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Comparison of DOE-2 with Measurements in the Pala Test Houses

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Final Report for the
Alternatives to Compressor Cooling
in California Transition Zones
Project

Submitted to
California Institute for Energy Efficiency
Berkeley CA 94720

by

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Comparison of DOE-2 with Measurements in the Pala Test Houses

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Abstract

The predictions of the DOE-2 program for building energy analysis have been compared with measurements in the Pala test houses near San Diego. This work is part of the California Institute for Energy Efficiency “Alternatives to Compressor Cooling in California Transition Zones” project in which DOE-2 is being used for parametric analysis of cooling strategies that reduce peak electrical power in hot, dry climates. To establish the validity of DOE-2 for this kind of analysis the program was compared with room air temperature measurements in a “low-mass” house with conventional insulated stud wall construction and a “high-mass” house with insulated concrete walls. To test different aspects of the DOE-2 calculation, four different unconditioned thermal configurations of these houses were considered: unshaded windows, shaded windows, white exterior surfaces, and forced night ventilation. In all cases DOE-2 agreed well with the air temperature measurements, with a mean deviation between simulation and measurement ranging from 0.2 to 1.0 K depending on configuration and type of house. Using a development version of DOE-2 comparisons with inside surface temperature measurements were also made. These comparisons also showed good agreement.

1. Introduction

In the California Institute for Energy Efficiency "Alternatives to Compressor Cooling" project cooling strategies are being investigated that avoid the large and sporadic electrical peaks associated with compressor-based air conditioning of houses in California transition climates. As part of this project thermal measurements on test houses at the Pala site near San Diego were made by the UCLA Energy Laboratory (Givoni and Labib, 1995). We report here on a comparison between these measurements and the predictions of version 2.1E of the DOE-2 computer program for building energy analysis (Winkelmann et al., 1993). The goal of the comparison was to establish the accuracy of DOE-2 for thermal analysis of the types of residential structures that are being investigated in this project.

In Section 2 we describe the buildings that were measured. Section 3 gives an overview of the Pala climate. The DOE-2 input is discussed in Section 4. In Section 5 we describe some of the analyses that were performed to determine the sensitivity of the buildings to a number of key parameters such as cloud cover, ground surface temperature, and infiltration rate. In Section 6 we show and discuss comparisons between DOE-2 and room air and surface temperature measurements for different configurations of the low-mass and high-mass test houses, including window shading, light-colored exterior surfaces, and night ventilation. Finally, we give our conclusions in Section 7.

2. Building Description

The Pala site, located 75 km north of San Diego, has eight test buildings that were originally built in 1981 to study passive solar heating strategies. **Figure 1** shows the layout of the buildings.

Three of the buildings were measured for the Alternatives to Compressor Cooling project:

(1) a house with conventional stud wall construction, called here the "low-mass house."

(2) a house of the same geometry, but with 4-inch thick concrete walls with exterior insulation, called here the "high-mass house."

(3) a medium-mass house with a clerestory.

In the following we consider only the first two of these, the low-mass and high-mass houses, which are identical except for the construction of the exterior and interior walls. Each house has two rooms and an attic. **Figure 2** shows a perspective drawing with the roof removed. **Figure 3** shows sections and **Figure 4** shows the floor plan.

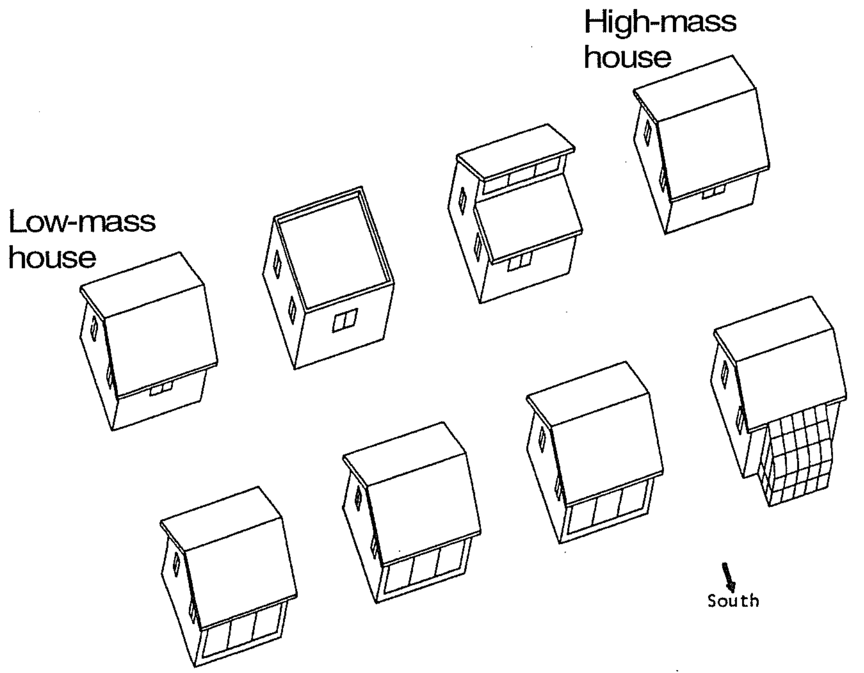


Figure 1. Layout of the test houses on the Pala site (from Clinton, 1983).

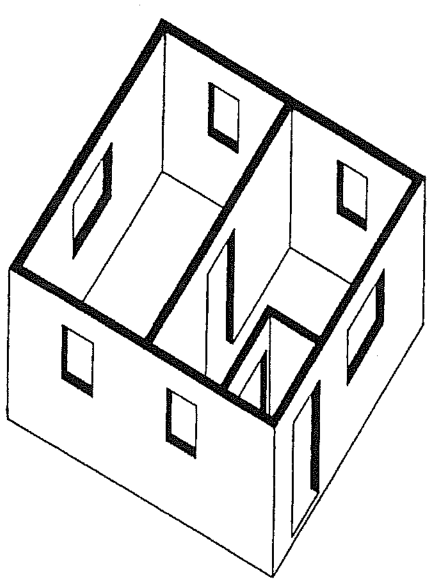


Figure 2. Perspective drawing of house with attic removed (from Clinton, 1983).

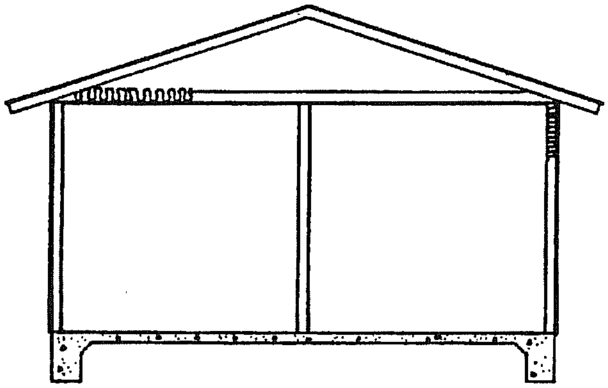


Figure 3. Section through low-mass building (from Clinton, 1983).

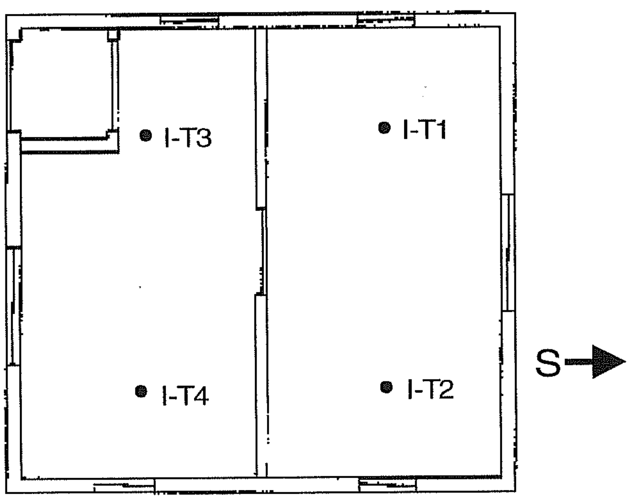


Figure 4. Floor plan showing location of inside air temperature sensors. The doorway between the rooms was open during the measurements.

Figure 4 also shows the locations of the inside air temperature measurement points. There are two measurement points in each room located midway between floor and ceiling. The following temperatures were also measured for each room: globe temperature, inside surface temperature of the three exterior walls, inside surface temperature of the ceiling, and the surface temperature of both sides of the interior wall.

Each house is roughly square with a floor area of 27 m^2. The interior wall separating the two rooms has an open doorway. Above these rooms is a vented attic with a roof that extends 0.46 m beyond the walls on all sides.The floor is a carpetted, 10-cm thick concrete slab on grade. The windows are single glazed with aluminum frame, have a total glazed area of about 2.8 m^2, and are equally distributed in area among the four exterior walls.

The low-mass house has stud-wall construction. The exterior walls consist of stucco, building paper, R-11 (1.94 m^2K/W) fiberglass insulation and interior gypsum drywall. The ceiling is gypsum drywall and studs, with R-19 (3.35 m^2K/W) fiberglass insulation on the attic side. The interior wall between the rooms is an uninsulated stud wall with gypsum drywall sheathing.

The high-mass house has 10-cm thick solid concrete walls with exterior rigid foam insulation and stucco that, according to Clinton (1983), yields the same overall U-value as the walls of the low-mass house. The interior wall between the two rooms is also 10-cm thick concrete.

Table 1 summarizes the geometrical data, which is based on on-site measurements of the as-built houses. Table 2 gives surface properties, U-values, and glazing characterisitics, which unless indicated otherwise, are the same for both houses. Table 3 gives the thermophysical properties of the construction materials. With the exception of the surface absorptances, the thermal properties of the materials that were used in the simulations were not measured but are based on data from the DOE-2 library for materials that Clinton (1983) indicates were used in the Pala houses.

Table 1: Room geometrical data

Volume [m^3]	33.11
Floor area [m^2]	13.58
Exterior wall area[a] [m^2]	25.41
Interior wall area[b] [m^2]	10.22
Ceiling area [m^2]	13.58
Glazed area [m^2]	1.40
Window/wall ratio	5.5%
Window/floor ratio	10.3%

a. Including windows
b. Excluding doorway

Table 2: U-values and other building properties

U-value of exterior walls, high-mass house [W/m^2K] [a]	0.56
U-value of exterior walls, low-mass house insulated portion [W/m^2K] [a]	0.41

U-value of exterior walls, low-mass house framed portion [W/m^{2}K] [a]	0.87
Solar absorptance, original exterior walls [b]	0.60
Solar absorptance, white-painted exterior walls [b]	0.36
Solar absorptance, original roof [b]	0.88
Solar absorptance, white-painted roof [b]	0.40
U-value of the floor [W/m^{2}K] [a]	1.09
U-value of the ceiling [W/m^{2}K] [a]	0.26
U-value of interior wall, high-mass house [W/m^{2}K] [a]	3.15
U-value of interior wall, low-mass house unframed portion [W/m^{2}K] [a]	1.80
U-value of interior wall, low-mass house framed portion [W/m^{2}K] [a]	0.86
Glass solar transmittance at normal incidence [W/m^{2}K] [a]	0.84
Leakage area [m^2] [b]	0.0068

a. From Clinton (1983)
b. From on-site measurements

Table 3: Thermophysical properties of materials

DOE-2 code	Description	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	Specific heat [J/kg-K]
CC03	Heavy weight concrete (4 in)	0.1016	1.31	2243	837
GP01	Plaster board (0.5 in)	0.0127	0.16	801	837
IN02	R-11 fiberglass	0.0901	0.043	10	837
IN03	R-19 fiberglass	0.1557	0.043	10	837
IN44	Expanded polyurethane (1.25 in)	0.0318	0.023	24	1590
PW04	Plywood (5/8 in)	0.0159	0.115	545	1213
SC01	Stucco (1.0 in)	0.0254	0.721	2659	837
WD04	Wood (3.5 in)	0.0889	0.115	513	1381

3. Climatic Data

The Pala facility is located 33 km from the coast in northern San Diego County. Winters and summers have generally clear skies and high solar radiation. Summer daytime highs are typically in the 25-35C range and nightime lows are in the 15-20C range, so that there is a large day-night temperature swing. Winds generally come from the west and are highest in the afternoon as sea breezes blow inland.

An on-site weather station measured ambient drybulb temperature, relative humidity, wind speed, wind direction, and global (direct plus diffuse) horizontal solar radiation. These measurements were averaged or integrated to obtain hourly values, then put through the DOE-2 weather processor to produce a weather file for use in the DOE-2 simulations. Using the model of Erbs, Klein and Duffy (1982) hourly horizontal diffuse solar radiation was calculated from the global horizontal solar radiation, extraterrestrial solar radiation, and sun position and added to the weather file. **Figures 5 and 6** show typical distributions of the resulting temperature, wind speed and solar data for periods in July and September.

