetative Canopies: Micro-Meteorological Field-Measurements," *Theoretical and Applied Climatology*, **44**, pp. 123-138.

Taha, H., H. Akbari, D. Sailor, and R. Ritschard. 1992. "Urban Microclimates and Energy Use: Sensitivity to Surface Parameters and Anthropogenic Heat," Lawrence Berkeley Laboratory Draft Report, to be submitted to *Energy and Buildings*.

VI. SAVINGS ESTIMATES FOR FOUR CALIFORNIA REGIONS

A. Introduction and Approach

In this chapter, we use the calibrated simulation models for the six houses and the school bungalow to estimate cooling energy savings for other combinations of tree and albedo strategies and in four climates regions in California. In this parametric study, we model the direct shading impact of varying amounts of tree cover as well as the effects of changes in roof and wall albedos. We consider these cases alone and in combination, and consider the same parametric cases for each of the seven buildings.

The study buildings, while not a statistically representative sample of buildings in California, do represent buildings with a range of construction types, cooling efficiencies, occupancy characteristics, shading conditions, and albedos. Thus, rather than using prototypical buildings for this extrapolation, we use the calibrated building models exactly as they are, except that we vary the vegetation, albedo, and climate characteristics. As a result, this analysis shows a range of impacts one could expect among buildings in California, but not necessarily average or typical results.

In order to make this analysis more useful, we model albedo and shading conditions that were not actually studied in the experimental measurement project and therefore not actually part of the calibration process. For example, because the experimental trees were small, DOE-2 predicted minimal impacts from trees, and we had expected the actual effect to be rather small. Thus, from the measured data we were not able to fully verify our strategies for modeling the shading impact of trees. Consequently, the savings estimates from shade trees presented in this chapter must be viewed as being derived from, but not themselves calibrated simulations. However, our ability to model the base case condition at Site 2 (which is heavily impacted by tree cover) with reasonable accuracy suggests that our tree modeling method is reliable.

In addition, our strategy for modeling changes in albedo using DOE-2 is extremely simple; we adjust the absorptivity of the roof or wall surface. For the two experimental sites where high albedo surfaces were employed, we achieved relatively good agreement with the measured data. Yet it is important to note that both buildings had almost flat roofs with no attics. Thus, we are fairly confident in our ability to model the effect of albedo changes on heat flows to the conditioned space for buildings without attics. However, in this extrapolation we are modeling light-colored roofs on houses with ducts in the attic space (in all buildings except for Site 2 and Site B). For these buildings, the effect is two-fold. The high albedo roof reduces heat gain to the conditioned space as well as improves duct efficiency by lowering the attic temperature. None of the experimental albedo cases were actually buildings with attics. Therefore, our modeling of the effect of the white roofs on cooling consumption in attic-duct houses should also be considered preliminary. More consideration to the attic interaction with the duct system performance will be given in future phases of the project.

B. Methodology

The parametric cases we considered are (1) changing the albedos of the roof and walls, (2) adding trees to the south, east, and west sides of the buildings, and (3) combinations of these strategies. For the albedo cases, we simulated albedos of 0.20, 0.40 and 0.70 for the roofs and 0.15, 0.30, and 0.50 for the walls. These are the ranges of albedo one can expect in actual field conditions.

For the trees, we simulated three conditions as well. The first case was with no shading from trees. In the second case, we added 1 tree to the west and east sides of the building and 2 trees on the south side. These were positioned at each building to give the maximum amount of shading over unshaded windows. Thus, the application of this measure will be specific to the configuration of each building. Each of the trees was 15 feet in diameter, with a canopy height of 10 feet. In the third case, we modeled full shading from several trees on the west, south, and east sides of the building so that they completely shade all the three walls and will shade portions of the roof depending on the time of year. The trees were of the same diameter and height as the individual trees mentioned previously but were spaced so that each touches the adjacent tree. This typically takes 2 trees on the short sides of the house and 4 trees along the long side of the house, or 8 trees total. The description of the parametric cases is given in **Table VI-1.**

We also simulated each of the buildings in four California climates. The climates we simulated were those of Fresno, Riverside, Sacramento, and Pasadena, which are listed here from the more severe to the less severe cooling climates. We used the CTZ weather tapes from the California Energy Commission (CEC) as the weather inputs. Some climate parameters from these weather tapes are given in **Table VI-2.**

Finally, we modeled the base case building in each climate region. This is the building with the roof and wall albedos as modeled for the calibration exercise (see Chapter V) with the actual tree shading at each site. Note that for the parametric runs, surface albedos and existing trees are removed and replaced with the parametric parameters. Simulations for base case conditions show the magnitude of savings already being achieved at each site through higher albedo materials and tree shading. In addition, they show the magnitude of potential savings that can be achieved through further modifications.

Table VI-1. Listing of Parametric Run Descriptions

	Albedo		Number of Trees		
	Roof	Wall	East	South	West
Case 1	Low	Low	0	0	0
Case 2	Med	Med	0	0	0
Case 3	High	High	0	0	0
Case 4	Low	Low	1	2	1
Case 5	Med	Med	1	2	1
Case 6	High	High	1	2	1
Case 7	Low	Low	2	4	2
Case 8	Med	Med	2	4	2
Case 9	High	High	2	4	2

Albedos for Cases:

Low: Roof Albedo=0.2, Wall Albedo=0.15
Med: Roof Albedo=0.4, Wall Albedo=0.3
High: Roof Albedo=0.7, Wall Albedo=0.5

Tree Parameters:

All trees 15 ft diameter, 10 ft to base of canopy, shading windows.

Table VI-2. California Climate Zone Data for Parametric Simulations

	Month						
	May	Jun	Jul	Aug	Sep	Oct	Year
Fresno (CTZ13R)							
Daily Averages (°F)							
Dry Bulb	70	78	82	80	74	65	64
Wet Bulb	56	60	63	64	59	54	54
Maximum	85	93	97	96	90	81	77
Minimum	55	61	66	65	61	53	52
Wind (mph)	8.6	7.6	6.2	5.8	6.6	5.2	6.3
Degree Days (base 65°F)							
Heating	29	3	0	0	4	44	2228
Cooling	184	367	519	492	310	92	1997
Cooling Degree Hours/24 (base 75°F)							
	93	198	283	241	128	41	1012
Average Daily Solar (Btu/ft^2)							
Dir. Normal	2867	3108	3136	2761	2681	2055	2077
Tot. Horiz.	2502	2719	2706	2398	2023	1455	1727
Riverside (CTZ10R)							
Daily Averages (°F)							
Dry Bulb	65	70	76	76	73	66	64
Wet Bulb	55	60	64	62	59	52	53
Maximum	79	86	94	93	89	81	79
Minimum	53	56	61	62	59	53	50
Wind (mph)	5.3	4.4	3.0	3.6	3.2	3.9	3.8
Degree Days (base 65°F)							
Heating	31	0	0	0	4	58	1637
Cooling	60	190	374	381	281	115	1437
Cooling Degree Hours/24 (base 75°F)							
	30	89	181	172	131	70	725
Average Daily Solar (Btu/ft^2)							
Dir. Normal	1575	1696	2116	1815	1891	1420	1809
Tot. Horiz.	1931	2039	2303	1969	1756	1321	1633

Table VI-2. California Climate Zone Data for Parametric Simulations (cont.)

	Month May	Jun	Jul	Aug	Sep	Oct	Year
Sacramento (CTZ12R)							
Daily Averages (°F)							
Dry Bulb	64	70	73	72	68	62	60
Wet Bulb	55	58	60	60	57	53	52
Maximum	80	87	92	91	87	78	74
Minimum	50	55	57	57	55	49	48
Wind (mph)	7.6	8.9	9.6	9.0	7.7	6.6	8.0
Degree Days (base 65°F)							
Heating	58	13	3	8	7	86	2649
Cooling	64	185	294	283	173	35	1038
Cooling Degree Hours/24 (base 75°F)							
	44	95	147	134	76	24	527
Average Daily Solar (Btu/ft^2)							
Dir. Normal	2715	3015	3090	2819	2522	1865	2016
Tot. Horiz.	2395	2671	2691	2391	1928	1298	1652
Pasadena (CTZ09R)							
Daily Averages (°F)							
Dry Bulb	64	68	73	73	72	67	64
Wet Bulb	56	60	62	65	62	57	55
Maximum	77	83	89	89	87	81	78
Minimum	53	57	61	62	60	55	52
Wind (mph)	4.4	5.0	7.8	7.6	4.0	6.0	5.6
Degree Days (base 65°F)							
Heating	30	2	0	0	0	29	1260
Cooling	38	151	306	320	248	118	1215
Cooling Degree Hours/24 (base 75°F)							
	26	60	120	111	92	51	498
Average Daily Solar (Btu/ft^2)							
Dir. Normal	1577	1761	2308	1837	1836	1628	1762
Tot. Horiz.	1820	2012	2387	1908	1737	1364	1589

C. Results

We present the results for both annual cooling energy consumption and peak annual electricity demand in a series of tables and graphs. **Table VI-3** gives the changes in annual cooling electricity consumption for the base case and the 9 different sensitivity cases in each climate region. **Table VI-4** shows the impact on peak electricity consumption for cooling. Note that in this analysis, we include the supply fan energy as well as the condenser energy. In these tables, the basecase results are presented in the units of kWh per year and kW. The results for all the parametric simulations are presented as percentage changes from the simulated base case value. Positive changes are energy and demand penalties, negative changes are savings.

The tabulated results for annual cooling energy consumption are also plotted in **Figures VI-1** through **VI-7**. In each chart, there are three lines as well as the location of the base case. The top line is for the no-shade case (cases C1, C2, and C3), the middle line is for the 4-tree case (cases C4, C5, C6), and the bottom line is for the 8-tree case (cases C7, C8, and C9). The base case is marked by the black diamond. Note that the position of the base case is not exact. The plots have been simplified so that the x-axis is the roof albedo, whereas it actually represents both the roof albedo (0.2, 0.4, and 0.7) and wall albedos (0.15, 0.3, 0.5). The base case building albedos are not always matched like the parameters used in the simulations.

For the high-albedo and high-tree shading cases, the results suggest the range of potential energy and peak savings in existing buildings from implementing these strategies. These range from about 25% in annual energy savings at Site 1 across all climates to 60% in annual savings for Site 6 in Pasadena. Higher percentage savings are found in the less extreme climates. Some of the savings from high albedo roofs arise also from increased duct system performance resulting from lower attic temperatures.

At Sites 1 and 2, cooling energy is already reduced by the current levels of shading when they are compared to no-tree simulation cases. The base case is plotted between the "4-Tree" and "8-Tree" cases for Sites 1 and 2. For the other four residential sites, as well as the school bungalow, the base case is close to the "No-Trees" case. With the calibrated simulations as the basecase, the simulations indicate that for most of the monitored buildings there is potential for energy savings between 18% to 60%. The potentials for energy savings are even higher if we assume the low-albedo and no-shade tree parametric as a basecase. In that condition, the simulations indicate potentials for energy savings of about 25% to 70%.

Table VI-3. Base Case Annual Cooling Energy and Percent Changes for Strategy Combinations (includes supply fan energy)

Site and Climate	Base Case (kWh)	Changes from Base Case (%)								
		No Trees Albedo			Four Trees Albedo			Eight Trees Albedo		
		Low	Med	High	Low	Med	High	Low	Med	High
Site 1 (base case has large trees to south and southwest; roof alb.=0.40, wall alb.=0.30)										
Fresno	2379	28	15	-3	15	4	-11	4	-5	-18
Riverside	1182	41	20	-7	23	5	-17	9	-5	-24
Sacramento	869	49	28	1	25	8	-14	6	-9	-26
Pasadena	732	48	25	-2	25	7	-16	8	-6	-25
Site 2 (base case has heavy vegetation on south, west, and north; roof alb.=0.18, wall alb.=0.30)										
Fresno	1786	11	-5	-27	5	-9	-29	-6	-18	-34
Riverside	940	15	-10	-41	8	-15	-44	-7	-26	-49
Sacramento	653	17	-7	-38	9	-12	-40	-9	-27	-48
Pasadena	536	21	-10	-45	11	-17	-48	-9	-30	-54
Site 5 (base case has no trees, south overhang; roof alb.=0.16, wall alb.=0.50)										
Fresno	4055	4	-9	-27	-8	-19	-35	-16	-26	-38
Riverside	2114	10	-12	-36	-7	-24	-45	-18	-32	-48
Sacramento	1372	9	-10	-34	-14	-29	-47	-26	-38	-52
Pasadena	1284	11	-9	-34	-10	-26	-46	-22	-35	-51
Site 6 (base case has small trees to southwest and west; roof alb.=0.35, wall alb.=0.40)										
Fresno	2861	16	-0	-19	-2	-14	-29	-18	-28	-39
Riverside	1124	27	2	-26	-1	-19	-40	-22	-35	-52
Sacramento	868	21	2	-22	-10	-23	-40	-37	-46	-57
Pasadena	672	27	3	-25	-7	-26	-45	-36	-47	-60
Site 7 (base case has large east tree and small west tree; roof alb.=0.16, wall alb.=0.45)										
Fresno	4397	5	-7	-22	-7	-18	-31	-14	-23	-34
Riverside	2796	9	-9	-31	-7	-22	-40	-15	-27	-43
Sacramento	1977	9	-6	-24	-13	-25	-39	-22	-31	-43
Pasadena	1961	10	-6	-26	-10	-23	-39	-17	-28	-42
Site 8 (base case has no trees; roof alb.=0.16, wall alb.=0.30)										
Fresno	5163	1	-9	-24	-10	-19	-31	-18	-25	-35
Riverside	4198	2	-13	-33	-10	-23	-40	-18	-29	-43
Sacramento	2711	1	-11	-28	-16	-26	-40	-27	-35	-46
Pasadena	3188	1	-11	-28	-12	-23	-38	-20	-30	-43
Site B (base case has full shading on east and west from buildings; roof alb.=0.34 (metal), wall alb.=0.30)*										
Fresno	2498	-1	-8	-19	-10	-15	-24	-13	-18	-25
Riverside	2041	-3	-12	-26	-12	-20	-31	-16	-22	-32
Sacramento	1344	0	-9	-22	-11	-18	-28	-15	-21	-30
Pasadena	1618	-1	-11	-24	-11	-18	-29	-14	-21	-30

* Metalic roof emissivity is 0.4.

Table VI-4. Base Case Peak Cooling and Percentage Changes for Strategy Combinations (includes supply fan energy)‡

Site and Climate	Base Case (kW)	Changes from Base Case (%)								
		No Trees Albedo			Four Trees Albedo			Eight Trees Albedo		
		Low	Med	High	Low	Med	High	Low	Med	High
Site 1 (base case has large trees to south and southwest; roof alb.=0.40, wall alb.=0.30)†										
Fresno	4.15	-0	0	-2	-0	0	-0	0	0	0
Riverside	4.02	-3	-0	0	-0	-0	0	-0	0	0
Sacramento	4.01	-0	-0	0	-0	0	0	0	0	-3
Pasadena	3.40	14	13	-1	14	4	-5	4	-2	-9
Site 2 (base case has heavy vegetation on south, west, and north; roof alb.=0.18, wall alb.=0.30)										
Fresno	3.28	3	-5	-16	1	-6	-17	-3	-9	-19
Riverside	2.64	4	-6	-19	2	-8	-20	-2	-11	-21
Sacramento	2.57	4	-4	-13	2	-5	-14	-3	-9	-16
Pasadena	2.37	4	-3	-11	2	-4	-12	-3	-8	-14
Site 5 (base case has no trees, south overhang; roof alb.=0.16, wall alb.=0.50)										
Fresno	4.99	0	-7	-10	0	-7	-11	-6	-8	-11
Riverside	4.62	0	-3	-24	0	-4	-28	-3	-10	-30
Sacramento	4.53	0	-5	-18	-2	-10	-22	-6	-14	-24
Pasadena	4.04	1	-10	-22	-7	-17	-25	-13	-21	-27
Site 6 (base case has small trees to southwest and west; roof alb.=0.35, wall alb.=0.40)										
Fresno	5.75	2	-1	-25	2	-6	-29	-4	-19	-37
Riverside	3.41	21	-1	-16	8	-9	-22	-1	-17	-30
Sacramento	3.74	14	-2	-17	2	-10	-23	-17	-23	-31
Pasadena	2.96	11	-0	-13	-2	-11	-20	-12	-20	-28
Site 7 (base case has large east tree and small west tree; roof alb.=0.16, wall alb.=0.45)										
Fresno	4.81	0	-10	-12	-2	-10	-12	-10	-11	-12
Riverside	4.36	0	-4	-20	-1	-11	-26	-2	-15	-27
Sacramento	4.27	0	-1	-14	-2	-11	-22	-5	-13	-22
Pasadena	3.73	1	-8	-18	-2	-16	-23	-7	-18	-24
Site 8 (base case has no trees; roof alb.=0.16, wall alb.=0.30)										
Fresno	4.09	0	-7	-9	0	-7	-10	-6	-8	-10
Riverside	3.79	0	-1	-4	-0	-3	-8	-1	-3	-10
Sacramento	3.73	0	-1	-2	-1	-1	-3	-1	-2	-6
Pasadena	3.59	0	0	-17	0	-10	-19	-8	-18	-24
Site B (base case has full shading on east and west from buildings; roof alb.=0.34 (metal), wall alb.=0.30)*										
Fresno	2.87	0	-3	-7	-2	-5	-9	-4	-6	-9
Riverside	2.97	0	-3	-7	-3	-6	-9	-5	-7	-9
Sacramento	3.64	0	-9	-20	-9	-16	-26	-14	-20	-27
Pasadena	3.22	0	-2	-6	-2	-4	-7	-4	-5	-8

‡ Cooling capacity is kept constant at all sites; systems may be undersized for Fresno climate.

† Cooling schedule at Site 1 causes system undersizing in all locations but Pasadena with no peak savings.

* Metalic roof emissivity is 0.4.

Figure VI-1. Annual cooling energy consumption (including fan energy) for Site 1 in four location. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7. Base case (shown here as a black diamond) has large trees to south and southwest and high shrubbery along south wall. Major window area faces south and north. Savings for high albedo roofs are partly due to improvement in attic duct efficiency.

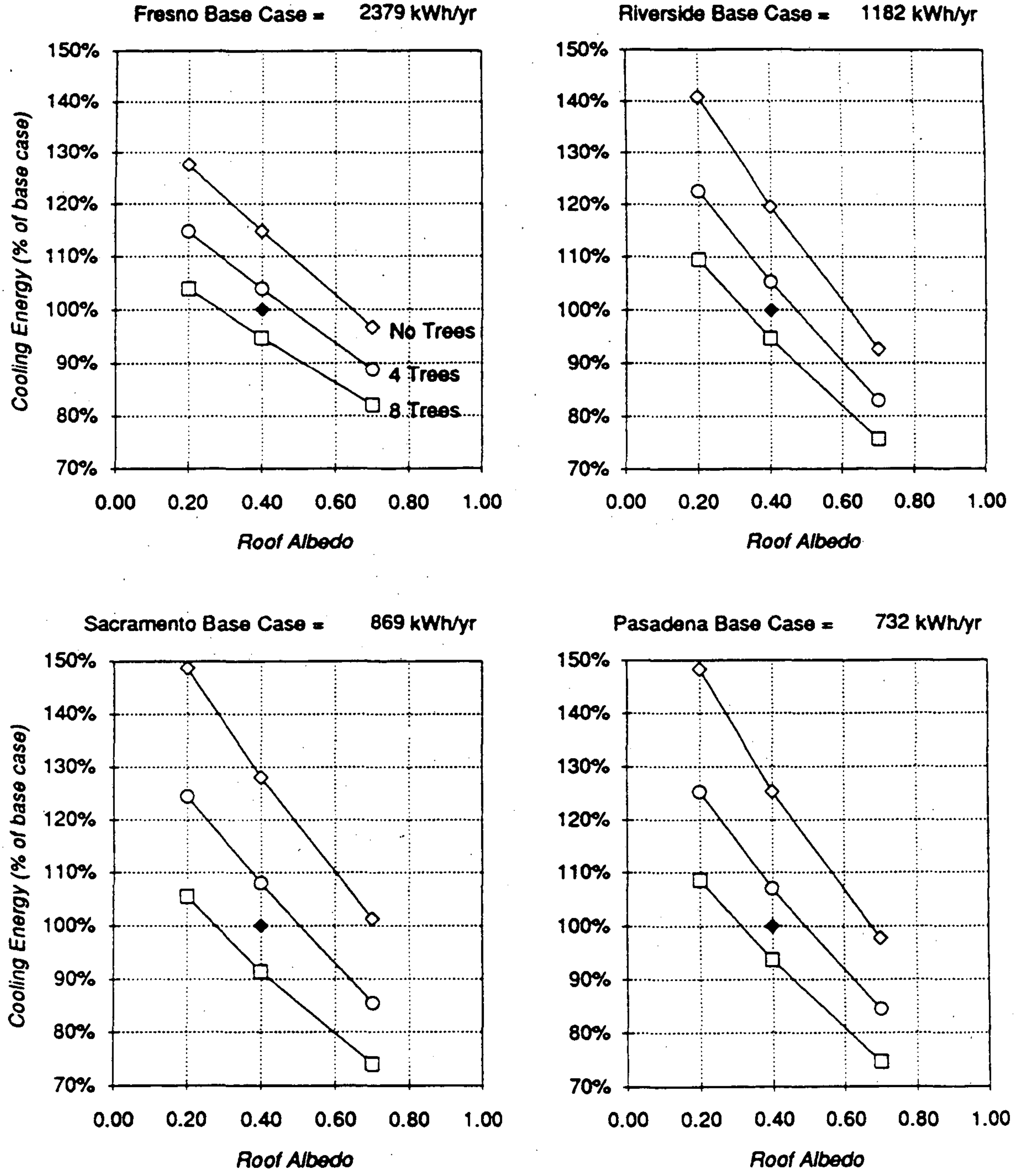


Figure VI-2. Annual cooling energy consumption (including fan energy) for Site 2 in four location. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7. Base case (shown here as a black diamond) has large trees along south, west, and north sides of house. Major exterior walls face south and north and window area faces north. Shading impact does not include microclimate effect of trees shown in measured data.

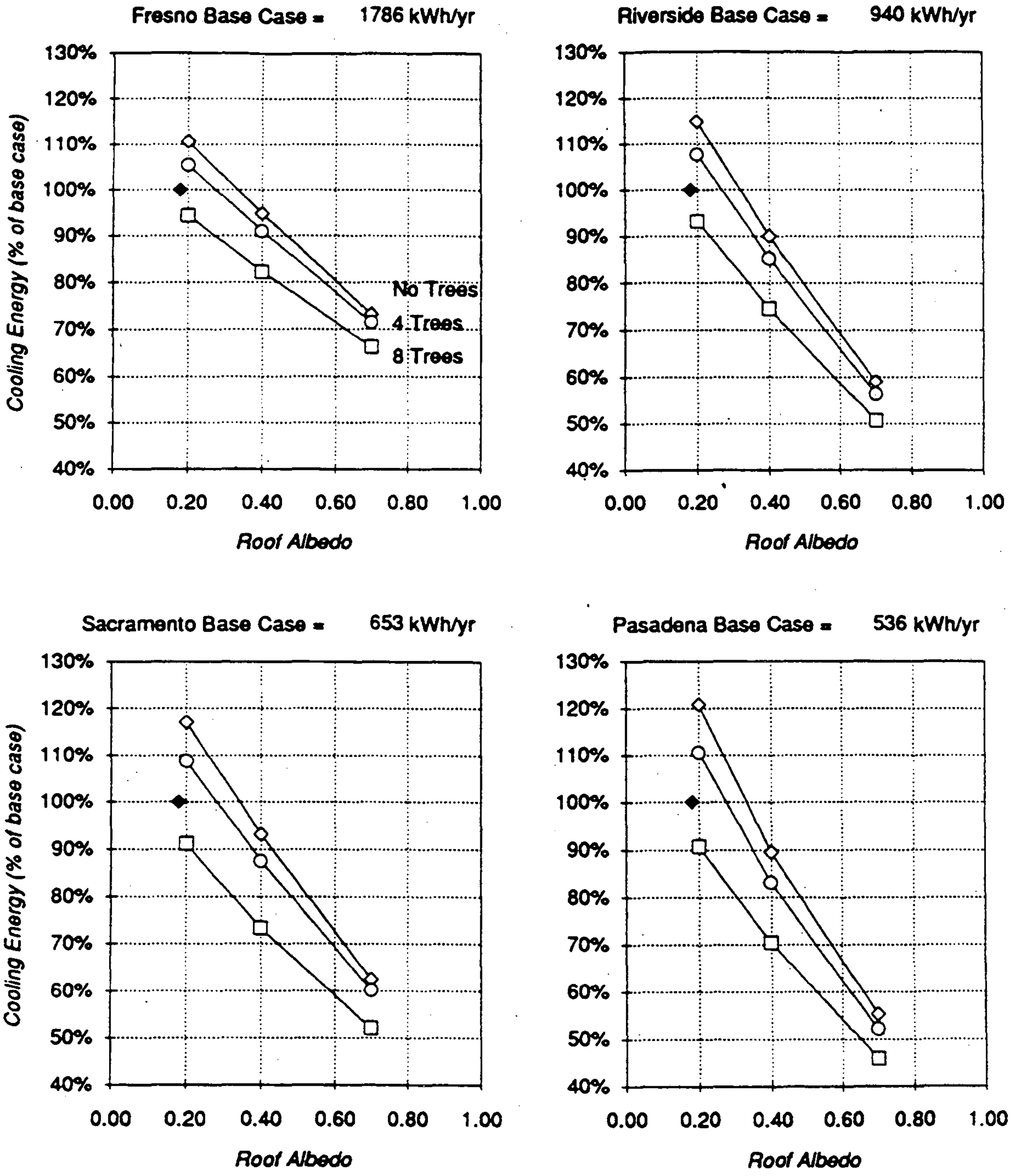


Figure VI-3. Annual cooling energy consumption (including fan energy) for Site 5 in four location. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7 Base case (shown here as a black diamond) has no trees but some shading from south overhang and neighboring buildings. Major exterior wall are faces north and south and window area faces north, south, and east. Savings for high albedo roofs are partly due to improvement in duct efficiency.

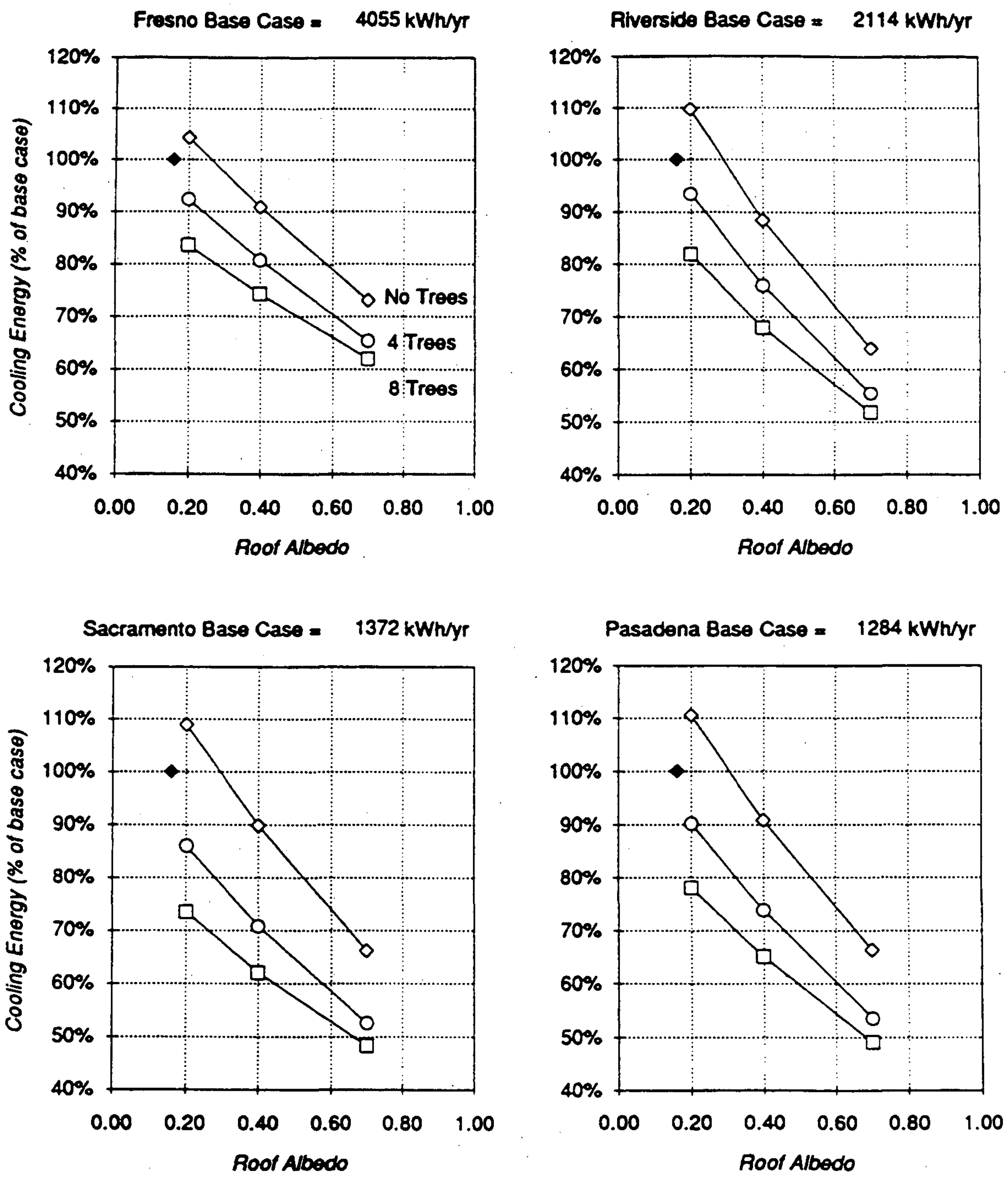


Figure VI-4. Annual cooling energy consumption (including fan energy) for Site 6 in four locations. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7 Base case (shown here as a black diamond) has three small trees at southwest corner and two small trees on west. Major exterior wall and window area faces west. Savings for high albedo roofs are partly due to improvement in duct efficiency.

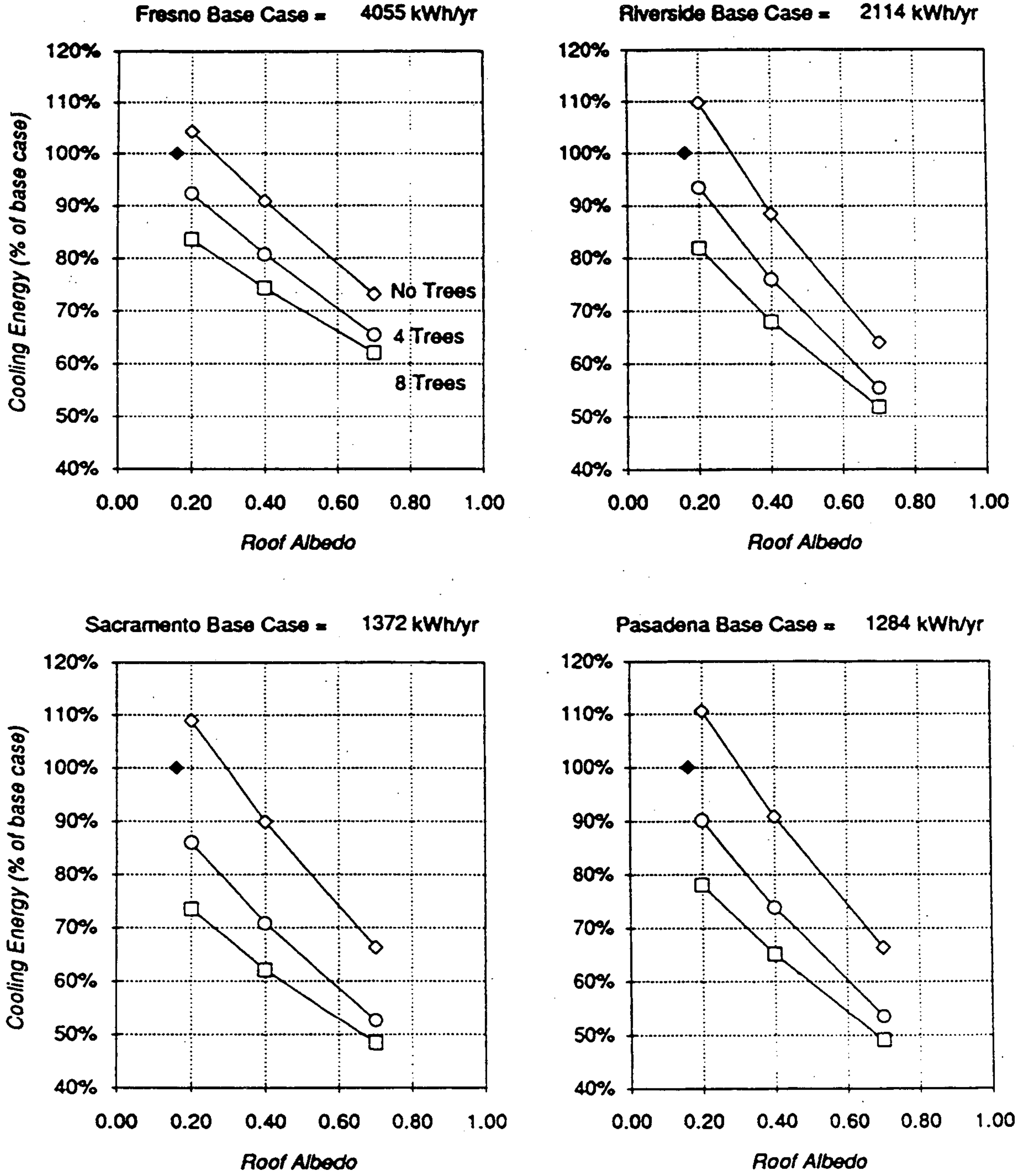


Figure VI-5. Annual cooling energy consumption (including fan energy) for Site 7 in four locations. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7 Base case (shown here as a black diamond) has large tree to east and small tree to west. Major windows face east and west with 2 small south windows. Walls face all directions. Savings for high albedo roofs are partly due to improvement in duct efficiency.

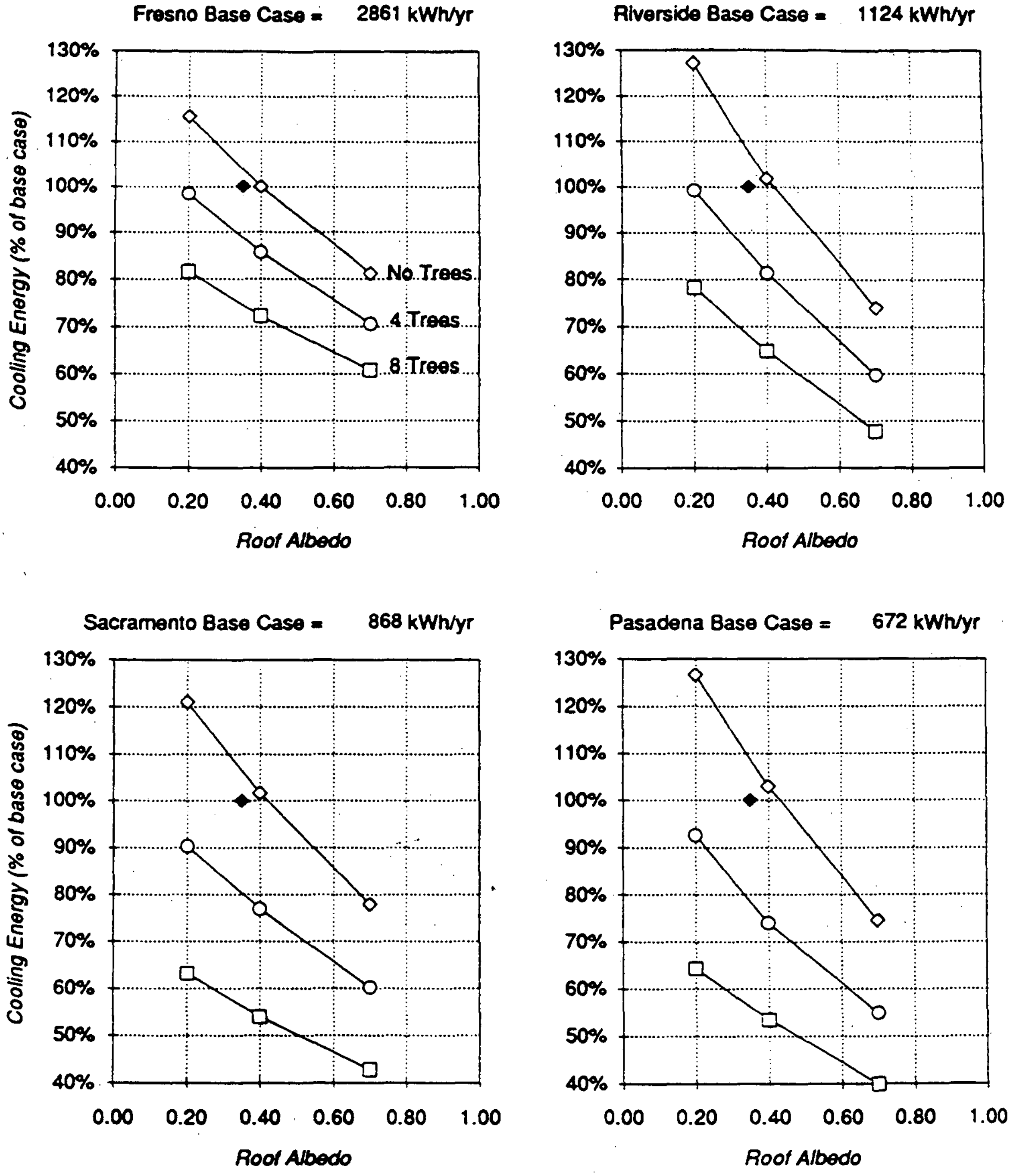


Figure VI-6. Annual cooling energy consumption (including fan energy) for Site 8 in four locations. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7 Base case (shown here as a black diamond) has no tree cover and little shading from neighboring buildings. Major window and wall areas face south and north. Savings for high albedo roofs are partly due to improvement in duct efficiency Savings for high albedo roofs are partly due to improvement in duct efficiency.