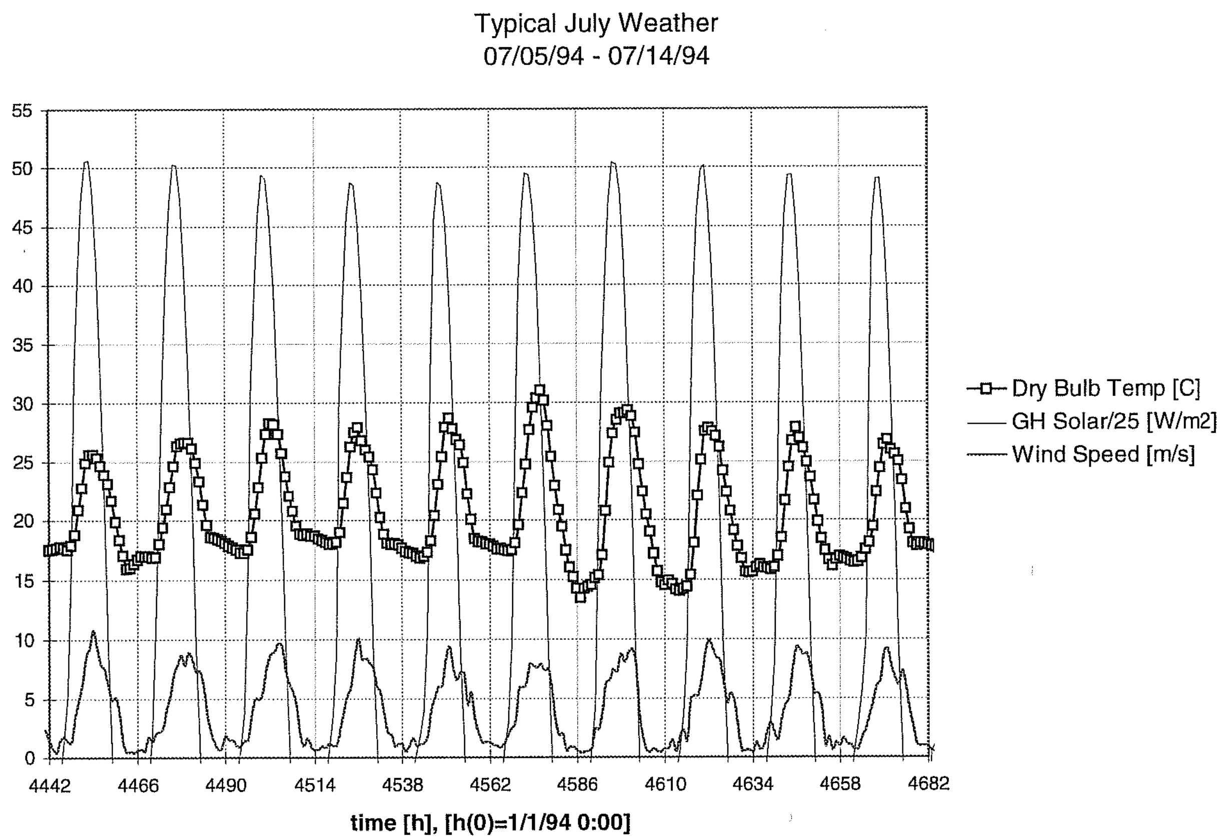


Figure 5: Typical Pala weather in July

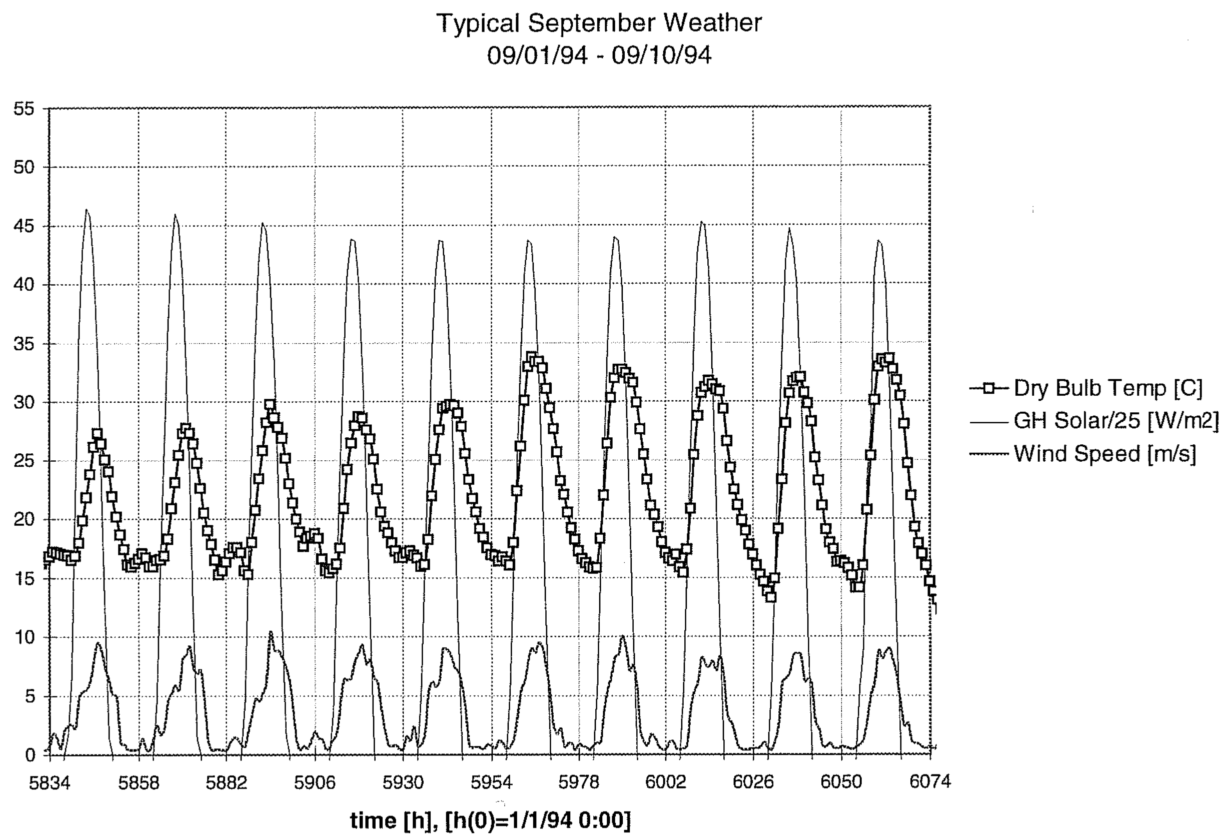


Figure 6: Typical Pala weather in September

Hourly atmospheric pressure, which is required by DOE-2 for the infiltration calculation but was not measured on site, was obtained from the weather file for El Toro, the nearest National Weather Service location. Initially, cloud cover, which is required for calculating long-wave radiation from the sky, was also obtained from El Toro but, as discussed in Section 5.7, the El Toro cloud cover was found not to be applicable to Pala and so a method was devised to estimate cloud cover from on-site pyranometer measurements.

4. DOE-2 Modeling of the Houses

The complete DOE-2 input for the baseline low-mass house configuration is given in Appendix A. The input for the high mass house is the same with two exceptions: (1) concrete rather than stud-wall construction is used for the exterior walls and interior wall of the high-mass house; and (2) the location of the shading surface that accounts for the shading by neighboring houses is different. In this section we describe some particular considerations involved in setting up the input models.

Each house was divided into three thermal zones corresponding to the two rooms and the attic. This allows separate air temperatures to be calculated for each zone.

The walls of the low-mass house were modeled with two different constructions, one representing the framed area and another representing the insulated area. Based on construction pictures before sheathing we estimated that the framed area is 20% of the total area. The same ratio was used for the gable ends, the ceiling, and the roof.

To approximate the heat exchange due to air flow between the rooms the open doorway was modeled as a massless "air wall" with a high U-value of 11.3 W/ m^2K. The heat transfer across the doorway is modeled as $UA\Delta T$, where A is the doorway area and ΔT is the temperature difference between the rooms. This is the same type of equation used by DOE-2 to calculate the heat transfer across the solid portion of the interior wall.

It was judged that the low-mass house is significantly shaded only by the building on its eastern side (see Figure 1). Similarly, the high-mass building is significantly shaded only by the building on its western side. Consequently, shading surfaces at the location of these buildings have been input. The shading by other buildings on the site and by the surrounding low-lying hills was considered to be negligible.

The heat gain from data logging equipment in the houses was estimated to be only a few watts and has, therefore, been neglected.

5. Exploratory Sensitivity Analyses

In the initial phase of this work a number of significant discrepancies were observed between the DOE-2 predictions and the measurements of inside air temperature. To help resolve these discrepancies we performed analyses with DOE-2 in which key input parameters were varied to determine the sensitivity of the results to those parameters. The outcome of this effort was to obtain more accurate measurements of some parameters, to improve the DOE-2 input description, or to improve the DOE-2 calculation. In the following we describe the key sensitivity analyses that were carried out. A description of the calculation procedures currently used in DOE-2 is given in BESG (1981) and Winkelmann et al. (1993).

5.1 Infiltration rate

Infiltration air flow rate was not continuously monitored as part of the regular measurement protocol. However, potentially high afternoon wind speeds and large inside-outside temperature differences can lead to high infiltration loads. It was decided to make a one-time measurement of the infiltration rate using a blower door, which determines the effective leakage area. This leakage area is then used in DOE-2 to calculate infiltration air flow as a function of wind speed. **Figure 7** illustrates the sensitivity to infiltration rate. Shown are the inside air temperatures for the high-mass house for loose construction (0.87 ACH at 10 mph), for tight construction (0.04 ACH at

10 mph), and for the measured air change rate (0.43 ACH at 10 mph). We see that the tight house is about 1.5C hotter than the loose house.

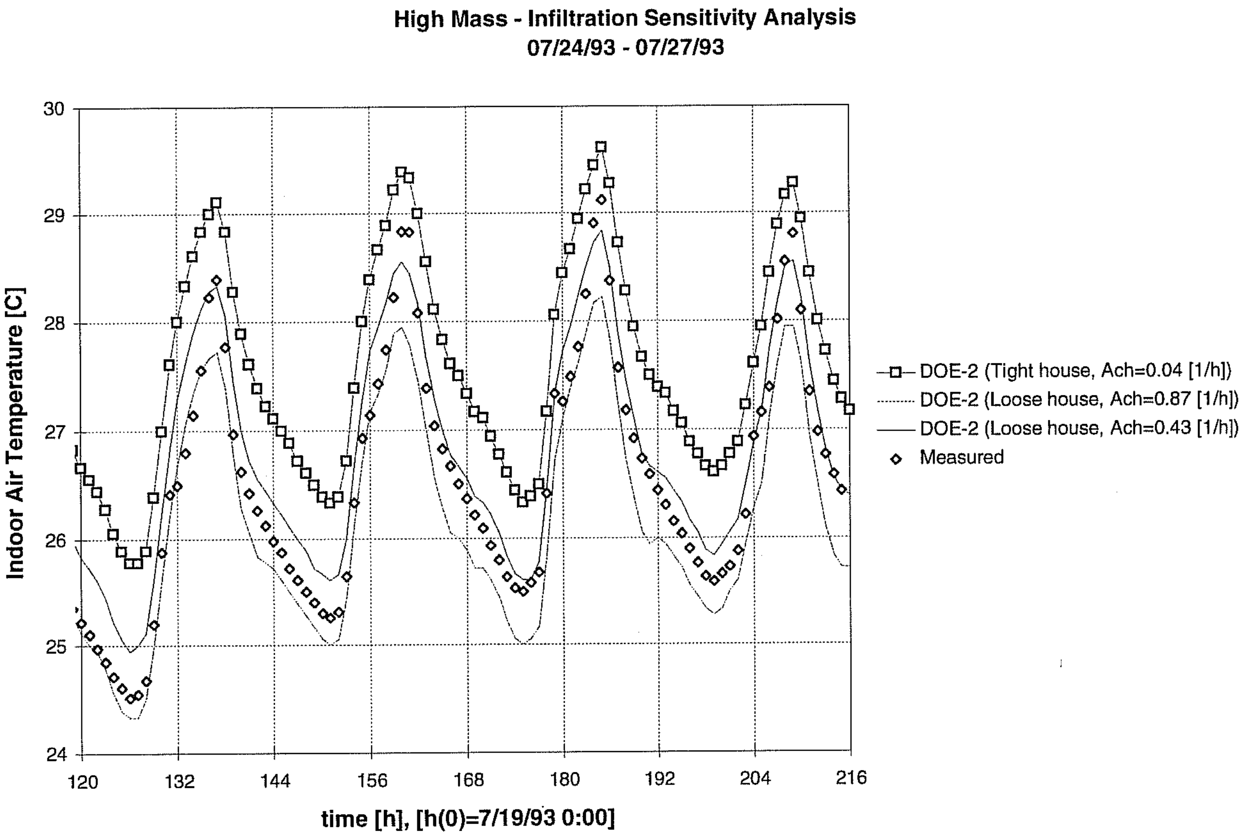


Figure 7: Sensitivity of the inside air temperature of the high mass house to infiltration rate

5.2 Ground surface absorptance

Ground surfaces are typically dark so that solar radiation reflected from the ground is usually not an important heat source. However, the ground at Pala is bare, light-colored gravel with potentially high reflectance. Initial DOE-2 runs using a default ground absorptance of 0.8 showed lower inside air temperatures than measured. We decided to measure the ground absorptance by taking the ratio of readings from a pyranometer facing the ground vs. facing the sky. We obtained an absorptance of 0.55. For the high-mass building with unshaded windows **Figure 8** shows the sensitivity of inside air temperature to ground absorptance for absorptance values of 0, 0.55 (measured) and 1.0. We see a temperature variation of about 1.5C over this range.