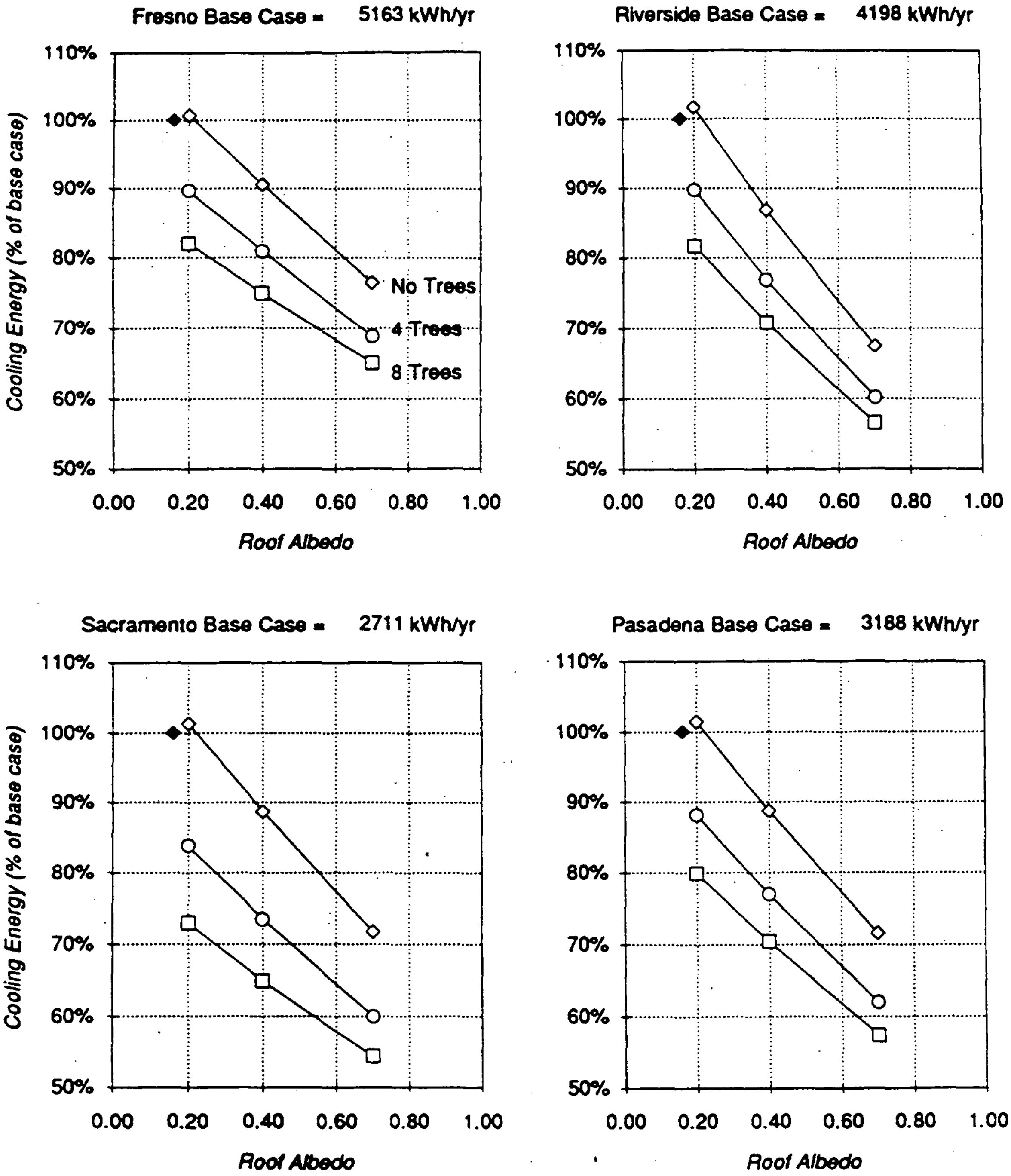
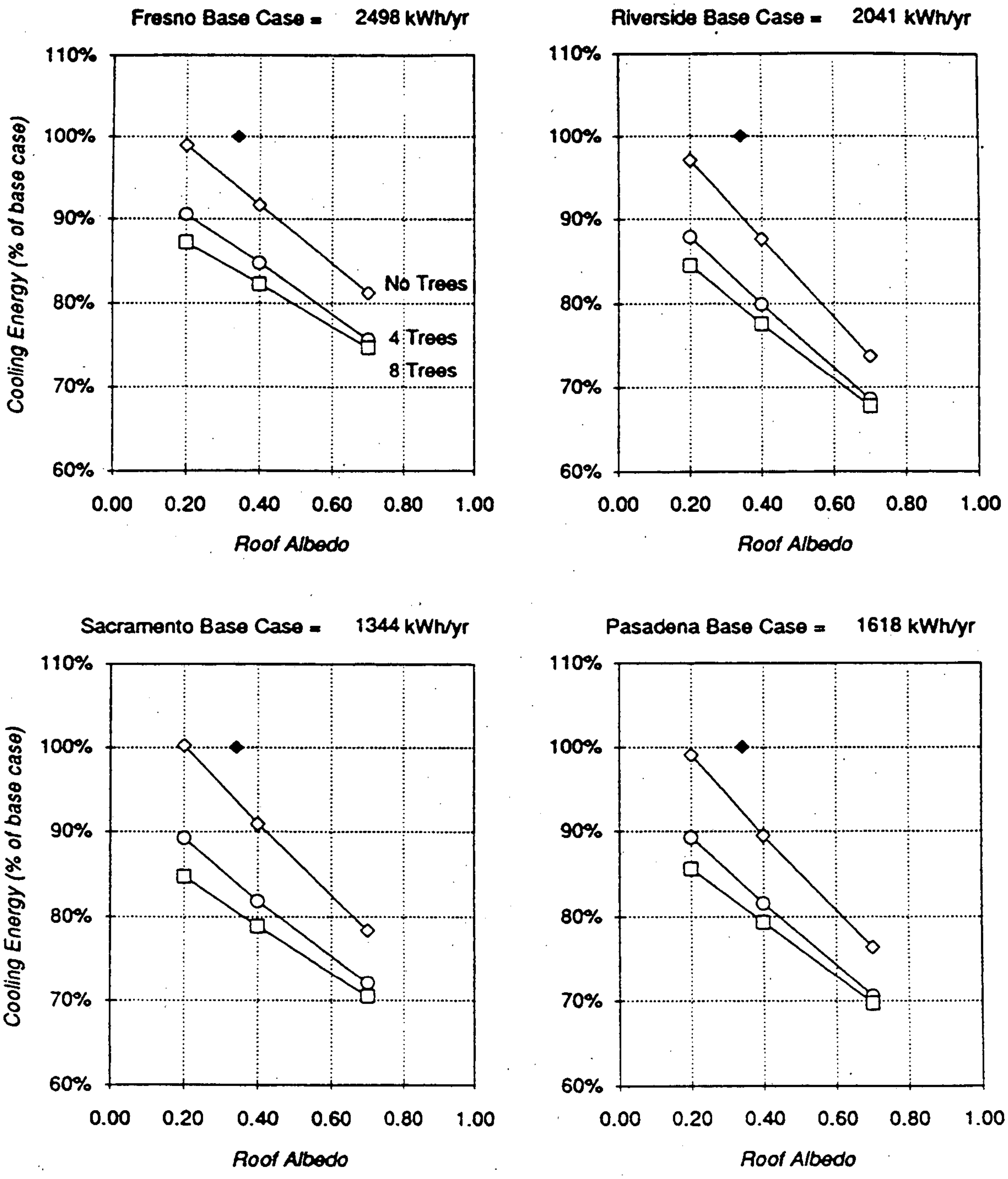


Figure VI-7. Annual cooling energy consumption (including fan energy) for Site 8 in four locations. Wall albedo = 0.15, 0.3 and 0.5 for roof albedo = 0.2, 0.4 and 0.7 Base case (shown here as a black diamond) has windows to south, south overhang, and east and west shading from buildings and trees. Buildings assumed to be unoccupied during June, July, August, and on weekends. Base case also includes the effect of the low emissivity of the unpainted metal roof.



The comparison of calibrated basecase simulations with the parametric indicates that, in general, less than 10% of the potential energy savings of shade trees are achieved in present conditions. There are over 90% of the potential savings available as a target. The potentials for changing albedo of roofs and walls are also as great as shade trees. Most sites have roof albedos less than 30% and there is room to increase the roof albedo to 50%-70%

It is also important to note that the air-conditioning systems in all climates are assumed to have the same capacity and characteristics as those of the basecase buildings in Sacramento. Hence, the simulated saving results for the hotter climates of Riverside and Fresno, where the capacity of the systems are undersized, are probably lower than the case where system were correctly designed for these climate conditions.

However, the impacts on peak electricity demand overall, as shown in Table VI-4, are not as significant as the impacts on annual energy use. This may be partly due to undersized cooling systems in these buildings for the more extreme cooling climates of Fresno and Riverside. In the Sacramento experimental period, the measured data showed maximum hourly cooling use only at Site 8. Peak demand is also affected by the duct efficiency in our model. The interactions between duct performance and roof albedo modifications, which affect attic temperature, will be addressed in more detail in future phases of the project. The simulated peak power savings are in the range of 3% to 30% in Sacramento with an average of about 20%. We expect comparable demand savings in other climate regions.

We have averaged and summarized the annual energy and peak power savings in **Table VI-5**. The savings are averaged using the basecase consumption for each building as a weighting factor. The average energy saving potentials is about 33% in Fresno and about 42% in other climate regions. The average potential peak power savings are about 17% to 20%. Note that, since the air-conditioning systems are designed for Sacramento climate, the peak power savings for other climates, particularly Fresno, may be underestimated.

Table VI-5. Average Annual Cooling Energy and Peak Power Saving Potentials of Shade Trees and White Surfaces. The savings are averaged using the basecase consumption for each building as a weighting factor.

	Base Case		Savings	
Climate	Energy (kWh)	Peak (kW)	Energy (%)	Peak (%)
Fresno	3306	4.28	33	17
Riverside	2056	3.69	42	19
Sacramento	1399	3.78	43	19
Pasadena	1427	3.30	42	20

VII. SUMMARY AND CONCLUSIONS

In this project we set to assess, monitor, and document the **direct effects** of shade trees and white surfaces on building cooling energy use. The specific goals of the first phase included assessing and documenting the albedo performance characteristics of various building and paving materials, specifying/recommending how they should be used in an incentive program, documenting the air-conditioning energy savings of shade trees and albedo changes by instrumenting a few selected sites in Sacramento, and comparing simulation results with monitored data.

This project was designed as a collaborative effort between LBL and SMUD. LBL's participation in this study involved project design, equipment installation, and data analysis whereas SMUD supplied the monitoring equipment and instrumentation and made an engineer's time available for instrumenting the selected buildings, collecting data, and transferring data to LBL for analysis.

Seven buildings (sites) were available for this study out of approximately 100 that were initially on a list of potential sites to participate in this project. Hence, the sample of monitored buildings is not representative of the current building stock in Sacramento and we caution against simplistic extrapolations of results from this report.

One of the sites was designated as a control, two sites (one house and one school) were used as albedo modification cases, and the rest of the sites was used for vegetation modifications. In the albedo cases, albedo was increased from a basecase value of about 0.15 to a new value of about 0.75. Vegetation modifications, on the other hand, were performed mainly with trees in movable containers placed adjacent to walls and windows. At the time of positioning (9-24-91), these trees had a leaf cover of about 50% based on our estimates.

Prior to the start of monitoring, we developed detailed experiment design protocols for each site. While the specifics at each site dictated variations in the experiment protocols, the essential features were the same. Sites were identified as either control (site 1), vegetation site (sites 5, 6, 7, and 8), or albedo site (sites 2 and B). Regardless of whether a test site was to be used as an albedo case or a vegetation case, similar indoor and outdoor variables were measured in most locations.

Depending upon the requirements at a given site, we employed a variety of sensors to measure the necessary variables: air temperature, surface temperature, relative humidity, wind speed, wind direction, solar radiation, air conditioner energy use, and sub-surface soil temperature and moisture.

Prior to the dynamic (field) calibration of sensors, bench calibration was carried out. When interpreting the output, conversion from analog to digital and to meaningful physical units was necessary. Before installation at the residential and school sites, the sensors and data-loggers were dynamically calibrated side by side in a large open yard at SMUD. At the end of the project, the sensors were recalibrated to make sure no drift had occurred during the monitoring period. Each combination of sensors, wires, connections, and a data-logger formed a "set" of components that we kept together during calibration and throughout the monitoring period. Pre-calibration was performed in August 1991, whereas post-calibration was performed in December 1991.

The data loggers were programmed to record all variables at 20 minutes and some variables at 10 minutes. As expected with a monitoring project of this size we encountered some problems, primarily related to equipment in the field. We were able to identify some of these problems and remedy them on-line. Other conditions, concerning site control, were not so easily remedied. Some site control conditions, including thermostat settings and windows covering schedules, depended on the occupant's cooperation. Sensor problems were minimal (3.5%); only four sensors out of one hundred and fifteen sensors had problems.

Two types of data were obtained from each site. The first included environmental characteristic data such as building albedo, vegetation type/tree cover, and view factors. The second include a microclimate and energy use data. Our initial analysis included checking for outliers, missing data, and signal-saturated output. Following that, we performed intercomparison among all sites within the pre-modification period as well as an intercomparison with concurrent data from other sites and prior data from the same site after modification.

The measurement period for some of the sites was limited to the months of September and October 1991. These months typically are transitional cooling months in Sacramento and, therefore, the results presented here are limited to these measurement periods. With the help of simulations, we were able to estimate the impacts of high-albedo roofs and shade trees on cooling energy use for the hot summer months of June, July, and August.

Another limitation that the project encountered was the small-sized trees made available for the shading experiment. Hence, the measured savings from shade trees need to be verified further in the next cooling season.

Data analysis proceeded under the assumption that reductions in air conditioner energy use were a result of albedo and vegetation modifications. As has been pointed out elsewhere in this report, this assumption may not be valid in some cases.

An important component of this monitoring project was to model and simulate the monitored buildings using the DOE-2.1D building energy analysis program to better understand and evaluate the measured data. We developed models based on building characteristic data and measured temperature data collected for each site. These models were the basis for initial comparisons with the measured data. These models were also used to estimate savings for an entire year to supplement measured data from the two-month period of monitoring.

To calibrate the model for each building, we compared simulated hourly compressor energy use and interior temperatures to corresponding measured data. At most monitoring sites, the measured data had significant gaps, which precluded the possibility of comparing the models with the measured data over long-term periods. Based on the available measured data, we chose one week of continuous hourly data from the pre- and post-modification periods for comparisons.

In our analysis of data from the control site (Site 1), we found that mechanical cooling started when the outdoor daily maximum temperature exceeded 30°C. Regression analysis indicated an increase in cooling load by about 1.2 kWh day^{-1} per °C of maximum daily temperature. The comparison of hourly measured and simulated data for Site 1 showed that, in general, the total daily cooling electricity matched well over the period for which consistent data exists.

In the residential albedo site (Site 2), the analysis of measured data indicated that after increasing the albedo of the roof from 0.18 to 0.77 the air conditioner was not required to maintain the indoor setpoint temperature on the immediate two weeks of post retrofit which had comparable outdoor temperature. It is worth noting, however, that solar intensity was generally lower during the post-monitoring period, and that might explain why 100% reductions were possible. The DOE-2.1D simulations of this site, performed for corresponding periods, indicated that about 20% of the measured reductions may have been caused by the effect of lower insolation during the post-monitoring period.

In the other albedo site (school) the analysis of measured data showed that cooling energy use in the white-coated test unit was about 50% of the amount of cooling energy used in the control unit (with yellow walls and metallic roof). One should keep in mind, however, that in addition to the effect of higher albedo coatings on the roof and southeast wall of the test unit, other factors that might haye contributed to the higher energy usage in the control unit included thermostat reset in the control classroom and lower emissivity (~0.30) of the metallic roof compared to the emissivity of the painted roof (~0.95) in the brown or white configurations. The DOE-2 simulations indicated that 15-20% of the measured savings were actually due to the high albedo coating. The rest was a result of thermostat setting and emissivity differences as was discussed in this report.

In the vegetation modification sites, varying results were obtained. In Site 5, for example, at 38°C outdoor air temperature, there were reductions of 2 kWh day^{-1} in cooling energy use after the placement of two trees on the east side. These reductions correspond to ~14% at that temperature. DOE-2 simulations of this site indicated that the reductions were mostly due to the effects of lower insolation during the post-monitoring period, rather than the placement of shade trees.

In Site 6 at 38°C, there was a reduction of 4.5 kWh day^{-1} (~30%) in cooling energy use resulting from the placement of two trees on the west and one tree on the south sides. The comparison of measured and simulated data for Site 6 showed that the simulated peak load coincided with the measured peak for the post-period, but overpredicted the peak by about 0.5 kW on average in the pre-period. The model overpredicted cooling energy use in the post-period more than in the pre-period. When the same climatic inputs were used in the model for the base and tree cases, there was virtually no difference in cooling energy consumption, that is, no savings.

In Site 7, and at 38°C outdoor air temperature, the placement of 2 southwest trees resulted in a reduction of ~5 kWh day^{-1} or about 34% of cooling electricity use. However, the DOE-2 simulations indicated that almost all these reductions were caused by lower insolation during the post-monitoring period.

Finally, our analysis of data from Site 8 (which is located just next to Site 1) showed that at 38°C, there were reduction of ~2.5 kWh day^{-1} in cooling electricity use, which amounts to a reduction of 12%, resulting from the placement of seven small trees on the south side. Compared to the measurements, the simulated conditions for this site were consistently about 4 kWh/day higher over the pre- monitoring period. As with the other tree sites, when the change in climatic conditions between the pre- and post-periods was accounted for, the simulated cooling energy savings from the trees was found to be minimal.

Overall, the calibration and comparison of measured and simulated conditions highlighted the difficulty of matching simulation results with measured data. The types and magnitudes of the errors were not consistent across the sites. The daily energy consumption was slightly overpredicted at Sites 2, 5 (pre-period), 6, 7, and 8, but the peaks matched well. Peak loads at Sites B and 5 matched well, but daily energy consumption at Site 5 did not match well. Our analysis suggests the models could benefit from further refinements. However, given the current level of characterization for each site, the models perform reasonably well. The necessary refinements would focus on details of the cooling systems, which is the primary method of assessing albedo and vegetation impacts, occupancy patterns, thermostat operations, building thermal mass, and the local climate characteristics.

Although in the first year project we have made significant progress in experiment design, debugging the system, obtaining base case condition, and a preliminary survey, we need to continue the experiment for another cooling season. During the second phase, the ducting system in each house should be tested for air leakage and conduction losses. These parameters could then be incorporated into the models to more accurately characterize duct performance at different climatic conditions. The cooling equipment efficiency may also be further characterized by simple spot testing or more complete monitoring of air flows and temperatures and electricity consumption.

More information about occupancy patterns and appliance usage schedules would improve the inputs for hourly internal gains simulations. The effect of improved characterization of internal gains is unclear, however. Some of the interior temperature data shows the buildings have a slower thermal response to diurnal temperature swings than the model predicts. Better model inputs for thermal mass may improve the models in this area.

More complete climatic data for each site would allow us to develop model inputs that are more specific to a site's microclimate. Significant gaps in site temperature data did not allow the data to be used in the simulations. In addition, the site solar data was not useful to the DOE-2 models because of the method of measurement. These problems should be addressed in future work.

Model calibration would also benefit from several indoor temperature sensors, which would help to understand the conditions throughout the building. In particular, a sensor located next to the thermostat would help explain and verify apparent thermostat abnormalities.

Another issue to keep in mind in the second year of this project is the start of monitoring. Preferably, measurements should begin early in summer to avoid the concerns of seasonal cooling. An ideal time to start would be the month of June. Also, plenty of time should be allowed for equipment acquisition, testing, calibrating, and installing in the field. These tasks are the most crucial and demanding of all project tasks. Finally, in the second year of this project, larger and more mature trees should be used instead of the small ones.

ATTACHMENT A

DOE-2 INPUT FILES

DOE-2 INPUT FILE FOR SITE 1 BASE CASE

```
       POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                      (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $-------------------------------------------------------------------
      INPUT  LOADS ..
$Resl  $ TITLE LINE-1 *SMUD 1 *
$BaseC $       LINE-2 *Base Case *
      LINE-3  *                                                 *
      LINE-4  *                                                 *
      LINE-5  *                                                 *
               ..
 $-------------------------------------------------------------------
         PARAMETER
 $-------------------------------------------------------------------
 $                                                               $
 $    IWALLAREA = area of interior walls                         $
 $                                                               $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $         + .10 x minimum month daily electric usage LATN,
 $         + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $         + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $         (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Resl        $ FLRAREA=1122 HOUSVOL=10098 PERIM=143 IWALLAREA=799.99
$Resl        $ GARAREA=468 NEX=40.5 NEY=30.0
$Resl        $ ROOFZ=7.999 ROOFHT=16.15 ROOFWD=40.5
$Resl        $ NWALLWD=2 SWALLWD=40.5 EWALLWD=30.0 WWALLWD=25.5
$Resl        $ WALLHT=7.999  SHADEHT=7.257
$Resl          INTLOAD=30006 LATLOAD=.215
$Resl        $ INTLOAD=27230 LATLOAD=.150 NUMOCC=1
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
```

```
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R19 Ceiling            $ VAULL = r19vaul CEILL = r19ceil
$R11 Stucco wall        $ WALLL = r11swall
$Basel $              WALLABS= 0.70  $ tan stucco
$Basel $              ROOFABS= 0.60  $ tan shingles
$Resl $ T1AX=12.4 T1DX=-1.6 T2AX=25.25 T2DX=11.25 T3AY=28.75 T3CY=14.75
$Resl $ T4AX=57.5 T4AY=8 T4CY=-6 T4DX=43.5
$Resl $ FSW1=40.5 FSW2=30.0 FSW3=45.0 FSW4=55.5 FSW5=70.5
$Sacram One  Slab  FM0   $ FDNUEFF =.0569  $ GndU=.0076 GndT= 0
 $ ---  end of parameters ------------------------------------------
          ..
$Year $ RUN-PERIOD          JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.52 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST=
                             (50,50,50,50,50,50,50,50,50,50,50,50)
$Resl $                     AZIMUTH=-45
                            SHIELDING-COEF=0.19
$Nownd$                     TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                     WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                             ..
         ABORT     ERRORS ..
         LOADS-REPORT
$HrRpt$             HOURLY-DATA-SAVE = YES
                    SUMMARY=(LS-E)  ..
 $-------------------------------------------------------------------
 $-----  Loads Schedules -------------------------------------------
 $-------------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                    (1) (.024)  (2) (.022)  (3,5) (.021)
                    (6) (.026)  (7) (.038)  (8) (.059)
                    (9) (.056) (10) (.060) (11) (.059)
                   (12) (.046) (13) (.045) (14) (.030)
                   (15) (.028) (16) (.031) (17) (.057)
                (18,19) (.064) (20) (.052) (21) (.050)
                   (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE   $CEC modified: appl on unoccupied day
                    (1) (.024)  (2) (.022)  (3,5) (.021)
                    (6) (.026)(7,8) (.075) (9,17) (.059)
                   (18) (.072) (19,22) (.080)
                   (23) (.072) (24) (.027) ..
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
                  (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
```

```
                 (10) (0.52)    (11) (0.63) (12) (0.21) (13) (0.14)
              (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
                 (22) (0.89)    (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)
               (9,18) (0.00)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
                 (22) (0.89)    (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Resl $ INTLDSCH SCHEDULE THRU DEC 31 (WD) UOCCAPPS  (WEH) DAYINTSCH ..
$Resl $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCNO     (WEH) OCCYES ..
 $------------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $------------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Resl $             THRU OCT 31 (ALL) (1,24) (0.60)
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $------------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $------------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $------------------------------------------------------------------
 $-----  Constructions  --------------------------------------------
 $------------------------------------------------------------------
WINDOWGT           GLASS-TYPE            $ Windows
                      GLASS-TYPE-CODE=1  $clear glass
$2-pane $             PANES = 2
                      ..
```

```
WALLCON             CONSTRUCTION     $ Wall section
                        ABSORPTANCE= WALLABS
$Resl  $                ROUGHNESS=1  $ stucco
                        LAYERS=WALLL ..
VAULCON             CONSTRUCTION     $ Vault ceiling section, with joist
                        ABSORPTANCE= ROOFABS
$Resl  $                ROUGHNESS=2 $ shingle
                        LAYERS=VAULL ..
CEILCON             CONSTRUCTION     $ Ceiling below attic section, with joist
                        LAYERS=CEILL ..
ROOFCON             CONSTRUCTION     $ Roof above attic section, with joist
                        ABSORPTANCE= ROOFABS
$Resl  $                ROUGHNESS=2 $ shingle
                        LAYERS=r0groof ..
IWALLCON            CONSTRUCTION     $ Interior walls
                        LAYERS=iwalll ..
GWALLCON            CONSTRUCTION     $ garage wall
                        ABSORPTANCE= WALLABS
$Resl  $                ROUGHNESS=1  $ stucco
$Stucco                   $ LAYERS  = r0scwall
                        ..
IGWALLCON            CONSTRUCTION     $ interior insulated garage wall
$Resl $ LAYERS = r1lgwall
                        ..
GROOFCON          CONSTRUCTION     $ garage roof
                        ABSORPTANCE= ROOFABS
$Resl  $                ROUGHNESS=2 $ shingle
                        LAYERS=r0groof ..
DOORCON             CONSTRUCTION     $ Solid door
                        U-VALUE=.7181 ..
GSLABCON            CONSTRUCTION     $ garage slab in contact with soil
                        LAYERS=CGNDL  ..
FSLABCON            CONSTRUCTION     $ Floor slab in contact with soil
$Slab concrete floor$  LAYERS=FSLABL ..
$Stucrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. stucco crawlspace walls
$Stucrawl $              LAYERS=r0scwall ..
 $------------------------------------------------------------------
 $-----  Shades  ---------------------------------------------------
 $------------------------------------------------------------------
$Resl $  SURROUND1 BUILDING-SHADE
$Resl                   house to northeast $
$Resl $                 HEIGHT=9.5 WIDTH=25
$Resl $                 X=65.199 Y=43.299 AZIMUTH=45 TILT=90 ..
$Resl $  SURROUND2 BUILDING-SHADE
$Resl                   house to northwest (Res8)$
$Resl $                 LIKE SURROUND1 WIDTH=49.5
$Resl $                 X=-21 Y=72 AZIMUTH=-45 ..
  $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
```

```
         EAVEN BUILDING-SHADE $ north eave
$Resl $              HEIGHT=2.15 WIDTH=21 X=NEX Y=32 TILT=21.8
                     Z=SHADEHT ..

         EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Resl $              HEIGHT=1.08 WIDTH=40.5 X=0 Y=-1 AZ=180
                     ..

         EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Resl $              HEIGHT=17.15 WIDTH=1 X=41.5 Y=31
                     ..
$Resl $  EAVEE2 BUILDING-SHADE LIKE EAVEE  X=40.5 Y=-1 AZ=180 ..

         EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Resl $              X=0
                     ..
$Resl $  EAVEW2 BUILDING-SHADE LIKE EAVEE2 X=-1 ..
$Resl $  DECKOH BUILDING-SHADE  $ backyard deck overhang
$Resl $              HEIGHT=16 WIDTH=27
$Resl $              X=52.5 Y=4 Z=WALLHT ..
 $------------------------------------------------------------------
 $-----  Trees: First existing, then test trees  --------------------
 $------------------------------------------------------------------

$ExTr1$   TREES1A B-S HEIGHT=5 WIDTH=22 X=25 Y=-0.1 Z=0 TILT=90
$ExTr1$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr1$   TREES1B B-S LIKE TREES1A WIDTH=5 AZ=270 ..
$ExTr1$   TREES1C B-S LIKE TREES1A Y=-5 ..
$ExTr1$   TREES1D B-S LIKE TREES1B X=3 ..
$ExTr1$   TREES1E B-S LIKE TREES1A Z=5 TILT=0 ..
$ExTr1$   TREET1A B-S HEIGHT=17 WIDTH=17 X=59.5 Y=-15.5 Z=7 TILT=90
$ExTr1$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr1$   TREET1B B-S LIKE TREET1A AZ=270 ..
$ExTr1$   TREET1C B-S LIKE TREET1A Y=-32.5 ..
$ExTr1$   TREET1D B-S LIKE TREET1B X=42.5 ..
$ExTr1$   TREET1E B-S LIKE TREET1A Z=24 TILT=0 X=59.5 Y=-15.5 AZ=0 ..
$ExTr1$   TREET2A B-S HEIGHT=26 WIDTH=26 X=23 Y=-16 Z=7 TILT=90
$ExTr1$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr1$   TREET2B B-S LIKE TREET2A AZ=270 ..
$ExTr1$   TREET2C B-S LIKE TREET2A Y=-42 ..
$ExTr1$   TREET2D B-S LIKE TREET2B X=-3 ..
$ExTr1$   TREET2E B-S LIKE TREET2A Z=33 TILT=0 X=23 Y=-16 AZ=0 ..
 $------------------------------------------------------------------
 $-----  Space ------------------------------------------------------
 $------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                    TEMPERATURE = (74)
```

```
                    SOURCE-TYPE=PROCESS
                    SOURCE-SCHEDULE=INTLDSCH
                    SOURCE-BTU/HR=INTLOAD
                    SOURCE-SENSIBLE=1.
                    SOURCE-LATENT=LATLOAD
                    PEOPLE-SCHEDULE=OCCSCH
                    NUMBER-OF-PEOPLE=NUMOCC
                    PEOPLE-HG-LAT=190
                    PEOPLE-HG-SENS=230
                    INF-METHOD=S-G
$Medium Infiltration     $ FRAC-LEAK-AREA = .0005
                    FLOOR-WEIGHT=0
                    FURNITURE-TYPE=LIGHT
                    FURN-FRACTION=0.29
                    FURN-WEIGHT=3.30
                    ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
SET-DEFAULT FOR EXTERIOR-WALL
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Resl $ NWALL1  EXTERIOR-WALL CONSTRUCTION=WALLCON X=NEX Y=NEY
                HEIGHT=WALLHT  WIDTH=NWALLWD
                ..
$Resl $ NWALL2  EXTERIOR-WALL LIKE NWALL1 X=38.5 WIDTH=3.0 AZ=48.9 ..
$Resl $  NWIND2A  WINDOW X=0.75 Y=1.8  HEIGHT=4.5 WIDTH=1.5  ..
$Resl $ NWALL3  EXTERIOR-WALL LIKE NWALL1 X=36.5 Y=32 WIDTH=6.0 ..
$Resl $  NWIND3A  WINDOW LIKE NWIND2A WIDTH=4.5  ..
$Resl $ NWALL4  EXTERIOR-WALL LIKE NWALL1 X=30.5 Y=32 WIDTH=3.0 AZ=-48.9 ..
$Resl $  NWIND4A  WINDOW LIKE NWIND2A ..
$Resl $ NWALL5  EXTERIOR-WALL LIKE NWALL1 X=28.5 WIDTH=2.0 ..
$Resl $ NWALL6  EXTERIOR-WALL LIKE NWALL1 X=26.5 WIDTH=1.5 AZ=-90 ..
$Resl $ NWALL7  EXTERIOR-WALL LIKE NWALL1 X=26.5 Y=28.5 WIDTH=7.0 ..
$Resl $  NDOOR7A  DOOR ..
$Resl $ NWALL8  INTERIOR-WALL CONSTRUCTION=IGWALLCON
$Resl $                  HEIGHT=WALLHT WIDTH=3 NEXT-TO=GARAGE ..
$Resl $ NWALL9  INTERIOR-WALL LIKE NWALL8 WIDTH=19.5 ..
        SWALL1  EXTERIOR-WALL
$Resl $         LIKE NWALL1 X=0.0
                HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
                ..
$Resl $  SWIND1A  WINDOW X= 3 Y=3.6 HEIGHT=2.7 WIDTH=4.8 ..
```

```
$Resl $  SWIND1B  WINDOW LIKE SWIND1A X=16 HEIGHT=3.0 WIDTH=4.5 ..
$Resl $  SWIND1C  WINDOW X=26 Y=2.7 HEIGHT=3.0 WIDTH=3.3 ..
$Resl $  SWIND1D  WINDOW X=33 Y=0.0 HEIGHT=6.0 WIDTH=5.4 ..
$Resl $ EWALL1  EXTERIOR-WALL LIKE NWALL1 Y=0 AZ=90
                WIDTH=EWALLWD ..
$Resl $  EWIND1A  WINDOW  X=1 Y=0.6 HEIGHT=5.7 WIDTH=2.4 ..
        WWALL1  EXTERIOR-WALL
$Resl $         LIKE NWALL1 Y=25.5
                X=0 WIDTH=WWALLWD AZIMUTH=270
                ..
$Resl $  WWIND1A  WINDOW  X=3 Y=4.20 HEIGHT=2.40 WIDTH=1.50 ..
$Slab  $ FOUNDATION UNDERGROUND-FLOOR $ Slab floor
$Slab  $            HEIGHT=10 WIDTH=FLRAREA TIMES .1
$Slab  $            TILT=180 CONSTRUCTION=FSLABCON
$Slab  $            U-EFFECTIVE=FDNUEFF
$Slab  $            FUNCTION =(*NONE*,*FNDQ*)  ..
$Attic$ CEILING    INTERIOR-WALL    $ Ceiling between House and Attic
$Attic$            TILT=0 CONSTRUCTION=CEILCON
$Attic$            AREA=FLRAREA NEXT-TO=ATTIC  ..
$Attic spaces
$Attic$  ATTIC      SPACE
$Attic$             AREA=FLRAREA VOLUME=FLRAREA TIMES 2.90 $ avg height
$Attic$             INF-METHOD=S-G
$Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
$Attic    ELF = 75% of vent area
$Resl $             FRAC-LEAK-AREA= .00167
$Attic$             FLOOR-WEIGHT=0
$Attic$             ZONE-TYPE=UNCONDITIONED T=(80)
$Attic$             ..
$Attic$ NROOF1    ROOF       Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Attic$             CONSTRUCTION=ROOFCON
$Resl $             X=NEX Y=NEY TILT=21.8
$Attic$              ..
$Attic$ SROOF1    ROOF        LIKE NROOF1
$Resl $             X=0 Y=0  AZIMUTH=180
$Attic$              ..
         GARAGE     SPACE
                    AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                    INF-METHOD=S-G
                    FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                    FLOOR-WEIGHT=0
                    ZONE-TYPE=UNCONDITIONED T=(60)
                    ..
         GAR1 EXTERIOR-WALL
                     HEIGHT=WALLHT TILT=90
$Resl $              WIDTH=21 X=19.5 Y=28.5 AZ=90     $ garage Ewall
                     CONSTRUCTION=GWALLCON
                     ..
```

```
$Resl $  GWIND1 WINDOW
$Resl $              X=13 Y=4 HEIGHT=3 WIDTH=5 ..     $ window
         GAR2 EXTERIOR-WALL
                     LIKE GAR1
$Resl $              WIDTH=24 X=0 Y=49.5 AZ=-90       $ garage Wwall
                     ..
         GAR3 EXTERIOR-WALL
                     LIKE GAR1        $ garage door wall
$Resl $              HEIGHT=9.8 WIDTH=19.5 X=19.5 Y=49.5 AZ=0  ..
$Resl $              GDOOR DOOR X=0.8 WIDTH=18   ..  $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Resl $       AREA=180    CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Resl $       LIKE GAR1 HEIGHT=11.4 TILT=31.6
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..
$Resl $  GROOF2 EXTERIOR-WALL
$Resl $       LIKE GAR2 HEIGHT=11.4 WIDTH=21 TILT=31.6
$Resl $       Z=ROOFZ CONSTRUCTION=GROOFCON   ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143  .. $ Ref j.huang - ashrae paper
$HrRpt---------------------------------------------------------
$HrRptLoads  Reports ------------------------------------------
$HrRpt---------------------------------------------------------
$HrRpt$   RB1         REPORT-BLOCK       $ Reports for wall temp
$HrRpt$            VARIABLE-TYPE=SWALL1
$HrRpt$            VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2         REPORT-BLOCK       $ Reports for roof temp
$HrRpt$            VARIABLE-TYPE=SROOF1
$HrRpt$            VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH       SCHEDULE           $ Hourly report schedule
$HrRpt$            THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR         HOURLY-REPORT
$HrRpt$            REPORT-SCHEDULE=HRSCH
$HrRpt$            REPORT-BLOCK=(RB1,RB2)
$HrRpt$            ..
         END ..

FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
```

```
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  0, -3336.3)(  1, -3389.2)(  2, -3462.1)(  3, -3450.6)(  4, -3494.9)
(  5, -3548.8)(  6, -3512.7)(  7, -3387.8)(  8, -3400.9)(  9, -3432.8)
( 10, -3467.4)( 11, -3408.3)( 12, -3335.8)( 13, -3164.1)( 14, -3056.2)
( 15, -3061.6)( 16, -3176.4)( 17, -3309.6)( 18, -3360.7)( 19, -3255.2)
( 20, -3035.1)( 21, -2849.8)( 22, -2809.7)( 23, -2858.6)( 24, -2872.7)
( 25, -2901.3)( 26, -2954.2)( 27, -2910.6)( 28, -2832.9)( 29, -2737.7)
( 30, -2508.2)( 31, -2379.1)( 32, -2303.7)( 33, -2479.3)( 34, -2686.4)
( 35, -2608.0)( 36, -2500.5)( 37, -2413.6)( 38, -2188.9)( 39, -2045.6)
( 40, -2134.6)( 41, -2002.3)( 42, -1946.5)( 43, -1931.6)( 44, -1942.3)
( 45, -2040.4)( 46, -1852.8)( 47, -1659.4)( 48, -1673.6)( 49, -1538.1)
( 50, -1285.3)( 51, -1176.9)( 52, -1189.2)( 53, -1122.8)( 54, -1020.4)
( 55, -1070.9)( 56, -1147.7)( 57,  -839.9)( 58,  -621.7)( 59,  -592.9)
( 60,  -577.7)( 61,  -569.9)( 62,  -507.0)( 63,  -493.0)( 64,  -494.7)
( 65,  -338.1)( 66,  -236.5)( 67,  -199.1)( 68,  -206.2)( 69,  -148.7)
( 70,   -30.5)( 71,    25.0)( 72,    81.5)( 73,    68.1)( 74,   -28.9)
( 75,   -49.4)( 76,    50.9)( 77,    73.1)( 78,    34.9)( 79,  -123.6)
( 80,  -331.5)( 81,  -320.9)( 82,  -271.8)( 83,  -264.4)( 84,  -250.2)
( 85,  -281.9)( 86,  -345.3)( 87,  -377.1)( 88,  -471.5)( 89,  -680.4)
( 90,  -661.4)( 91,  -665.3)( 92,  -717.0)( 93,  -771.9)( 94,  -825.7)
( 95,  -845.2)( 96, -1001.8)( 97, -1214.9)( 98, -1290.1)( 99, -1357.0)
(100, -1332.1)(101, -1377.6)(102, -1458.1)(103, -1635.8)(104, -1807.5)
(105, -1935.5)(106, -1957.5)(107, -2015.7)(108, -2097.4)(109, -2161.6)
(110, -2276.3)(111, -2428.2)(112, -2591.7)(113, -2814.8)(114, -2984.9)
(115, -2965.2)(116, -2985.4)(117, -2984.5)(118, -3194.8)(119, -3339.1)
(120, -3281.2)(121, -3316.4)(122, -3332.9) ..
     CALCULATE  ..
     WEEK = DOY / 3.0
     UGWQ = 0.0
     UGFQ = PWL(QTABL, WEEK)
C    PRINT 10, DOY, WEEK, UGWQ, UGFQ
  10 FORMAT('FNDQ',4F10.2)
     END-FUNCTION  ..
        COMPUTE LOADS ..
         POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
         INPUT    SYSTEMS ..
                    ..
         DIAGNOSTIC   CAUTIONS ECHO ..
$Duct $  SUBR-FUNCTIONS
```

```
$Duct $          RESYS-0=*DUCT*
$Duct $          RESYS-32=*SAVETEMP*
$Duct $          DAYCLS-4=*DUCT2* ..
        SYSTEMS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $-------------------------------------------------------------
        PARAMETER
 $-------------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
 $
$Res1 $   HEATSET=68    SETBACK=68     COOLSET=78   SETUP=88
$Res1 $   HPHCAP=-21400 HPBKUP=-15000  CTCAP=24000  CSCAP=19200
$Res1 $   ACCFM=800
 $
$Res1 $   VTYPE= 0                $ no venting
 $
$HP   $          HEIR=.3703       $ 2.7 COP Heat Pump
$HP   $          MAXTEMP=100
$Res1 $   CBF=.098      CEIR=.4762       $ est 2.1 COP HP
                    ..
 $-------------------------------------------------------------
 $-----  Systems Schedules  -----------------------------------
 $-------------------------------------------------------------
HTSCH     SCHEDULE  $ heat temperature schedule, 7 hour night setback
                    THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                      (7,23) (HEATSET)
                                      (24)   (SETBACK)  ..
CTSCH     SCHEDULE  $ cool temperature schedule, 7 hour day setup
                    THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                      (8,15) (SETUP)
                                      (16,24)   (COOLSET)  ..
VTSCH     SCHEDULE  $Vent schedule based on previous 4 days load
                    THRU MAY 14 (ALL) (1,24) (-4)
                    THRU SEP 30 (ALL) (1,24) (-4)
                    THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE  $Vent operation schedule
                    THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                    THRU DEC 31 (ALL) (1,6)  (0.0)
                                      (7,23) (1.0)
                                      (24)   (0.0)  ..
```

```
 $--------------------------------------------------------------
 $-----  Zones  ------------------------------------------------
 $--------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=70.
                              DESIGN-COOL-T=78.
                              COOL-TEMP-SCH=CTSCH
                              HEAT-TEMP-SCH=HTSCH
                              THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM             ZONE      ZONE-CONTROL=ZC1
                              ZONE-TYPE=CONDITIONED ..
$Attic $ ATTIC      ZONE      ZONE-TYPE=UNCONDITIONED  ..
GARAGE              ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $--------------------------------------------------------------
 $-----  Systems  ----------------------------------------------
 $--------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                 MAX-SUPPLY-T=MAXTEMP
                 MIN-SUPPLY-T=50
                   ..
SYSAIR    SYSTEM-AIR
                 SUPPLY-CFM=ACCFM
                 NATURAL-VENT-SCH=VOPSCH
                 VENT-TEMP-SCH=VTSCH
                 OPEN-VENT-SCH=WINDOPER
                 HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                 FRAC-VENT-AREA=0.018
                 VENT-METHOD=S-G
                 MAX-VENT-RATE=20
                   ..
SYSFAN    SYSTEM-FANS                $added by jim 11/25/92
                 SUPPLY-KW=0.000333   $average of 400 W for 1200 CFM
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-CAPACITY=CTCAP
                 COOLING-EIR=CEIR        $added by jim 1/13/92
                 COOL-SH-CAP=CSCAP
                 COIL-BF=CBF
                 CRANKCASE-HEAT=0.0      $added by jim 3/5/92
                 COMPRESSOR-TYPE=SINGLE-SPEED
$HP      Heatpump specifications    $
$HP    $         HEATING-CAPACITY=HPHCAP
$HP    $         HEATING-EIR=HEIR
$HP    $         HP-SUPP-HT-CAP=HPBKUP
$HP    $         MAX-HP-SUPP-T=40.
                    ..
```

```
RESIDEN  SYSTEM  SYSTEM-TYPE=RESYS
$Slab  $       ZONE-NAMES=(THEROOM,GARAGE
$Attic $                   ,ATTIC
$Slab  $                    )
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-FANS=SYSFAN
                 SYSTEM-EQUIPMENT=SYSEQP
$HP    $         HEAT-SOURCE=HEAT-PUMP
                 ..
$HrRpt-----------------------------------------------------
$HrRptSystem Reports ---------------------------------------
$HrRpt-----------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK   $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK       $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$           ..
          END ..
FUNCTION NAME = DUCT ..
 $
 $ This function multiplies the AC EIR
 $ by the duct efficiency which varies
 $ with attic temperature
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       DEFFC=-0.0077*TATT + 1.379
       COOLEIR = COOLEIR/DEFFC
       COOLCAP = COOLCAP*DEFFC
       COOLSEN = COOLSEN*DEFFC
```

```
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME = DUCT2 ..
 $
 $ This function resets AC EIR to the input value
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       COOLEIR = COOLEIR*DEFFC
       COOLCAP = COOLCAP/DEFFC
       COOLSEN = COOLSEN/DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME=SAVETEMP ..
$
$ saves last hours zone temps for next hour's heat load
$ calculations
$
ASSIGN TATT=XXX23 ..
ASSIGN TNOW = TNOW  ZNAME = ZONE-NAME DBT=DBT  NZ=NZ ..
ASSIGN HUMRAT=HUMRAT ..
      CALCULATE ..
C     IF (ZNAME.EQ."THER") GO TO 100
C     IF (ZNAME.EQ."GARA") GO TO 100
C     IF (ZNAME.EQ."ATTI") GO TO 70
      IF (NZ.EQ.1) GO TO 100
      IF (NZ.EQ.2) GO TO 100
      IF (NZ.EQ.3) GO TO 70
      GO TO 100
C attic
  70    TATT=TNOW
      GO TO 100
 100  CONTINUE
      END
END-FUNCTION ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE 2 BASE CASE