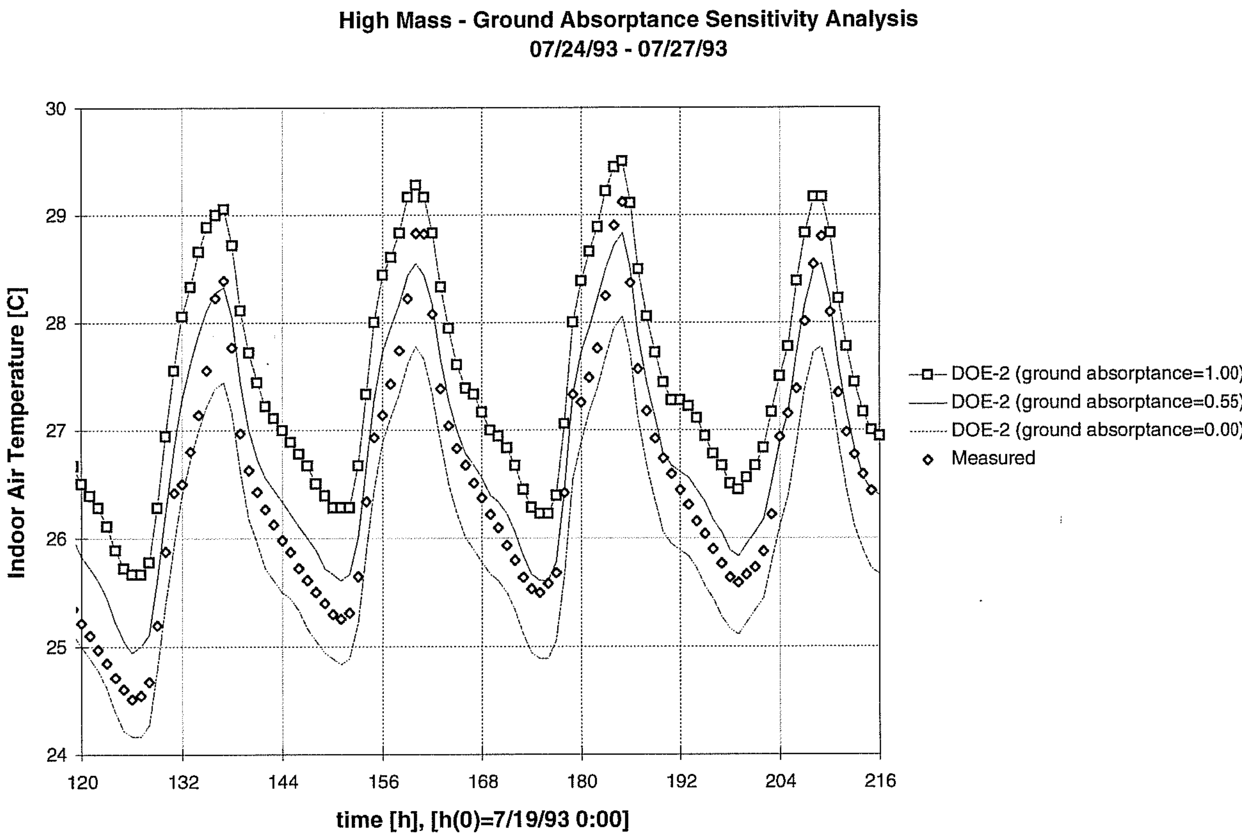


Figure 8: Sensitivity of the inside air temperature of the high mass house to ground absorptance

5.3 Ground surface temperature

To calculate the long-wave radiation from the ground DOE-2 normally assumes that the ground surface temperature is the same as the outside air temperature. But because the ground at Pala is bare and the incident solar is high, especially in the cooling season, the surface temperature can be much higher than the air temperature, which would cause DOE-2 to seriously underpredict the long-wave flux from the ground and, therefore, to underpredict the inside air temperature. Indeed, initial comparisons with measurements showed DOE-2 about 1C too low during the day and about 0.5C too low at night. To resolve this discrepancy we added an approximate ground surface temperature calculation to DOE-2 in which the ground is modeled as a 1-m thick horizontal dirt "roof" with the measured ground surface absorptance of 0.55, with an "inside air temperature" equal to the (calculated) deep ground temperature, and with measured outside air temperature and solar radiation. **Figure 9** compares results given by the default ground surface temperature model vs. the improved, "hot ground," model.

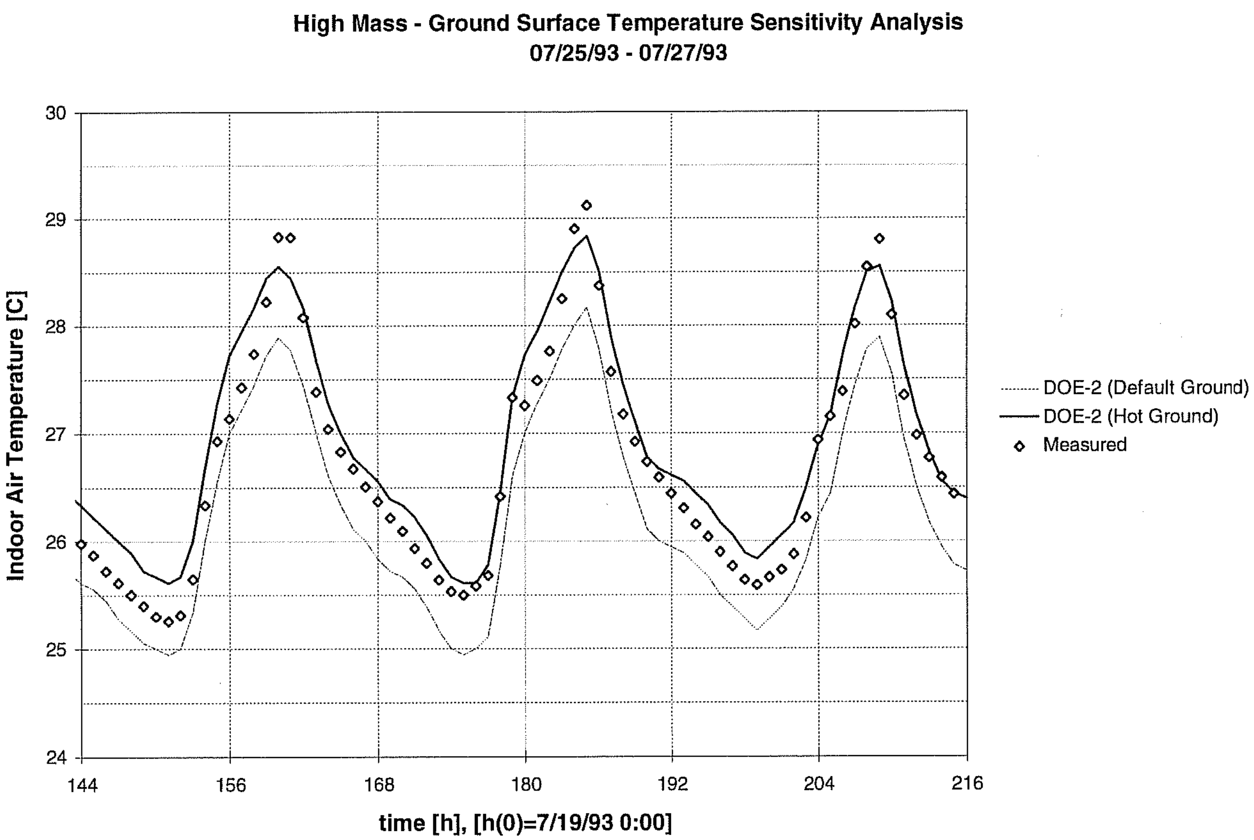


Figure 9. Sensitivity of high-mass house to ground surface temperature.

A target house can also absorb long-wave radiation from neighboring buildings and so it is necessary to know their surface temperatures. To avoid explicit modeling of each neighboring house we assume that their surface temperatures are close to the calculated ground surface temperature. That this is a fair assumption is illustrated in **Figure 10**, which compares the ground surface temperature to the surface temperatures of the high-mass house, which are expected to be close to those of the neighboring houses.

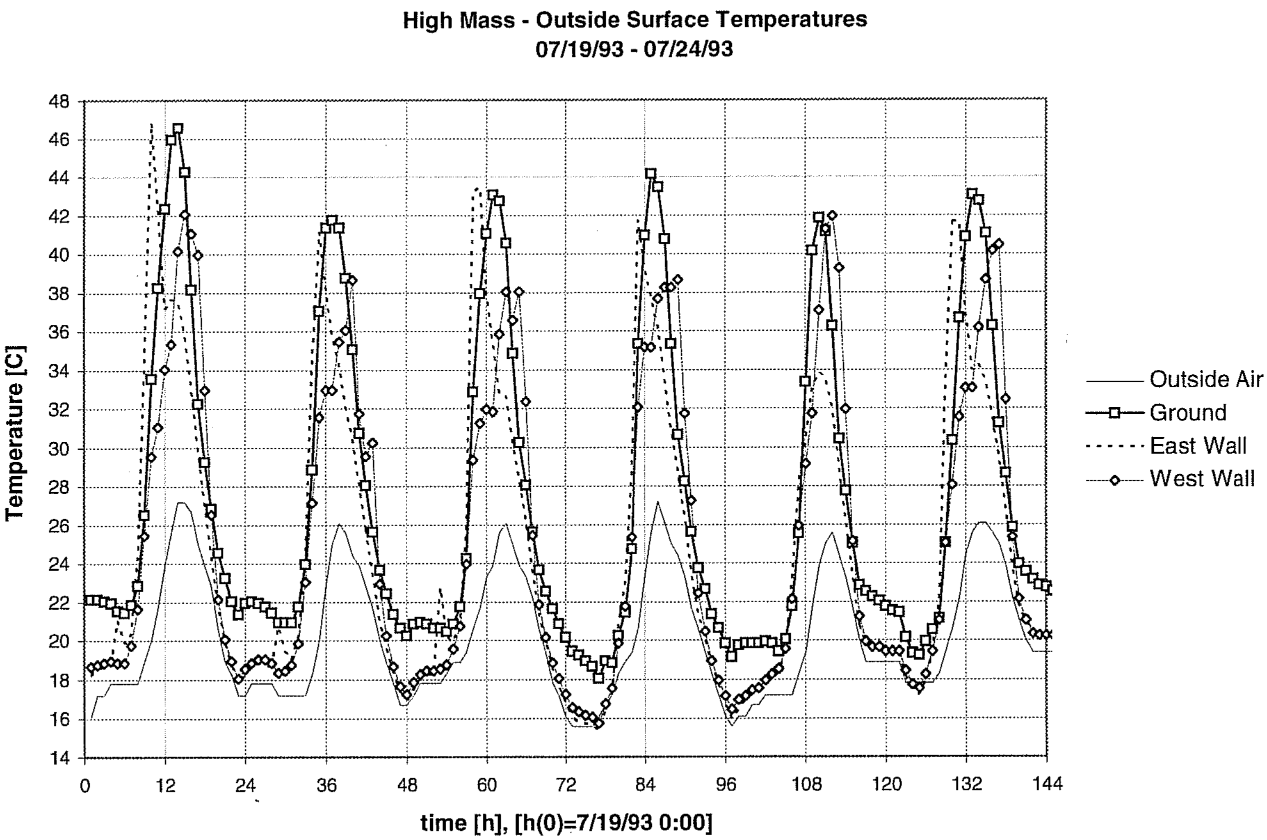


Figure 10. Predicted outside surface temperatures of high-mass house. Ground surface temperature and outside air temperature are shown for comparison.

5.4 Foundation heat transfer

The heat transfer from the building to the ground through the slab-on-grade is calculated by DOE-2 as UAΔT, where U is the conductance of the slab, A is its area, and ΔT is the temperature difference between the inside air and the ground. This formulation is over-simplified in that it ignores 2-dimensional conduction effects (especially those at the edge of the slab) and does not account for the effect of the building itself on the below-slab ground temperature. Consequently, we decided to test the difference between this simple model and a more accurate model in which ground heat fluxes calculated with a 2-dimensional finite difference model (Huang, 1988; Shen, 1988) are read into DOE-2 using input functions. The results are shown in **Figure 11**.