```
        POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $-------------------------------------------------------------------
       INPUT  LOADS ..
$Res2  $ TITLE LINE-1 *SMUD 2 *
$BaseC $       LINE-2 *Base Case *
      LINE-3  *                                        *
      LINE-4  *                                        *
      LINE-5  *                                        *
                 ..
 $-------------------------------------------------------------------
          PARAMETER
 $-------------------------------------------------------------------
 $                                                        $
 $   IWALLAREA = area of interior walls                   $
 $                                                        $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $         + .10 x minimum month daily electric usage LATN,
 $         + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $         + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $         (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Res2        $ FLRAREA=1701 HOUSVOL=15309 PERIM=201.2 IWALLAREA=1435.999
$Res2        $ GARAREA=510 NEX=64 NEY=38.3
$Res2        $ ROOFZ=7.999 ROOFHT=19.9 ROOFWD=39.7
$Res2        $ NWALLWD=64 SWALLWD=24.167 EWALLWD=38.3 WWALLWD=17.3
$Res2        $ WALLHT=7.999  SHADEHT=6.965
$Res2          INTLOAD=30753 LATLOAD=.218
$Res2        $ INTLOAD=25205 LATLOAD=.175 NUMOCC=2
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
```

```
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R11 Ceiling              $ VAULL = r11vaul CEILL = r11ceil
$R07 Reg siding wall      $ WALLL = r7rwall
$Base2 $                WALLABS= 0.70  $ khaki wood
$Base2 $                ROOFABS= 0.82  $ silver composition
$Res2 $ T1AX=52.7 T1DX=38.7 T2AX=67.7 T2DX=53.7 T3AY=21.21 T3CY=7.21
$Res2 $ T4AX=81 T4AY=12.83 T4CY=-1.17 T4DX=67
$Res2 $ FSW1=64.0 FSW2=38.3 FSW3=53.3 FSW4=79.0 FSW5=94.0
$Sacram One  Crawl FM0    $ FDNUEFF =.0411  $ GndU=***** GndT= 0
$FM0 Crawl                 $ FLRL=r0flr
 $ ---  end of parameters ------------------------------------------
                ..
$Year $ RUN-PERIOD          JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.52 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST=
                             (50,50,50,50,50,50,50,50,50,50,50,50)
$Res2                       AZIMUTH=30
$Res2 $                     AZIMUTH=10
                            SHIELDING-COEF=0.19
$Nownd$                     TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                     WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                             ..
             ABORT     ERRORS ..
             LOADS-REPORT
$HrRpt$             HOURLY-DATA-SAVE = YES
                    SUMMARY=(LS-E)  ..
 $------------------------------------------------------------------
 $-----  Loads Schedules -------------------------------------------
 $------------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                   (1) (.024)  (2) (.022)  (3,5) (.021)
                   (6) (.026)  (7) (.038)  (8) (.059)
                   (9) (.056) (10) (.060) (11) (.059)
                  (12) (.046) (13) (.045) (14) (.030)
                  (15) (.028) (16) (.031) (17) (.057)
               (18,19) (.064) (20) (.052) (21) (.050)
                  (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE   $CEC modified: appl on unoccupied day
                  (1) (.024)  (2) (.022)  (3,5) (.021)
                  (6) (.026)(7,8) (.075) (9,17) (.059)
                 (18) (.072) (19,22) (.080)
                 (23) (.072) (24) (.027) ..
```

```
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
                 (10) (0.52)     (11) (0.63) (12) (0.21) (13) (0.14)
              (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                 (19) (0.81)     (20) (1.00) (21) (0.96)
                 (22) (0.89)     (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)
               (9,18) (0.00)
                 (19) (0.81)     (20) (1.00) (21) (0.96)
                 (22) (0.89)     (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Res2 $ INTLDSCH SCHEDULE THRU DEC 31 (WD) UOCCAPPS  (WEH) DAYINTSCH ..
$Res2 $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCNO     (WEH) OCCYES ..
 $-------------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-------------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Res2 $             THRU OCT 31 (ALL) (1,24) (0.40)
$Res2     Ref. W.Bos, "closed shades 1/2 way down from top daily,
$Res2                  especially on SW corner"
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-------------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $-------------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $-------------------------------------------------------------------
 $-----  Constructions  ---------------------------------------------
 $-------------------------------------------------------------------
```

```
WINDOWGT             GLASS-TYPE              $ Windows
                         GLASS-TYPE-CODE=1  $clear glass
$1-pane $                PANES = 1
                         ..
WALLCON              CONSTRUCTION     $ Wall section
                         ABSORPTANCE= WALLABS
$Res2  $                 ROUGHNESS=4  $ wood
                         LAYERS=WALLL ..
VAULCON              CONSTRUCTION     $ Vault ceiling section, with joist
                         ABSORPTANCE= ROOFABS
$Res2  $                 ROUGHNESS=3 $ composition
                         LAYERS=VAULL ..
CEILCON              CONSTRUCTION     $ Ceiling below attic section, with joist
                         LAYERS=CEILL ..
ROOFCON              CONSTRUCTION     $ Roof above attic section, with joist
                         ABSORPTANCE= ROOFABS
$Res2  $                 ROUGHNESS=3 $ composition
                         LAYERS=r0groof ..
IWALLCON             CONSTRUCTION     $ Interior walls
                         LAYERS=iwalll ..
GWALLCON             CONSTRUCTION     $ garage wall
                         ABSORPTANCE= WALLABS
$Res2  $                 ROUGHNESS=4  $ wood
$Siding                    $ LAYERS  = r0rcwall
                         ..
IGWALLCON             CONSTRUCTION     $ interior insulated garage wall
$Res2 $ LAYERS = r0rwall     $should be r0gwall, but this is not in lib.
                         ..
GROOFCON           CONSTRUCTION     $ garage roof
                         ABSORPTANCE= ROOFABS
$Res2  $                 ROUGHNESS=3 $ composition
                         LAYERS=r0groof ..
DOORCON              CONSTRUCTION     $ Solid door
                         U-VALUE=.7181 ..
GSLABCON             CONSTRUCTION     $ garage slab in contact with soil
                         LAYERS=CGNDL  ..
FSLABCON             CONSTRUCTION     $ Floor slab in contact with soil
$Crawl dirt floor   $  LAYERS=CGNDL  ..
$Crawl space constructions ------------------------
$Crawl    $ FLRCON    CONSTRUCTION  $ Floor over unconditioned space
$Crawl    $               LAYERS=FLRL  ..
$Regcrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. siding crawlspace walls
$Regcrawl $               LAYERS=r0rcwall ..
 $-------------------------------------------------------------------
 $-----  Shades  ----------------------------------------------------
 $-------------------------------------------------------------------
  $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
        EAVEN BUILDING-SHADE $ north eave
```

```
$Res2 $             HEIGHT=4.14 WIDTH=64 X=NEX Y=42.3 TILT=15.0
                    Z=SHADEHT ..

        EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Res2 $             WIDTH=28.17 X=35.83 Y=-4 AZ=180
                    ..
$Res2 $ EAVES2 BUILDING-SHADE $ overhang over garage
$Res2 $             LIKE EAVES WIDTH=28.3 X=0 ..

        EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Res2 $             HEIGHT=23.81 WIDTH=4 X=64 Y=-4 AZ=180
                    ..
$Res2 $ EAVEE2 BUILDING-SHADE LIKE EAVEE  X=68 Y=42.3 AZ=0 ..

        EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Res2 $             X=-4
                    ..
$Res2 $ EAVEW2 BUILDING-SHADE LIKE EAVEW  X=0 Y=42.3 AZ=0 ..
$Res2 $ COURTYDN BUILDING-SHADE  $ courtyard north overhang
$Res2 $             HEIGHT=4 WIDTH=15.5
$Res2 $             X=39.83 Y=15.5 Z=WALLHT ..
$Res2 $ COURTYDE BUILDING-SHADE  $ courtyard east overhang
$Res2 $             LIKE COURTYDN
$Res2 $             Y=0 AZ=90 Z=WALLHT ..
$Res2 $ COURTYDW BUILDING-SHADE  $ courtyard west overhang
$Res2 $             LIKE COURTYDN
$Res2 $             X=24.3 AZ=-90 ..
 $----------------------------------------------------------------------
 $-----  Trees: First existing, then test trees  ----------------------
 $----------------------------------------------------------------------

$ExTr2$   TREES1A B-S HEIGHT=5 WIDTH=28 X=66 Y=-3 Z=0 TILT=90
               TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr2$   TREES1B B-S LIKE TREES1A WIDTH=4 AZ=270 ..
$ExTr2$   TREES1C B-S LIKE TREES1A Y=-7 ..
$ExTr2$   TREES1D B-S LIKE TREES1B X=38 ..
$ExTr2$   TREES1E B-S LIKE TREES1A HEIGHT=4 Z=5 TILT=0 ..
$ExTr2$   TREES2A B-S HEIGHT=5 WIDTH=4 X=71 Y=37 Z=0 TILT=90
               TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr2$   TREES2B B-S LIKE TREES2A WIDTH=34 AZ=270 ..
$ExTr2$   TREES2C B-S LIKE TREES2A Y=3 ..
$ExTr2$   TREES2D B-S LIKE TREES2B X=67 ..
$ExTr2$   TREES2E B-S LIKE TREES2A HEIGHT=34 Z=5 TILT=0 ..
$ExTr2$   TREET1A B-S HEIGHT=21 WIDTH=21 X=40.5 Y=-4.5 Z=7 TILT=90
               TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr2$   TREET1B B-S LIKE TREET1A AZ=270 ..
$ExTr2$   TREET1C B-S LIKE TREET1A Y=-25.5 ..
$ExTr2$   TREET1D B-S LIKE TREET1B X=19.5 ..
```

```
$ExTr2$   TREET1E B-S LIKE TREET1A Z=28 TILT=0 ..
$ExTr2$   TREET2A B-S HEIGHT=21 WIDTH=21 X=85.5 Y=-4.5 Z=7 TILT=90
               TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr2$   TREET2B B-S LIKE TREET2A AZ=270 ..
$ExTr2$   TREET2C B-S LIKE TREET2A Y=-25.5 ..
$ExTr2$   TREET2D B-S LIKE TREET2B X=64.5 ..
$ExTr2$   TREET2E B-S LIKE TREET2A Z=28 TILT=0 ..
$ExTr2    Several trees to south of house
$ExTr2$   TREET3A B-S HEIGHT=14 WIDTH=50 X=57 Y=57 Z=7 TILT=90
$ExTr2$        TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr2$   TREET3B B-S LIKE TREET3A WIDTH=14 AZ=270 ..
$ExTr2$   TREET3C B-S LIKE TREET3A Y=43 ..
$ExTr2$   TREET3D B-S LIKE TREET3B X=7 ..
$ExTr2$   TREET3E B-S LIKE TREET3A Z=21 TILT=0 ..
$ExTr2$   TREET4A B-S HEIGHT=14 WIDTH=14 X=-3 Y=37 Z=7 TILT=90
$ExTr2$        TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr2$   TREET4B B-S LIKE TREET4A WIDTH=37 AZ=270 ..
$ExTr2$   TREET4C B-S LIKE TREET4A Y=0 ..
$ExTr2$   TREET4D B-S LIKE TREET4B X=-17 ..
$ExTr2$   TREET4E B-S LIKE TREET4A HEIGHT=37 Z=21 TILT=0 ..
 $---------------------------------------------------------------------
 $-----  Space --------------------------------------------------------
 $---------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                    TEMPERATURE = (74)
                    SOURCE-TYPE=PROCESS
                    SOURCE-SCHEDULE=INTLDSCH
                    SOURCE-BTU/HR=INTLOAD
                    SOURCE-SENSIBLE=1.
                    SOURCE-LATENT=LATLOAD
                    PEOPLE-SCHEDULE=OCCSCH
                    NUMBER-OF-PEOPLE=NUMOCC
                    PEOPLE-HG-LAT=190
                    PEOPLE-HG-SENS=230
                    INF-METHOD=S-G
$Medium Infiltration     $ FRAC-LEAK-AREA = .0005
                    FLOOR-WEIGHT=0
                    FURNITURE-TYPE=LIGHT
                    FURN-FRACTION=0.29
                    FURN-WEIGHT=3.30
                    ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
SET-DEFAULT FOR EXTERIOR-WALL
$Res2   GND-FORM-FACTOR=0.1
$Res2   SKY-FORM-FACTOR=0.1
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
```

```
$Res2   GND-FORM-FACTOR=0.1
$Res2   SKY-FORM-FACTOR=0.1
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Res2 $ NWALL1  EXTERIOR-WALL CONSTRUCTION=WALLCON X=NEX Y=NEY
                HEIGHT=WALLHT  WIDTH=NWALLWD
                ..
$Res2 $  NWIND1A  WINDOW X=6.5 Y=0.0  HEIGHT=6.67 WIDTH=5.5  ..
$Res2 $  NWIND1B  WINDOW X=15 Y=3.83 HEIGHT=2.75 WIDTH=3.67 ..
$Res2 $  NWIND1C  WINDOW LIKE NWIND1A X=26 WIDTH=11 ..
$Res2 $  NWIND1D  WINDOW LIKE NWIND1B X=42 WIDTH=5.5 ..
$Res2 $  NWIND1E  WINDOW LIKE NWIND1A X=48.5 ..
        SWALL1  EXTERIOR-WALL
$Res2 $         LIKE NWALL1 X=39.83
                HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
                ..
$Res2 $  SWIND1A  WINDOW X=3 Y=5.5 HEIGHT=1.83 WIDTH=5.67 ..
$Res2 $  SWIND1B  WINDOW LIKE SWIND1A X=18 ..
$Res2 $ SWALL2  EXTERIOR-WALL LIKE SWALL1 Y=15.5 AZIMUTH=-90
$Res2 $         WIDTH = 15.5 ..
$Res2 $  SWIND2A  WINDOW  LIKE SWIND1A X=9 ..
$Res2 $ SWALL3  EXTERIOR-WALL LIKE SWALL1 X=24.33 Y=15.5
$Res2 $         WIDTH = 15.5 ..
$Res2 $  SDOOR3A  DOOR X=6.33999 ..
$Res2 $  SWIND3A  WINDOW  X=8.33 Y=7.33 HEIGHT=1.00 WIDTH=3.33 ..
$Res2 $  SWIND3B  WINDOW  LIKE SWIND3A X= 2 ..
$Res2 $ SWALL4  INTERIOR-WALL  CONSTRUCTION=IGWALLCON
$Res2 $          HEIGHT=WALLHT WIDTH=5.5 NEXT-TO=GARAGE ..
$Res2 $ SWALL5  INTERIOR-WALL LIKE SWALL4 WIDTH=24.3 ..
$Res2 $ EWALL1  EXTERIOR-WALL LIKE NWALL1 Y=0 AZ=90
                WIDTH=EWALLWD ..
$Res2 $  EWIND1A  WINDOW  X=3 Y=5.67 HEIGHT=1.83 WIDTH=5.67 ..
$Res2 $  EWIND1B  WINDOW  LIKE EWIND1A X=15 WIDTH=6.67 ..
$Res2 $  EWIND1C  WINDOW  LIKE EWIND1A X=32 ..
        WWALL1  EXTERIOR-WALL
$Res2 $         LIKE NWALL1 Y=NEY
                X=0 WIDTH=WWALLWD AZIMUTH=270
                ..
$Res2 $  WWIND1A  WINDOW  X=0.57 Y=7.00 HEIGHT=1.67 WIDTH=5.00 ..
$Res2 $  WWIND2A  WINDOW  LIKE WWIND1A X=6.15 HEIGHT=1.33 ..
$Res2 $  WWIND3A  WINDOW  LIKE WWIND1A X=11.71 HEIGHT=1.00 ..
$Crawl $ INTERFLR   INTERIOR-WALL     $ Floor bet Theroom and Crawlspace
$Crawl $            TILT=180 CONSTRUCTION=FLRCON
```

```
$Crawl $            AREA=FLRAREA NEXT-TO=CRAWLSPACE  ..
$Vault$ NROOF1    ROOF      Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Vault$             CONSTRUCTION=VAULCON
$Res2 $             X=NEX Y=NEY TILT=15.0 ..
$Res2 $ NROOF2    ROOF       LIKE NROOF1
$Res2 $             X=24.3 Y=NEY HEIGHT=17.9 WIDTH=24.3 ..
$Vault$ SROOF1    ROOF       LIKE NROOF1
$Res2 $             X=39.9 Y=0 WIDTH=24.3  AZIMUTH=180 ..
$Res2 $ SROOF2    ROOF      LIKE SROOF1
$Res2 $             X=24.3 Y=15.5 Z=12.15 HEIGHT=3.695 WIDTH=15.5 ..
         GARAGE     SPACE
                    AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                    INF-METHOD=S-G
                    FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                    FLOOR-WEIGHT=0
                    ZONE-TYPE=UNCONDITIONED T=(60)
                    ..
         GAR1 EXTERIOR-WALL
                     HEIGHT=WALLHT TILT=90
$Res2 $              WIDTH=21 X=0 Y=21 AZ=-90         $ garage Wwall
                     CONSTRUCTION=GWALLCON
                     ..
         GAR2 EXTERIOR-WALL
                     LIKE GAR1
$Res2 $              WIDTH=15.5 X=24.3 Y=0 AZ=90      $ garage Ewall
                     ..
         GAR3 EXTERIOR-WALL
                     LIKE GAR1        $ garage door wall
$Res2 $              HEIGHT=8.0 WIDTH=24.3 X=0 Y=0 AZ=180 ..
$Res2 $              GDOOR DOOR X=2 WIDTH=20  .. $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Res2 $       AREA=238.7  CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Res2 $       LIKE GAR3 HEIGHT=19.9 TILT=15.0
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..
$Res2 $  GROOF2 EXTERIOR-WALL
$Res2 $       LIKE GROOF1 X=24.3 Y=21 Z=12.6 AZ=0 HEIGHT=2.0 ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143  .. $ Ref j.huang - ashrae paper
$Crawl $  CRAWLSPACE SPACE
$Crawl $            AREA=FLRAREA VOLUME=FLRAREA TIMES 3.00
```

```
$Crawl $            INF-METHOD=S-G
$Crawl     assume 1 ft2 of vents per 150 ft2 of crawl space area,
$Crawl     effective-leakage-area = 75% of vent area
$Crawl $            FRAC-LEAK-AREA= .005
$Crawl $            FLOOR-WEIGHT=0 Z=-3.0
$Crawl $            ZONE-TYPE=UNCONDITIONED T=(60)
$Crawl $             ..
$Crawl $ NCWALL1    EXTERIOR-WALL   LIKE NWALL1
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Crawl $ SCWALL1    EXTERIOR-WALL   LIKE SWALL1
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Res2  $ SCWALL2    EXTERIOR-WALL   LIKE SWALL2
$Res2  $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Res2  $ SCWALL3    EXTERIOR-WALL   LIKE SWALL3
$Res2  $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Crawl $ ECWALL1    EXTERIOR-WALL   LIKE EWALL1
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Crawl $ WCWALL1    EXTERIOR-WALL   LIKE WWALL1
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=1.50  ..
$Crawl $ FOUNDATION UNDERGROUND-FLOOR  $ Crawlspace dirt floor
$Crawl $            HEIGHT=10 WIDTH=FLRAREA TIMES .1
$Crawl $            TILT=180 CONSTRUCTION=FSLABCON
$Crawl $            U-EFFECTIVE=FDNUEFF
$Crawl $            FUNCTION=(*NONE*,*FNDQ*)    ..
$HrRpt-----------------------------------------------------
$HrRptLoads  Reports ----------------------------------------
$HrRpt-----------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK      $ Reports for wall temp
$HrRpt$           VARIABLE-TYPE=SWALL1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2        REPORT-BLOCK      $ Reports for roof temp
$HrRpt$           VARIABLE-TYPE=SROOF1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH      SCHEDULE          $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2)
$HrRpt$              ..
         END ..

FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  0,  -932.0)(  1,  -970.7)(  2, -1034.0)(  3, -1048.3)(  4, -1079.2)
(  5, -1128.2)(  6, -1121.9)(  7, -1034.6)(  8, -1024.4)(  9, -1043.8)
( 10, -1073.1)( 11, -1044.6)( 12,  -983.8)( 13,  -858.8)( 14,  -749.8)
( 15,  -730.2)( 16,  -791.0)( 17,  -905.5)( 18,  -965.5)( 19,  -915.7)
( 20,  -754.4)( 21,  -587.8)( 22,  -520.4)( 23,  -533.8)( 24,  -547.7)
( 25,  -566.3)( 26,  -604.3)( 27,  -591.0)( 28,  -532.2)( 29,  -458.6)
( 30,  -282.3)( 31,  -146.2)( 32,   -64.8)( 33,  -144.9)( 34,  -320.5)
( 35,  -307.0)( 36,  -229.4)( 37,  -157.9)( 38,    10.0)( 39,   154.5)
( 40,   132.1)( 41,   214.0)( 42,   278.9)( 43,   301.2)( 44,   307.5)
( 45,   238.6)( 46,   347.9)( 47,   519.3)( 48,   543.7)( 49,   638.7)
( 50,   851.0)( 51,   970.8)( 52,   995.7)( 53,  1045.6)( 54,  1136.0)
( 55,  1129.6)( 56,  1062.6)( 57,  1272.9)( 58,  1482.2)( 59,  1541.2)
( 60,  1570.1)( 61,  1587.3)( 62,  1635.8)( 63,  1662.3)( 64,  1667.0)
( 65,  1778.5)( 66,  1874.8)( 67,  1926.5)( 68,  1936.4)( 69,  1981.3)
( 70,  2075.1)( 71,  2137.9)( 72,  2194.4)( 73,  2204.5)( 74,  2145.8)
( 75,  2110.9)( 76,  2176.1)( 77,  2208.5)( 78,  2196.5)( 79,  2060.9)
( 80,  1889.1)( 81,  1862.0)( 82,  1892.5)( 83,  1905.9)( 84,  1919.5)
( 85,  1898.0)( 86,  1854.9)( 87,  1818.2)( 88,  1758.9)( 89,  1582.3)
( 90,  1558.8)( 91,  1553.4)( 92,  1515.6)( 93,  1466.1)( 94,  1415.4)
( 95,  1393.7)( 96,  1290.6)( 97,  1105.7)( 98,  1014.4)( 99,   937.3)
(100,   934.5)(101,   900.5)(102,   841.2)(103,   710.6)(104,   555.1)
(105,   427.5)(106,   371.4)(107,   320.3)(108,   245.0)(109,   183.5)
(110,    84.3)(111,   -40.1)(112,  -181.7)(113,  -357.3)(114,  -536.0)
(115,  -566.9)(116,  -601.4)(117,  -604.4)(118,  -745.9)(119,  -895.5)
(120,  -893.2)(121,  -918.5)(122,  -933.9) ..
      CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
         COMPUTE LOADS ..
          POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
          INPUT     SYSTEMS ..
                        ..
          DIAGNOSTIC   CAUTIONS ECHO ..
          SYSTEMS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $-------------------------------------------------------------
```

```
         PARAMETER
 $---------------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
 $
$Res2 $   HEATSET=68    SETBACK=65     COOLSET=80    SETUP=80
$Res2 $   HCAPF=-90000  CTCAP=40000    CSCAP=32000
$Res2 $   ACCFM=1200
 $
$Res2     VTYPE=-1                 enthalpic venting
$Res2 $   VTYPE= 0               $ no venting
 $
$Furn $          FHIR=1.4286   $ 77% efficiency + 10% duct losses
$Furn $          MAXTEMP=120
$Res2 $   CBF=.098      CEIR=.2801       $ 3.57 COP air conditioner
                         ..
 $---------------------------------------------------------------
 $-----  Systems Schedules --------------------------------------
 $---------------------------------------------------------------
HTSCH     SCHEDULE  $ heat temperature schedule, 7 hour night setback
                    THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                      (7,23) (HEATSET)
                                      (24)   (SETBACK)  ..
CTSCH     SCHEDULE  $ cool temperature schedule, 7 hour day setup
                    THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                      (8,15) (SETUP)
                                      (16,24)   (COOLSET)  ..
VTSCH     SCHEDULE  $Vent schedule based on previous 4 days load
                    THRU MAY 14 (ALL) (1,24) (-4)
                    THRU SEP 30 (ALL) (1,24) (-4)
                    THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE  $Vent operation schedule
                    THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                    THRU DEC 31 (ALL) (1,6)  (0.0)
                                      (7,23) (1.0)
                                      (24)   (0.0)  ..
 $---------------------------------------------------------------
 $-----  Zones --------------------------------------------------
 $---------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=70.
                              DESIGN-COOL-T=78.
```

```
                                 COOL-TEMP-SCH=CTSCH
                                 HEAT-TEMP-SCH=HTSCH
                                 THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM              ZONE        ZONE-CONTROL=ZC1
                                 ZONE-TYPE=CONDITIONED ..
GARAGE               ZONE        ZONE-TYPE=UNCONDITIONED  ..
$Crawl $ CRAWLSPACE  ZONE        ZONE-TYPE=UNCONDITIONED  ..
 $---------------------------------------------------------------
 $-----  Systems ------------------------------------------------
 $---------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                   MAX-SUPPLY-T=MAXTEMP
                   MIN-SUPPLY-T=50
                     ..
SYSAIR    SYSTEM-AIR
                   SUPPLY-CFM=ACCFM
                   NATURAL-VENT-SCH=VOPSCH
                   VENT-TEMP-SCH=VTSCH
                   OPEN-VENT-SCH=WINDOPER
                   HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                   FRAC-VENT-AREA=0.018
                   VENT-METHOD=S-G
                   MAX-VENT-RATE=20
                     ..
SYSFAN    SYSTEM-FANS                  $added by jim 11/25/92
                   SUPPLY-KW=0.000333  $average of 400 W for 1200 CFM
                     ..
SYSEQP    SYSTEM-EQUIPMENT
                   COOLING-CAPACITY=CTCAP
                   COOLING-EIR=CEIR        $added by jim 1/13/92
                   COOL-SH-CAP=CSCAP
                   COIL-BF=CBF
                   CRANKCASE-HEAT=0.0      $added by jim 3/5/92
                   COMPRESSOR-TYPE=SINGLE-SPEED
$Furn     Furnace specifications    $
$Furn  $           HEATING-CAPACITY=HCAPF
$Furn  $           FURNACE-AUX=0.
$Furn  $           FURNACE-HIR=FHIR $ duct losses in FHIR already
                     ..
RESIDEN  SYSTEM    SYSTEM-TYPE=RESYS
$Crawl $         ZONE-NAMES=(THEROOM,GARAGE,CRAWLSPACE)
                   SYSTEM-CONTROL=SYSCONTRL
                   SYSTEM-AIR=SYSAIR
                   SYSTEM-FANS=SYSFAN
                   SYSTEM-EQUIPMENT=SYSEQP
$Furn  $           HEAT-SOURCE=GAS-FURNACE
```

```
                 ..
$HrRpt---------------------------------------------------------
$HrRptSystem Reports -----------------------------------------
$HrRpt---------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK   $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK       $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$           ..
          END ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE 5 BASE CASE

```
         POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
.$ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $----------------------------------------------------------------------
        INPUT  LOADS ..
$Res5  $ TITLE LINE-1 *SMUD 5 *
$BaseC $       LINE-2 *Base Case *
        LINE-3  *                                    *
        LINE-4  *                                    *
        LINE-5  *                                    *
                  ..
 $----------------------------------------------------------------------
           PARAMETER
 $----------------------------------------------------------------------
 $                                                              $
 $    IWALLAREA = area of interior walls                        $
 $                                                              $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $        + .10 x minimum month daily electric usage LATN,
 $        + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $        + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $        (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Res5         $ FLRAREA=1544 HOUSVOL=13896 PERIM=191.7 IWALLAREA=1479.999
$Res5         $ GARAREA=466 NEX=50.5 NEY=23.3
$Res5         $ ROOFZ=7.999 ROOFHT=19.08 ROOFWD=31.5
$Res5         $ NWALLWD=20 SWALLWD=41.67 EWALLWD=23.3 WWALLWD=36.5
$Res5         $ WALLHT=7.999  SHADEHT=7.024
$Res5           INTLOAD=46631 LATLOAD=.189
$Res5         $ INTLOAD=41083 LATLOAD=.159 NUMOCC=2
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
```

```
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R30 Ceiling              $ VAULL = r30vaul CEILL = r30ceil
$R11 Reg siding wall      $ WALLL = r11rwall
$Base5 $                 WALLABS= 0.50  $ lt tan wood
$Base5 $                 ROOFABS= 0.84  $ med brown shingle
$Res5 $ T1AX=11.42 T1DX=-2.58 T2AX=21.21 T2DX=7.21 T3AY=28.3 T3CY=14.3
$Res5 $ T4AX=67.5 T4AY=13.46 T4CY=-0.54 T4DX=53.5
$Res5 $ FSW1=50.5 FSW2=38.3 FSW3=53.3 FSW4=65.5 FSW5=80.5
$Sacram One  Slab  FM0   $ FDNUEFF =.0569  $ GndU=.0076 GndT= 0
 $ ---  end of parameters ------------------------------------------
                 ..
$Year $ RUN-PERIOD           JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC           CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION    LAT=38.52 LON=121.50 T-Z=8  ALT=17
                             WS-HEIGHT-LIST=
                              (50,50,50,50,50,50,50,50,50,50,50,50)
$Res5 $                      AZIMUTH=0
                             SHIELDING-COEF=0.19
$Nownd$                      TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                      WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                               ..
         ABORT     ERRORS ..
         LOADS-REPORT
$HrRpt$             HOURLY-DATA-SAVE = YES
                    SUMMARY=(LS-E)  ..
 $-------------------------------------------------------------------
 $-----  Loads Schedules --------------------------------------------
 $-------------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                         (1) (.024)  (2) (.022)  (3,5) (.021)
                         (6) (.026)  (7) (.038)  (8) (.059)
                         (9) (.056) (10) (.060) (11) (.059)
                        (12) (.046) (13) (.045) (14) (.030)
                        (15) (.028) (16) (.031) (17) (.057)
                     (18,19) (.064) (20) (.052) (21) (.050)
                        (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE  $CEC modified: appl on unoccupied day
                         (1) (.024)  (2) (.022)  (3,5) (.021)
                         (6) (.026)(7,8) (.075) (9,17) (.059)
                        (18) (.072) (19,22) (.080)
                        (23) (.072) (24) (.027) ..
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
                       (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
```

```
                 (10) (0.52)    (11) (0.63) (12) (0.21) (13) (0.14)
              (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
               . (22) (0.89)    (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)
               (9,18) (0.00)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
                 (22) (0.89)    (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Res5 $ INTLDSCH SCHEDULE THRU DEC 31 (WD) UOCCAPPS  (WEH) DAYINTSCH ..
$Res5 $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCNO     (WEH) OCCYES ..
 $-------------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-------------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Res5 $             THRU OCT 31 (ALL) (1,24) (0.60)
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-------------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $-------------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $-------------------------------------------------------------------
 $-----  Constructions  ---------------------------------------------
 $-------------------------------------------------------------------
WINDOWGT             GLASS-TYPE            $ Windows
                         GLASS-TYPE-CODE=1  $clear glass
$2-pane $                PANES = 2
                         ..
```

```
WALLCON            CONSTRUCTION     $ Wall section
                       ABSORPTANCE= WALLABS
$Res5  $               ROUGHNESS=4  $ wood
                       LAYERS=WALLL ..
VAULCON            CONSTRUCTION     $ Vault ceiling section, with joist
                       ABSORPTANCE= ROOFABS
$Res5  $               ROUGHNESS=3 $ shingle
                       LAYERS=VAULL ..
CEILCON            CONSTRUCTION     $ Ceiling below attic section, with joist
                       LAYERS=CEILL ..
ROOFCON            CONSTRUCTION     $ Roof above attic section, with joist
                       ABSORPTANCE= ROOFABS
$Res5  $               ROUGHNESS=3 $ shingle
                       LAYERS=r0groof ..
IWALLCON           CONSTRUCTION     $ Interior walls
                       LAYERS=iwalll ..
GWALLCON           CONSTRUCTION     $ garage wall
                       ABSORPTANCE= WALLABS
$Res5  $               ROUGHNESS=4  $ wood
$Siding                  $ LAYERS  = r0rcwall
                       ..
IGWALLCON           CONSTRUCTION     $ interior insulated garage wall
$Res5 $ LAYERS = r1lgwall
                       ..
GROOFCON         CONSTRUCTION     $ garage roof
                       ABSORPTANCE= ROOFABS
$Res5  $               ROUGHNESS=3 $ shingle
                       LAYERS=r0groof ..
DOORCON            CONSTRUCTION     $ Solid door
                       U-VALUE=.7181 ..
GSLABCON           CONSTRUCTION     $ garage slab in contact with soil
                       LAYERS=CGNDL  ..
FSLABCON           CONSTRUCTION     $ Floor slab in contact with soil
$Slab concrete floor$  LAYERS=FSLABL ..
 $------------------------------------------------------------------
 $-----  Shades  ---------------------------------------------------
 $------------------------------------------------------------------
$Res5 $  SURROUND1 BUILDING-SHADE
$Res5                  house to east $
$Res5 $                HEIGHT=9.5 WIDTH=36.5
$Res5 $                X=63.5 Y=36.5 AZIMUTH=-90 TILT=90 ..
$Res5 $  SURROUND2 BUILDING-SHADE
$Res5                  house to west $
$Res5 $                LIKE SURROUND1 HEIGHT=9.5 WIDTH=46
$Res5 $                X=-12 Y=0 AZIMUTH=90 ..
 $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
         EAVEN BUILDING-SHADE $ north eave
$Res5 $              HEIGHT=2.22 WIDTH=31.5 X=31.5 Y=38.5 TILT=26
```

```
                    Z=SHADEHT ..

        EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Res5 $             HEIGHT=7.5 WIDTH=50.5 X=0 Y=-7.6 Z=WALLHT
$Res5 $             TRANSMITTANCE=0.10 AZ=180 TILT=0
                    ..

        EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Res5 $             HEIGHT=0.001   $ no eave
                    ..

        EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Res5 $             HEIGHT=0.001   $ no eave
                    ..
$Res5 $  ENTRY BUILDING-SHADE  $ entry overhang
$Res5 $             HEIGHT=7.5 WIDTH=8.0
$Res5 $             X=21 Y=36.5 Z=WALLHT ..
 $------------------------------------------------------------------
 $-----  Trees: First existing, then test trees  -------------------
 $------------------------------------------------------------------

 $------------------------------------------------------------------
 $-----  Space -----------------------------------------------------
 $------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                   TEMPERATURE = (74)
                   SOURCE-TYPE=PROCESS
                   SOURCE-SCHEDULE=INTLDSCH
                   SOURCE-BTU/HR=INTLOAD
                   SOURCE-SENSIBLE=1.
                   SOURCE-LATENT=LATLOAD
                   PEOPLE-SCHEDULE=OCCSCH
                   NUMBER-OF-PEOPLE=NUMOCC
                   PEOPLE-HG-LAT=190
                   PEOPLE-HG-SENS=230
                   INF-METHOD=S-G
$Medium Infiltration     $ FRAC-LEAK-AREA = .0005
                   FLOOR-WEIGHT=0
                   FURNITURE-TYPE=LIGHT
                   FURN-FRACTION=0.29
                   FURN-WEIGHT=3.30
                   ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
SET-DEFAULT FOR EXTERIOR-WALL
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
```

```
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Res5 $ NWALL1  INTERIOR-WALL CONSTRUCTION=IGWALLCON NEXT-TO=GARAGE
                HEIGHT=WALLHT  WIDTH=NWALLWD
                ..
$Res5 $ NWALL2  INTERIOR-WALL LIKE NWALL1 WIDTH=13.25 ..
$Res5 $ NWALL3  EXTERIOR-WALL CONSTRUCTION=WALLCON
$Res5 $                  HEIGHT=WALLHT WIDTH=10.5
$Res5 $                  X=31.5 Y=36.5 AZ=0 ..
$Res5 $  NWIND3A  WINDOW X=3.3 Y=3.67 HEIGHT=3.67 WIDTH=6.00  ..
$Res5 $ NWALL4  EXTERIOR-WALL LIKE NWALL3
$Res5 $                  WIDTH=7.5  X=21 AZ=-90 ..
$Res5 $ NWALL5  EXTERIOR-WALL LIKE NWALL3
$Res5 $                  WIDTH=8 X=21 Y=29 ..
$Res5 $  NDOOR5A  DOOR   X=2.5 ..
$Res5 $ NWALL6  EXTERIOR-WALL LIKE NWALL4
$Res5 $                  X=13 Y=29 AZ=90 ..
$Res5 $ NWALL7  EXTERIOR-WALL LIKE NWALL3
$Res5 $                  WIDTH=13 X=13 ..
$Res5 $  NWIND7B  WINDOW LIKE NWIND3A X=3.3 ..
        SWALL1  EXTERIOR-WALL
$Res5 $         LIKE NWALL3 X=8.83
                HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
                ..
$Res5 $  SWIND1A  WINDOW X=3.2 Y=0.0 HEIGHT=6.58 WIDTH=4.75 ..
$Res5 $  SWIND1B  WINDOW X=13.2 Y=5.5 HEIGHT=2.0  WIDTH=4.00 ..
$Res5 $  SWALL2  EXTERIOR-WALL LIKE SWALL1
$Res5 $           X=7.414 Y=-1.414 WIDTH=2 AZ=135 ..
$Res5 $  SWALL3  EXTERIOR-WALL LIKE SWALL1
$Res5 $           X=1.414 Y=-1.414 WIDTH=6 ..
$Res5 $  SWIND3A  WINDOW X=1.125 Y=4.0 HEIGHT=2.75 WIDTH=3.75 ..
$Res5 $  SWALL4  EXTERIOR-WALL LIKE SWALL1
$Res5 $           X=0 WIDTH=2 AZ=225 ..
$Res5 $ EWALL1  EXTERIOR-WALL LIKE NWALL3 X=50.5 Y=0 AZ=90
                WIDTH=EWALLWD ..
$Res5 $  EWIND1A  WINDOW  X=3.5 Y=3.33 HEIGHT=3.92 WIDTH=5.91 ..
$Res5 $  EWIND1B  WINDOW  X=15.5 Y=3.83 HEIGHT=3.42 WIDTH=5.00 ..
        WWALL1  EXTERIOR-WALL
$Res5 $         LIKE NWALL3 Y=36.5
                X=0 WIDTH=WWALLWD AZIMUTH=270
                ..
$Res5 $  WWIND1A  WINDOW  X=15 Y=4.08 HEIGHT=3.00 WIDTH=4.00 ..
$Slab  $ FOUNDATION UNDERGROUND-FLOOR $ Slab floor
$Slab  $             HEIGHT=10 WIDTH=FLRAREA TIMES .1
```

```
$Slab  $            TILT=180 CONSTRUCTION=FSLABCON
$Slab  $            U-EFFECTIVE=FDNUEFF
$Slab  $            FUNCTION =(*NONE*,*FNDQ*)  ..
$Attic$ CEILING    INTERIOR-WALL    $ Ceiling between House and Attic
$Attic$            TILT=0 CONSTRUCTION=CEILCON
$Attic$            AREA=FLRAREA NEXT-TO-ATTIC  ..
$Attic spaces
$Attic$  ATTIC      SPACE
$Attic$             AREA=FLRAREA VOLUME=FLRAREA TIMES 2.90 $ avg height
$Attic$             INF-METHOD=S-G
$Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
$Attic    ELF = 75% of vent area
$Res5 $             FRAC-LEAK-AREA= .00167
$Attic$             FLOOR-WEIGHT=0
$Attic$             ZONE-TYPE=UNCONDITIONED T=(80)
$Attic$             ..
$Attic$ NROOF1    ROOF      Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Attic$             CONSTRUCTION=ROOFCON
$Res5 $             X=31.5 Y=36.5 TILT=17.0
$Attic$             ..
$Attic$ SROOF1    ROOF       LIKE NROOF1
$Res5 $             X=0 Y=0  AZIMUTH=180
$Attic$             ..
$Res5 $ SROOF2    ROOF      LIKE SROOF1
$Res5 $             X=31.5 HEIGHT=24.3 WIDTH=19 ..
         GARAGE     SPACE
                    AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                    INF-METHOD=S-G
                    FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                    FLOOR-WEIGHT=0
                    ZONE-TYPE=UNCONDITIONED T=(60)
                    ..
         GAR1 EXTERIOR-WALL
                     HEIGHT=WALLHT TILT=90
$Res5 $              WIDTH=23.3 X=50.5 Y=23.2 AZ=90   $ garage Ewall
                     CONSTRUCTION=GWALLCON
                     ..
         GAR2 EXTERIOR-WALL
                     LIKE GAR1
$Res5 $              WIDTH=10.0 X=31.5 Y=46.5 AZ=-90  $ garage Wwall
                     ..
         GAR3 EXTERIOR-WALL
                     LIKE GAR1        $ garage door wall
$Res5 $              HEIGHT=8.0 WIDTH=19 X=50.5 Y=46.5 AZ=0 ..
$Res5 $              GDOOR DOOR X=1 WIDTH=17  .. $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Res5 $       AREA=266    CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
```

```
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Res5 $       LIKE GAR3 HEIGHT=24.3 TILT=17.0
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143   .. $ Ref j.huang - ashrae paper
$HrRpt-----------------------------------------------------------
$HrRptLoads  Reports ------------------------------------------
$HrRpt-----------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK       $ Reports for wall temp
$HrRpt$           VARIABLE-TYPE=SWALL1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for roof temp
$HrRpt$           VARIABLE-TYPE=SROOF1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2)
$HrRpt$           ..
         END ..

FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  0, -3336.3)(  1, -3389.2)(  2, -3462.1)(  3, -3450.6)(  4, -3494.9)
(  5, -3548.8)(  6, -3512.7)(  7, -3387.8)(  8, -3400.9)(  9, -3432.8)
( 10, -3467.4)( 11, -3408.3)( 12, -3335.8)( 13, -3164.1)( 14, -3056.2)
( 15, -3061.6)( 16, -3176.4)( 17, -3309.6)( 18, -3360.7)( 19, -3255.2)
( 20, -3035.1)( 21, -2849.8)( 22, -2809.7)( 23, -2858.6)( 24, -2872.7)
( 25, -2901.3)( 26, -2954.2)( 27, -2910.6)( 28, -2832.9)( 29, -2737.7)
( 30, -2508.2)( 31, -2379.1)( 32, -2303.7)( 33, -2479.3)( 34, -2686.4)
( 35, -2608.0)( 36, -2500.5)( 37, -2413.6)( 38, -2188.9)( 39, -2045.6)
( 40, -2134.6)( 41, -2002.3)( 42, -1946.5)( 43, -1931.6)( 44, -1942.3)
( 45, -2040.4)( 46, -1852.8)( 47, -1659.4)( 48, -1673.6)( 49, -1538.1)
( 50, -1285.3)( 51, -1176.9)( 52, -1189.2)( 53, -1122.8)( 54, -1020.4)
( 55, -1070.9)( 56, -1147.7)( 57,  -839.9)( 58,  -621.7)( 59,  -592.9)
( 60,  -577.7)( 61,  -569.9)( 62,  -507.0)( 63,  -493.0)( 64,  -494.7)
( 65,  -338.1)( 66,  -236.5)( 67,  -199.1)( 68,  -206.2)( 69,  -148.7)
```

```
( 70,    -30.5)( 71,     25.0)( 72,     81.5)( 73,     68.1)( 74,    -28.9)
( 75,    -49.4)( 76,     50.9)( 77,     73.1)( 78,     34.9)( 79,   -123.6)
( 80,   -331.5)( 81,   -320.9)( 82,   -271.8)( 83,   -264.4)( 84,   -250.2)
( 85,   -281.9)( 86,   -345.3)( 87,   -377.1)( 88,   -471.5)( 89,   -680.4)
( 90,   -661.4)( 91,   -665.3)( 92,   -717.0)( 93,   -771.9)( 94,   -825.7)
( 95,   -845.2)( 96,  -1001.8)( 97,  -1214.9)( 98,  -1290.1)( 99,  -1357.0)
(100,  -1332.1)(101,  -1377.6)(102,  -1458.1)(103,  -1635.8)(104,  -1807.5)
(105,  -1935.5)(106,  -1957.5)(107,  -2015.7)(108,  -2097.4)(109,  -2161.6)
(110,  -2276.3)(111,  -2428.2)(112,  -2591.7)(113,  -2814.8)(114,  -2984.9)
(115,  -2965.2)(116,  -2985.4)(117,  -2984.5)(118,  -3194.8)(119,  -3339.1)
(120,  -3281.2)(121,  -3316.4)(122,  -3332.9) ..
      CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
         COMPUTE LOADS ..
          POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
          INPUT     SYSTEMS ..
                     ..
          DIAGNOSTIC    CAUTIONS ECHO ..
$Duct $   SUBR-FUNCTIONS
$Duct $          RESYS-0=*DUCT*
$Duct $          RESYS-3Z=*SAVETEMP*
$Duct $          DAYCLS-4=*DUCT2* ..
          SYSTEMS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $-------------------------------------------------------------
          PARAMETER
 $-------------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
```

```
 $
$Res5 $   HEATSET=70    SETBACK=70     COOLSET=78   SETUP=78
$Res5 $   HPHCAP=-29000 HPBKUP=-15000  CTCAP=29000  CSCAP=23200
$Res5 $   ACCFM=1060
 $
$Res5 $   VTYPE= 0             $ no venting
 $
$HP   $          HEIR=.3703    $ 2.7 COP Heat Pump
$HP   $          MAXTEMP=100
$Res5 $   CBF=.098      CEIR=.4785       $ 2.09 COP HP
                    ..
 $--------------------------------------------------------------
 $-----  Systems Schedules  ------------------------------------
 $--------------------------------------------------------------
HTSCH     SCHEDULE  $ heat temperature schedule, 7 hour night setback
                    THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                      (7,23) (HEATSET)
                                      (24)   (SETBACK)  ..
CTSCH     SCHEDULE  $ cool temperature schedule, 7 hour day setup
                    THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                      (8,15) (SETUP)
                                      (16,24)    (COOLSET)  ..
VTSCH     SCHEDULE  $Vent schedule based on previous 4 days load
                    THRU MAY 14 (ALL) (1,24) (-4)
                    THRU SEP 30 (ALL) (1,24) (-4)
                    THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE  $Vent operation schedule
                    THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                    THRU DEC 31 (ALL) (1,6)  (0.0)
                                      (7,23) (1.0)
                                      (24)   (0.0)  ..
 $--------------------------------------------------------------
 $-----  Zones  -----------------------------------------------
 $--------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=70.
                              DESIGN-COOL-T=78.
                              COOL-TEMP-SCH=CTSCH
                              HEAT-TEMP-SCH=HTSCH
                              THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM             ZONE      ZONE-CONTROL=ZC1
                              ZONE-TYPE=CONDITIONED ..
$Attic $ ATTIC      ZONE      ZONE-TYPE=UNCONDITIONED  ..
GARAGE              ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $--------------------------------------------------------------
 $-----  Systems  ---------------------------------------------
 $--------------------------------------------------------------
```

```
SYSCONTRL SYSTEM-CONTROL
                 MAX-SUPPLY-T=MAXTEMP
                 MIN-SUPPLY-T=50
                   ..
SYSAIR    SYSTEM-AIR
                 SUPPLY-CFM=ACCFM
                 NATURAL-VENT-SCH=VOPSCH
                 VENT-TEMP-SCH=VTSCH
                 OPEN-VENT-SCH=WINDOPER
                 HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                 FRAC-VENT-AREA=0.018
                 VENT-METHOD=S-G
                 MAX-VENT-RATE=20
                   ..
SYSFAN    SYSTEM-FANS               $added by jim 11/25/92
                 SUPPLY-KW=0.000333   $average of 400 W for 1200 CFM
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-CAPACITY=CTCAP
                 COOLING-EIR=CEIR        $added by jim 1/13/92
                 COOL-SH-CAP=CSCAP
                 COIL-BF=CBF
                 CRANKCASE-HEAT=0.0      $added by jim 3/5/92
                 COMPRESSOR-TYPE=SINGLE-SPEED
$HP      Heatpump specifications    $
$HP     $        HEATING-CAPACITY=HPHCAP
$HP     $        HEATING-EIR=HEIR
$HP     $        HP-SUPP-HT-CAP=HPBKUP
$HP     $        MAX-HP-SUPP-T=40.
                   ..
RESIDEN  SYSTEM  SYSTEM-TYPE=RESYS
$Slab   $      ZONE-NAMES=(THEROOM,GARAGE
$Attic  $                  ,ATTIC
$Slab   $                  )
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-FANS=SYSFAN
                 SYSTEM-EQUIPMENT=SYSEQP
$HP     $        HEAT-SOURCE=HEAT-PUMP
                 ..
$HrRpt-------------------------------------------------------
$HrRptSystem Reports -----------------------------------------
$HrRpt-------------------------------------------------------
$HrRpt$    RB1        REPORT-BLOCK    $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
```

```
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK       $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$           ..
          END ..
FUNCTION NAME = DUCT ..
 $
 $ This function multiplies the AC EIR
 $ by the duct efficiency which varies
 $ with attic temperature
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       DEFFC=-0.0077*TATT + 1.379
       COOLEIR = COOLEIR/DEFFC
       COOLCAP = COOLCAP*DEFFC
       COOLSEN = COOLSEN*DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME = DUCT2 ..
 $
 $ This function resets AC EIR to the input value
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       COOLEIR = COOLEIR*DEFFC
```

```
       COOLCAP = COOLCAP/DEFFC
       COOLSEN = COOLSEN/DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME=SAVETEMP ..
$
$ saves last hours zone temps for next hour's heat load
$ calculations
$
ASSIGN TATT=XXX23 ..
ASSIGN TNOW = TNOW  ZNAME = ZONE-NAME DBT=DBT  NZ=NZ ..
ASSIGN HUMRAT=HUMRAT ..
      CALCULATE ..
C     IF (ZNAME.EQ."THER") GO TO 100
C     IF (ZNAME.EQ."GARA") GO TO 100
C     IF (ZNAME.EQ."ATTI") GO TO 70
      IF (NZ.EQ.1) GO TO 100
      IF (NZ.EQ.2) GO TO 100
      IF (NZ.EQ.3) GO TO 70
      GO TO 100
C attic
  70    TATT=TNOW
      GO TO 100
 100  CONTINUE
      END
END-FUNCTION ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE 6 BASE CASE

```
          POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                     (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                     (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $---------------------------------------------------------------------
         INPUT  LOADS ..
$Res6  $ TITLE LINE-1 *SMUD 6 *
$BaseC $       LINE-2 *Base Case *
        LINE-3  *                                        *
        LINE-4  *                                        *
        LINE-5  *                                        *
                    ..
 $---------------------------------------------------------------------
            PARAMETER
 $---------------------------------------------------------------------
 $                                                             $
 $    IWALLAREA = area of interior walls                       $
 $                                                             $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $         + .10 x minimum month daily electric usage LATN,
 $         + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $         + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $         (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Res6        $ FLRAREA=1291 HOUSVOL=11619 PERIM=156.3 IWALLAREA=989.999
$Res6        $ GARAREA=299 NEX=26.5 NEY=42.5
$Res6        $ ROOFZ=8.5 ROOFHT=18.1 ROOFWD=42.5
$Res6        $ NWALLWD=26.5 SWALLWD=32.5 EWALLWD=19 WWALLWD=42.5
$Res6        $ WALLHT=8.5  SHADEHT=8.06
$Res6          INTLOAD=46567 LATLOAD=.195
$Res6        $ INTLOAD=36858 LATLOAD=.184 NUMOCC=3.5
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
```

```
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R30 Ceiling             $ VAULL = r30vaul CEILL = r30ceil
$R11 Stucco wall         $ WALLL = r11swall
$Base6 $               WALLABS= 0.60  $ lt blue stucco
$Base6 $               ROOFABS= 0.65  $ lt brown shingle
$Res6 $ T1AX=9.3 T1DX=-4.7 T2AX=24.3 T2DX=10.3 T3AY=20.7 T3CY=6.7
$Res6 $ T4AX=49.6 T4AY=30.75 T4CY=16.75 T4DX=35.6
$Res6 $ FSW1=48.1 FSW2=42.5 FSW3=57.5 FSW4=63.1 FSW5=78.1
$Sacram One  Slab  FM0   $ FDNUEFF =.0569  $ GndU=.0076 GndT= 0
 $ ---  end of parameters -----------------------------------------------
                ..
$Year $ RUN-PERIOD          JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.52 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST=
                             (50,50,50,50,50,50,50,50,50,50,50,50)
$Res6 $                     AZIMUTH=0
                            SHIELDING-COEF=0.19
$Nownd$                     TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                     WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                              ..
          ABORT     ERRORS ..
          LOADS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(LS-E)  ..
 $----------------------------------------------------------------------
 $-----  Loads Schedules -----------------------------------------------
 $----------------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                  (1) (.024)  (2) (.022)  (3,5) (.021)
                  (6) (.026)  (7) (.038)  (8) (.059)
                  (9) (.056) (10) (.060) (11) (.059)
                 (12) (.046) (13) (.045) (14) (.030)
                 (15) (.028) (16) (.031) (17) (.057)
              (18,19) (.064) (20) (.052) (21) (.050)
                 (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE   $CEC modified: appl on unoccupied day
                  (1) (.024)  (2) (.022)  (3,5) (.021)
                  (6) (.026)(7,8) (.075) (9,17) (.059)
                 (18) (.072) (19,22) (.080)
                 (23) (.072) (24) (.027) ..
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
```

```
                (10) (0.52)    (11) (0.63) (12) (0.21) (13) (0.14)
             (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                (19) (0.81)    (20) (1.00) (21) (0.96)
                (22) (0.89)    (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
               (1,6) (0.44)     (7) (0.53)  (8) (0.87)
              (9,18) (0.00)
                (19) (0.81)    (20) (1.00) (21) (0.96)
                (22) (0.89)    (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Res6 $ INTLDSCH SCHEDULE THRU DEC 31 (WD) UOCCAPPS  (WEH) DAYINTSCH ..
$Res6 $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCNO     (WEH) OCCYES ..
 $-----------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-----------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Res6 $             THRU OCT 31 (ALL) (1,24) (0.40)
$Res6     Ref. W.Bos, "site6 has been keeping their shades closed
$Res6                  opposite per our request"
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-----------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $-----------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $-----------------------------------------------------------------
 $-----  Constructions --------------------------------------------
 $-----------------------------------------------------------------
WINDOWGT          GLASS-TYPE              $ Windows
                      GLASS-TYPE-CODE=1  $clear glass
```

```
$2-pane $                   PANES = 2
                            ..
WALLCON             CONSTRUCTION     $ Wall section
                            ABSORPTANCE= WALLABS
$Res6  $                    ROUGHNESS=1  $ stucco
                            LAYERS=WALLL ..
VAULCON             CONSTRUCTION     $ Vault ceiling section, with joist
                            ABSORPTANCE= ROOFABS
$Res6  $                    ROUGHNESS=3 $ shingle
                            LAYERS=VAULL ..
CEILCON             CONSTRUCTION     $ Ceiling below attic section, with joist
                            LAYERS=CEILL ..
ROOFCON             CONSTRUCTION     $ Roof above attic section, with joist
                            ABSORPTANCE= ROOFABS
$Res6  $                    ROUGHNESS=3 $ shingle
                            LAYERS=r0groof ..
IWALLCON            CONSTRUCTION     $ Interior walls
                            LAYERS=iwalll ..
GWALLCON            CONSTRUCTION     $ garage wall
                            ABSORPTANCE= WALLABS
$Res6  $                    ROUGHNESS=1  $ stucco
$Stucco                       $ LAYERS  = r0scwall
                            ..
IGWALLCON            CONSTRUCTION     $ interior insulated garage wall
$Res6 $ LAYERS = r11gwall
                            ..
GROOFCON          CONSTRUCTION     $ garage roof
                            ABSORPTANCE= ROOFABS
$Res6  $                    ROUGHNESS=3 $ shingle
                            LAYERS=r0groof ..
DOORCON             CONSTRUCTION     $ Solid door
                            U-VALUE=.7181 ..
GSLABCON            CONSTRUCTION     $ garage slab in contact with soil
                            LAYERS=CGNDL  ..
FSLABCON            CONSTRUCTION     $ Floor slab in contact with soil
$Slab concrete floor$  LAYERS=FSLABL ..
$Stucrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. stucco crawlspace walls
$Stucrawl $             LAYERS=r0scwall ..
 $----------------------------------------------------------------
 $-----  Shades --------------------------------------------------
 $----------------------------------------------------------------
$Res6 $  SURROUND1 BUILDING-SHADE
$Res6                       house to north $
$Res6 $                     HEIGHT=9.5 WIDTH=48
$Res6 $                     X=0 Y=62.5 AZIMUTH=180 TILT=90 ..
  $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
        EAVEN BUILDING-SHADE $ north eave
$Res6 $                   HEIGHT=19.2 WIDTH=1 X=-1 Y=43.5 AZ=-90 TILT=26
```

```
                Z=SHADEHT ..
$Res6 $  EAVEN2 BUILDING-SHADE $ north eave
$Res6 $             LIKE EAVEN X=33.5 Y=42.5 AZ=90 ..

         EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Res6 $             Y=0.0 AZ=-90
                    ..
$Res6 $  EAVES2 BUILDING-SHADE $ north eave
$Res6 $             LIKE EAVES X=33.5 Y=-1 AZ=90 ..

         EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Res6 $             HEIGHT=10.3 WIDTH=23.5 X=33 Y=19 Z=WALLHT
$Res6 $             AZ=90 TILT=0
                    ..

         EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Res6 $             HEIGHT=1.11 WIDTH=42.5 X=-1 Y=42.5 Z=SHADEHT
$Res6 $             AZ=-90 TILT=26
                    ..
$Res6 $  PATIO BUILDING-SHADE  $ backyard patio overhang
$Res6 $             HEIGHT=6 WIDTH=12 TRANSMITTANCE=0.50
$Res6 $             X=0 Y=30.5 Z=WALLHT AZ=90 ..
 $---------------------------------------------------------------------
 $-----  Trees: First existing, then test trees  ---------------------
 $---------------------------------------------------------------------

$ExTr6$   TREET1A B-S HEIGHT=3 WIDTH=3 X=-21.5 Y=35 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.894 SHADE-SCHEDULE=TREETRANS2 ..
$ExTr6$   TREET1B B-S LIKE TREET1A AZ=270 ..
$ExTr6$   TREET1C B-S LIKE TREET1A Y=32 ..
$ExTr6$   TREET1D B-S LIKE TREET1B X=-24.5 ..
$ExTr6$   TREET1E B-S LIKE TREET1A Z=10 TILT=0 X=-21.5 Y=35 AZ=0 ..
$ExTr6$   TREET2A B-S HEIGHT=3 WIDTH=3 X=-15.5 Y=26 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.894 SHADE-SCHEDULE=TREETRANS2 ..
$ExTr6$   TREET2B B-S LIKE TREET2A AZ=270 ..
$ExTr6$   TREET2C B-S LIKE TREET2A Y=23 ..
$ExTr6$   TREET2D B-S LIKE TREET2B X=-18.5 ..
$ExTr6$   TREET2E B-S LIKE TREET2A Z=10 TILT=0 X=-15.5 Y=26 AZ=0 ..
$ExTr6$   TREET4A B-S HEIGHT=2 WIDTH=2 X=-8 Y=11 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.894 SHADE-SCHEDULE=TREETRANS2 ..
$ExTr6$   TREET4B B-S LIKE TREET4A AZ=270 ..
$ExTr6$   TREET4C B-S LIKE TREET4A Y=9 ..
$ExTr6$   TREET4D B-S LIKE TREET4B X=-10 ..
$ExTr6$   TREET4E B-S LIKE TREET4A Z=9 TILT=0 X=-8 Y=11 AZ=0 ..
$ExTr6$   TREET6A B-S HEIGHT=4 WIDTH=4 X=-20 Y=-3 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr6$   TREET6B B-S LIKE TREET6A AZ=270 ..
$ExTr6$   TREET6C B-S LIKE TREET6A Y=-7 ..
```

```
$ExTr6$   TREET6D B-S LIKE TREET6B X=-24 ..
$ExTr6$   TREET6E B-S LIKE TREET6A Z=11 TILT=0 ..
$ExTr6$   TREET7A B-S HEIGHT=4 WIDTH=4 X=-12 Y=-3 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr6$   TREET7B B-S LIKE TREET7A AZ=270 ..
$ExTr6$   TREET7C B-S LIKE TREET7A Y=-7 ..
$ExTr6$   TREET7D B-S LIKE TREET7B X=-16 ..
$ExTr6$   TREET7E B-S LIKE TREET7A Z=11 TILT=0 ..
$ExTr6$   TREET8A B-S HEIGHT=4 WIDTH=4 X=-6 Y=-3 Z=7 TILT=90
$ExTr6$        TRANSMITTANCE=0.707 SHADE-SCHEDULE=TREETRANS5 ..
$ExTr6$   TREET8B B-S LIKE TREET8A AZ=270 ..
$ExTr6$   TREET8C B-S LIKE TREET8A Y=-7 ..
$ExTr6$   TREET8D B-S LIKE TREET8B X=-10 ..
$ExTr6$   TREET8E B-S LIKE TREET8A Z=11 TILT=0 ..
 $---------------------------------------------------------------------
 $-----  Space --------------------------------------------------------
 $---------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                    TEMPERATURE = (74)
                    SOURCE-TYPE=PROCESS
                    SOURCE-SCHEDULE=INTLDSCH
                    SOURCE-BTU/HR=INTLOAD
                    SOURCE-SENSIBLE=1.
                    SOURCE-LATENT=LATLOAD
                    PEOPLE-SCHEDULE=OCCSCH
                    NUMBER-OF-PEOPLE=NUMOCC
                    PEOPLE-HG-LAT=190
                    PEOPLE-HG-SENS=230
                    INF-METHOD=S-G
$Medium Infiltration     $ FRAC-LEAK-AREA = .0005
                    FLOOR-WEIGHT=0
                    FURNITURE-TYPE=LIGHT
                    FURN-FRACTION=0.29
                    FURN-WEIGHT=3.30
                    ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
SET-DEFAULT FOR EXTERIOR-WALL
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Res6 $ NWALL1  EXTERIOR-WALL CONSTRUCTION=WALLCON X=NEX Y=NEY
```

```
               HEIGHT=WALLHT  WIDTH=NWALLWD
               ..
$Res6 $  NWIND1A  WINDOW X=15.5 Y=3 HEIGHT=3.6 WIDTH=3.00  ..
        SWALL1  EXTERIOR-WALL
$Res6 $        LIKE NWALL1 X=0.0
               HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
               ..
$Res6 $  SWIND1A  WINDOW X=15.5 Y=2.999 HEIGHT=3.90 WIDTH=3.60 ..
$Res6 $ EWALL1  INTERIOR-WALL CONSTRUCTION=IGWALLCON
$Res6 $            HEIGHT=WALLHT NEXT-TO=GARAGE
               WIDTH=EWALLWD ..
$Res6 $ EWALL2  EXTERIOR-WALL CONSTRUCTION=WALLCON
$Res6 $           X=32.6 Y=19 HEIGHT=WALLHT WIDTH=9.5 AZ=90 ..
$Res6 $  EWIND2A  WINDOW  X=2.5 Y=2.5 HEIGHT=4.8 WIDTH=4.5 ..
$Res6 $ EWALL3  EXTERIOR-WALL LIKE EWALL2 Y=28.5 AZ=0 WIDTH=8.5   ..
$Res6 $ EWALL4  EXTERIOR-WALL LIKE EWALL3 X=24.5 AZ=90 WIDTH=4   ..
$Res6 $  EDOOR4A  DOOR X=1 ..
$Res6 $ EWALL5  EXTERIOR-WALL LIKE EWALL4 Y=32.5 AZ=180 WIDTH=2   ..
$Res6 $ EWALL6  E-W LIKE EWALL2 X=26.5 Y=32.5 AZ=135 WIDTH=3   ..
$Res6 $  EWIND6A  WINDOW  X=.75 Y=2.999 HEIGHT=4.50 WIDTH=1.50 ..
$Res6 $ EWALL7  E-W LIKE EWALL2 X=28.7 Y=34.6 AZ=90 WIDTH=5.8  ..
$Res6 $  EWIND7A  WINDOW  X=.75 Y=2.999 HEIGHT=4.50 WIDTH=4.50 ..
$Res6 $ EWALL8  E-W LIKE EWALL2 X=28.7 Y=40.4 AZ=45 WIDTH=3   ..
$Res6 $  EWIND8A  WINDOW  X=.75 Y=2.999 HEIGHT=4.50 WIDTH=1.50 ..
        WWALL1  EXTERIOR-WALL
$Res6 $        LIKE NWALL1 Y=42.5
               X=0 WIDTH=WWALLWD AZIMUTH=270
               ..
$Res6 $  WWIND1A  WINDOW  X=2 Y=0  HEIGHT=6.7 WIDTH=6.7 ..
$Res6 $  WWIND1B  WINDOW  X=10.8 Y=2  HEIGHT=4.7 WIDTH=2 ..
$Res6 $  WWIND1C  WINDOW  LIKE WWIND1B X=20.0 ..
$Res6 $  WWIND1D  WINDOW  X=26.3 Y=3  HEIGHT=3.70 WIDTH=5. ..
$Res6 $  WWIND1E  WINDOW  X=37 Y=6.2  HEIGHT=1.50 WIDTH=4.5 ..
$Slab  $ FOUNDATION UNDERGROUND-FLOOR $ Slab floor
$Slab  $            HEIGHT=10 WIDTH=FLRAREA TIMES .1
$Slab  $            TILT=180 CONSTRUCTION=FSLABCON
$Slab  $            U-EFFECTIVE=FDNUEFF
$Slab  $            FUNCTION =(*NONE*,*FNDQ*)  ..
$Attic$ CEILING    INTERIOR-WALL    $ Ceiling between House and Attic
$Attic$            TILT=0 CONSTRUCTION=CEILCON
$Attic$            AREA=FLRAREA NEXT-TO=ATTIC  ..
$Attic spaces
$Attic$  ATTIC      SPACE
$Attic$             AREA=FLRAREA VOLUME=FLRAREA TIMES 2.90 $ avg height
$Attic$             INF-METHOD=S-G
$Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
$Attic    ELF = 75% of vent area
$Res6 $             FRAC-LEAK-AREA= .00167
```

```
$Attic$                FLOOR-WEIGHT=0
$Attic$                ZONE-TYPE=UNCONDITIONED T=(80)
$Attic$                ..
$Attic$ NROOF1    ROOF       Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Attic$                CONSTRUCTION=ROOFCON
$Res6 $                X=32.5 Y=0.0 AZIMUTH=90 TILT=26
$Attic$                 ..
$Attic$ SROOF1    ROOF        LIKE NROOF1
$Res6 $                X=0 Y=42.5 AZIMUTH=-90
$Attic$                 ..
         GARAGE        SPACE
                       AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                       INF-METHOD=S-G
                       FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                       FLOOR-WEIGHT=0
                       ZONE-TYPE=UNCONDITIONED T=(60)
                       ..
         GAR1 EXTERIOR-WALL
                        HEIGHT=WALLHT TILT=90
$Res6 $                 WIDTH=15.5 X=48 Y=19.3 AZ=0      $ garage Nwall
                        CONSTRUCTION=GWALLCON
                        ..
         GAR2 EXTERIOR-WALL
                        LIKE GAR1
$Res6 $                 X=32.5 Y=0 AZ=180                $ garage Swall
                        ..
         GAR3 EXTERIOR-WALL
                        LIKE GAR1        $ garage door wall
$Res6 $                 HEIGHT=9.8 WIDTH=19.3 Y=0 AZ=90 ..
$Res6 $                 GDOOR DOOR X=1 WIDTH=17  .. $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Res6 $       AREA=164.5  CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Res6 $       LIKE GAR1 HEIGHT=11.65 TILT=33.9
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..
$Res6 $  GROOF2 EXTERIOR-WALL
$Res6 $       LIKE GAR2 HEIGHT=11.65 TILT=33.9
$Res6 $       Z=ROOFZ CONSTRUCTION=GROOFCON   ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143  .. $ Ref j.huang - ashrae paper
$HrRpt--------------------------------------------------------
```

```
$HrRptLoads  Reports ------------------------------------
$HrRpt--------------------------------------------------
$HrRpt$  RB1       REPORT-BLOCK      $ Reports for wall temp
$HrRpt$         VARIABLE-TYPE=SWALL1
$HrRpt$         VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$  RB2       REPORT-BLOCK      $ Reports for roof temp
$HrRpt$         VARIABLE-TYPE=SROOF1
$HrRpt$         VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$  HRSCH     SCHEDULE          $ Hourly report schedule
$HrRpt$         THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$  SHR       HOURLY-REPORT
$HrRpt$         REPORT-SCHEDULE=HRSCH
$HrRpt$         REPORT-BLOCK=(RB1,RB2)
$HrRpt$         ..
        END ..

FUNCTION NAME = FNDQ
        LEVEL = UNDERGROUND-WALL  ..
ASSIGN  DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN  QTABL = TABLE
(  0, -3336.3)(  1, -3389.2)(  2, -3462.1)(  3, -3450.6)(  4, -3494.9)
(  5, -3548.8)(  6, -3512.7)(  7, -3387.8)(  8, -3400.9)(  9, -3432.8)
( 10, -3467.4)( 11, -3408.3)( 12, -3335.8)( 13, -3164.1)( 14, -3056.2)
( 15, -3061.6)( 16, -3176.4)( 17, -3309.6)( 18, -3360.7)( 19, -3255.2)
( 20, -3035.1)( 21, -2849.8)( 22, -2809.7)( 23, -2858.6)( 24, -2872.7)
( 25, -2901.3)( 26, -2954.2)( 27, -2910.6)( 28, -2832.9)( 29, -2737.7)
( 30, -2508.2)( 31, -2379.1)( 32, -2303.7)( 33, -2479.3)( 34, -2686.4)
( 35, -2608.0)( 36, -2500.5)( 37, -2413.6)( 38, -2188.9)( 39, -2045.6)
( 40, -2134.6)( 41, -2002.3)( 42, -1946.5)( 43, -1931.6)( 44, -1942.3)
( 45, -2040.4)( 46, -1852.8)( 47, -1659.4)( 48, -1673.6)( 49, -1538.1)
( 50, -1285.3)( 51, -1176.9)( 52, -1189.2)( 53, -1122.8)( 54, -1020.4)
( 55, -1070.9)( 56, -1147.7)( 57,  -839.9)( 58,  -621.7)( 59,  -592.9)
( 60,  -577.7)( 61,  -569.9)( 62,  -507.0)( 63,  -493.0)( 64,  -494.7)
( 65,  -338.1)( 66,  -236.5)( 67,  -199.1)( 68,  -206.2)( 69,  -148.7)
( 70,   -30.5)( 71,    25.0)( 72,    81.5)( 73,    68.1)( 74,   -28.9)
( 75,   -49.4)( 76,    50.9)( 77,    73.1)( 78,    34.9)( 79,  -123.6)
( 80,  -331.5)( 81,  -320.9)( 82,  -271.8)( 83,  -264.4)( 84,  -250.2)
( 85,  -281.9)( 86,  -345.3)( 87,  -377.1)( 88,  -471.5)( 89,  -680.4)
( 90,  -661.4)( 91,  -665.3)( 92,  -717.0)( 93,  -771.9)( 94,  -825.7)
( 95,  -845.2)( 96, -1001.8)( 97, -1214.9)( 98, -1290.1)( 99, -1357.0)
(100, -1332.1)(101, -1377.6)(102, -1458.1)(103, -1635.8)(104, -1807.5)
(105, -1935.5)(106, -1957.5)(107, -2015.7)(108, -2097.4)(109, -2161.6)
(110, -2276.3)(111, -2428.2)(112, -2591.7)(113, -2814.8)(114, -2984.9)
(115, -2965.2)(116, -2985.4)(117, -2984.5)(118, -3194.8)(119, -3339.1)
(120, -3281.2)(121, -3316.4)(122, -3332.9) ..
     CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
        COMPUTE LOADS ..
         POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
         INPUT    SYSTEMS ..
                   ..
         DIAGNOSTIC    CAUTIONS ECHO ..
$Duct $  SUBR-FUNCTIONS
$Duct $        RESYS-0=*DUCT*
$Duct $        RESYS-3Z=*SAVETEMP*
$Duct $        DAYCLS-4=*DUCT2* ..
         SYSTEMS-REPORT
$HrRpt$        HOURLY-DATA-SAVE = YES
               SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $--------------------------------------------------------
         PARAMETER
 $--------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
 $
$Res6 $  HEATSET=68   SETBACK=68   COOLSET=82  SETUP=82
$Res6 $  HCAPF=-60000 CTCAP=38000  CSCAP=30400
$Res6 $  ACCFM=1200
 $
$Res6 $  VTYPE= 0           $ no venting
 $
$Furn $        FHIR=1.4286  $ 77% efficiency + 10% duct losses
$Furn $        MAXTEMP=120
$Res6 $  CBF=.098     CEIR=.4255     $ 2.35 COP air conditioner
                  ..
 $--------------------------------------------------------
```

```
 $-----  Systems Schedules -----------------------------------
 $------------------------------------------------------------
HTSCH     SCHEDULE  $ heat temperature schedule, 7 hour night setback
                    THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                      (7,23) (HEATSET)
                                      (24)   (SETBACK)  ..
CTSCH     SCHEDULE  $ cool temperature schedule, 7 hour day setup
                    THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                      (8,15) (SETUP)
                                      (16,24)   (COOLSET)  ..
VTSCH     SCHEDULE  $Vent schedule based on previous 4 days load
                    THRU MAY 14 (ALL) (1,24) (-4)
                    THRU SEP 30 (ALL) (1,24) (-4)
                    THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE  $Vent operation schedule
                    THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                    THRU DEC 31 (ALL) (1,6)  (0.0)
                                      (7,23) (1.0)
                                      (24)   (0.0)  ..
 $------------------------------------------------------------
 $-----  Zones -----------------------------------------------
 $------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=70.
                              DESIGN-COOL-T=78.
                              COOL-TEMP-SCH=CTSCH
                              HEAT-TEMP-SCH=HTSCH
                              THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM             ZONE      ZONE-CONTROL=ZC1
                              ZONE-TYPE=CONDITIONED ..
$Attic $ ATTIC      ZONE      ZONE-TYPE=UNCONDITIONED  ..
GARAGE              ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $------------------------------------------------------------
 $-----  Systems ---------------------------------------------
 $------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                 MAX-SUPPLY-T=MAXTEMP
                 MIN-SUPPLY-T=50
                   ..
SYSAIR    SYSTEM-AIR
                 SUPPLY-CFM=ACCFM
                 NATURAL-VENT-SCH=VOPSCH
                 VENT-TEMP-SCH=VTSCH
                 OPEN-VENT-SCH=WINDOPER
                 HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
```

```
                 FRAC-VENT-AREA=0.018
                 VENT-METHOD=S-G
                 MAX-VENT-RATE=20
                   ..
SYSFAN    SYSTEM-FANS                    $added by jim 11/25/92
                 SUPPLY-KW=0.000333      $average of 400 W for 1200 CFM
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-CAPACITY=CTCAP
                 COOLING-EIR=CEIR            $added by jim 1/13/92
                 COOL-SH-CAP=CSCAP
                 COIL-BF=CBF
                 CRANKCASE-HEAT=0.0          $added by jim 3/5/92
                 COMPRESSOR-TYPE=SINGLE-SPEED
$Furn     Furnace specifications     $
$Furn  $         HEATING-CAPACITY=HCAPF
$Furn  $         FURNACE-AUX=0.
$Furn  $         FURNACE-HIR=FHIR $ duct losses in FHIR already
                    ..
RESIDEN  SYSTEM  SYSTEM-TYPE=RESYS
$Slab  $       ZONE-NAMES=(THEROOM,GARAGE
$Attic $                   ,ATTIC
$Slab  $                   )
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-FANS=SYSFAN
                 SYSTEM-EQUIPMENT=SYSEQP
$Furn  $         HEAT-SOURCE=GAS-FURNACE
                 ..
$HrRpt-----------------------------------------------------
$HrRptSystem Reports ---------------------------------------
$HrRpt-----------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK    $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK        $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK        $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE            $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
```

```
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$           ..
          END ..
FUNCTION NAME = DUCT ..
 $
 $ This function multiplies the AC EIR
 $ by the duct efficiency which varies
 $ with attic temperature
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       DEFFC=-0.0077*TATT + 1.379
       COOLEIR = COOLEIR/DEFFC
       COOLCAP = COOLCAP*DEFFC
       COOLSEN = COOLSEN*DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME = DUCT2 ..
 $
 $ This function resets AC EIR to the input value
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       COOLEIR = COOLEIR*DEFFC
       COOLCAP = COOLCAP/DEFFC
       COOLSEN = COOLSEN/DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME=SAVETEMP ..
$
$ saves last hours zone temps for next hour's heat load
$ calculations
$
ASSIGN TATT=XXX23 ..
```

```
ASSIGN TNOW = TNOW  ZNAME = ZONE-NAME DBT=DBT  NZ=NZ ..
ASSIGN HUMRAT=HUMRAT ..
      CALCULATE ..
C     IF (ZNAME.EQ."THER") GO TO 100
C     IF (ZNAME.EQ."GARA") GO TO 100
C     IF (ZNAME.EQ."ATTI") GO TO 70
      IF (NZ.EQ.1) GO TO 100
      IF (NZ.EQ.2) GO TO 100
      IF (NZ.EQ.3) GO TO 70
      GO TO 100
C attic
  70    TATT=TNOW
      GO TO 100
 100  CONTINUE
      END
END-FUNCTION ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE 7 BASE CASE

```
          POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SHUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $----------------------------------------------------------------------
         INPUT  LOADS ..
$Res7  $ TITLE LINE-1 *SMUD 7 *
$BaseC $       LINE-2 *Base Case *
        LINE-3  *                                         *
        LINE-4  *                                         *
        LINE-5  *                                         *
                   ..
 $----------------------------------------------------------------------
            PARAMETER
 $----------------------------------------------------------------------
 $                                                             $
 $    IWALLAREA = area of interior walls                       $
 $                                                             $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $         + .10 x minimum month daily electric usage LATN,
 $         + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $         + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $         (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Res7        $ FLRAREA=1165 HOUSVOL=10485 PERIM=188.6 IWALLAREA=999
$Res7        $ GARAREA=468 NEX=40.88 NEY=48
$Res7        $ ROOFZ=8.5 ROOFHT=15.16 ROOFWD=28.58
$Res7        $ NWALLWD=16.33 SWALLWD=46.33 EWALLWD=22.5 WWALLWD=28.5
$Res7        $ WALLHT=8.5  SHADEHT=8.136
$Res7          INTLOAD=66293 LATLOAD=.180
$Res7        $ INTLOAD=52423 LATLOAD=.184 NUMOCC=5
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
```

```
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R19 Ceiling             $ VAULL = r19vaul CEILL = r19ceil
$R11 Stucco wall         $ WALLL = r11swall
$Base7 $               WALLABS= 0.55  $ offwhite stucco
$Base7 $               ROOFABS= 0.84  $ med brown shingle
$Res7 $ T1AX=21.7 T1DX=7.78 T2AX=31.7 T2DX=17.7 T3AY=14.8 T3CY=0.8
$Res7 $ T4AX=63.33 T4AY=13.74 T4CY=-0.26 T4DX=49.33
$Res7 $ FSW1=46.4 FSW2=28.5 FSW3=43.5 FSW4=61.4 FSW5=76.4
$Sacram One  Slab  FM0   $ FDNUEFF =.0569  $ GndU=.0076 GndT= 0
 $ ---  end of parameters ---------------------------------------------
                ..
$Year $ RUN-PERIOD          JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.52 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST=
                             (50,50,50,50,50,50,50,50,50,50,50,50)
$Res7 $                     AZIMUTH=40
                            SHIELDING-COEF=0.19
$Nownd$                     TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                     WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                             ..
          ABORT     ERRORS ..
          LOADS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(LS-E)  ..
 $----------------------------------------------------------------------
 $-----  Loads Schedules ----------------------------------------------
 $----------------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                  (1) (.024)  (2) (.022)  (3,5) (.021)
                  (6) (.026)  (7) (.038)  (8) (.059)
                  (9) (.056) (10) (.060) (11) (.059)
                 (12) (.046) (13) (.045) (14) (.030)
                 (15) (.028) (16) (.031) (17) (.057)
              (18,19) (.064) (20) (.052) (21) (.050)
                 (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE   $CEC modified: appl on unoccupied day
                  (1) (.024)  (2) (.022)  (3,5) (.021)
                  (6) (.026)(7,8) (.075) (9,17) (.059)
                 (18) (.072) (19,22) (.080)
                 (23) (.072) (24) (.027) ..
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
```

```
                 (10) (0.52)    (11) (0.63) (12) (0.21) (13) (0.14)
              (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
                 (22) (0.89)    (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
                (1,6) (0.44)     (7) (0.53)  (8) (0.87)
               (9,18) (0.00)
                 (19) (0.81)    (20) (1.00) (21) (0.96)
                 (22) (0.89)    (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Res7 $ INTLDSCH SCHEDULE THRU DEC 31 (WD) DAYINTSCH (WEH) DAYINTSCH ..
$Res7 $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCYES    (WEH) OCCYES ..
 $-----------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-----------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Res7 $             THRU OCT 31 (ALL) (1,24) (0.60)
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-----------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $-----------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $-----------------------------------------------------------------
 $-----  Constructions  -------------------------------------------
 $-----------------------------------------------------------------
WINDOWGT           GLASS-TYPE            $ Windows
                     GLASS-TYPE-CODE=1  $clear glass
$2-pane $            PANES = 2
                     ..
```

```
WALLCON          CONSTRUCTION     $ Wall section
                      ABSORPTANCE= WALLABS
$Res7  $              ROUGHNESS=1  $ stucco
                      LAYERS=WALLL ..
VAULCON          CONSTRUCTION     $ Vault ceiling section, with joist
                      ABSORPTANCE= ROOFABS
$Res7  $              ROUGHNESS=3 $ shingle
                      LAYERS=VAULL ..
CEILCON          CONSTRUCTION     $ Ceiling below attic section, with joist
                      LAYERS=CEILL ..
ROOFCON          CONSTRUCTION     $ Roof above attic section, with joist
                      ABSORPTANCE= ROOFABS
$Res7  $              ROUGHNESS=3 $ shingle
                      LAYERS=r0groof ..
IWALLCON         CONSTRUCTION     $ Interior walls
                      LAYERS=iwalll ..
GWALLCON         CONSTRUCTION     $ garage wall
                      ABSORPTANCE= WALLABS
$Res7  $              ROUGHNESS=1  $ stucco
$Stucco                 $ LAYERS  = r0scwall
                        ..
IGWALLCON         CONSTRUCTION     $ interior insulated garage wall
$Res7 $ LAYERS = r11gwall
                        ..
GROOFCON        CONSTRUCTION     $ garage roof
                      ABSORPTANCE= ROOFABS
$Res7  $              ROUGHNESS=3 $ shingle
                      LAYERS=r0groof ..
DOORCON          CONSTRUCTION     $ Solid door
                      U-VALUE=.7181 ..
GSLABCON         CONSTRUCTION     $ garage slab in contact with soil
                      LAYERS=CGNDL  ..
FSLABCON         CONSTRUCTION     $ Floor slab in contact with soil
$Slab concrete floor$  LAYERS=FSLABL ..
$Stucrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. stucco crawlspace walls
$Stucrawl $            LAYERS=r0scwall ..
 $-----------------------------------------------------------------
 $-----  Shades  --------------------------------------------------
 $-----------------------------------------------------------------
$Res7 $  SURROUND1 BUILDING-SHADE
$Res7                 house to north $
$Res7 $               HEIGHT=9.5 WIDTH=36
$Res7 $               X=24.5 Y=68 AZIMUTH=180 TILT=90 ..
$Res7 $  SURROUND2 BUILDING-SHADE
$Res7                 house to west $
$Res7 $               LIKE SURROUND1 HEIGHT=9.5 WIDTH=30
$Res7 $               X=-35 Y=0 AZIMUTH=90 ..
  $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
```

```
        EAVEN BUILDING-SHADE $ north eave
$Res7 $              HEIGHT=9.75 WIDTH=1 X=23.5 Y=49 AZ=-90 TILT=20
                     Z=SHADEHT ..
$Res7 $  EAVEN2 BUILDING-SHADE $ north eave
$Res7 $              LIKE EAVEN X=41.9 Y=48 AZ=90 ..
$Res7 $  EAVEN3 BUILDING-SHADE $ northwest eave
$Res7 $              HEIGHT=1.06 WIDTH=18.5 X=23.5 Y=48 Z=SHADEHT
$Res7 $              AZ=-90 TILT=20 ..
$Res7 $  EAVEN4 BUILDING-SHADE $ north eave #2
$Res7 $              HEIGHT=1.06 WIDTH=24.5 X=24.5 Y=29.5 Z=SHADEHT
$Res7 $              TILT=20 ..

        EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Res7 $              HEIGHT=1.06 WIDTH=28.58 X=0 Y=-1 AZ=180
                     ..

        EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Res7 $              HEIGHT=7.8 WIDTH=12 X=48.21 Y=13.5 Z=7.14
$Res7 $              AZ=90 TILT=10
                     ..
$Res7 $  EAVEE2 BUILDING-SHADE LIKE EAVEE  HEIGHT=2 WIDTH=13.6 Y=0
$Res7 $              TILT=20 Z=5.96 ..

        EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Res7 $              HEIGHT=16.23 WIDTH=1.5 X=0 Y=29.5 Z=SHADEHT
$Res7 $              AZ=0 TILT=20
                     ..
$Res7 $  EAVEW2 BUILDING-SHADE LIKE EAVEW  X=-1.5 Y=-1 AZ=180 ..
 $------------------------------------------------------------------
 $-----  Trees: First existing, then test trees  ---------------------
 $------------------------------------------------------------------

$ExTr7$   TREET1A B-S HEIGHT=21 WIDTH=21 X=82.8 Y=10.5 Z=7 TILT=90
               TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr7$   TREET1B B-S LIKE TREET1A AZ=270 ..
$ExTr7$   TREET1C B-S LIKE TREET1A Y=-10.5 ..
$ExTr7$   TREET1D B-S LIKE TREET1B X=61.8 ..
$ExTr7$   TREET1E B-S LIKE TREET1A Z=28 TILT=0 X=82.8 Y=10.5 AZ=0 ..
$ExTr7$   TREET2A B-S HEIGHT=14 WIDTH=14 X=-13 Y=7 Z=7 TILT=90
               TRANSMITTANCE=0.775 SHADE-SCHEDULE=TREETRANS4 ..
$ExTr7$   TREET2B B-S LIKE TREET2A AZ=270 ..
$ExTr7$   TREET2C B-S LIKE TREET2A Y=-7 ..
$ExTr7$   TREET2D B-S LIKE TREET2B X=-27 ..
$ExTr7$   TREET2E B-S LIKE TREET2A Z=21 TILT=0 X=-13 Y=7 AZ=0 ..
 $------------------------------------------------------------------
 $-----  Space -------------------------------------------------------
 $------------------------------------------------------------------
 $
```

```
ROOMCOND  SPACE-CONDITIONS
                    TEMPERATURE = (74)
                    SOURCE-TYPE=PROCESS
                    SOURCE-SCHEDULE=INTLDSCH
                    SOURCE-BTU/HR=INTLOAD
                    SOURCE-SENSIBLE=1.
                    SOURCE-LATENT=LATLOAD
                    PEOPLE-SCHEDULE=OCCSCH
                    NUMBER-OF-PEOPLE=NUMOCC
                    PEOPLE-HG-LAT=190
                    PEOPLE-HG-SENS=230
                    INF-METHOD=S-G
$Medium Infiltration       $ FRAC-LEAK-AREA = .0005
                    FLOOR-WEIGHT=0
                    FURNITURE-TYPE=LIGHT
                    FURN-FRACTION=0.29
                    FURN-WEIGHT=3.30
                    ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
SET-DEFAULT FOR EXTERIOR-WALL
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Res7 $ NWALL1  EXTERIOR-WALL CONSTRUCTION=WALLCON X=NEX Y=NEY
                HEIGHT=WALLHT  WIDTH=NWALLWD
                ..
$Res7 $ NWALL2  EXTERIOR-WALL LIKE NWALL1 X=24.5 WIDTH=19.5 AZ=-90 ..
$Res7 $  NWIND2A  WINDOW X=7.5 HEIGHT=6.5 WIDTH=7.2  ..
$Res7 $ NWALL3  EXTERIOR-WALL LIKE NWALL1 X=24.5 Y=28.5 WIDTH=24.5 ..
$Res7 $  NWIND3A  WINDOW X=0.5 Y=6  HEIGHT=1.5 WIDTH=3.6  ..
$Res7 $  NWIND3B  WINDOW X=6 Y=6  HEIGHT=1.5 WIDTH=3.6  ..
$Res7 $  NWIND3C  WINDOW X=14 Y=3.5  HEIGHT=3.3 WIDTH=5.4  ..
        SWALL1  EXTERIOR-WALL
$Res7 $         LIKE NWALL1 X=0.0
                HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
                ..
$Res7 $  SWIND1A  WINDOW X=12 Y=3.5 HEIGHT=3.3 WIDTH=5.4 ..
$Res7 $  SWIND1B  WINDOW LIKE SWIND1A X=22 ..
$Res7 $ EWALL1  INTERIOR-WALL CONSTRUCTION=IGWALLCON
$Res7 $              HEIGHT=WALLHT NEXT-TO=GARAGE
                WIDTH=EWALLWD ..
$Res7 $ EWALL2  EXTERIOR-WALL CONSTRUCTION=WALLCON
```

```
$Res7 $            X=40.83 Y=13.5 HEIGHT=WALLHT WIDTH=12 AZ=90 ..
$Res7 $  EDOOR2A  DOOR X=1 ..
$Res7 $  EWIND2A  WINDOW X=5. Y=2 HEIGHT=4.5 WIDTH=5 ..
$Res7 $ EWALL3  EXTERIOR-WALL LIKE EWALL2 X=46.33 AZ=0
$Res7 $           HEIGHT=7.58 WIDTH=5.5   ..
$Res7 $ EWALL4  EXTERIOR-WALL LIKE EWALL3 HEIGHT=6.65
$Res7 $           Y=0 AZ=90 WIDTH=13.5   ..
$Res7 $  EWIND4A  WINDOW  X=2.8 Y=2. HEIGHT=4.5 WIDTH=7.875 ..
        WWALL1  EXTERIOR-WALL
$Res7 $         LIKE NWALL1 Y=28.5
                X=0 WIDTH=WWALLWD AZIMUTH=270
                ..
$Res7 $  WWIND1A  WINDOW  X=18 Y=3.5 HEIGHT=3.5 WIDTH=5.4 ..
$Slab  $ FOUNDATION UNDERGROUND-FLOOR $ Slab floor
$Slab  $            HEIGHT=10 WIDTH=FLRAREA TIMES .1
$Slab  $            TILT=180 CONSTRUCTION=FSLABCON
$Slab  $            U-EFFECTIVE=FDNUEFF
$Slab  $            FUNCTION =(*NONE*,*FNDQ*)  ..
$Attic$ CEILING    INTERIOR-WALL    $ Ceiling between House and Attic
$Attic$            TILT=0 CONSTRUCTION=CEILCON
$Attic$            AREA=FLRAREA NEXT-TO=ATTIC  ..
$Attic spaces
$Attic$  ATTIC      SPACE
$Attic$             AREA=FLRAREA VOLUME=FLRAREA TIMES 2.90 $ avg height
$Attic$             INF-METHOD=S-G
$Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
$Attic    ELF = 75% of vent area
$Res7 $             FRAC-LEAK-AREA= .00167
$Attic$             FLOOR-WEIGHT=0
$Attic$             ZONE-TYPE=UNCONDITIONED T=(80)
$Attic$             ..
$Attic$ NROOF1    ROOF       Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Attic$             CONSTRUCTION=ROOFCON
$Res7 $             X=28.58 Y=28.5 TILT=20
$Attic$              ..
$Attic$ SROOF1    ROOF        LIKE NROOF1
$Res7 $             X=0 Y=0 AZIMUTH=180
$Attic$              ..
$Res7 $ EROOF1    ROOF  CONSTRUCTION=ROOFCON
$Res7 $             X=40.88 Y=13.55 Z=WALLHT AZ=90
$Res7 $             HEIGHT=8.69 WIDTH=34.45 TILT=20 ..
$Res7 $ WROOF1    ROOF       LIKE EROOF1
$Res7 $             X=24.5 Y=48 WIDTH=19.5 AZ=-90 ..
$Res7 $ EROOF2    ROOF       LIKE EROOF1
$Res7 $             X=46.33 Y=0 Z=6.65 HEIGHT=14.47 WIDTH=13.5 ..
$Res7 $ WROOF2    ROOF       LIKE WROOF1
$Res7 $             X=28.58 Y=28.5 Z=9.98 WIDTH=28.5 HEIGHT=4.34 ..
         GARAGE     SPACE
```

```
                    AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                    INF-METHOD=S-G
                    FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                    FLOOR-WEIGHT=0
                    ZONE-TYPE=UNCONDITIONED T=(60)
                    ..
         GAR1 EXTERIOR-WALL
                     HEIGHT=WALLHT TILT=90
$Res7 $              WIDTH=19.67 X=60.55 Y=48 AZ=0    $ garage Nwall
                     CONSTRUCTION=GWALLCON
                     ..
         GAR2 EXTERIOR-WALL
                     LIKE GAR1
$Res7 $              X=40.83 Y=25.5 AZ=180            $ garage Swall
                     ..
         GAR3 EXTERIOR-WALL
                     LIKE GAR1        $ garage door wall
$Res7 $              HEIGHT=9.8 WIDTH=22.5 X=60.55 Y=25.5 AZ=90 ..
$Res7 $              GDOOR DOOR X=1 WIDTH=20.5  .. $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Res7 $      AREA=191.25 CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Res7 $       LIKE GAR1 HEIGHT=11.97 TILT=20.0
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..
$Res7 $  GROOF2 EXTERIOR-WALL
$Res7 $       LIKE GAR2 HEIGHT=11.97 TILT=20.0
$Res7 $       Z=ROOFZ CONSTRUCTION=GROOFCON   ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143  .. $ Ref j.huang - ashrae paper
$HrRpt------------------------------------------------------
$HrRptLoads  Reports ----------------------------------------
$HrRpt------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK       $ Reports for wall temp
$HrRpt$           VARIABLE-TYPE=SWALL1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for roof temp
$HrRpt$           VARIABLE-TYPE=SROOF1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
```

```
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2)
$HrRpt$           ..
        END ..

FUNCTION NAME = FNDQ
        LEVEL = UNDERGROUND-WALL  ..
ASSIGN  DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN  QTABL = TABLE
(  0, -3336.3)(  1, -3389.2)(  2, -3462.1)(  3, -3450.6)(  4, -3494.9)
(  5, -3548.8)(  6, -3512.7)(  7, -3387.8)(  8, -3400.9)(  9, -3432.8)
( 10, -3467.4)( 11, -3408.3)( 12, -3335.8)( 13, -3164.1)( 14, -3056.2)
( 15, -3061.6)( 16, -3176.4)( 17, -3309.6)( 18, -3360.7)( 19, -3255.2)
( 20, -3035.1)( 21, -2849.8)( 22, -2809.7)( 23, -2858.6)( 24, -2872.7)
( 25, -2901.3)( 26, -2954.2)( 27, -2910.6)( 28, -2832.9)( 29, -2737.7)
( 30, -2508.2)( 31, -2379.1)( 32, -2303.7)( 33, -2479.3)( 34, -2686.4)
( 35, -2608.0)( 36, -2500.5)( 37, -2413.6)( 38, -2188.9)( 39, -2045.6)
( 40, -2134.6)( 41, -2002.3)( 42, -1946.5)( 43, -1931.6)( 44, -1942.3)
( 45, -2040.4)( 46, -1852.8)( 47, -1659.4)( 48, -1673.6)( 49, -1538.1)
( 50, -1285.3)( 51, -1176.9)( 52, -1189.2)( 53, -1122.8)( 54, -1020.4)
( 55, -1070.9)( 56, -1147.7)( 57,  -839.9)( 58,  -621.7)( 59,  -592.9)
( 60,  -577.7)( 61,  -569.9)( 62,  -507.0)( 63,  -493.0)( 64,  -494.7)
( 65,  -338.1)( 66,  -236.5)( 67,  -199.1)( 68,  -206.2)( 69,  -148.7)
( 70,   -30.5)( 71,    25.0)( 72,    81.5)( 73,    68.1)( 74,   -28.9)
( 75,   -49.4)( 76,    50.9)( 77,    73.1)( 78,    34.9)( 79,  -123.6)
( 80,  -331.5)( 81,  -320.9)( 82,  -271.8)( 83,  -264.4)( 84,  -250.2)
( 85,  -281.9)( 86,  -345.3)( 87,  -377.1)( 88,  -471.5)( 89,  -680.4)
( 90,  -661.4)( 91,  -665.3)( 92,  -717.0)( 93,  -771.9)( 94,  -825.7)
( 95,  -845.2)( 96, -1001.8)( 97, -1214.9)( 98, -1290.1)( 99, -1357.0)
(100, -1332.1)(101, -1377.6)(102, -1458.1)(103, -1635.8)(104, -1807.5)
(105, -1935.5)(106, -1957.5)(107, -2015.7)(108, -2097.4)(109, -2161.6)
(110, -2276.3)(111, -2428.2)(112, -2591.7)(113, -2814.8)(114, -2984.9)
(115, -2965.2)(116, -2985.4)(117, -2984.5)(118, -3194.8)(119, -3339.1)
(120, -3281.2)(121, -3316.4)(122, -3332.9) ..
      CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
         COMPUTE LOADS ..
          POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
```

```
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                     (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
         INPUT    SYSTEMS ..
                    ..
         DIAGNOSTIC   CAUTIONS ECHO ..
$Duct $  SUBR-FUNCTIONS
$Duct $         RESYS-0=*DUCT*
$Duct $         RESYS-3Z=*SAVETEMP*
$Duct $         DAYCLS-4=*DUCT2* ..
         SYSTEMS-REPORT
$HrRpt$         HOURLY-DATA-SAVE = YES
                SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $---------------------------------------------------------
         PARAMETER
 $---------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
 $
$Res7 $  HEATSET=68   SETBACK=68    COOLSET=78   SETUP=78
$Res7 $  HCAPF=-47000 CTCAP=36000   CSCAP=28800
$Res7 $  ACCFM=1200
 $
$Res7 $  VTYPE= 0              $ no venting
 $
$Furn $         FHIR=1.4286   $ 77% efficiency + 10% duct losses
$Furn $         MAXTEMP=120
$Res7 $  CBF=.098     CEIR=.3610       $ 2.7  COP air conditioner
                    ..
 $---------------------------------------------------------
 $-----  Systems Schedules ---------------------------------
 $---------------------------------------------------------
HTSCH    SCHEDULE  $ heat temperature schedule, 7 hour night setback
                   THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                     (7,23) (HEATSET)
                                     (24)   (SETBACK)  ..
CTSCH    SCHEDULE  $ cool temperature schedule, 7 hour day setup
                   THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                     (8,15) (SETUP)
                                     (16,24)   (COOLSET)  ..
VTSCH    SCHEDULE  $Vent schedule based on previous 4 days load
```

```
                     THRU MAY 14 (ALL) (1,24) (-4)
                     THRU SEP 30 (ALL) (1,24) (-4)
                     THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE   $Vent operation schedule
                     THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE   $No window operation between 11 p.m. and 6 a.m.
                     THRU DEC 31 (ALL) (1,6)  (0.0)
                                       (7,23) (1.0)
                                       (24)   (0.0)  ..
 $----------------------------------------------------------------
 $-----  Zones  --------------------------------------------------
 $----------------------------------------------------------------
ZC1                  ZONE-CONTROL
                               DESIGN-HEAT-T=70.
                               DESIGN-COOL-T=78.
                               COOL-TEMP-SCH=CTSCH
                               HEAT-TEMP-SCH=HTSCH
                               THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM              ZONE      ZONE-CONTROL=ZC1
                               ZONE-TYPE=CONDITIONED ..
$Attic $ ATTIC       ZONE      ZONE-TYPE=UNCONDITIONED  ..
GARAGE               ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $----------------------------------------------------------------
 $-----  Systems  ------------------------------------------------
 $----------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                  MAX-SUPPLY-T=MAXTEMP
                  MIN-SUPPLY-T=50
                    ..
SYSAIR    SYSTEM-AIR
                  SUPPLY-CFM=ACCFM
                  NATURAL-VENT-SCH=VOPSCH
                  VENT-TEMP-SCH=VTSCH
                  OPEN-VENT-SCH=WINDOPER
                  HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                  FRAC-VENT-AREA=0.018
                  VENT-METHOD=S-G
                  MAX-VENT-RATE=20
                    ..
SYSFAN    SYSTEM-FANS                $added by jim 11/25/92
                  SUPPLY-KW=0.000333   $average of 400 W for 1200 CFM
                    ..
SYSEQP    SYSTEM-EQUIPMENT
                  COOLING-CAPACITY=CTCAP
                  COOLING-EIR=CEIR          $added by jim 1/13/92
                  COOL-SH-CAP=CSCAP
                  COIL-BF=CBF
                  CRANKCASE-HEAT=0.0        $added by jim 3/5/92
                  COMPRESSOR-TYPE=SINGLE-SPEED
$Furn      Furnace specifications    $
$Furn  $          HEATING-CAPACITY=HCAPF
$Furn  $          FURNACE-AUX=0.
$Furn  $          FURNACE-HIR=FHIR $ duct losses in FHIR already
                    ..
RESIDEN  SYSTEM   SYSTEM-TYPE=RESYS
$Slab  $        ZONE-NAMES=(THEROOM,GARAGE
$Attic $                   ,ATTIC
$Slab  $                   )
                  SYSTEM-CONTROL=SYSCONTRL
                  SYSTEM-AIR=SYSAIR
                  SYSTEM-FANS=SYSFAN
                  SYSTEM-EQUIPMENT=SYSEQP
$Furn  $          HEAT-SOURCE=GAS-FURNACE
                    ..
$HrRpt-------------------------------------------------------------
$HrRptSystem Reports ---------------------------------------------
$HrRpt-------------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK   $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK       $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$             ..
          END ..
FUNCTION NAME = DUCT ..
 $
 $ This function multiplies the AC EIR
 $ by the duct efficiency which varies
 $ with attic temperature
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
```

```
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       DEFFC=-0.0077*TATT + 1.379
       COOLEIR = COOLEIR/DEFFC
       COOLCAP = COOLCAP*DEFFC
       COOLSEN = COOLSEN*DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME = DUCT2 ..
 $
 $ This function resets AC EIR to the input value
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       COOLEIR = COOLEIR*DEFFC
       COOLCAP = COOLCAP/DEFFC
       COOLSEN = COOLSEN/DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME=SAVETEMP ..
$
$ saves last hours zone temps for next hour's heat load
$ calculations
$
ASSIGN TATT=XXX23 ..
ASSIGN TNOW = TNOW  ZNAME = ZONE-NAME DBT=DBT  NZ=NZ ..
ASSIGN HUMRAT=HUMRAT ..
      CALCULATE ..
C     IF (ZNAME.EQ."THER") GO TO 100
C     IF (ZNAME.EQ."GARA") GO TO 100
C     IF (ZNAME.EQ."ATTI") GO TO 70
      IF (NZ.EQ.1) GO TO 100
      IF (NZ.EQ.2) GO TO 100
      IF (NZ.EQ.3) GO TO 70
      GO TO 100
C attic
```

```
  70    TATT=TNOW
      GO TO 100
 100  CONTINUE
      END
END-FUNCTION ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE 8 BASE CASE