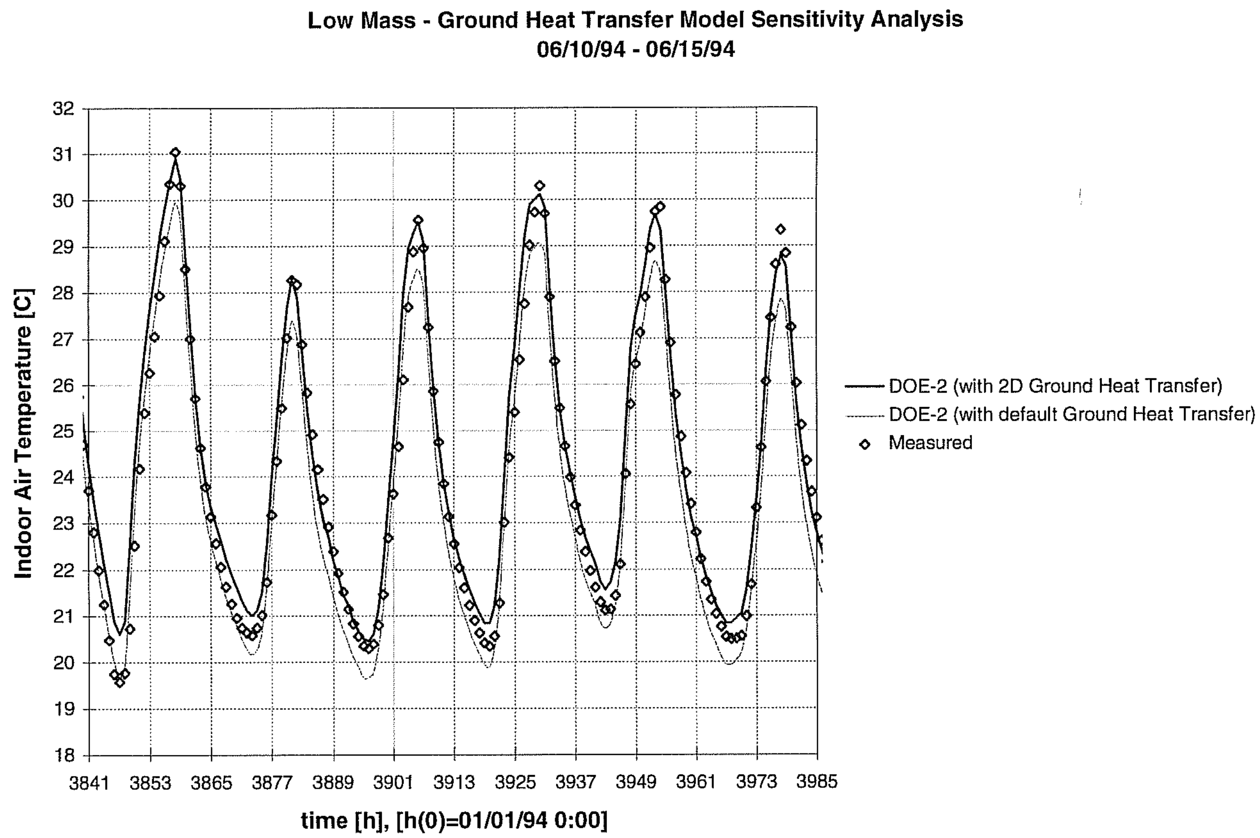


Figure 11. Sensitivity of low-mass house to slab heat transfer model.

5.5 Warm-up period

Initial comparisons for the high-mass house showed that differences between DOE-2 and measurements were often large during the first few days of simulation, then diminished as the simulation period progressed. This was not observed for the low-mass house. An example is shown in **Figure 12**. This effect was traced to the "warm-up" period in DOE-2. This is a period of seven days over which the simulation is repeated over and over with the same weather profile to allow the building to reach "steady-state." The DOE-2 results are then reported for the following time period using the corresponding weather data. The warm-up period is needed since the starting values of temperatures and heat flows that the program uses never match the actual values at the beginning of the simulation.

The conclusion from Figure 12 is that a warm-up period of 11 days is more appropriate for the high-mass building. Therefore, in all comparisons that are reported here we show only results after at least 11 days of simulation. A needed improvement to DOE-2 is to have the program automatically adjust the warm-up period depending on the heat capacity of the building, which is the primary determinant in how long the building takes to reach steady state.

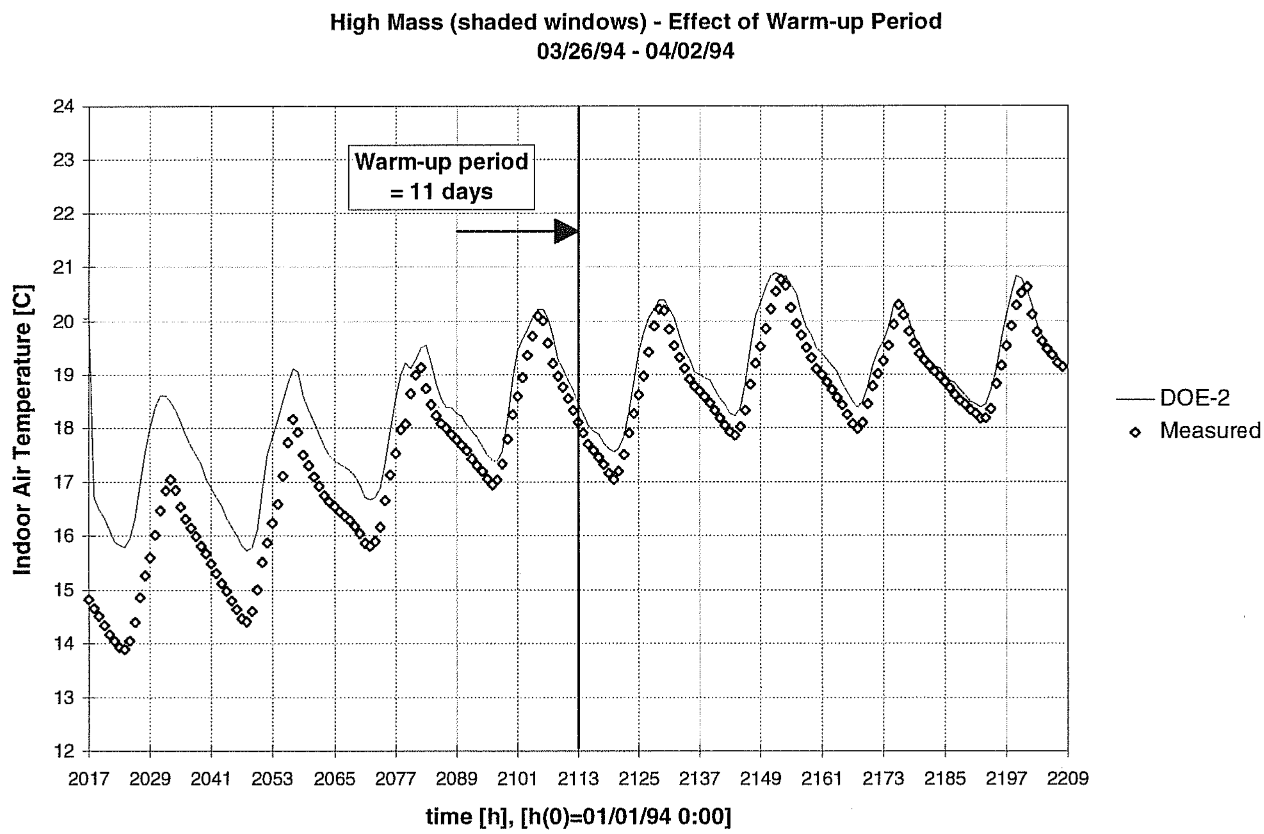


Figure 12. Effect of the DOE-2 warm-up period on the high-mass house with shaded windows.

5.6 Solar fractions

DOE-2 uses a weighting-factor method to calculate loads. For the solar load this requires that the user specify so-called "solar fractions," which correspond to the fraction of solar radiation that is transmitted into a space that is absorbed by each of the interior surfaces of the space. If not input, the program assigns solar fractions such that 60% of the solar is absorbed by the floor and the remaining 40% is assumed to be distributed over the other surfaces according to their area. Since, in actuality, the solar fractions vary hour to hour according to sun position and sky conditions (whereas only one fixed set of solar fractions is used by DOE-2) and since these fractions also depend on the absorptance of surfaces, not just their area, they represent a well-defined source of uncertainty in DOE-2.

To determine the error associated with solar fractions we modeled the low-mass house with three ways of choosing solar fractions: using the default values, using values weighted by surface area, and using values weighted by the product of surface area and surface absorptance. **Figure 13** shows the results. We conclude that the choice of solar fractions for the houses studied is not critical.

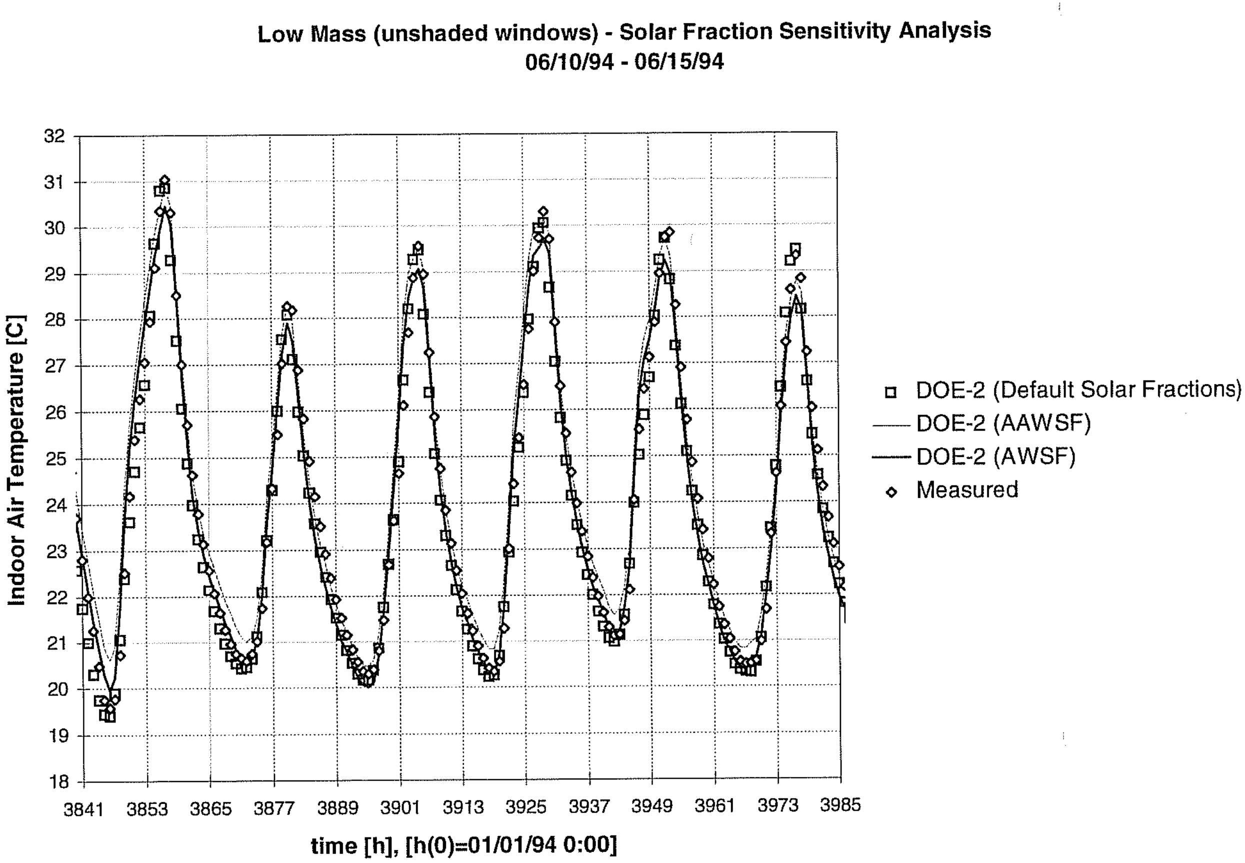


Figure 13. Sensitivity of low-mass house with unshaded windows to choice of solar fractions. AWF corresponds to solar fractions obtained by area weighting. AAWF corresponds to solar fractions obtained by area*absorptance weighting.

5.7 Cloud cover

DOE-2 uses hourly cloud cover to calculate the long-wave radiance of the sky and the diffuse solar irradiance from the sky on tilted surfaces. The first is important to the long-wave heat balance on the Pala houses, especially at night. The second is important to the solar radiation absorbed by the exterior walls and transmitted through the windows. Since cloud cover was not measured on site, it was first decided to use the cloud cover from the El Toro weather station, which is 16 km from the coast and 75 km from Pala. However, El Toro is foggier than Pala, especially in the summer when marine fog is a common occurrence near the coast. We were thus constrained to use available on-site weather measurements and so devised the following cloud cover model:

When the sun is up the fraction of the sky covered by clouds is approximated by the following ratio suggested by Lomas et al. (1994):

$$[\text{(diffuse horizontal solar irradiance)} / \text{(total horizontal solar irradiance)}]^2$$

At night, the pyranometer signal is used. Unlike during the day, the nighttime signal is negative (because the pyranometer is cooled at night by net long-wave radiation loss) and the clearer the sky the more negative the signal is. Clear conditions give *less* long-wave radiation from the sky than overcast conditions, resulting in *more* heat loss from the pyranometer and, therefore, a *larger* negative signal. This is illustrated in **Figure 14**, which shows the pyranometer output for a six-day period in July. Note that when the pyranometer signal is small at night the corresponding temperature profile is relatively flat, which is a supporting indication that a marine cloud layer (fog) is present that is stabilizing the temperature. This figure also shows the cloud cover (in tenths of sky covered by clouds) resulting from this model.

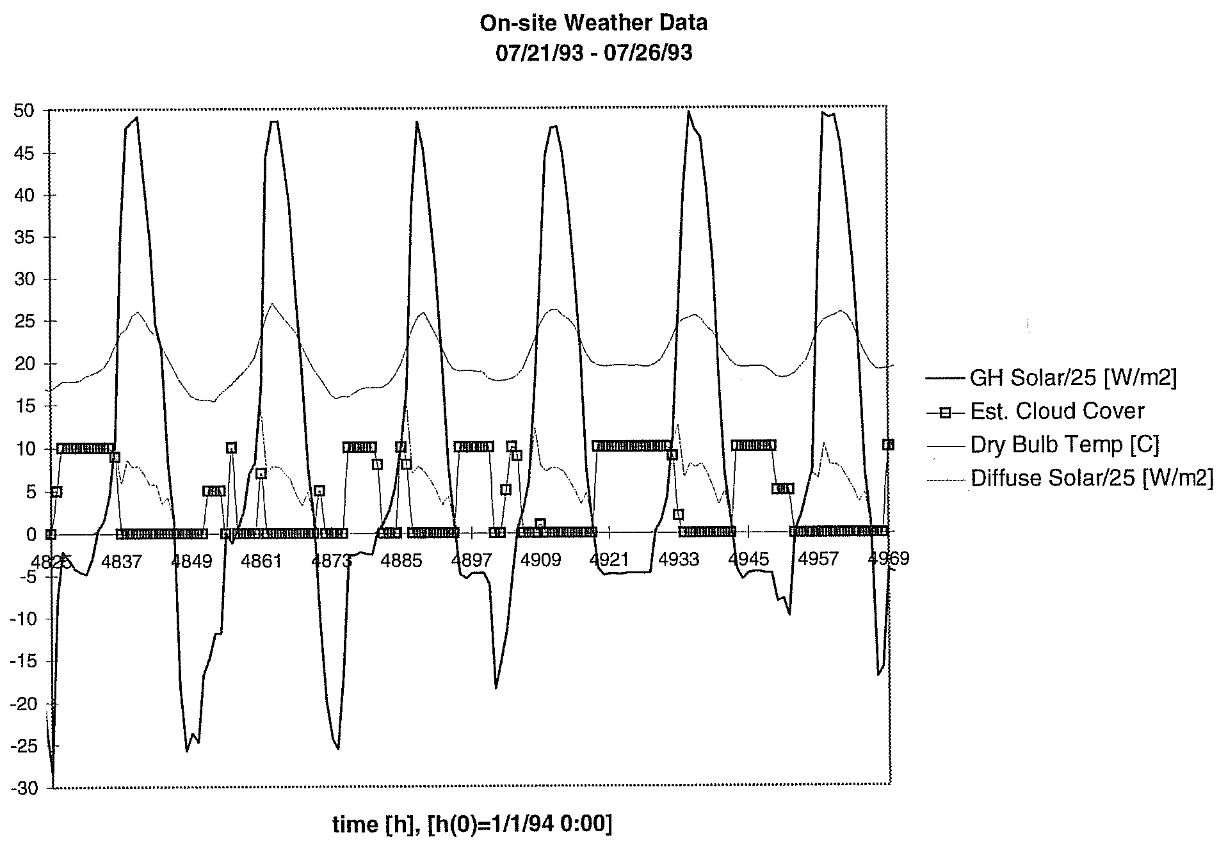


Figure 14. July weather showing cloud cover as obtained from the pyranometer signal (labeled GH Solar/25). The cloud cover varies from 0 for clear skies to 10 for overcast skies. In this plot the pyranometer signal has been divided by 25 when it is positive (daytime) and multiplied by 5 when it is negative (nighttime).

6. Comparison of DOE-2 with Measurements

To test the accuracy of DOE-2 we compared the DOE-2 predictions for the inside air temperature with measurements for four of the building configurations that were measured in 1993 and 1994. The configurations, which apply to both the low- and high-mass houses, are:

1. Baseline configuration in which the windows are closed and unshaded, the exterior walls and roof have their original color, and there is no ventilation.

2. Same as (1) but all windows except the north window are shaded.

3. Same as (2) but with the roof and exterior walls painted white.

4. Same as (3) but with fan-forced ventilation at night.

Table 4 summarizes the configurations.

Table 4. Summary of configurations for DOE-2 vs measurement comparisons

Configuration	Special feature	Figure No.	Mean deviation [K]	
			Low-mass	High-mass
1. Original color, unshaded windows, no ventilation	Baseline	15	0.5	0.4
2. Original color, shaded windows, no ventilation	Shaded windows	16	0.4	0.2
3. White surfaces, shaded windows, no ventilation	White roof and walls	17	1.1	0.4
4. White surfaces, shaded windows, night ventilation	Night ventilation	18	0.9	0.6

The quantity chosen for comparison is the average temperature of the two inside air temperature sensors in the north room. We chose this single temperature as representative for the following reasons:

1. DOE-2 assumes the air in each room is fully mixed so that the air temperature at a given time is the same at all points in the room.

2. The measured temperature difference between the two sensors in the north room is always small (less than 0.5C) for both buildings and for all configurations, which justifies taking the average. The south room sensors also show a small temperature difference.

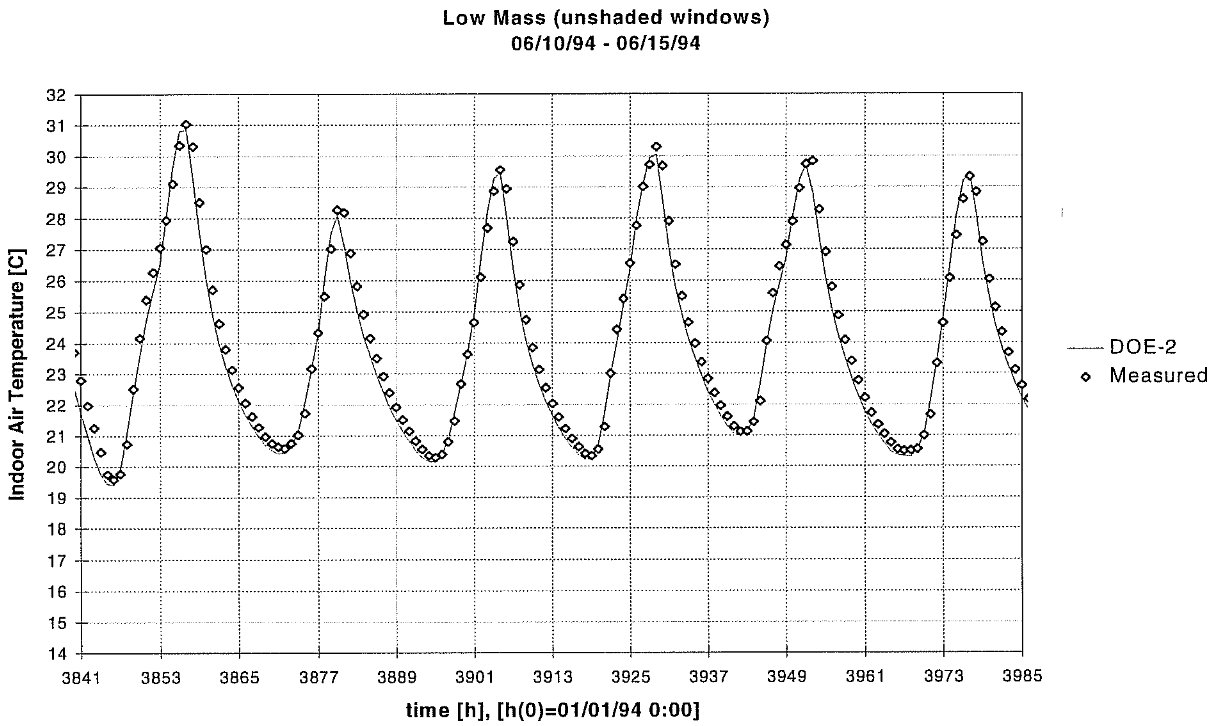
3. The measured air temperature difference between the rooms is always small (less than 0.5C) because of air exchange through the open doorway is large enough to equalize the temperatures. The same small temperature difference is observed in the DOE-2 predictions.

The comparison results are shown in **Figures 15 to 18.** As a measure of the level of agreement for each configuration, Table 4 gives the mean deviation — the absolute value of the difference between DOE-2 prediction and measurement averaged over the time period displayed in the figures. For all configurations, for both the low-mass and high-mass houses, excellent agreement is observed between predictions and measurements.

6.1 Baseline configuration

Figure 15 shows the baseline configuration, in which the windows are unshaded and the walls and roof have their original color (solar absorptance of 0.60 for the walls and 0.88 for the roof). The windows and exterior door are closed at all times so that there is no ventilation.

DOE-2 report LS-E, "Space Monthly Load Components," (not shown) indicates that the dominant source of heat gain in this case is solar gain through the windows. Therefore, this configuration is primarily a test of DOE-2's ability to calculate the solar radiation incident on the windows (beam radiation from the sun and diffuse radiation from the sky and ground), the transmission of this radiation by the glazing, the absorption of the transmitted radiation by the interior surfaces and the associated heating of these surfaces, and the resultant convective heat transfer from these surfaces to the room air (which occurs with a time delay that is related is the building's heat capacity). Because agreement is observed for both the low-mass and high-mass houses, which have significantly different heat capacities, we conclude that DOE-2 is properly accounting for thermal mass effects.



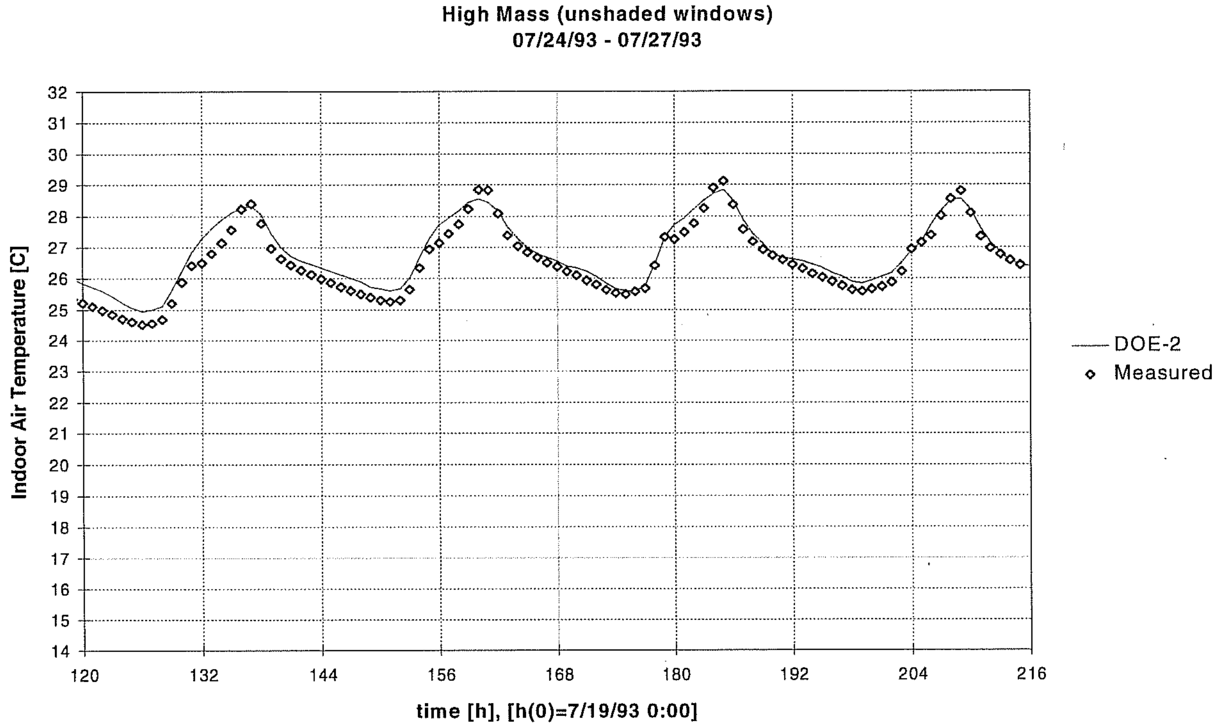


Figure 15. DOE-2 vs. measurement for Configuration 1: original outside color, unshaded windows and no ventilation.

6.2 Shaded windows

Figure 16 shows the second configuration, which is the same as the previous one except that the south, east and west windows are covered by exterior shades to reduce solar gain. The shades are attached at the top of the window and slope outward at a 20^0 angle so that the bottom of the shade is 28 cm from from the 67-cm high window. The shades are 12 cm wider than the window and have an opaque aluminized finish on both sides.