```
         POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SHUDLDS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Oct 18 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                    (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
 $------------------------------------------------------------------
        INPUT  LOADS ..
$Res8  $ TITLE LINE-1 *SHUD 8 *
$BaseC $       LINE-2 *Base Case *
       LINE-3  *                                      *
       LINE-4  *                                      *
       LINE-5  *                                      *
                  ..
 $------------------------------------------------------------------
           PARAMETER
 $------------------------------------------------------------------
 $                                                             $
 $    IWALLAREA = area of interior walls                       $
 $                                                             $
 $
 $ IWALLAREA is estimated from Haider's drawings (see notes)
 $ For HOUSVOL, assume average ceiling Ht of 9 ft.
 $ INTLOAD = .75 x minimum month daily electric usage SENS,
 $        + .10 x minimum month daily electric usage LATN,
 $        + ( 290 Btu/day SENS +  580 Btu/day LATN)/person for DHW use
 $        + (2770 Btu/day SENS + 2290 Btu/day LATN)/person for occupancy
 $        (children counted as .75 x Adults)
 $
 $ 10/5 internal loads changed to include only appliances and dhw
 $ occupants calculated differently
 $
$Res8       $ FLRAREA=1122 HOUSVOL=10098 PERIM=143 IWALLAREA=799.99
$Res8       $ GARAREA=468 NEX=40.5 NEY=25.5
$Res8       $ ROOFZ=7.999 ROOFHT=16.15 ROOFWD=40.5
$Res8       $ NWALLWD=19.5 SWALLWD=40.5 EWALLWD=25.5 WWALLWD=30.0
$Res8       $ WALLHT=7.999  SHADEHT=7.07
$Res8         INTLOAD=46888 LATLOAD=.185
$Res8       $ INTLOAD=44114 LATLOAD=.145 NUMOCC=1
$Sacramento C$ FSLABL=FSLABLDP BSLABL=BSLABLDP CGNDL=CGNDLDP
$Sacramento C$ R5BWALL=R5BWLLDP R10BWALL=R10BWLDP R0BWALL=R0BWLLDP
$R19 Ceiling             $ VAULL = r19vaul CEILL = r19ceil
$R11 Stucco wall         $ WALLL = r11swall
$Base8 $               WALLABS= 0.70  $ tan stucco
$Base8 $               ROOFABS= 0.84  $ med brown shingle
$Res8 $ T1AX=29.25 T1DX=15.25 T2AX=42.1 T2DX=28.1 T3AY=9.2 T3CY=-4.8
$Res8 $ T4AX=57.5 T4AY=28.75 T4CY=14.75 T4DX=43.5
$Res8 $ FSW1=40.5 FSW2=30.0 FSW3=45.0 FSW4=55.5 FSW5=70.5
$Sacram One  Slab  FM0   $ FDNUEFF =.0569  $ GndU=.0076 GndT= 0
 $ ---  end of parameters ------------------------------------------
               ..
$Year $ RUN-PERIOD          JAN 1 1991 THRU DEC 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.52 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST=
                             (50,50,50,50,50,50,50,50,50,50,50,50)
$Res8 $                     AZIMUTH=10
                            SHIELDING-COEF=0.19
$Nownd$                     TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
$Nownd$                     WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                             ..
          ABORT     ERRORS ..
          LOADS-REPORT
$HrRpt$         HOURLY-DATA-SAVE = YES
                SUMMARY=(LS-E)  ..
 $-----------------------------------------------------------------
 $-----  Loads Schedules ------------------------------------------
 $-----------------------------------------------------------------
DAYINTSCH DAY-SCHEDULE   $CEC internal loads profile- fraction of total
                 (1) (.024)  (2) (.022)  (3,5) (.021)
                 (6) (.026)  (7) (.038)  (8) (.059)
                 (9) (.056) (10) (.060) (11) (.059)
                (12) (.046) (13) (.045) (14) (.030)
                (15) (.028) (16) (.031) (17) (.057)
             (18,19) (.064) (20) (.052) (21) (.050)
                (22) (.055) (23) (.044) (24) (.027) ..
UOCCAPPS DAY-SCHEDULE   $CEC modified: appl on unoccupied day
                 (1) (.024)  (2) (.022)  (3,5) (.021)
                 (6) (.026)(7,8) (.075) (9,17) (.059)
                (18) (.072) (19,22) (.080)
                (23) (.072) (24) (.027) ..
OCCYES DAY-SCHEDULE     $old CEC/GRI occ schedule - fraction of peak
               (1,6) (0.44)     (7) (0.53)  (8) (0.87)  (9) (0.43)
```

```
                (10) (0.52)    (11) (0.63) (12) (0.21) (13) (0.14)
             (14,15) (0.00) (16,17) (0.29) (18) (0.64)
                (19) (0.81)    (20) (1.00) (21) (0.96)
                (22) (0.89)    (23) (0.77) (24) (0.44) ..
OCCNO  DAY-SCHEDULE     $old CEC/GRI occ schedule mod for unocc
               (1,6) (0.44)     (7) (0.53)  (8) (0.87)
              (9,18) (0.00)
                (19) (0.81)    (20) (1.00) (21) (0.96)
                (22) (0.89)    (23) (0.77) (24) (0.44) ..
 $ internal loads includes all loads- electric and dhw
 $ occupant loads are occupant only
$Res8 $ INTLDSCH SCHEDULE THRU DEC 31 (WD) UOCCAPPS  (WEH) DAYINTSCH ..
$Res8 $ OCCSCH   SCHEDULE THRU DEC 31 (WD) OCCNO     (WEH) OCCYES ..
 $-------------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-------------------------------------------------------------------
SHADCO    SCHEDULE  THRU MAY 31 (ALL) (1,24) (0.80)
$Res8 $             THRU OCT 31 (ALL) (1,24) (0.60)
                    THRU DEC 31 (ALL) (1,24) (0.80) ..
 $-------------------------------------------------------------------
 $ The following tree shading schedules produce the follwing effective
 $ trasmittances of 0.50 down to 0.10 during the summer and of 0.90
 $ down to 0.50 during the winter. The square root of the transmittance
 $ is input under building-shades since light passing through a "tree"
 $ goes through two surfaces.
 $-------------------------------------------------------------------
TREETRANS1  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.745)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS2  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.707)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS3  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.655)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS4  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.577)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $-------------------------------------------------------------------
 $-----  Constructions  ---------------------------------------------
 $-------------------------------------------------------------------
WINDOWGT           GLASS-TYPE           $ Windows
                       GLASS-TYPE-CODE=1  $clear glass
$2-pane $              PANES = 2
                       ..
```

```
WALLCON            CONSTRUCTION     $ Wall section
                       ABSORPTANCE= WALLABS
$Res8  $               ROUGHNESS=1  $ stucco
                       LAYERS=WALLL ..
VAULCON            CONSTRUCTION     $ Vault ceiling section, with joist
                       ABSORPTANCE= ROOFABS
$Res8  $               ROUGHNESS=3 $ shingle
                       LAYERS=VAULL ..
CEILCON            CONSTRUCTION     $ Ceiling below attic section, with joist
                       LAYERS=CEILL ..
ROOFCON            CONSTRUCTION     $ Roof above attic section, with joist
                       ABSORPTANCE= ROOFABS
$Res8  $               ROUGHNESS=3 $ shingle
                       LAYERS=r0groof ..
IWALLCON           CONSTRUCTION     $ Interior walls
                       LAYERS=iwalll ..
GWALLCON           CONSTRUCTION     $ garage wall
                       ABSORPTANCE= WALLABS
$Res8  $               ROUGHNESS=1  $ stucco
$Stucco                  $ LAYERS  = r0scwall
                       ..
IGWALLCON           CONSTRUCTION     $ interior insulated garage wall
$Res8 $ LAYERS = r11gwall
                       ..
GROOFCON         CONSTRUCTION     $ garage roof
                       ABSORPTANCE= ROOFABS
$Res8  $               ROUGHNESS=3 $ shingle
                       LAYERS=r0groof ..
DOORCON            CONSTRUCTION     $ Solid door
                       U-VALUE=.7181 ..
GSLABCON           CONSTRUCTION     $ garage slab in contact with soil
                       LAYERS=CGNDL  ..
FSLABCON           CONSTRUCTION     $ Floor slab in contact with soil
$Slab concrete floor$  LAYERS=FSLABL ..
$Stucrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. stucco crawlspace walls
$Stucrawl $             LAYERS=r0scwall ..
 $-------------------------------------------------------------------
 $-----  Shades  ----------------------------------------------------
 $-------------------------------------------------------------------
$Res8 $  SURROUND1 BUILDING-SHADE
$Res8                  house to east $
$Res8 $                HEIGHT=9.5 WIDTH=49
$Res8 $                X=70.7 Y=28.3 AZIMUTH=225 TILT=90 ..
$Res8 $  SURROUND2 BUILDING-SHADE
$Res8                  house to northwest $
$Res8 $                LIKE SURROUND1 HEIGHT=9.5 WIDTH=40
$Res8 $                X=-21.2 Y=51.2 AZIMUTH=-45 ..
  $ note: eave "heights" are multiplied by cos(tilt) for tilted surfaces
```

```
         EAVEN BUILDING-SHADE $ north eave
$Res8 $              HEIGHT=2.69 WIDTH=21 X=21 Y=32.5 TILT=21.8
                     Z=SHADEHT ..

         EAVES BUILDING-SHADE LIKE EAVEN    $ south eave
$Res8 $              HEIGHT=1.08 WIDTH=40.5 X=0 Y=-1.0 Z=7.62 AZ=180
                     ..

         EAVEE BUILDING-SHADE LIKE EAVEN   $ east eave
$Res8 $              HEIGHT=18.8 WIDTH=1 X=41.5 Y=32.5 Z=SHADEHT
                     ..
$Res8 $  EAVEE2 BUILDING-SHADE LIKE EAVEE  HEIGHT=17.2
$Res8 $              X=40.5 Y=-1 Z=7.62 AZ=180 ..

         EAVEW BUILDING-SHADE LIKE EAVEE   $ west eave
$Res8 $              X=0
                     ..
$Res8 $  EAVEW2 BUILDING-SHADE LIKE EAVEE2 X=-1 ..
$Res8 $  DECKOH BUILDING-SHADE  $ backyard deck overhang
$Res8 $              HEIGHT=11 WIDTH=16 TRANSMITTANCE=0.70
$Res8 $              X=16. Y=0 Z=WALLHT ..
 $-------------------------------------------------------------------
 $-----  Trees: First existing, then test trees ----------------------
 $-------------------------------------------------------------------

 $-------------------------------------------------------------------
 $-----  Space -------------------------------------------------------
 $-------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                    TEMPERATURE = (74)
                    SOURCE-TYPE=PROCESS
                    SOURCE-SCHEDULE=INTLDSCH
                    SOURCE-BTU/HR=INTLOAD
                    SOURCE-SENSIBLE=1.
                    SOURCE-LATENT=LATLOAD
                    PEOPLE-SCHEDULE=OCCSCH
                    NUMBER-OF-PEOPLE=NUMOCC
                    PEOPLE-HG-LAT=190
                    PEOPLE-HG-SENS=230
                    INF-METHOD=S-G
$Medium Infiltration     $ FRAC-LEAK-AREA = .0005
                    FLOOR-WEIGHT=0
                    FURNITURE-TYPE=LIGHT
                    FURN-FRACTION=0.29
                    FURN-WEIGHT=3.30
                    ..
SET-DEFAULT FOR DOOR HEIGHT=6.5 WIDTH=3.0 CONSTRUCTION=DOORCON ..
```

```
SET-DEFAULT FOR EXTERIOR-WALL
        SHADING-SURFACE=YES ..
SET-DEFAULT FOR WINDOW
        GLASS-TYPE=WINDOWGT SHADING-SCHEDULE=SHADCO ..
THEROOM   SPACE
                    SPACE-CONDITIONS=ROOMCOND
                    AREA=FLRAREA VOLUME=HOUSVOL ..
        INTWALL INTERIOR-WALL
                         INT-WALL-TYPE=INTERNAL
                         AREA=IWALLAREA CONSTRUCTION=IWALLCON ..
$Res8 $ NWALL1  INTERIOR-WALL CONSTRUCTION=IGWALLCON NEXT-TO=GARAGE
                HEIGHT=WALLHT  WIDTH=NWALLWD
                ..
$Res8 $ NWALL2  INTERIOR-WALL LIKE NWALL1 WIDTH=3 ..
$Res8 $ NWALL3  EXTERIOR-WALL CONSTRUCTION=WALLCON
$Res8 $      X=21 Y=28.5 HEIGHT=WALLHT WIDTH=7.0 AZ=0 ..
$Res8 $  NDOOR4A  DOOR X=4 ..
$Res8 $ NWALL4  EXTERIOR-WALL LIKE NWALL3 X=14 WIDTH=1.5 AZ=90 ..
$Res8 $ NWALL5  EXTERIOR-WALL LIKE NWALL3 X=14 Y=30 WIDTH=2 ..
$Res8 $ NWALL6  EXTERIOR-WALL LIKE NWALL3 X=12 Y=30 WIDTH=3.0 AZ=46 ..
$Res8 $  NWIND6A  WINDOW X=0.75 Y=1.8  HEIGHT=4.5 WIDTH=1.5  ..
$Res8 $ NWALL7  EXTERIOR-WALL LIKE NWALL3 X=10 Y=32 WIDTH=6 ..
$Res8 $  NWIND7A  WINDOW LIKE NWIND6A WIDTH=4.5  ..
$Res8 $ NWALL8  EXTERIOR-WALL LIKE NWALL3 X=4 Y=32 WIDTH=3.0 AZ=-46 ..
$Res8 $  NWIND8A  WINDOW LIKE NWIND6A ..
$Res8 $ NWALL9  EXTERIOR-WALL LIKE NWALL3 X=2 Y=30 WIDTH =2 ..
        SWALL1  EXTERIOR-WALL
$Res8 $         LIKE NWALL3 X=0.0
                HEIGHT=WALLHT WIDTH=SWALLWD Y=0.0 AZ=180
                ..
$Res8 $  SWIND1A  WINDOW X= 2.1 Y=0.0 HEIGHT=6.0 WIDTH=5.4 ..
$Res8 $  SWIND1B  WINDOW X=11.2 Y=2.7 HEIGHT=3.0 WIDTH=3.3 ..
$Res8 $  SWIND1C  WINDOW X=20.0 Y=3.6 HEIGHT=3.0 WIDTH=4.5 ..
$Res8 $  SWIND1D  WINDOW X=32.7 Y=3.6 HEIGHT=2.7 WIDTH=4.8 ..
$Res8 $ EWALL1  EXTERIOR-WALL LIKE NWALL3 X=40.5 Y=0 AZ=90
                WIDTH=EWALLWD ..
$Res8 $  EWIND1A  WINDOW  X=21 Y=4.20 HEIGHT=2.40 WIDTH=1.50 ..
        WWALL1  EXTERIOR-WALL
$Res8 $         LIKE NWALL3 Y=30.0
                X=0 WIDTH=WWALLWD AZIMUTH=270
                ..
$Res8 $  WWIND1A  WINDOW  X=26.6 Y=0.6 HEIGHT=5.7 WIDTH=2.4 ..
$Slab  $ FOUNDATION UNDERGROUND-FLOOR $ Slab floor
$Slab  $              HEIGHT=10 WIDTH=FLRAREA TIMES .1
$Slab  $              TILT=180 CONSTRUCTION=FSLABCON
$Slab  $              U-EFFECTIVE=FDNUEFF
$Slab  $              FUNCTION =(*NONE*,*FNDQ*)  ..
$Attic$ CEILING    INTERIOR-WALL    $ Ceiling between House and Attic
```

```
$Attic$            TILT=0 CONSTRUCTION=CEILCON
$Attic$            AREA=FLRAREA NEXT-TO=ATTIC  ..
$Attic spaces
$Attic$  ATTIC      SPACE
$Attic$             AREA=FLRAREA VOLUME=FLRAREA TIMES 2.90 $ avg height
$Attic$             INF-METHOD=S-G
$Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
$Attic    ELF = 75% of vent area
$Res8 $             FRAC-LEAK-AREA= .00167
$Attic$             FLOOR-WEIGHT=0
$Attic$             ZONE-TYPE=UNCONDITIONED T=(80)
$Attic$             ..
$Attic$ NROOF1    ROOF     Z=ROOFZ HEIGHT=ROOFHT WIDTH=ROOFWD
$Attic$             CONSTRUCTION=ROOFCON
$Res8 $             X=NEX Y=30 TILT=21.8
$Attic$              ..
$Attic$ SROOF1    ROOF      LIKE NROOF1
$Res8 $             X=0 Y=0  AZIMUTH=180
$Attic$              ..
         GARAGE     SPACE
                    AREA=GARAREA VOLUME=GARAREA TIMES 9.80 $ avg height
                    INF-METHOD=S-G
                    FRAC-LEAK-AREA= .0015 $ assume 3 times normal infilt
                    FLOOR-WEIGHT=0
                    ZONE-TYPE=UNCONDITIONED T=(60)
                    ..
         GAR1 EXTERIOR-WALL
                     HEIGHT=WALLHT TILT=90
$Res8 $              WIDTH=21 X=21 Y=49.5 AZIMUTH=-90 $ garage Wwall
                     CONSTRUCTION=GWALLCON
                     ..
         GAR2 EXTERIOR-WALL
                     LIKE GAR1
$Res8 $              WIDTH=24 X=40.5 Y=25.5 AZ=90     $ garage Ewall
                     ..
         GAR3 EXTERIOR-WALL
                     LIKE GAR1        $ garage door wall
$Res8 $              HEIGHT=9.8 WIDTH=19.5 X=40.5 Y=49.5 AZ=0    ..
$Res8 $              GDOOR DOOR X=1 WIDTH=18   .. $ garage door

         GAR4 INTERIOR-WALL   $ insulated wall against house
$Res8 $       AREA=180    CONSTRUCTION=IGWALLCON INT-WALL-TYPE=STANDARD
              NEXT-TO=THEROOM
              ..
         GROOF1 EXTERIOR-WALL
$Res8 $       LIKE GAR1 HEIGHT=11.4 TILT=31.6
              Z=ROOFZ CONSTRUCTION=GROOFCON
              ..
```

```
$Res8 $  GROOF2 EXTERIOR-WALL
$Res8 $       LIKE GAR2 HEIGHT=11.4 WIDTH=21 TILT=31.6
$Res8 $       Y=28.5 Z=ROOFZ CONSTRUCTION=GROOFCON   ..

         GSLAB UNDERGROUND-FLOOR   $ Garage floor
              HEIGHT=10 WIDTH=GARAREA TIMES .1
              TILT=180 CONSTRUCTION=GSLABCON
              U-EFFECTIVE= .143  .. $ Ref j.huang - ashrae paper
$HrRpt-----------------------------------------------------
$HrRptLoads  Reports ----------------------------------------
$HrRpt-----------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK       $ Reports for wall temp
$HrRpt$           VARIABLE-TYPE=SWALL1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for roof temp
$HrRpt$           VARIABLE-TYPE=SROOF1
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2)
$HrRpt$           ..
         END ..

FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  0, -3336.3)(  1, -3389.2)(  2, -3462.1)(  3, -3450.6)(  4, -3494.9)
(  5, -3548.8)(  6, -3512.7)(  7, -3387.8)(  8, -3400.9)(  9, -3432.8)
( 10, -3467.4)( 11, -3408.3)( 12, -3335.8)( 13, -3164.1)( 14, -3056.2)
( 15, -3061.6)( 16, -3176.4)( 17, -3309.6)( 18, -3360.7)( 19, -3255.2)
( 20, -3035.1)( 21, -2849.8)( 22, -2809.7)( 23, -2858.6)( 24, -2872.7)
( 25, -2901.3)( 26, -2954.2)( 27, -2910.6)( 28, -2832.9)( 29, -2737.7)
( 30, -2508.2)( 31, -2379.1)( 32, -2303.7)( 33, -2479.3)( 34, -2686.4)
( 35, -2608.0)( 36, -2500.5)( 37, -2413.6)( 38, -2188.9)( 39, -2045.6)
( 40, -2134.6)( 41, -2002.3)( 42, -1946.5)( 43, -1931.6)( 44, -1942.3)
( 45, -2040.4)( 46, -1852.8)( 47, -1659.4)( 48, -1673.6)( 49, -1538.1)
( 50, -1285.3)( 51, -1176.9)( 52, -1189.2)( 53, -1122.8)( 54, -1020.4)
( 55, -1070.9)( 56, -1147.7)( 57,  -839.9)( 58,  -621.7)( 59,  -592.9)
( 60,  -577.7)( 61,  -569.9)( 62,  -507.0)( 63,  -493.0)( 64,  -494.7)
( 65,  -338.1)( 66,  -236.5)( 67,  -199.1)( 68,  -206.2)( 69,  -148.7)
( 70,   -30.5)( 71,    25.0)( 72,    81.5)( 73,    68.1)( 74,   -28.9)
( 75,   -49.4)( 76,    50.9)( 77,    73.1)( 78,    34.9)( 79,  -123.6)
( 80,  -331.5)( 81,  -320.9)( 82,  -271.8)( 83,  -264.4)( 84,  -250.2)
```

```
( 85,  -281.9)( 86,  -345.3)( 87,  -377.1)( 88,  -471.5)( 89,  -680.4)
( 90,  -661.4)( 91,  -665.3)( 92,  -717.0)( 93,  -771.9)( 94,  -825.7)
( 95,  -845.2)( 96, -1001.8)( 97, -1214.9)( 98, -1290.1)( 99, -1357.0)
(100, -1332.1)(101, -1377.6)(102, -1458.1)(103, -1635.8)(104, -1807.5)
(105, -1935.5)(106, -1957.5)(107, -2015.7)(108, -2097.4)(109, -2161.6)
(110, -2276.3)(111, -2428.2)(112, -2591.7)(113, -2814.8)(114, -2984.9)
(115, -2965.2)(116, -2985.4)(117, -2984.5)(118, -3194.8)(119, -3339.1)
(120, -3281.2)(121, -3316.4)(122, -3332.9) ..
      CALCULATE  ..
      WEEK = DOY / 3.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
C     PRINT 10, DOY, WEEK, UGWQ, UGFQ
   10 FORMAT('FNDQ',4F10.2)
      END-FUNCTION  ..
         COMPUTE LOADS ..
          POST-PROCESSOR PARTIAL ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                     (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: SMUDSYS  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date: Oct 18 1991  (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)                     (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $
          INPUT     SYSTEMS ..
                     ..
          DIAGNOSTIC    CAUTIONS ECHO ..
$Duct $   SUBR-FUNCTIONS
$Duct $          RESYS-0=*DUCT*
$Duct $          RESYS-3Z=*SAVETEMP*
$Duct $          DAYCLS-4=*DUCT2* ..
          SYSTEMS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $--------------------------------------------------------------
          PARAMETER
 $--------------------------------------------------------------
 $ CSCAP is 80% of CTCAP where no literature available
 $ Assume heat pump backup of 15000 Btu/hr is valid for all HP
 $ Default DOE2 curve for cooling equipment used.
 $ Cooling COPs from product literature for Res2,5,6,7
 $ Site1 and Site6 assumed same as Res5
 $ All other data from product literature.
 $ Cooling thermostat setpoints from investigating measured data
 $
$Res8 $   HEATSET=70    SETBACK=70     COOLSET=76   SETUP=76
$Res8 $   HPHCAP=-21400 HPBKUP=-15000  CTCAP=24000  CSCAP=19200
```

```
$Res8 $   ACCFM=800
 $
$Res8 $   VTYPE= 0              $ no venting
 $
$HP   $          HEIR=.3703     $ 2.7 COP Heat Pump
$HP   $          MAXTEMP=100
$Res8 $   CBF=.098      CEIR=.4762        $ est 2.1 COP HP
                     ..
 $---------------------------------------------------------------
 $-----  Systems Schedules  -------------------------------------
 $---------------------------------------------------------------
HTSCH     SCHEDULE  $ heat temperature schedule, 7 hour night setback
                    THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                      (7,23) (HEATSET)
                                      (24)   (SETBACK)  ..
CTSCH     SCHEDULE  $ cool temperature schedule, 7 hour day setup
                    THRU DEC 31 (ALL) (1,7)  (COOLSET)
                                      (8,15) (SETUP)
                                      (16,24)   (COOLSET)  ..
VTSCH     SCHEDULE  $Vent schedule based on previous 4 days load
                    THRU MAY 14 (ALL) (1,24) (-4)
                    THRU SEP 30 (ALL) (1,24) (-4)
                    THRU DEC 31 (ALL) (1,24) (-4) ..
VOPSCH    SCHEDULE  $Vent operation schedule
                    THRU DEC 31 (ALL) (1,24) (VTYPE) ..
WINDOPER  SCHEDULE  $No window operation between 11 p.m. and 6 a.m.
                    THRU DEC 31 (ALL) (1,6)  (0.0)
                                      (7,23) (1.0)
                                      (24)   (0.0)  ..
 $---------------------------------------------------------------
 $-----  Zones  -------------------------------------------------
 $---------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=70.
                              DESIGN-COOL-T=78.
                              COOL-TEMP-SCH=CTSCH
                              HEAT-TEMP-SCH=HTSCH
                              THERMOSTAT-TYPE=TWO-POSITION ..
THEROOM             ZONE      ZONE-CONTROL=ZC1
                              ZONE-TYPE=CONDITIONED ..
$Attic $ ATTIC      ZONE      ZONE-TYPE=UNCONDITIONED  ..
GARAGE              ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $---------------------------------------------------------------
 $-----  Systems  -----------------------------------------------
 $---------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                 MAX-SUPPLY-T=MAXTEMP
                 MIN-SUPPLY-T=50
```

```
                   ..
SYSAIR    SYSTEM-AIR
                 SUPPLY-CFM=ACCFM
                 NATURAL-VENT-SCH=VOPSCH
                 VENT-TEMP-SCH=VTSCH
                 OPEN-VENT-SCH=WINDOPER
                 HOR-VENT-FRAC=0.0
 $ assume 1/4 of total window area opened for venting,
 $ and discharge coefficient of 0.6
                 FRAC-VENT-AREA=0.018
                 VENT-METHOD=S-G
                 MAX-VENT-RATE=20
                   ..
SYSFAN    SYSTEM-FANS                 $added by jim 11/25/92
                 SUPPLY-KW=0.000333   $average of 400 W for 1200 CFM
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-CAPACITY=CTCAP
                 COOLING-EIR=CEIR         $added by jim 1/13/92
                 COOL-SH-CAP=CSCAP
                 COIL-BF=CBF
                 CRANKCASE-HEAT=0.0       $added by jim 3/5/92
                 COMPRESSOR-TYPE=SINGLE-SPEED
$HP      Heatpump specifications    $
$HP    $         HEATING-CAPACITY=HPHCAP
$HP    $         HEATING-EIR=HEIR
$HP    $         HP-SUPP-HT-CAP=HPBKUP
$HP    $         MAX-HP-SUPP-T=40.
                    ..
RESIDEN  SYSTEM  SYSTEM-TYPE=RESYS
$Slab  $       ZONE-NAMES=(THEROOM,GARAGE
$Attic $                  ,ATTIC
$Slab  $                   )
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-FANS=SYSFAN
                 SYSTEM-EQUIPMENT=SYSEQP
$HP    $         HEAT-SOURCE=HEAT-PUMP
                 ..
$HrRpt---------------------------------------------------------------
$HrRptSystem Reports ----------------------------------------------
$HrRpt---------------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK   $ Reports for temp and humidity
$HrRpt$           VARIABLE-TYPE=GLOBAL
$HrRpt$           VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for zone
$HrRpt$           VARIABLE-TYPE=THEROOM
```

```
$HrRpt$           VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3        REPORT-BLOCK       $ Reports for system
$HrRpt$           VARIABLE-TYPE=RESIDEN
$HrRpt$           VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$           THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$           REPORT-SCHEDULE=HRSCH
$HrRpt$           REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$           ..
          END ..
FUNCTION NAME = DUCT ..
 $
 $ This function multiplies the AC EIR
 $ by the duct efficiency which varies
 $ with attic temperature
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       DEFFC=-0.0077*TATT + 1.379
       COOLEIR = COOLEIR/DEFFC
       COOLCAP = COOLCAP*DEFFC
       COOLSEN = COOLSEN*DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME = DUCT2 ..
 $
 $ This function resets AC EIR to the input value
 $ old ducts in attic
 $
ASSIGN MON=IMO DAY=IDAY HR=IHR TOUT=DBT
       COOLEIR=COOLING-EIR COOLCAP=COOLING-CAPACITY
       COOLSEN=COOL-SH-CAP
       DEFFC=XXX22 TATT=XXX23 ..
       CALCULATE  ..
       COOLEIR = COOLEIR*DEFFC
       COOLCAP = COOLCAP/DEFFC
       COOLSEN = COOLSEN/DEFFC
C      PRINT 20, MON,DAY,HR,TATT,DEFFC,COOLEIR
```

```
C  20  FORMAT('DUCT  ',3F4.0,' TATT=',F4.0,' DEFFC=',
C    +        F5.3,' EIR=',F5.3)
       END
       END-FUNCTION ..
FUNCTION NAME=SAVETEMP ..
$
$ saves last hours zone temps for next hour's heat load
$ calculations
$
ASSIGN TATT=XXX23 ..
ASSIGN TNOW = TNOW  ZNAME = ZONE-NAME DBT=DBT  NZ=NZ ..
ASSIGN HUMRAT=HUMRAT ..
      CALCULATE ..
C     IF (ZNAME.EQ."THER") GO TO 100
C     IF (ZNAME.EQ."GARA") GO TO 100
C     IF (ZNAME.EQ."ATTI") GO TO 70
      IF (NZ.EQ.1) GO TO 100
      IF (NZ.EQ.2) GO TO 100
      IF (NZ.EQ.3) GO TO 70
      GO TO 100
C attic
  70    TATT=TNOW
      GO TO 100
 100  CONTINUE
      END
END-FUNCTION ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

DOE-2 INPUT FILE FOR SITE B BASE CASE

```
          POST-PROCESSOR PARTIAL  ..
 $
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*) File name: smud.inp (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)  Date:  Jun 13 1991 (*)*(*)*(*)*(*)*(*)*
 $ *(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*(*)*
 $-------------------------------------------------------------------
        INPUT  LOADS ..
$Schl $ TITLE  LINE-1  *Test   Bungalow Crawl (30-19-FM1-M-2/.3)*
$BaseC$        LINE-2  *Base Case (A1:W1=0.30,Rf= 0.34;Rfe=0.30)*
               LINE-3  *Siding HP                               *
$Schl $        LINE-4  *78F thermostat setting entire monitoring*
               LINE-5  *                                        *
      -            ..
 $-------------------------------------------------------------------
            PARAMETER
 $-------------------------------------------------------------------
WINDOWWD=12.125
CGNDL=CGNDLDP
$Medium Infiltration     $ INFILT = .0005
$1-pane Windows            NPANE = 1   GTYPE = 1   UWINDOW = 1.35
$1-pane Windows          $ NPANE = 1   GTYPE = 10  UWINDOW = 1.35
$R19 Ceiling             $ ROOFL = r19roof
$R11 Reg siding wall     $ WALLL = r11rwall
$FM1 Crawl               $ FLRL=r11flr
FSW1=30.0 FSW2=32.0 FSW3=47.0 FSW4=45.0 FSW5=90.0
T1AX=22 T1DX=8 T2AX=33 T2DX=19 T3AY=17 T3CY=3
T4AX=47 T4AY=17 T4CY=3 T4DX=33
$Sacram One  Crawl FM1   $ FDNUEFF =.0411  $ GndU=***** GndT= 0
 $ ---  end of parameters -------------------------------------------
                ..
$ASO  $ RUN-PERIOD          AUG 1 1991 THRU OCT 31 1991  ..
        DIAGNOSTIC          CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
        BUILDING-LOCATION   LAT=38.50 LON=121.50 T-Z=8  ALT=17
                            WS-HEIGHT-LIST= (50)
                            AZIMUTH=-45 SHIELDING-COEF=0.19
                            TERRAIN-PAR1=.85 TERRAIN-PAR2=.20
                            WS-TERRAIN-PAR1=.85 WS-TERRAIN-PAR2=.20
                             ..
          ABORT     WARNINGS ..
          LOADS-REPORT
$HrRpt$                 HOURLY-DATA-SAVE=YES
                        SUMMARY=(LS-E)  ..
```

```
 $----------------------------------------------------------------------
 $-----  Fixed Window Shading Schedules  -------------------------------
 $----------------------------------------------------------------------
SHADCO    SCHEDULE  THRU DEC 31 (ALL) (1,24) (0.77) ..
 $----------------------------------------------------------------------
 $-----  Tree Shading Schedule  ----------------------------------------
 $----------------------------------------------------------------------
TREETRANS5  SCHEDULE  THRU FEB 28 (ALL) (1,24) (1.00)
                      THRU OCT 31 (ALL) (1,24) (0.447)
                      THRU DEC 31 (ALL) (1,24) (1.00) ..
 $----------------------------------------------------------------------
 $-----  Class Occupancy Schedules for Lights and People --------------
 $----------------------------------------------------------------------
SCHD-1 = DAY-SCHEDULE (1,9) (0) (10,16) (1) (17,24) (0) ..
SCHD-2 = DAY-SCHEDULE (1,24) (0) ..
CLASSCH = SCHEDULE    THRU JUN 1  (WD) SCHD-1 (WEH) SCHD-2
                      THRU SEP 2 (ALL) SCHD-2
                      THRU DEC 31 (WD) SCHD-1 (WEH) SCHD-2  ..
 $----------------------------------------------------------------------
 $-----  Constructions  ------------------------------------------------
 $----------------------------------------------------------------------
WINDOWGT           GLASS-TYPE
                       PANES=NPANE
                       G-T-C=GTYPE
                       GLASS-CONDUCTANCE = UWINDOW  ..
WALLCON            CONSTRUCTION     $ Wall section
                       LAYERS=WALLL ..
WALLCON2           CONSTRUCTION     $ Wall section
$BaseC$                ABS=0.70
                       LAYERS=WALLL ..
ROOFCON            CONSTRUCTION     $ Roof section, with joist
$BaseC$                ABS=0.66
                       LAYERS=ROOFL ..
DOORCON            CONSTRUCTION     $ Solid door
                       U-VALUE=.7181 ..
FSLABCON           CONSTRUCTION     $ Floor slab in contact with soil
$Crawl dirt floor   $  LAYERS=CGNDL  ..
$Crawl space constructions ------------------------
$Crawl    $ FLRCON    CONSTRUCTION  $ Floor over unconditioned space
$Crawl    $             LAYERS=FLRL  ..
$Regcrawl $ CWALLCON  CONSTRUCTION  $ Uninsul. siding crawlspace walls
$Regcrawl $             LAYERS=r0rwall ..
 $----------------------------------------------------------------------
```

```
 $-----  Shades  --------------------------------------------------------
 $-----------------------------------------------------------------------
OVERHANGN BUILDING-SHADE      $ North overhang
                    HEIGHT=2 WIDTH=60.
                    X=45 Y=34 Z=10 AZIMUTH=0 ..
OVERHANGS BUILDING-SHADE      $ South overhang
                    LIKE OVERHANGN HEIGHT=5
                    X=-15 Y=-5 AZIMUTH=180 ..
SURROUNDE BUILDING-SHADE      $ Effect of neighboring bungalows east
                    HEIGHT=11 WIDTH=32.
                    X=31 Y=32 Z=-1.5 AZIMUTH=270 TILT=90 ..
SURROUNDW BUILDING-SHADE      $ Effect of neighboring bungalows west
                    LIKE SURROUNDE
                    X=-1.5 Y=0 AZIMUTH=90 ..
 $-----------------------------------------------------------------------
 $-----  Space  ---------------------------------------------------------
 $-----------------------------------------------------------------------
 $
ROOMCOND  SPACE-CONDITIONS
                   TEMPERATURE = (74)
                   INF-METHOD=S-G
                   FRAC-LEAK-AREA = INFILT
                   FLOOR-WEIGHT=0
                   FURNITURE-TYPE=LIGHT
                   FURN-FRACTION=0.10  $ minimal furniture assumed
                   FURN-WEIGHT=2.00     $
                   PEOPLE-SCHEDULE=CLASSCH
                   NUMBER-OF-PEOPLE=25
                   PEOPLE-HEAT-GAIN=350  $ 475*.75 for children
                   LIGHTING-SCHEDULE=CLASSCH
                   LIGHTING-W/SQFT=1.5   $ estimated
                   ..
THEROOM   SPACE
                   SPACE-CONDITIONS=ROOMCOND
                   AREA=960
                   VOLUME=9600 ..
NWALL     EXTERIOR-WALL
                   WIDTH=30  CONSTRUCTION=WALLCON
                   X=30 Y=32 HEIGHT=10.0  ..
NDOOR     DOOR     HEIGHT=6.5 WIDTH=3 CONSTRUCTION=DOORCON X=1.0 ..
NWIND1    WINDOW   GLASS-TYPE=WINDOWGT X=7.75 Y=3
                   HEIGHT=4.0 WIDTH=2.5 SHADING-SCHEDULE=SHADCO ..
NWIND2    WINDOW   LIKE NWIND1 X=20.5 ..
SWALL     EXTERIOR-WALL     LIKE NWALL X=0 Y=0 AZIMUTH=180
                   CONSTRUCTION=WALLCON2  ..
SDOOR     DOOR     LIKE NDOOR   ..
SWIND1    WINDOW   LIKE NWIND1 X=12.5 WIDTH=5.0 ..
SWIND2    WINDOW   LIKE SWIND1 X=23.5  ..
```

```
EWALL     EXTERIOR-WALL  LIKE NWALL WIDTH=32 X=30 Y=0 AZIMUTH=90 ..
WWALL     EXTERIOR-WALL  LIKE NWALL WIDTH=32 X=0 Y=32 AZIMUTH=270 ..
$Crawl $ INTERFLR   INTERIOR-WALL    $ Floor bet Theroom and Crawlspace
$Crawl $            TILT=180 CONSTRUCTION=FLRCON
$Crawl $            AREA=960. NEXT-TO=CRAWLSPACE  ..
TROOF    ROOF       X=30 Y= 32 Z=10.0 HEIGHT=32 WIDTH=30 TILT=0
                    CONSTRUCTION=ROOFCON
$LowE  $            FUNCTION=(*EMIS1*,*NONE*)
                    ..
$Crawl $  CRAWLSPACE SPACE AREA=960 VOLUME=1440
$Crawl $            INF-METHOD=S-G
$Crawl     assume 1 ft2 of vents per 150 ft2 of crawl space area,
$Crawl     effective-leakage-area = 75% of vent area
$Crawl     increase to a higher value - jh
$Crawl $            FRAC-LEAK-AREA= .007
$Crawl $            FLOOR-WEIGHT=0
$Crawl $            ZONE-TYPE=UNCONDITIONED T=(60)
$Crawl $             ..
$Crawl $ NCWALL     EXTERIOR-WALL   LIKE NWALL
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.00 Z=-1.00  ..
$Crawl $ SCWALL     EXTERIOR-WALL   LIKE SWALL
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.00 Z=-1.00  ..
$Crawl $ ECWALL     EXTERIOR-WALL   LIKE EWALL
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.00 Z=-1.00  ..
$Crawl $ WCWALL     EXTERIOR-WALL   LIKE WWALL
$Crawl $            CONSTRUCTION=CWALLCON   HEIGHT=1.50 Z=-1.00  ..
$Crawl $ FOUNDATION UNDERGROUND-FLOOR  $ Crawlspace dirt floor
$Crawl $            HEIGHT=10 WIDTH=96.
$Crawl $            TILT=180 CONSTRUCTION=FSLABCON
$Crawl $            U-EFFECTIVE=FDNUEFF
$Crawl $            FUNCTION=(*NONE*,*FNDQ*)    ..
$HrRpt-----------------------------------------------------------
$HrRptLoads  Reports -------------------------------------------
$HrRpt-----------------------------------------------------------
$HrRpt$   RB1        REPORT-BLOCK       $ Reports for wall temp
$HrRpt$            VARIABLE-TYPE=SWALL
$HrRpt$            VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   RB2        REPORT-BLOCK       $ Reports for roof temp
$HrRpt$            VARIABLE-TYPE=TROOF
$HrRpt$            VARIABLE-LIST=(6) ..
$HrRpt6=surface T
$HrRpt$   HRSCH      SCHEDULE           $ Hourly report schedule
$HrRpt$            THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR        HOURLY-REPORT
$HrRpt$            REPORT-SCHEDULE=HRSCH
$HrRpt$            REPORT-BLOCK=(RB1,RB2)
$HrRpt$            ..
```

```
        END ..

FUNCTION NAME = FNDQ
        LEVEL = UNDERGROUND-WALL  ..
ASSIGN  DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN  QTABL = TABLE
(  0,  -932.0)(  1,  -970.7)(  2, -1034.0)(  3, -1048.3)(  4, -1079.2)
(  5, -1128.2)(  6, -1121.9)(  7, -1034.6)(  8, -1024.4)(  9, -1043.8)
( 10, -1073.1)( 11, -1044.6)( 12,  -983.8)( 13,  -858.8)( 14,  -749.8)
( 15,  -730.2)( 16,  -791.0)( 17,  -905.5)( 18,  -965.5)( 19,  -915.7)
( 20,  -754.4)( 21,  -587.8)( 22,  -520.4)( 23,  -533.8)( 24,  -547.7)
( 25,  -566.3)( 26,  -604.3)( 27,  -591.0)( 28,  -532.2)( 29,  -458.6)
( 30,  -282.3)( 31,  -146.2)( 32,   -64.8)( 33,  -144.9)( 34,  -320.5)
( 35,  -307.0)( 36,  -229.4)( 37,  -157.9)( 38,    10.0)( 39,   154.5)
( 40,   132.1)( 41,   214.0)( 42,   278.9)( 43,   301.2)( 44,   307.5)
( 45,   238.6)( 46,   347.9)( 47,   519.3)( 48,   543.7)( 49,   638.7)
( 50,   851.0)( 51,   970.8)( 52,   995.7)( 53,  1045.6)( 54,  1136.0)
( 55,  1129.6)( 56,  1062.6)( 57,  1272.9)( 58,  1482.2)( 59,  1541.2)
( 60,  1570.1)( 61,  1587.3)( 62,  1635.8)( 63,  1662.3)( 64,  1667.0)
( 65,  1778.5)( 66,  1874.8)( 67,  1926.5)( 68,  1936.4)( 69,  1981.3)
( 70,  2075.1)( 71,  2137.9)( 72,  2194.4)( 73,  2204.5)( 74,  2145.8)
( 75,  2110.9)( 76,  2176.1)( 77,  2208.5)( 78,  2196.5)( 79,  2060.9)
( 80,  1889.1)( 81,  1862.0)( 82,  1892.5)( 83,  1905.9)( 84,  1919.5)
( 85,  1898.0)( 86,  1854.9)( 87,  1818.2)( 88,  1758.9)( 89,  1582.3)
( 90,  1558.8)( 91,  1553.4)( 92,  1515.6)( 93,  1466.1)( 94,  1415.4)
( 95,  1393.7)( 96,  1290.6)( 97,  1105.7)( 98,  1014.4)( 99,   937.3)
(100,   934.5)(101,   900.5)(102,   841.2)(103,   710.6)(104,   555.1)
(105,   427.5)(106,   371.4)(107,   320.3)(108,   245.0)(109,   183.5)
(110,    84.3)(111,   -40.1)(112,  -181.7)(113,  -357.3)(114,  -536.0)
(115,  -566.9)(116,  -601.4)(117,  -604.4)(118,  -745.9)(119,  -895.5)
(120,  -893.2)(121,  -918.5)(122,  -933.9) ..
     CALCULATE  ..
     WEEK = DOY / 3.0
     UGWQ = 0.0
     UGFQ = PWL(QTABL, WEEK)
C    PRINT 10, DOY, WEEK, UGWQ, UGFQ
  10 FORMAT('FNDQ',4F10.2)
     END-FUNCTION  ..
FUNCTION  NAME=EMIS1 ..
ASSIGN T1    =T
      QIREW1=QIREW          $ IR CORRECTION
      FILMU1=FILMU          $ OSA FILM CONDUCTANCE
      EMISRF=0.3            $ OUTSIDE SURFACE EMISSIVITY
      DBTR  =DBTR           $ OUTSIDE AIR TEMPERATURE
      SIGMA = 0.1714E-08 .. $ STEFAN-BOLTZMANN
CALCULATE ..
C    PRINT 100,QIREW,QIREW1,QIREW2,FILMU,FILMU1,FILMU2
     QIREW2=(EMISRF/0.9)*QIREW1
```

```
C    FILMU2=FILMU1-0.9+4.*EMISRF*SIGMA*
C   +      ((T1+460.0+DBTR)/2.0)**3
     FILMU2=FILMU1-0.9+4.*EMISRF*SIGMA*(DBTR**3)
     QIREW1=QIREW2
     FILMU1=FILMU2
C    PRINT 100,QIREW,QIREW1,QIREW2,FILMU,FILMU1,FILMU2
C 100 FORMAT(1X,6F10.3)
     END
END-FUNCTION  ..
        COMPUTE LOADS ..
         POST-PROCESSOR PARTIAL ..
         INPUT     SYSTEMS ..
                    ..
         DIAGNOSTIC    CAUTIONS ECHO ..
         SYSTEMS-REPORT
$HrRpt$          HOURLY-DATA-SAVE = YES
                 SUMMARY=(SS-A,SS-B,SS-C,SS-F,SS-H,SS-I) ..
 $-----------------------------------------------------------
         PARAMETER
 $-----------------------------------------------------------
         HEATSET=68    SETBACK=60    $ night setback
$Schl $  COOLSET1=78    SETUP1=78    $ no day setup, unoccupied per.
$Schl $  COOLSET2=78    SETUP2=78    $ no day setup, occupied per.
$HP   $          HEIR=.3703    $ 2.7 COP heat pump
$HP   $          MAXTEMP=100
  CBF=.098       CEIR=.3703    $ 2.7 COP air conditioner
HCAPF=-50000.  HPHCAP=-33000  HPBKUP=-17000
CTCAP=34600    CSCAP=27680.
 $               ACCFM=1050
                 ACCFM=1760 $ from plans
                    ..
 $-----------------------------------------------------------
 $-----  Systems Schedules  ---------------------------------
 $-----------------------------------------------------------
HTSCH    SCHEDULE  $ heat temperature schedule, 7 hour night setback
                   THRU DEC 31 (ALL) (1,6)  (SETBACK)
                                     (7,23) (HEATSET)
                                     (24)   (SETBACK)  ..
CTSCH    SCHEDULE  $ cool temperature schedule, 7 hour day setup
                   THRU JUN 1  (ALL) (1,9)   (COOLSET2)
                                     (10,16) (SETUP2)
                                     (17,24) (COOLSET2)
$Schl $            THRU AUG 19 (ALL) (1,9)   (COOLSET1)
$Schl $                              (10,16) (SETUP1)
$Schl $                              (17,24) (COOLSET1)
$Schl $            THRU AUG 23 (ALL) (1,18)  (99)
$Schl $                              (19,24) (SETUP1)
                   THRU SEP 2  (ALL) (1,9)   (COOLSET1)
```

```
                                   (10,16) (SETUP1)
                                   (17,24) (COOLSET1)
                    THRU DEC 31 (ALL) (1,9)   (COOLSET2)
                                   (10,16) (SETUP2)
                                   (17,24) (COOLSET2)  ..
FANSCH    SCHEDULE  $ fan schedule for PSZ system, only when occupied
                    THRU DEC 31 (WD)  (1,9)   (0)
                                   (10,16) (1)
                                   (17,24) (0)
                              (WEH) (1,24)  (0) ..
 $-------------------------------------------------------------
 $-----  Zones  -----------------------------------------------
 $-------------------------------------------------------------
ZC1                 ZONE-CONTROL
                              DESIGN-HEAT-T=68.
                              DESIGN-COOL-T=78.
                              COOL-TEMP-SCH=CTSCH
                              HEAT-TEMP-SCH=HTSCH
                              THERMOSTAT-TYPE=TWO-POSITION ..
ZA1                 ZONE-AIR
                              OA-CFM/PER=15 ..
THEROOM             ZONE      ZONE-CONTROL=ZC1
                              ZONE-TYPE=CONDITIONED ..
$Crawl $ CRAWLSPACE ZONE      ZONE-TYPE=UNCONDITIONED  ..
 $-------------------------------------------------------------
 $-----  Systems  ---------------------------------------------
 $-------------------------------------------------------------
SYSCONTRL SYSTEM-CONTROL
                 MAX-SUPPLY-T=MAXTEMP
                 MIN-SUPPLY-T=50
                   ..
SYSAIR    SYSTEM-AIR
                 SUPPLY-CFM=ACCFM
                   ..
SYSFAN    SYSTEM-FANS                $added by jim 11/25/92
 $               FAN-SCHEDULE=FANSCH
                 SUPPLY-KW=0.0004166  $average of 500 W for 1200 CFM
                   ..
SYSEQP    SYSTEM-EQUIPMENT
                 COOLING-CAPACITY=CTCAP
                 COOL-SH-CAP=CSCAP
                 COIL-BF=CBF
                 CRANKCASE-MAX-T=40.0     $added by jim 4/29/92
                 COMPRESSOR-TYPE=SINGLE-SPEED  $ use for RESYS
                 COOLING-EIR=CEIR
$HP      Heatpump specifications    $
$HP     $        HEATING-CAPACITY=HPHCAP
$HP     $        HEATING-EIR=HEIR
```

```
$HP    $         HP-SUPP-HT-CAP=HPBKUP
$HP    $         MAX-HP-SUPP-T=40.
                    ..
SCHLSYS  SYSTEM
                 SYSTEM-TYPE=RESYS
 $               SYSTEM-TYPE=PSZ
$Crawl $         ZONE-NAMES=(THEROOM,CRAWLSPACE)
                 SYSTEM-CONTROL=SYSCONTRL
                 SYSTEM-AIR=SYSAIR
                 SYSTEM-FANS=SYSFAN
                 SYSTEM-EQUIPMENT=SYSEQP
$HP    $         HEAT-SOURCE=HEAT-PUMP
                    ..
$HrRpt-----------------------------------------------------
$HrRptSystem Reports ---------------------------------------
$HrRpt-----------------------------------------------------
$HrRpt$   RB1       REPORT-BLOCK   $ Reports for temp and humidity
$HrRpt$          VARIABLE-TYPE=GLOBAL
$HrRpt$          VARIABLE-LIST=(7,8,10) ..
$HrRpt7=WBT 8=DBT 10=HUMRAT
$HrRpt$   RB2       REPORT-BLOCK       $ Reports for zone
$HrRpt$          VARIABLE-TYPE=THEROOM
$HrRpt$          VARIABLE-LIST=(6) ..
$HrRpt6=TNOW
$HrRpt$   RB3       REPORT-BLOCK       $ Reports for system
$HrRpt$          VARIABLE-TYPE=SCHLSYS
$HrRpt$          VARIABLE-LIST=(5,6,33,47,61) ..
$HrRpt5=QH 6=QC 33=FANKW 47=SKWQC 61=PLRC
$HrRpt$   HRSCH     SCHEDULE           $ Hourly report schedule
$HrRpt$          THRU DEC 31 (ALL) (1,24) (1)  ..
$HrRpt$   SHR       HOURLY-REPORT
$HrRpt$          REPORT-SCHEDULE=HRSCH
$HrRpt$          REPORT-BLOCK=(RB1,RB2,RB3)
$HrRpt$          ..
          END ..
          COMPUTE  SYSTEMS ..
          STOP  ..
```

ATTACHMENT B

EXPERIMENT DESIGN/PROTOCOL

Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 1

Case: This is the control station for other sites.

A. Measurements goals:

The objective in this case is to provide a control site with which the performance of the other sites may be compared. This site will undergo no changes in albedo or vegetative cover.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include solar radiation, dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature and solar radiation at the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air-conditioner will be monitored. All of these variables will be measured under a variety of weather conditions. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data from other sites will be normalized to this control station based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) intercomparison among all sites within the basecase (no modification) period, 3) intercomparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) comparisons after the sites have been returned to the basecase configurations.

Output will be presented in several interim reports and a final draft report. Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

Since this site will be the control site, the experiment schedule is simple: The site will remain in its basecase configuration throughout the duration of this project.

The building will be simulated with the DOE-2 program for confirmation and validation purposes.

Note that this house and house #8 have identical plans (mirror images of each other) except for orientation and tree cover. Site 8 has much less vegetation and higher cooling energy bills, according to the owner. A comparison of these two houses during the basecase monitoring period will give an estimate of tree effects, despite the fact that Site 1 is the control case. After trees have been added to Site 8, comparison with Site 1 will also be useful.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 1-5 will be placed on a station post at or above roof level (~3-4 m above ground) possibly on the deck's overhang (first choice), or in the large backyard, at an unobstructed location that is not affected by local turbulence (second choice). Sensors 6-8 will be placed at a representative location that is unobstructed and non-shaded during all daylight hours. Representative areas are those of large extent: abnormal or atypical spots should be avoided. Sensors 9-11 will be located on the exterior of the building adjacent to the walls/roof of the south-east and south bedrooms (sensors 9-10 will be on walls at an elevation of 1.5 m above ground, whereas sensor 11 will be on the roof at an unshaded/unobstructed location above the south bedroom). Sensors 12-13 will not be used at this location. Sensors 14-16 will be located inside at spots corresponding to those of outside sensors 9-11. Sensors 17-18 will be in both bedrooms, whereas sensor 19 will be located in the south bedroom (sensors 17-19 will be at a height of 1.5 above floor to avoid stratification effects). Finally, sensors 20-22 will be located as appropriate.

A high precision pyranometer will be used to measure the albedo of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%) and Leaf-Area-Index

---

** The basecase field-monitoring (~first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

(LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

D. Data analysis

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases and vegetation cases, and also based on their surrounding environmental conditions (neighborhoods).

syntax error file -, between lines 278 and 279 The following table gives the sampling/averaging and logging intervals :

Sensor #	1,2	3-5	6-8	9-11	14-19	20	21,22
Sampling (min)	5	2	5	5	5	1	2
Avrg/logging (min)	20	10	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature
Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation

---

† These intervals are flexible and may be changed as appropriate.

Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature
Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Air-conditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air-conditioner energy use over the conditioned floor area. A modified energy use index (EUI) will thus be obtained for comparison with other sites. If only portions of roofs will be modified, the ratio of the modified area to the total roof area (over conditioned zones) must be equal. Also, roof orientations treated with albedo modifications should be similar. Consideration to insulation level and material type should also be given.

E. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis

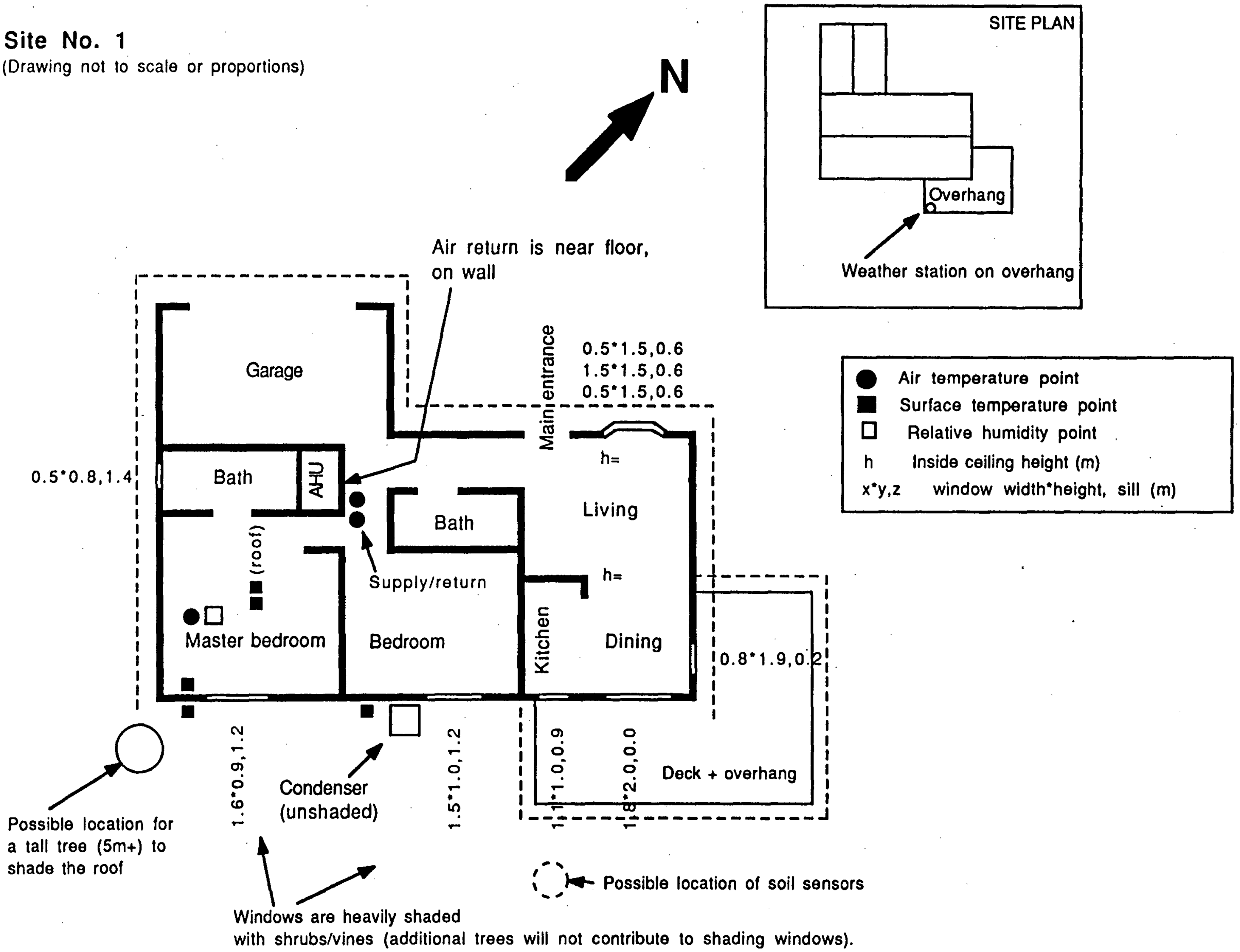
of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 1

(Drawing not to scale or proportions)



Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 2
Case: This is an albedo site.

A. Measurements goals:

The objective in this case is to determine the impact of albedo on the air conditioner's energy use.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature and solar radiation at the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air-conditioner will be monitored. All of these variables will be measured under a variety of weather conditions and before and after albedo modification. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site)

based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) intercomparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) comparisons after sites have been returned to basecase configurations.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be made.

The experiment schedule for this house is as follows:

weeks 1-2	weeks 3-8
basecase	albedo modification

Note: The albedo modification to this building will be in the form of a permanent elastomeric coating of the roof.

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and in a case with albedo modification.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 1, 2, and 4 will be placed on a station post on the roof (~3-4 m above ground). Sensors 3, and 6-8 will not be used at this location. Sensors 9-10 will be located on the exterior of the building adjacent to the walls/roof of the south-east and east bedrooms at an elevation of 1.5 m above ground. Sensor 11 will be on the roof at an unshaded/unobstructed location above the hallway near the main entrance. Sensors 12-13 will not be used at this location. Sensors 14-16 will be located inside at spots corresponding to those of outside sensors 9-11. Sensors 17-18 will be in the south-east and the east bedrooms. Sensor 19 will be located in the south-east bedroom (sensors 17-19 will be at a height of 1.5 above floor to avoid stratification effects). Finally, sensors 20-22 will be located as appropriate.

Roof albedo modification will be performed using a permanent white elastomeric coating applied to the entire roof. The outside unit (condenser) should not be shaded nor should its albedo be modified. It should be left in its original condition.

A high precision pyranometer will be used to measure the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%) and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

[**] The basecase field-monitoring (~first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

D. Data analysis

Data analysis will proceed assuming that the changes in air conditioner energy use are results of modifications in albedo. That implies all other factors to be as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases (this site) and vegetation cases, and also based on their surrounding environmental conditions (neighborhoods).

The following table gives the sampling/averaging and logging intervals: XX there is an error in this table, butI can't find it.

Sensor #	1,2	4	9-11	14-19	20	21,22
Sampling (min)	5	5	5	5	1	2
Avrg/logging (min)	20	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Outside wall1 surface temperature (°C)	Average temperature
Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation

Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature
Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air conditioner energy use over the conditioned floor area. A modified energy use index (EUI) will thus be obtained for comparison with other albedo cases. If only portions of roofs will be modified, the ratio of the modified area to the total roof area (over conditioned zones) must be equal. Also, roof orientations treated with albedo modifications should be similar. Consideration to insulation level and material type should also be given.

E. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis

of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

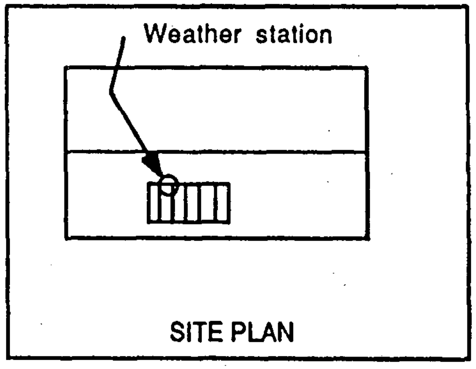
Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

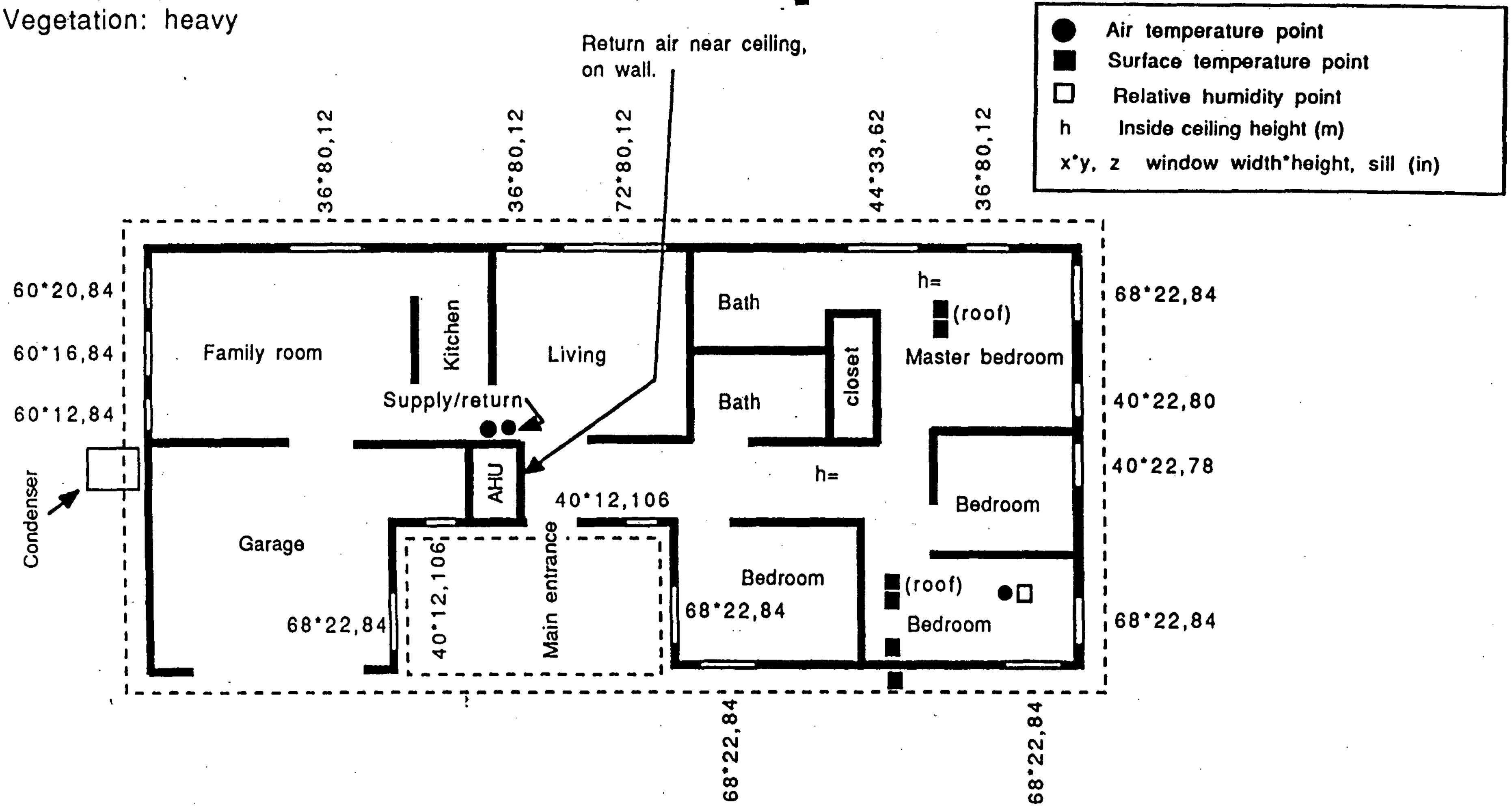
Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 2

(Drawing not to scale or proportions)

Built ~1962
No. of stories: 1
Square footage (garage excluded): 1825
Ceiling: R-11
Walls: R-6 to R-8
A/C capacity: 42,000 Btu
Vegetation: heavy





Heavily shaded windows (with trees) on east, south, and west sides

Monitoring Energy Savings from Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 5

Case: This is primarily an albedo site, although some vegetative modifications will be made during the test program.

A. Measurements goals:

The primary objective in this case is to determine the impact of albedo on the air conditioner's energy use. A secondary objective is to determine the combined impact of vegetative and albedo modifications on air conditioner energy use.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature of the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air-conditioner will be monitored. All of these variables will be measured under a variety of weather conditions and of albedo modifications, including a period of time during which albedo and vegetative modifications coexist. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site) based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) comparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) comparisons after site has been returned to basecase configuration.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

The experiment schedule for this house is as follows:

weeks 1-2	weeks 3-4	weeks 5-6	weeks 7-8
basecase	albedo modification	albedo and vegetation	base configuration

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and in a case with albedo and modification alone, followed by a simulation of concurrent albedo and vegetation modification.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 1, 2, and 4 will be placed on a station post attached to the deck's overhang in the backyard (~3-4 m above ground). Sensors 6-8 will not be used at this site. Sensors 9 and 10 will be located on the exterior of the building adjacent to the south wall of the living room and the east wall of the master bedroom (at an elevation of 1.5 m above ground). Sensor 11 will be located on the roof above the living room. Sensors 12-13 will not be used at this location. Sensors 14-16 will be located inside at spots corresponding to those of outside sensors 9-11. Sensors 17-18 will be in the living room and master bedroom. Sensor 19 will be located in the living room (sensors 17-19 will be at a height of 1.5 above floor to avoid stratification effects). Finally, sensors 20-22 will be located as appropriate.

Roof albedo modification will be performed using a white cloth fixed in place with counter-weights. The outside unit (condenser) should not be shaded nor should its albedo be modified. It should be run as it currently is.

A high precision pyranometer will be used to measure the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%)

** The basecase field-monitoring (~first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

D. Data analysis

Data analysis will proceed assuming that the changes in airconditioner energy use are results of modifications in albedo. That implies all other factors to be as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases (this site) and vegetation cases, and also based on their surrounding environmental conditions (neighborhoods).

The following table gives the sampling/averaging and logging intervals:

Sensor #	1,2	4	9-11	14-19	20	21,22
Sampling (min)	5	5	5	5	1	2
Avrg/logging (min)	20	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature

Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation
Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature
Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air conditioner energy use over the conditioned floor area. A modified energy use index (EUI) will thus be obtained for comparison with other albedo cases. If only portions of roofs will be modified, the ratio of the modified area to the total roof area (over conditioned zones) must be equal. Also, roof orientations treated with albedo modifications should be similar. Consideration to insulation level and material type should also be given.

F. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

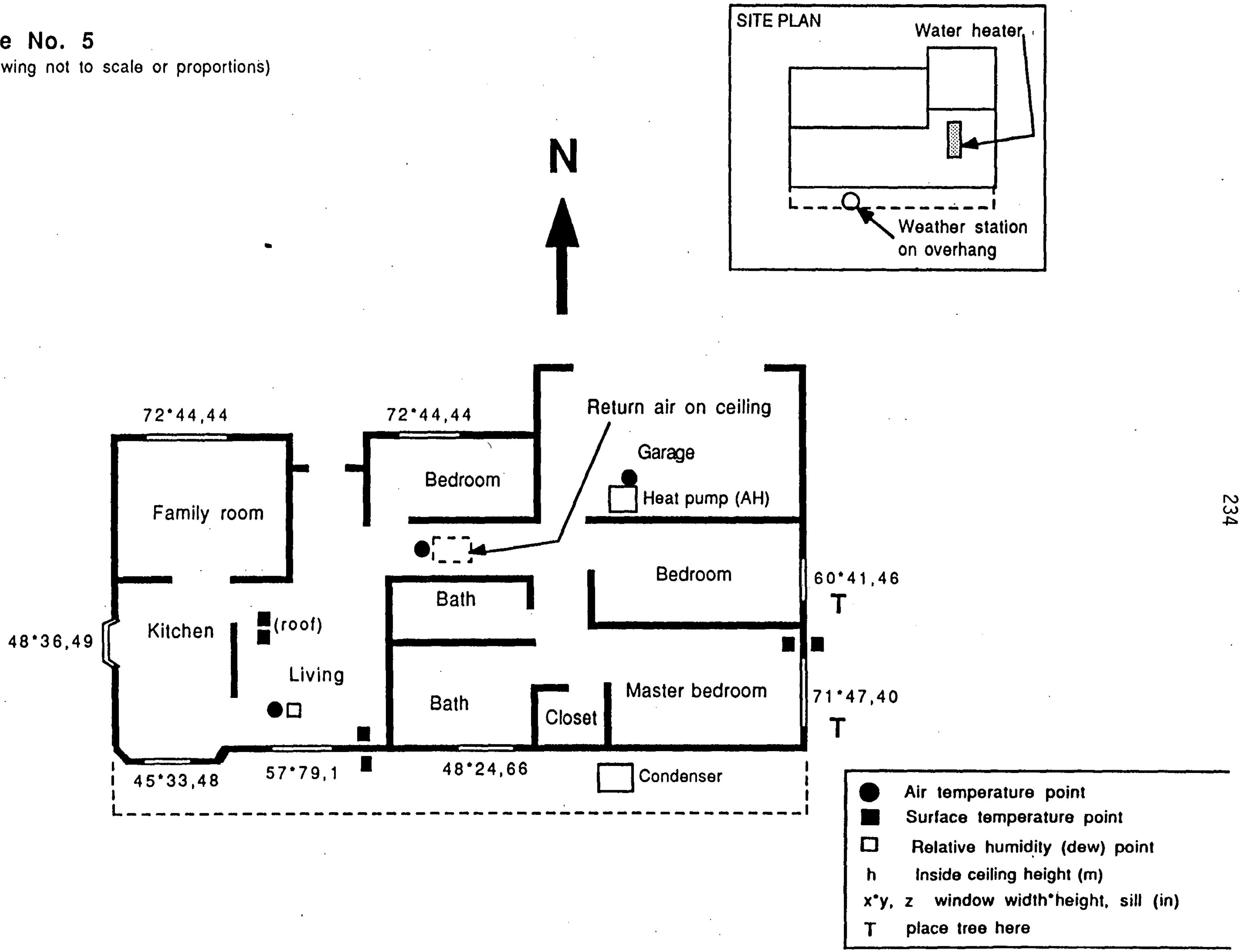
After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 5

(Drawing not to scale or proportions)



Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 6
Case: This site is a vegetation study site.

A. Measurements goals:

The objective in this case is to determine the impact of increased vegetation on the air conditioner's energy use.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include solar radiation, dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature and solar radiation at the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air-conditioner will be monitored. All of these variables will be measured under a variety of weather conditions and before and after modifications are made. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site)

based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) comparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) comparisons after site has been returned to basecase configuration.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

The experiment schedule for this house is as follows:

weeks 1-2	weeks 3-6	weeks 7-8
basecase	vegetation mod.	base configuration

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and in a case with vegetative modifications.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

** The basecase field-monitoring (first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 1,2,4, and 5 will be placed on a station post on the deck's overhang in the backyard (~3-4 m above ground)

Sensors 6-8 will be placed at a representative location that is unobstructed and non-shaded during all daylight hours. Representative areas are those of large extent: abnormal or atypical spots should be avoided. Sensors 9-10 will be located on the exterior of the building adjacent to the walls of the south and master bedrooms at an elevation of 1.5 m above ground. Sensor 11 will be on the roof above the master bedroom. Sensor 12 will be located with the sensors on the deck's overhang. Sensor 13 will be located on an exterior wall which is to be shaded by the addition of a tree. This sensor may be moved during the study so that the impacts of the shading of each tree may be evaluated. Sensors 14-16 will be located inside at spots corresponding to those of outside sensors 9-11. Sensors 17-18 will be in the living room and master bedroom. Sensor 19 will be located in the master bedroom. Sensors 17-19 will all be at a height of 1.5 above floor to avoid stratification effects. Finally, sensors 20-22 will be located as appropriate.

Vegetation modification will be accomplished by addition of shade trees. Trees will either be planted (if appropriate), or simply placed (with their containers) at several beneficial locations. For this site, one tree will be required to shade a south-facing window, one tree will be required to shade a west-facing window, and one or two trees will be needed to shade the condenser unit.

A high precision pyranometer will be used to measure the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%)

and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

D. Data analysis

Data analysis will proceed assuming that the changes in airconditioner energy use are results of modifications in albedo. That implies all other factors to be as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases and vegetation cases (this site), and also based on their surrounding environmental conditions (neighborhoods).

The following table gives the sampling/averaging and logging intervals:

Sensor #	1,2	4-5	6-8	9-13	14-19	20	21,22
Sampling (min)	5	2	5	5	5	1	2
Avrg/logging (min)	20	10	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature

Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation
Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature
Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air conditioner energy use over the conditioned floor area. Consideration to insulation level and material type should also be given.

E. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis

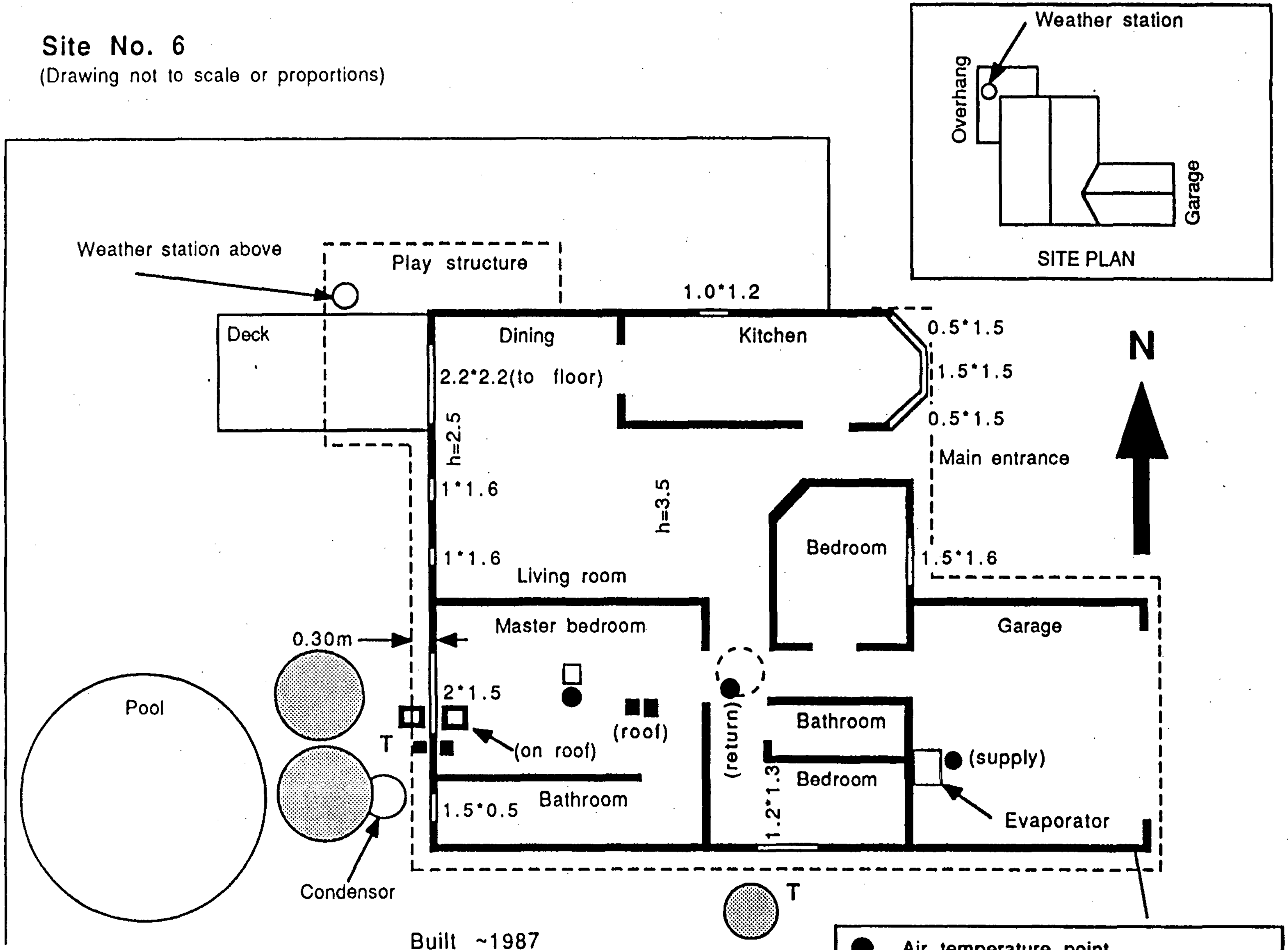
of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 6

(Drawing not to scale or proportions)



Built ~1987
No. of stories: 1
Square footage (garage excluded): 1200
Ceiling: R-30
Walls: R-11
A/C capacity: 3 tons
Vegetation: moderate-low

●	Air temperature point
■	Surface temperature point
□	Relative humidity (dew) point
h	Inside ceiling height (m)
x*y	window dimensions (m), width*height
T	place tree here
▣	Photometer

Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 7

Case: This site is a vegetation study site. Albedo will be modified if time permits.

A. Measurements goals:

The objective in this case is to determine the impact of increased vegetation on the air conditioner's energy use.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include solar radiation, dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature at the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air-conditioner will be monitored. All of these variables will be measured under a variety of weather conditions and before and after vegetation modifications are made. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site)

based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) comparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) comparisons after site has been returned to basecase configuration.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

The experiment schedule for this house is as follows:

weeks 1-2	weeks 3-6	weeks 7-8
basecase	vegetation mod. albedo mod.	

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and in a case with shading modifications.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

** The basecase field-monitoring (˜first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 1 and 2 will be placed below an overhang adjacent to the garage. Sensors 4 and 5 will be on the roof above the main entrance.

Sensor 9 will be located on the exterior of the building corresponding to the wall of the bedroom adjacent to the living room at an elevation of 1.5 m above ground. Sensor 11 will be on the roof above the same bedroom. Sensors 14 and 16 will be located inside at spots corresponding to those of outside sensors 9 and 11. Sensors 17 and 19 will also be in the bedroom adjacent to the living room. Sensors 17 and 19 will be at a height of 1.5 above floor to avoid stratification effects. Finally, sensors 20-22 will be located as appropriate.

Vegetation modification will be accomplished by addition of shade trees. Trees will either be planted (if appropriate), or simply placed (with their containers) at several beneficial locations. For this site, trees will be required to shade a south-facing windows.

A high precision pyranometer will be used to measure the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%) and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

D. Data analysis

Data analysis will proceed assuming that the changes in air conditioner energy use are results of modifications in albedo. All other factors will be assumed to be as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-

2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases and vegetation cases (this site), and also based on their surrounding environmental conditions (neighborhoods).

The following table gives the sampling/averaging and logging intervals:

Sensor #	1,2	4-5	6-8	9-13	14-19	20	21,22
Sampling (min)	5	2	5	5	5	1	2
Avrg/logging (min)	20	10	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature
Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation
Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature

Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air conditioner energy use over the conditioned floor area. Consideration to insulation level and material type should also be given.

E. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

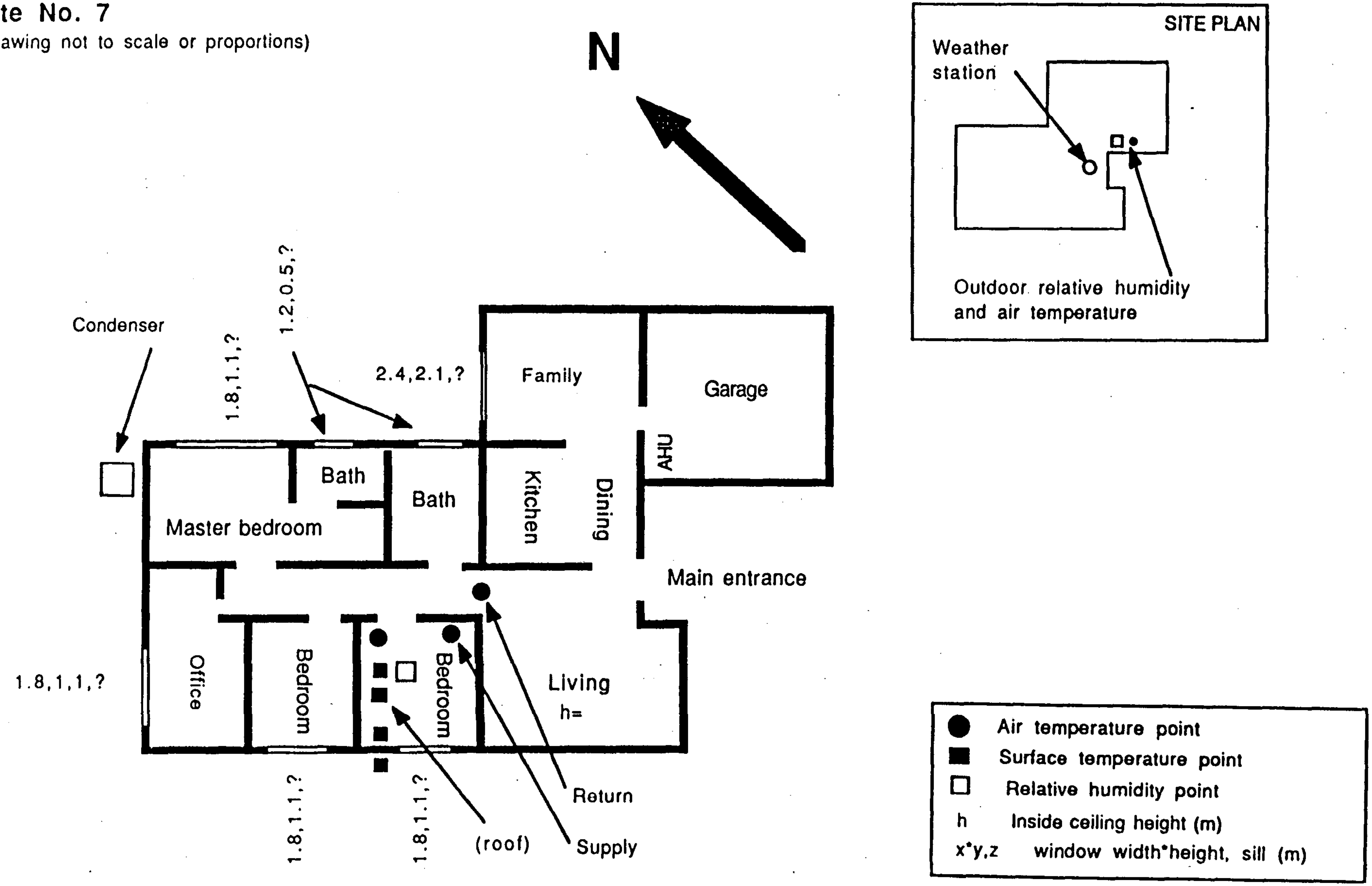
After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 7

(Drawing not to scale or proportions)



Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: Site 8

Case: This site is a vegetation study site.

A. Measurements goals:

The objective in this case is to determine the impact of increased vegetation on the air conditioner's energy use.

We plan to measure the outdoor microclimate variables in the vicinity of the building. Variables to be measured include solar radiation, dry-bulb temperature, relative humidity, wind speed, and wind direction.

We will measure the surface temperature and solar radiation at the outside walls and roof. We will also measure the inside surface temperature of the roof and walls. Additional measurements of the indoor microclimate variables including air temperature and relative humidity will be made. The energy used by the air conditioner will be monitored. All of these variables will be measured under a variety of weather conditions and before and after vegetation modifications are made. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site)

based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) comparison with concurrent data from other sites (parallel) and with prior data from same site (series) after vegetation modifications have been performed, 4) comparisons after site has been returned to basecase configuration.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

The experiment schedule for this house is as follows:

weeks 1-2	weeks 3-8
basecase	vegetation modification

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and in a case with shading modifications.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the houses have mostly similar configurations (2-3 bedrooms) and have the same kind of occupant schedules** , the main variables to factor out are:

** The basecase field-monitoring (~first two weeks) and supporting computer simulations should minimize the noise from occupancy and related factors. This will also help identify differences in baseloads if they are large.

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: Energy use of appliances will be estimated based on qualitative estimates to be provided by the occupants.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. In this site, sensors 4 and 5 will be placed at Site 1, the neighboring house to the east (~3-4 m above ground).

Sensor 9 will be located on the exterior of the building adjacent to the wall of the dining room at an elevation of 1.5 m above ground. Sensor 11 will be on the roof above the dining room. Sensors 14 and 15 will be located inside at spots corresponding to those of outside sensors 9 and 11. Sensors 18 and 19 will be in the living room. Sensors 18 and 19 will be at a height of 1.5 above floor to avoid stratification effects. Finally, sensors 20-22 will be located as appropriate.

Vegetation modification will be accomplished by addition of shade trees. Trees will be planted at several beneficial locations. For this site, trees will be required to shade south-facing windows.

A high precision pyranometer will be used to measure the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be described via cover (%) and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a hand-held infrared thermometer.

D. Data analysis

Data analysis will proceed assuming that the changes in air-conditioner energy use are results of modifications in albedo. All other factors will be assumed to be as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-

2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm. Additionally, analyses will be performed separately for albedo cases and vegetation cases (this site), and also based on their surrounding environmental conditions (neighborhoods).

The following table gives the sampling/averaging and logging intervals:

Sensor #	1,2	4-5	6-8	9-13	14-19	20	21,22
Sampling (min)	5	2	5	5	5	1	2
Avrg/logging (min)	20	10	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Total horizontal radiation
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature
Outside wall2 surface temperature (°C)	Average temperature
Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Total horizontal radiation
Wall solar radiation estimate (W/m2)	Total vertical radiation
Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature

Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index would consist of normalizing the air conditioner energy use over the conditioned floor area. Consideration to insulation level and material type should also be given.

E. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Daily diagnosis of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

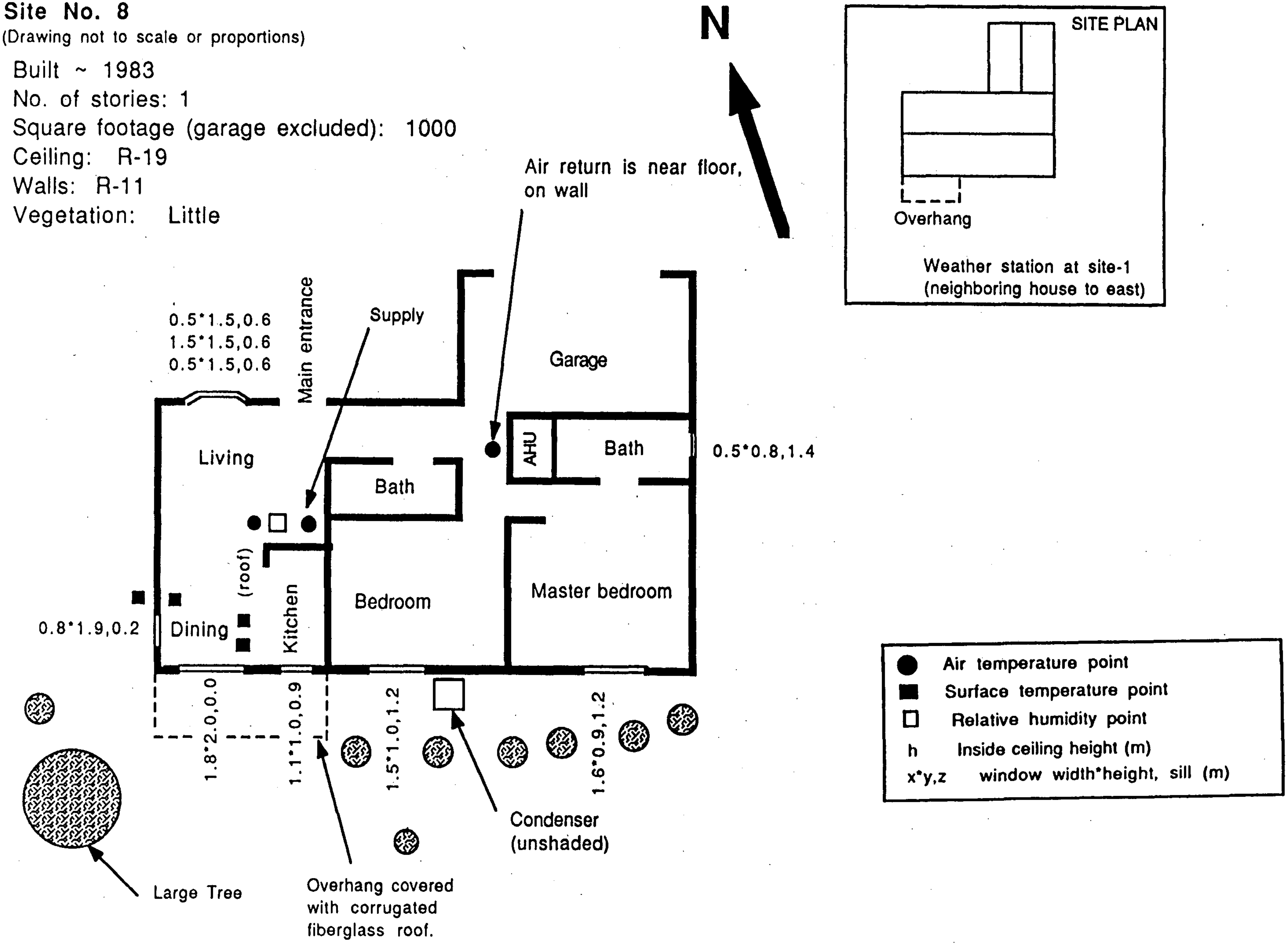
Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. At project start-up, SMUD will provide LBL with daily data (96 15-min intervals times 8 stations times 22 variables), but later into the project, data will be supplied to LBL on a weekly basis (672 15-min intervals times 8 stations times 22 variables).

Site No. 8

(Drawing not to scale or proportions)

Built ~ 1983
No. of stories: 1
Square footage (garage excluded): 1000
Ceiling: R-19
Walls: R-11
Vegetation: Little



Monitoring Energy Savings from
Vegetation and High-Albedo Surfaces
SMUD/CIEE/LBL

Experiment design/protocol

Site ID: School Bungalow

Case: Albedo. Two adjacent bungalows will be used. One will remain unchanged and act as the control case. The other will undergo two albedo modifications: from existing (moderate) to low, then from low to high.

A. Measurements goals:

The objective in this case is to determine the impact of albedo on the air conditioner's energy use.

Outdoor microclimate variables in the vicinity of the bungalows will be measured. These variables include solar radiation, dry-bulb temperature, relative humidity, wind speed, and wind direction.

Additional measurements will consist of exterior and interior surface temperatures, solar radiation, and indoor microclimate variables including air temperature and relative humidity. The energy used by the air-conditioner will also be monitored. All of these variables will be measured under a variety of weather conditions and of albedo modifications. One-time, characteristic descriptors, such as albedo of the building and surroundings, and the vegetation type and cover within the site and surroundings, will be measured before and after modifications.

B. Data product and output:

There will be two types of products. The first includes environmental characteristic data such as the albedo of the building and surroundings, the vegetation type/tree cover on site and in the building's vicinity, building materials, landscape elements, and view factor estimations. The second type of data includes the microclimate, envelope, and energy use data mentioned in **Measurement goals** above. These data will be averaged at 10 or 20 minute intervals (see **Data analysis** below). Data will be normalized to a control station (site) based on results from dynamic calibration prior to equipment installation in the field.

The data analysis stage will involve: 1) examination of data and handling of missing entries, errors, and irrelevant/outlier data, 2) comparison among all sites within the basecase (no modification) period, 3) comparison with concurrent data from other sites (parallel) and with prior data from same site (series) after albedo and/or vegetation modifications have been performed, 4) intercomparisons after site has been returned to basecase configuration.

Data analysis will be performed while collection is in progress. Refer to Table 1 (attached) for a summary of items to be reported.

C. Experimental design approach

A combination of before-after and test-reference experimental approaches will be used. Analysis and comparisons for microclimate and envelope conditions and building energy use figures will be performed. During the basecase monitoring, a test-reference comparison with other sites will be performed.

The experiment schedule for this building is as follows:

Aug. 9	Aug. 10-14	Aug. 15-16	Aug. 17-21	Aug. 22-23	Aug. 24-31
Install Equip.	monitor basecase	paint dark	monitor	paint light	monitor

Note: Due to the start of the school year, the building will be occupied starting approximately September 3. Monitoring will continue into the first several weeks of the school year to determine the impact of the albedo change. The building should remain relatively unoccupied during the weekends, allowing us to augment the data set for the unoccupied building.

The building will be simulated with the DOE-2 program for confirmation and validation purposes. It will be simulated as a basecase and as a case for each albedo modification.

In order to be able to compare buildings in terms of their response to certain modifications in albedo and/or vegetation, it is necessary to make sure that their operating conditions are as similar to each other as possible. Since the two adjacent bungalows have similar configurations** the main variables to factor out are:

Window operation: Windows should be closed at all times.
Air conditioner operation: Thermostat setting should be the same in all cases.
Lights: Lights should be turned on/off in a consistent, similar, and predictable fashion.
Appliances: There will be no additional appliances in operation.

The attached floor plan shows the locations of sensors and the inventory for this particular site. Also refer to Table 1. At this site, sensors 1-5 will be placed either on the roof or on the roof of an adjacent bungalow. Sensors 6-8 will be placed at a representative location that is unobstructed and non-shaded during all daylight hours. Representative areas are those of large extent: abnormal or atypical spots should be avoided. Sensors 9-11 will be located on the exterior of the building adjacent to the walls/roof (sensors 9-10 will be on walls at an elevation of 1.5 m above ground, whereas sensor 11 will be on the roof at an unshaded/unobstructed location). Sensors 12-13 will not be used at this location. Sensors 14-16 will be located inside at spots corresponding to those of outside sensors 9-11. Sensors 17-19 will be located inside the building at appropriate locations 1.5 m above the floor. Finally, sensors 20-22 will be located as appropriate.

Roof albedo modification will be performed in two phases. First, the original metallic roof will be painted dark brown or grey. After a sufficient monitoring period (see table) the roof will be painted with a light color paint. If possible, we will extend our albedo modification to include painting the south-east wall and possibly the north-west wall. The outside unit (condenser) should not be shaded nor should its albedo be modified. It should remain in its original condition.

A high precision pyranometer will be used to perform measurements of the current and modified albedos of the roof, walls, and surroundings of the building. Limited albedo measurements in the neighborhood will also be performed. Measurements will be performed under clear sky conditions. Vegetation type will be identified and density will be

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** The basecase field-monitoring (~first five days) and supporting computer simulations should minimize the noise from miscellaneous factors. This will also help identify differences in baseloads if they are large.

described via cover (%) and Leaf-Area-Index (LAI) at the building site and in the neighborhood. Limited surface temperatures of the surroundings will also be taken with a handheld infrared thermometer.

D. Data analysis

Data analysis will proceed assuming that the changes in air conditioner energy use are results of modifications in albedo. We will assume that all other factors are as close to constant as possible. Factors that cannot be held constant must be varied in a predictable manner (see **Experimental design approach** above). In addition, we will use the DOE-2.1D program to investigate the effects of variations in such parameters on air conditioner energy use.

The data will be grouped into several sub-categories, i.e., daytime, nighttime, clear, overcast, windy, and calm.

The following table gives the sampling/averaging and logging intervals:

Sensor #	1,2	3-5	6-8	9-11	14-19	20	21,22
Sampling (min)	5	2	5	5	5	1	2
Avrg/logging (min)	20	10	20	20	20	10	10

At each recording period, the stored value for each of these variable is as follows:

Outdoor air temp (°C)	Average temperature
Outdoor relative humidity (%)	Average humidity
Solar radiation (W/m2)	Average horizontal flux
Wind speed (m/s)	Average speed
Wind direction (°)	Average direction
Ground surface temperature (°C)	Average temperature
Subsoil surface temperature (°C)	Average temperature
Subsoil moisture content (%)	Average concentration
Outside wall1 surface temperature (°C)	Average temperature
Outside wall2 surface temperature (°C)	Average temperature

Outside roof surface temperature (°C)	Average temperature
Roof solar radiation estimate (W/m2)	Average horizontal flux
Wall solar radiation estimate (W/m2)	Average vertical flux
Inside roof surface temperature (°C)	Average temperature
Inside wall1 surface temperature (°C)	Average temperature
Inside wall2 surface temperature (°C)	Average temperature
Inside room1 air temperature (°C)	Average temperature
Inside room2 air temperature (°C)	Average temperature
Inside room2 relative humidity (%)	Average humidity
Airconditioner energy use (kWh)	Total consumption
Supply air temperature (°C)	Average temperature
Return air temperature (°C)	Average temperature

In order to be able to compare the performance of buildings, a simple index will be developed for normalizing the air-conditioner energy use over the conditioned floor area. A modified energy use index (EUI) will thus be obtained for comparison with other albedo cases. If only portions of roofs will be modified, the ratio of the modified area to the total roof area (over conditioned zones) must be equal. Also, roof orientations treated with albedo modifications should be similar. Consideration will be given to insulation level and material type.

E. Building and site characteristics:

Description:	Attached Bungalow 1 room.
Square footage:	960 ft^2.
No. of stories:	1.
Roof:	Corrugated metal roof.
Walls:	Plywood siding.
Roof insulation:	R-19
Wall insulation:	R-11
Windows:	Double pane.
Foundation:	Crawl space.
Occupants:	0 in summer.
Weekday schedule:	Not occupied over summer.

Weekend schedule:	Not occupied.
Airconditioner:	Heat Pump, Capacity: 34600 BTUH
Heater:	33000 BTUH.
Typical thermostat setting:	Cooling 78 °F.

F. Data accuracy, quality control/verification, and format.

The precision of data products will be determined based on the precision of the data acquisition system and the relationship between the variables being measured due to variations induced by weather, occupant behavior, operational variations, and measurement periods. The potential bias in the final products will be estimated assuming that the uncertainties in the measured parameters are small compared to the mean parameter values. Once a specific data reduction procedure has been established, there will be many techniques available to incorporate uncertainties into the final data product.

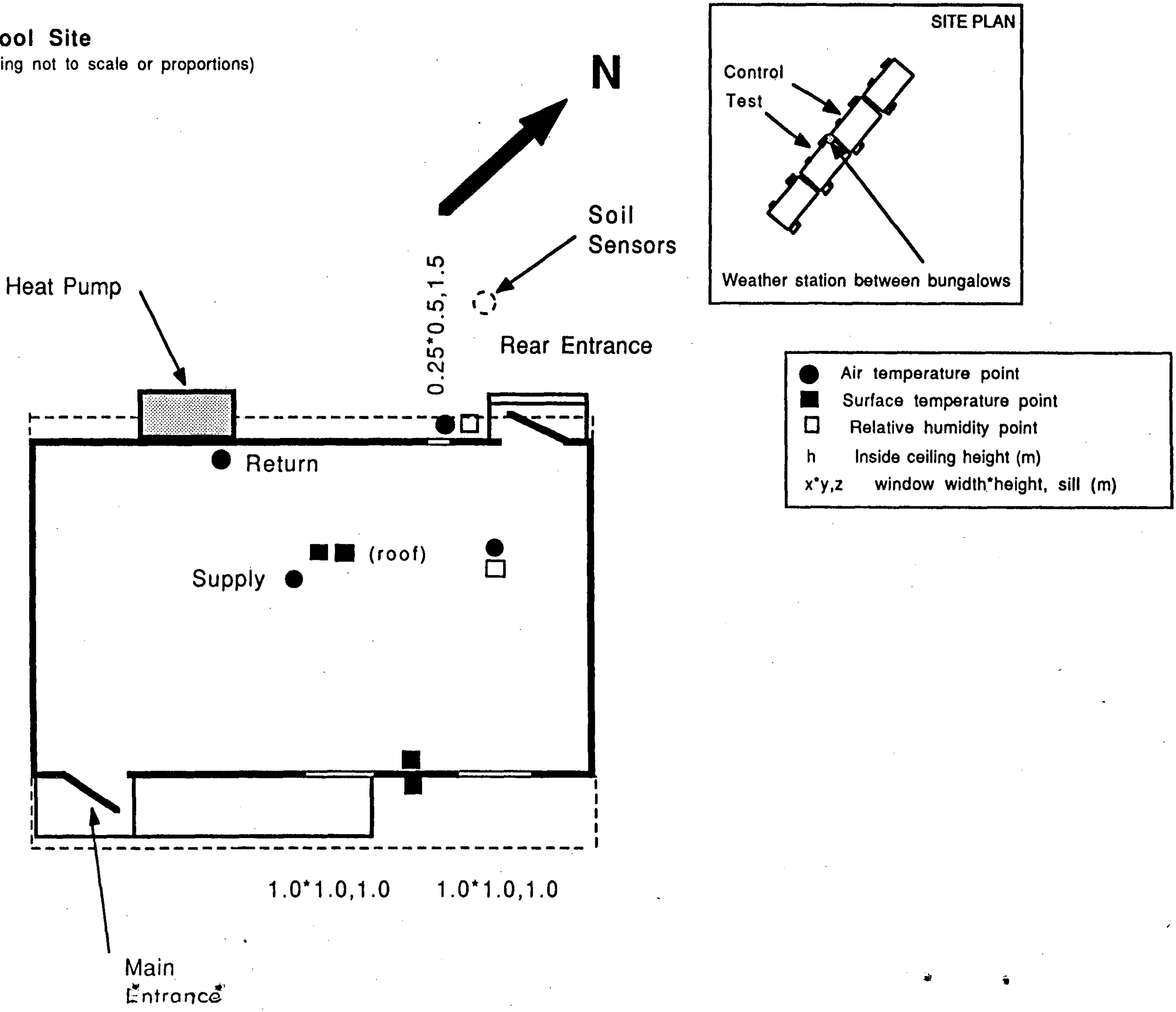
After initial static calibration, all sensors/equipment will be dynamically calibrated in one location for about one week to establish calibration curves and assign a control station for later normalization of data. After dynamic calibration, matched sets of sensors/equipment will be kept together and transported to the field. The data flow path (from sensor to logger to modem) will be continuously checked for equipment failure and unexpected modifications. Downloaded data, at the other end of the phone line, will be analyzed in progress to identify potential errors in transmission or sensors operation. Frequent diagnosis of data at all stages (start-up, ongoing, periodic, and final) will be performed to screen for these potential errors so that immediate action can be taken to correct them.

Data will also be compared to simulation results to get an order of magnitude for expected output and identify severe deviations therefrom. Finally, post calibration at the end of the data collection period will be performed to ensure that no major drift has occurred.

Data will be downloaded via modems to SMUD. This raw data will then be transferred to LBL on floppy disks in comma-separated ASCII or spreadsheet formats (other separators are also acceptable). Macintosh- readable disks can also be used. SMUD will provide LBL with a copy of the downloaded data on a weekly basis.

School Site

(Drawing not to scale or proportions)



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