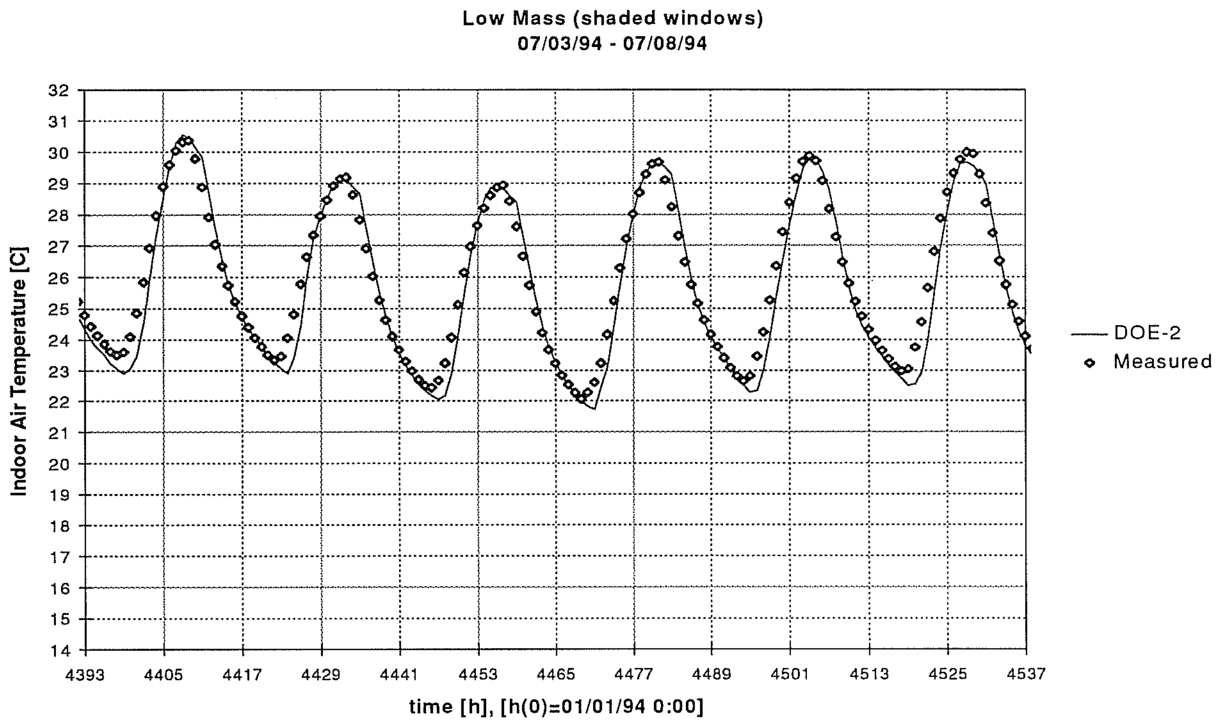
The shades reduce the overall solar gain by about 80%. We note that DOE-2 calculates the blockage by the shades of beam radiation from the sun and diffuse radiation from sky and ground but does not consider the reflection of solar radiation by the underside of the shades into the windows, although this effect is expected to be small.

The DOE-2 load component report indicates that the heat transfers for this configuration are roughly equally divided between solar gain, exterior wall conduction, window conduction, ceiling conduction (attic to room heat transfer), and floor conduction. The infiltration heat transfer is relatively small. This configuration is, therefore, a test of the program's ability to simulate exterior solar shading and envelope conduction.

6.3 White exterior surfaces

Figure 17 shows the third configuration, which is the same as the previous one except that the exterior opaque surfaces have been painted white, reducing the roof absorptance from 0.88 to 0.40 and the wall absorptance from 0.60 to 0.36.

This configuration, taken together with the previous configuration, is a test of DOE-2's ability to calculate (1) the solar radiation absorbed by walls and roof (which requires accurate calculation of the intensity of beam and diffuse radiation on surfaces of different orientations) and (2) the fraction of the absorbed radiation that is conducted into the rooms, either directly through the exterior walls or indirectly through the attic. This fraction is sensitive to the outside air film conductance, which DOE-2 calculates as a function wind speed, wind direction and surface-to-air temperature difference using an empirical correlation recently determined by Yazdanian and Klems (1994).



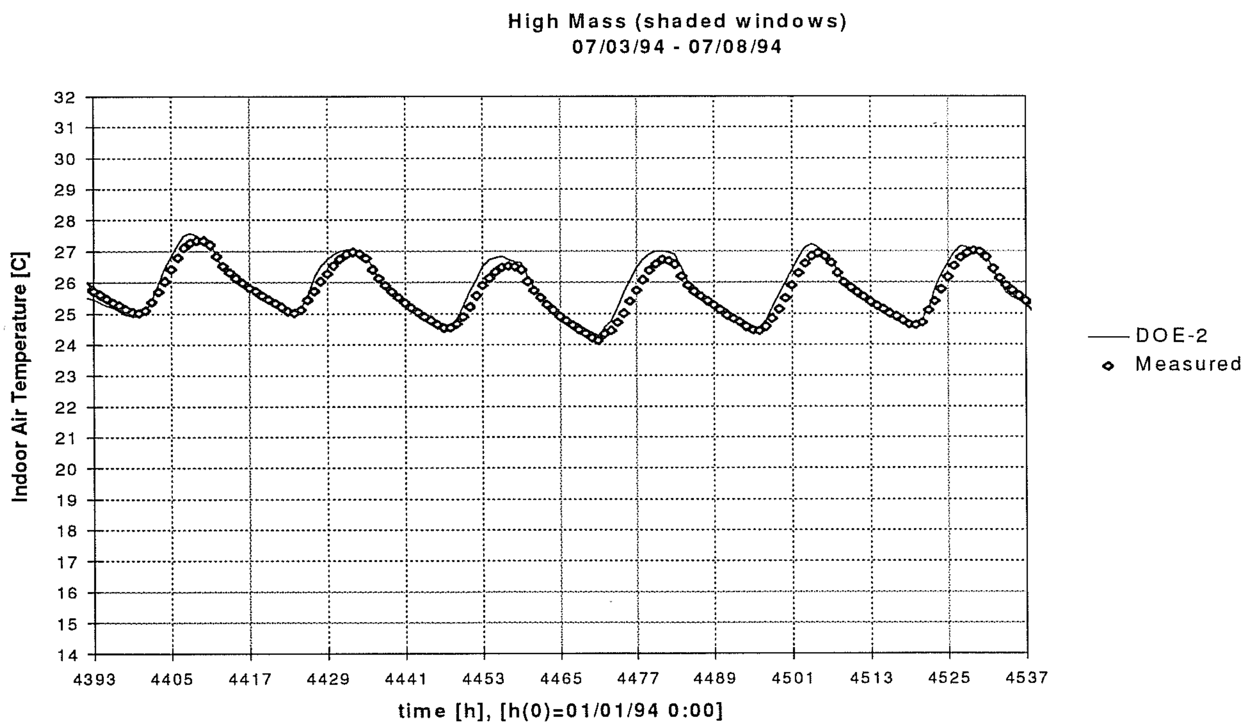
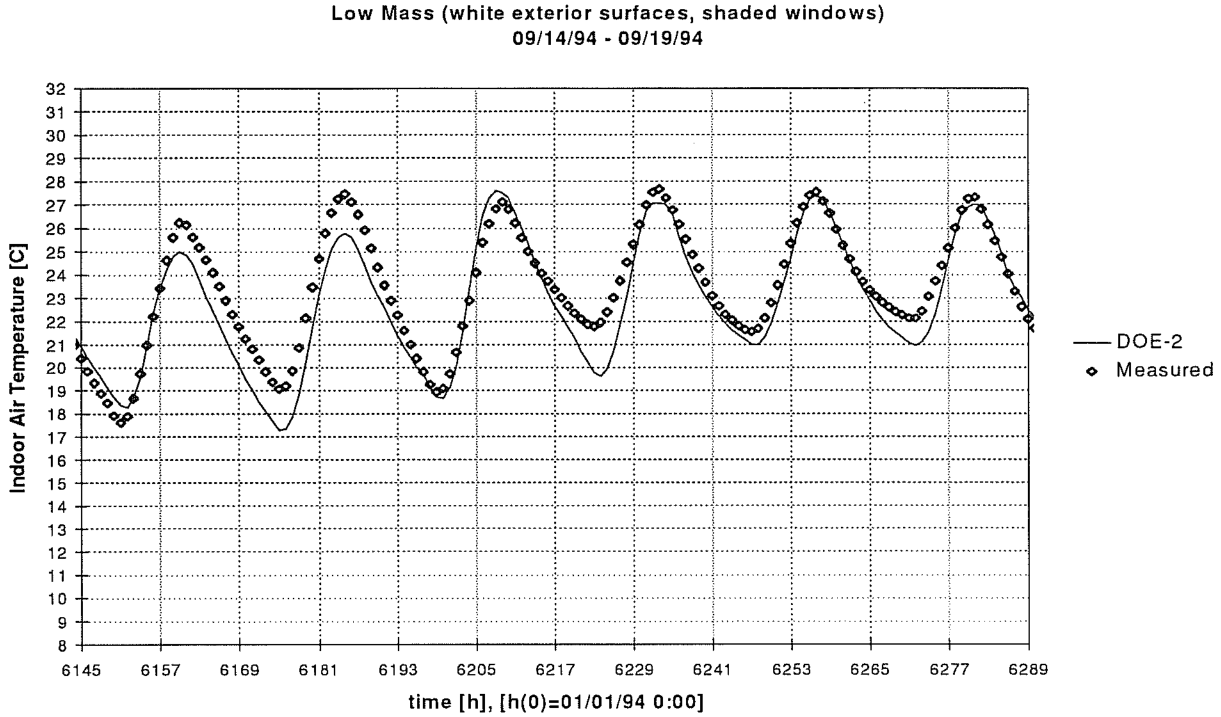


Figure 16. DOE-2 vs. measurement for low-mass house (top) and high-mass house (bottom) for Configuration 2: original outside color, shaded windows and no ventilation.



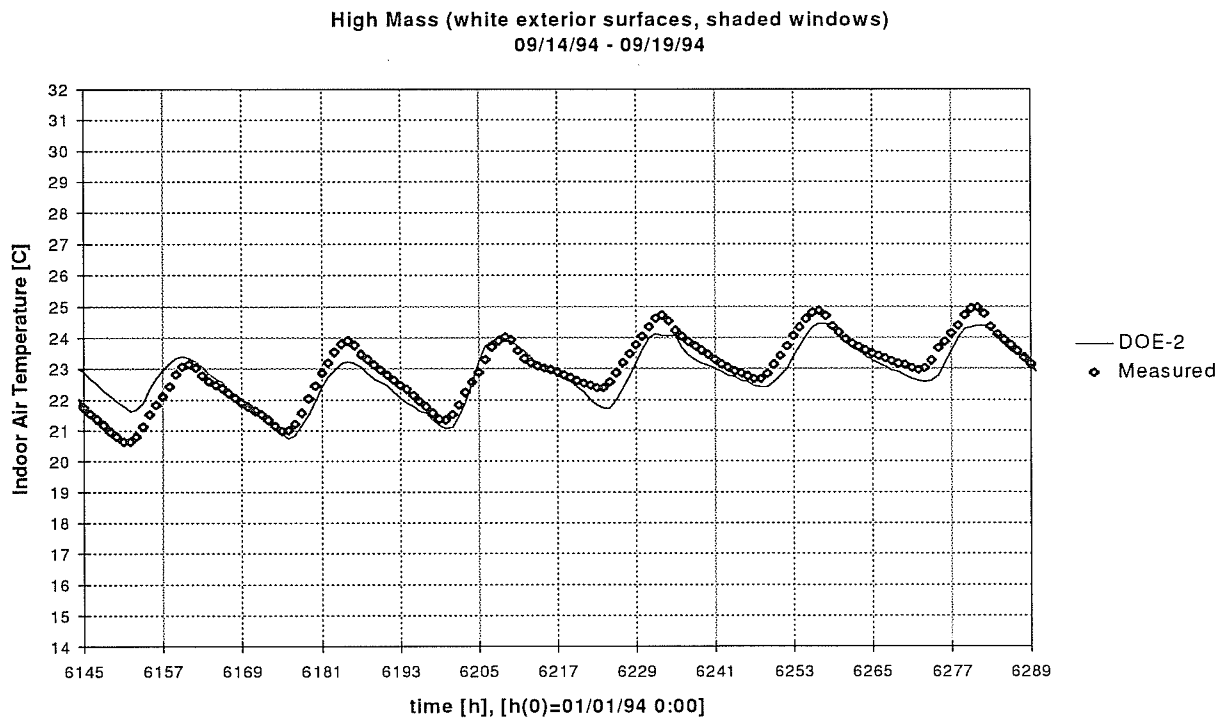


Figure 17. DOE-2 vs. measurement for low-mass house (top) and high mass house (bottom) for Configuration 3: white outside color, shaded windows and no ventilation.

6.4 Night ventilation

Figure 18 shows the fourth and final configuration, which is the same as the previous one except that the rooms are ventilated at 30 air changes per hour from 7pm to 7am. The ventilation is produced by a fan in a window of the south room that exhausts air drawn in through an open window in the north room after passing through the open doorway between the rooms. (When the fan is off both of these windows are closed.) The air flow rate was determined by measuring the air velocity profile across the area of the fan (Givoni and Labib, 1995).

This configuration shows that DOE-2 correctly calculates forced convective cooling of the building mass.

6.5 Inside surface temperature

As an additional test of the accuracy of DOE-2 we show in **Figure 19** the inside surface temperatures of the north room for the low-mass building, Configuration 1. The inside surface temperature calculation in DOE-2 is a recent addition to the program that allows determination of mean radiant room temperature, which can be an important consideration for occupant comfort. As for the inside air temperatures, we see good agreement with the measurements. A comparable level of agreement is seen for the other configurations.

7. Conclusions

The comparison results show that DOE-2 is in excellent agreement with the measurements for all of the configurations for both the low-mass and high-mass houses. The cases considered are representative of the kind of real-world houses that are the subject of investigation in the Alternatives to Compressor Cooling project. Therefore, DOE-2 can be expected to give accurate results for the calculation of the basic heat transfer processes and cooling loads in these houses. It should be noted, however, that the validation described here only applies to cases when the houses are unconditioned. Further validation of DOE-2 is required to test its accuracy in modeling houses conditioned by evaporative cooling or other mechanical systems.

As a result of this work we make three recommendations for improving DOE-2:

1. The warm-up period in DOE-2, which is now a fixed seven days, should be made to depend on the effective heat capacity of the building being modeled, so that the higher the heat capacity the longer the warm-up period. It should be possible to extract a measure of the effective heat capacity from the thermal properties of the building materials or from the weighting factors that are calculated by DOE-2.

2. The simple UAΔT ground heat transfer model should be replaced by a dynamic model that takes into account 2-D conduction effects, especially those at the edge

of the foundation. This model could be based on the finite-difference formulation (Huang, 1988; Shen, 1988) that was used to determine the slab heat transfer fluxes that were inserted into DOE-2 for this validation effort.

3. To improve the estimate of long-wave radiation from the ground, the ground surface temperature should be calculated rather than assuming it equals the outside air temperature. This is calculation should account for the shading of the ground by the target building and neighboring obstructions.

Finally, we make the following recommendations for additional measurements that would have been useful in validating DOE-2:

1. Because envelope loads are sensitive to long-wave radiation, we recommend that on-site weather stations include a pyrometer to measure horizontal IR irradiance from the sky. The pyrometer measurements could also be used to develop or validate sky IR models, which typically depend on cloud cover and atmospheric humidity.

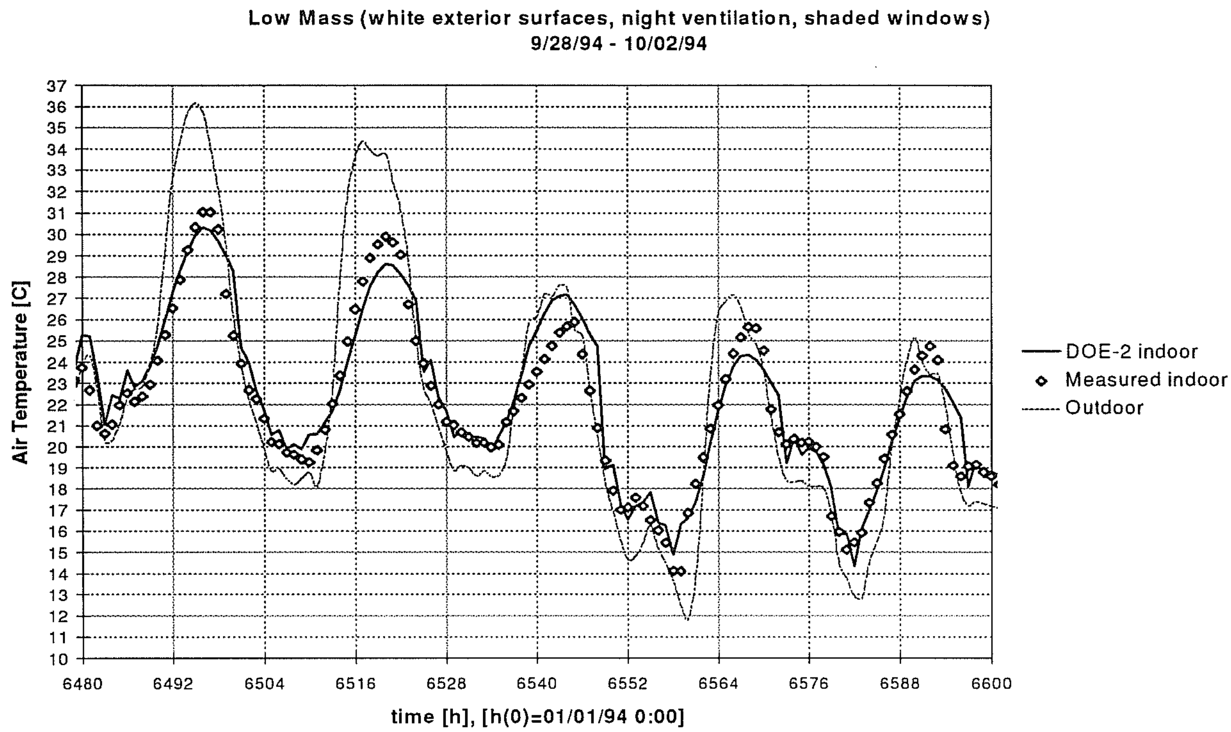
2. As an aid in checking foundation heat transfer models, the ground temperature should be measured at different depths near and away from the building. To check the ground surface temperature model, the ground temperature should be measured just below the surface.

3. Measurements of the attic air temperature and attic surface temperatures would allow validation of the attic heat transfer model. Although the attics in the both the high-mass and low-mass test buildings are fairly well decoupled from the rooms below because of the R-19 ceiling insulation, it would have been worthwhile to do a direct validation of the DOE-2 attic calculation since spaces of this kind, with their high surface temperatures and, consequently, high levels of IR radiation exchange, can be difficult to model.

4. The thermophysical properties of the building materials (density, specific heat and conductivity) and material surface properties (emissivity and solar absorptance) should be measured since they directly effect the basic heat transfer mechanisms of absorption, radiation, conduction and storage.

8. Acknowledgments

We thank Baruch Givoni and Tarek Labib of UCLA for providing the measurements and assisting in their interpretation; Fred Buhl of LBNL for putting together the weather files; Joe Huang of LBNL for providing the 2-D foundation heat fluxes; Markus Koschenz of EMPA (Switzerland) for developing the DOE-2 inside surface temperature calculation; and Karl Brown, CIEE program manager, for guidance and support.



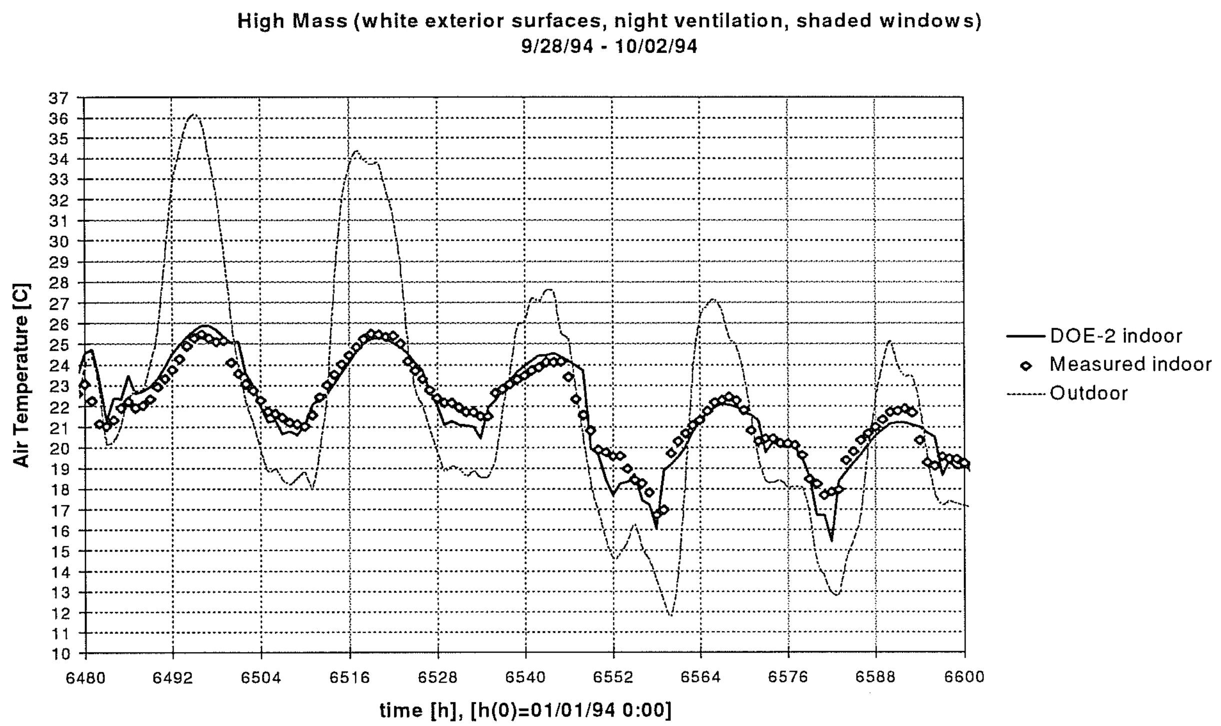


Figure 18. DOE-2 vs. measurement for low-mass house (top) and high mass house (bottom) for Configuration 4: white outside color, shaded windows and night ventilation.

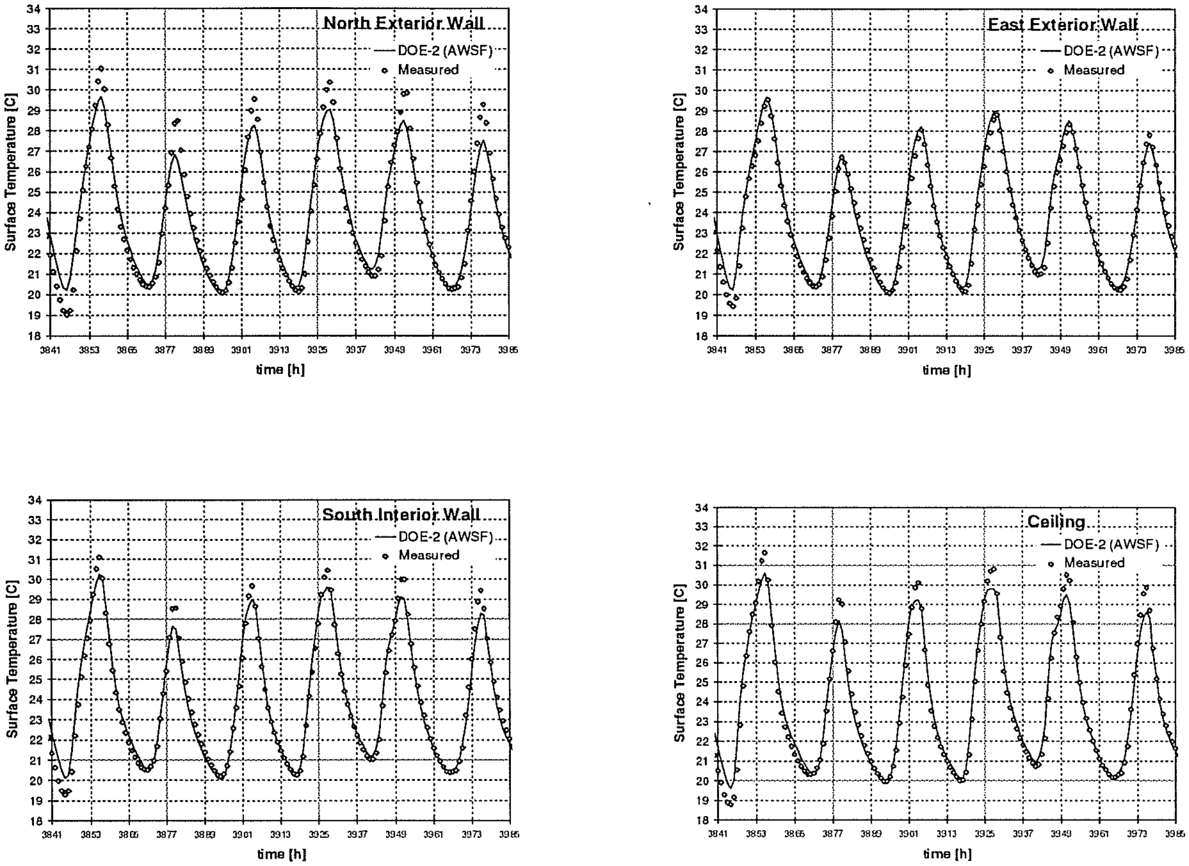


Figure 5. DOE-2 vs. inside surface temperature measurements for the north room of the low-mass house, Configuration 1 (original outside color, unshaded windows and no ventilation). "South Interior Wall" refers to the north-room side of the partition separating the two rooms.

9. References

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APPENDIX A

DOE-2.1E input for the low-mass house, Configuration 1

```
INPUT  LOADS    OUTPUT-UNITS = METRIC  ..

TITLE
LINE-1 * Input Prototype for the PALA House *
LINE-2 * Pala-El Toro 1993 and 1994 Weather *
LINE-3 * Low Mass House *
LINE-4 * 20% framed area *
LINE-5 * *
..
 $--------------------------------------------------------------------
            PARAMETER
 $--------------------------------------------------------------------
 $
 $ COMMENTS
 $
 $ 1. U-EFFECTIVE is calculated as follows: we assumed that the wall was
 $    0-1 ft deep in the ground and is uninsulated, 0.41*(17.5+16.7/2)=10.6
 $    The heat loss through the floor is 0.032*146.15=4.7, The sum is 15.3
 $    Btu/h F, FDNUEFF=15.3/(8.75*16.7)=0.1045
 $
 $ 2. The window frame dimensions have been estimated from photographs of the houses.
 $
 $ 3. THIS FILE REPRESENTS THE BASE CASE FOR THE SIMULATION.
 $
 $ 4. An improved ground surface temperature model is used.
 $

FLRAREA = 146.15        $ Half Estimated Floor Area 292.3/2 $
HOUSVOL = 1169.2        $ Half Estimated Volume = FLRAREA*WALLHT $
PERIM = 68.5            $ Estimated Perimeter $
IWALLAREA = 133.6       $ Estimated Interior Wall Area $
ROOFZ = 8.0             $ Estimated Z Coordinate of the Roof $
ROOFHT = 9.25           $ Estimated Lenght of the Roof $
ROOFWD = 16.7           $ Estimated Width of the Roof $
NWALLWD = 16.7                 $ Estimated North Wall Width $
SWALLWD = 16.7                 $ Estimated South Wall Width $
EWALLWD = 8.75          $ Estimated East Wall Width $
WWALLWD = 8.75                 $ Estimated West Wall Width $
WALLHT = 8.0            $ Estimated Wall Height $
SHADEHT = 8.0           $ Estimated Shade Height $
INFILT  = .0005                $ Estimated Infiltration $
FDNUEFF  = .1045          $ Estimated U-Value of the Underground-Floor $
WALLABS =  0.60         $ on site measurements
ROOFABS =  0.88         $ on site measurements
FRAMEPER = 0.2
GTCODE  =  1000

$ WALLABS =  0.25 $  $  off-white
$ ROOFABS =  0.25 $  $ off-white
$ FSLABL =  FSLABL0 $  $ 1/2 slab with carpet
$ FSLABL1 =  BSLABL0 $  $ 1/2 exposed slab
..

$ ---  end of parameters -------------------------------------------

RUN-PERIOD
               APR 04 1994 THRU APR 30 1994   $ unshaded & closed 94
               JUN 06 1994 THRU JUN 18 1994   $ unshaded & closed 94
..

DIAGNOSTIC  CAUTIONS,WIDE,ECHO,SINGLE-SPACED ..
ABORT       ERRORS ..
```

```
BUILDING-LOCATION

        LATITUDE = 32.73      LONGITUDE = 117.17     T-Z = 8 ALT = 326
        AZIMUTH = 0
        SHIELDING-COEF = 0.19
        TERRAIN-PAR1 = .85     TERRAIN-PAR2 = .20
        WS-TERRAIN-PAR1 = .85  WS-TERRAIN-PAR2 = .20
        WS-HEIGHT = 18
..
LOADS-REPORT   VERIFICATION = (ALL-VERIFICATION)
               $ SUMMARY = (ALL-SUMMARY)
                 HOURLY-DATA-SAVE=FORMATTED
..

 $-----------------------------------------------------------------------
 $-----  Loads Schedules  ---------------------------------------------
 $-----------------------------------------------------------------------

OCCSCH     SCHEDULE THRU DEC 31 (ALL) (1,24) (0) ..

 $-----------------------------------------------------------------------
 $ The following shading schedule is set for each house.
 $-----------------------------------------------------------------------

SHADCO  = SCHEDULE     THRU MAY 31 (ALL) (1,24) (0.80)
                       THRU OCT 31 (ALL) (1,24) (0.60)
                       THRU DEC 31 (ALL) (1,24) (0.80)
..

 $-----------------------------------------------------------------------
 $-----  Constructions  -----------------------------------------------
 $-----------------------------------------------------------------------

$ ground properties, from Joe Huang for default dry soil $
GNDMAT-1        =MATERIAL THICKNESS=2.0
                          CONDUCTIVITY=0.70
                          DENSITY=115
                          SPECIFIC-HEAT=0.28
                                  ..
GNDLAY-1           =LAYERS  MATERIAL=(GNDMAT-1) THICKNESS = (3) I-F-R=.3 ..

GNDCON-1           =CONSTRUCTION  LAYERS=GNDLAY-1
                                  ABSORPTANCE=0.55 ..

WINDOWGT = GLASS-TYPE GLASS-TYPE-CODE =  GTCODE
                      FRAME-ABS = 0.7
                      FRAME-CONDUCTANCE = 3.037  ..

HIMX_W  = LAYERS       MATERIAL=(SC01,IN33,CB02)  ..
$ exterior wall: stucco, building paper, 5/8" plywoood, R-11 batt, 0.5" gyp board
LOMX_W  = LAYERS       MATERIAL=(SC01,BP01,PW04,IN02,GP01)  ..
LOMF_W  = LAYERS       MATERIAL=(SC01,BP01,PW04,WD04,GP01)  ..
HIMI_W  = LAYERS       MATERIAL=(CB02)  ..
$ interior wall: 0.5" gyp board, wood or air , 0.5" gyp board
LMIF_W  = LAYERS       MATERIAL=(GP01,WD04,GP01)  ..
LMIA_W  = LAYERS       MATERIAL=(GP01,AL21,GP01)  ..
$ interior ceiling: R-19 batt, 0.5" gyp board
HILING   = LAYERS      MATERIAL=(IN03,GP01) ..
$ exterior roof: asphalt shingle, building paper, 5/8" plywood
HIROOF   = LAYERS      MATERIAL=(AR03,BP01,PW04)  ..
$ floor: 1-ft earth, 4-in concrete, carpet+pad
HIFLOR   = LAYERS      MATERIAL=(GNDMAT-1,CB02,CP02) ..
$ gable ends
HIGABL   = LAYERS        MATERIAL=(SC01,BP01,PW04) ..

XWCON = CONSTRUCTION  ABSORPTANCE =  WALLABS
                              ROUGHNESS = 1
                              LAYERS = HIMX_W  ..

XWINS = CONSTRUCTION  ABSORPTANCE =  WALLABS
                              ROUGHNESS = 1
                              LAYERS = LOMX_W  ..

XWFRM = CONSTRUCTION  ABSORPTANCE =  WALLABS
                              ROUGHNESS = 1
```

```
                              LAYERS = LOMF_W  ..

CEILCON = CONSTRUCTION LAYERS = HILING  ..
ROOFCON = CONSTRUCTION ABSORPTANCE =  ROOFABS
                              ROUGHNESS = 3         $ shingle
                              LAYERS = HIROOF  ..
GABLCON = CONSTRUCTION  ABSORPTANCE = WALLABS
                        ROUGHNESS = 1
                        LAYERS = HIGABL ..
IWAL_A = CONSTRUCTION  LAYERS = LMIA_W  ..
IWAL_F = CONSTRUCTION  LAYERS = LMIF_W  ..
IWALCON = CONSTRUCTION LAYERS = HIMI_W  ..
AIRWALL = CONSTRUCTION U-VALUE=2.0  ..
DOORCON = CONSTRUCTION U-VALUE=.4292  ..
FLORCON = CONSTRUCTION        LAYERS = HIFLOR  ..

 $---------------------------------------------------------------------
 $-----  Shades  ------------------------------------------------------
 $---------------------------------------------------------------------

$                             ROOF-POND BUILDING
SURROUND1 = BUILDING-SHADE    HEIGHT = 8.0   WIDTH = 17.5
                              X = 33.4       Y = -17.5
                              AZIMUTH = 90   TILT = 90  ..

O_HANG-W1 =  BUILDING-SHADE     HEIGHT = 11         WIDTH = 1.5
                                X = -1.5            Y = -19.1      Z = 7.4
                                AZIMUTH = 180   TILT = 19  ..

O_HANG-W2 =  BUILDING-SHADE     HEIGHT = 11         WIDTH = 1.5
                                X = 0.00            Y = 1.6        Z = 7.4
                                AZIMUTH = 00   TILT = 19  ..

O_HANG-E1  =  BUILDING-SHADE    HEIGHT = 11 WIDTH = 1.5
                                X = 16.7       Y = -19.1   Z = 7.4
                                AZIMUTH = 180   TILT = 19  ..

O_HANG-E2  =  BUILDING-SHADE    HEIGHT = 11         WIDTH = 1.5
                                X = 18.2       Y = 1.6             Z = 7.4
                                AZIMUTH = 0         TILT = 19  ..

O_HANG-S =  BUILDING-SHADE     HEIGHT = 1.5   WIDTH = 16.7
                                X = 00.0       Y = -17.5       Z = 8.0
                                AZIMUTH = 180  TILT = 180  ..

O_HANG-N  =  BUILDING-SHADE     HEIGHT = 1.5   WIDTH = 16.7
                                X = 16.7       Y = 00.0        Z = 8.0
                                AZIMUTH = 0    TILT = 180  ..

 $---------------------------------------------------------------------
 $-----  Space -------------------------------------------------------
 $---------------------------------------------------------------------

ROOMCOND = SPACE-CONDITIONS   TEMPERATURE  =  (74)
                              PEOPLE-SCHEDULE = OCCSCH
                              NUMBER-OF-PEOPLE = 0
                              PEOPLE-HG-LAT = 190
                              PEOPLE-HG-SENS = 230
                              INF-METHOD = S-G
                              FRAC-LEAK-AREA  = INFILT
                              FLOOR-WEIGHT = 0
                              FURNITURE-TYPE = LIGHT
                              FURN-FRACTION = 0.1
                              FURN-WEIGHT = 1.0  ..

SET-DEFAULT FOR EXTERIOR-WALL
                              INSIDE-SURF-TEMP = YES
..
SET-DEFAULT FOR INTERIOR-WALL
                              INSIDE-SURF-TEMP = YES
..
SET-DEFAULT FOR UNDERGROUND-WALL
                              INSIDE-SURF-TEMP = YES
..
SET-DEFAULT FOR DOOR
```

```
                              INSIDE-SURF-TEMP = YES
..
SET-DEFAULT FOR WINDOW
                              INSIDE-SURF-TEMP = YES
                                GLASS-TYPE = WINDOWGT  ..
 $------------------------------------------------------------------
 $-----  Building Description ---------------------------------------
 $------------------------------------------------------------------

$dummy space with roof = ground for ground surface temperature calculation
$for use in calc of IR from ground; requires modified version of DOE-2.1E

ROOMGND-1      =SPACE           AREA = 100
                                VOLUME=200
                                TEMPERATURE=(64) $Pala weather file gnd temp$
                                     ..

    ROOF-1    =EXTERIOR-WALL    HEIGHT = 10            WIDTH = 10
                                AZIMUTH = 0  TILT = 0
                                CONSTRUCTION = GNDCON-1    ..
$actual building

ROOM1  =   SPACE              X = 0   Y = 0   Z = 0   AZ = 180
                              SPACE-CONDITIONS = ROOMCOND
                              AREA = FLRAREA
                              VOLUME = HOUSVOL ..

NWALL_F = EXTERIOR-WALL             X = -3.34      Y = 0.0        AZ = 180
                              HEIGHT = WALLHT               WIDTH = NWALLWD TIMES 0.2
                              SOLAR-FRACTION = 0.04
                              CONSTRUCTION = XWFRM  GND-REFLECTANCE = 0.45  ..

NWALL_I = EXTERIOR-WALL             X = -16.7      Y = 0.0        AZ = 180
                              HEIGHT = WALLHT               WIDTH = 13.36
                               SOLAR-FRACTION = 0.15
                               CONSTRUCTION = XWINS  GND-REFLECTANCE = 0.45  ..

  NWIND = WINDOW                $ takes the frame width into account $
                                $ window's size = 3.8*2.5           $
                              X = 8.3        Y = 3.67
                              HEIGHT = 2.34  WIDTH = 3.47
                              FRAME-WIDTH = 0.098  ..

  NDOOR = DOOR                      X = 0.75       Y = 0.0
                              WIDTH = 3      HEIGHT = 7
                              CONSTRUCTION = DOORCON          ..

EWALL1_I = EXTERIOR-WALL      LIKE NWALL_I
                              X = -16.7      Y = 8.75       AZ = 270
                               SOLAR-FRACTION = 0.08
                              WIDTH = 7.00  ..

  EWIND1 = WINDOW             $ takes the frame width into account $
                              $ total window's size = 1.9*2.5           $
                              LIKE NWIND     FRAME-WIDTH = 0.153
                              X = 1.54       Y = 3.67
                              HEIGHT = 2.2   WIDTH = 1.38  ..

EWALL1_F = EXTERIOR-WALL      LIKE NWALL_F
                              X = -16.7      Y = 1.75       AZ = 270
                               SOLAR-FRACTION = 0.02
                              WIDTH = EWALLWD TIMES 0.2  ..

IWAL1F = INTERIOR-WALL        X = 0.0 Y = 8.75       AZ = 0.0
                              HEIGHT = WALLHT               WIDTH = 2.7
                              NEXT-TO = ROOM2        INT-WALL-TYPE  =  STANDARD
                               SOLAR-FRACTION = (0.03,0.03)
                              CONSTRUCTION = IWAL_F  .. $stud portion

IWAL1A = INTERIOR-WALL        X = -2.7       Y = 8.75       AZ = 0.0
                              HEIGHT = WALLHT               WIDTH = 4.65
                              NEXT-TO = ROOM2        INT-WALL-TYPE  =  STANDARD
                               SOLAR-FRACTION = (0.05,0.05)
                              CONSTRUCTION = IWAL_A  .. $air portion
```

```
IWAL2 = INTERIOR-WALL          X = -7.35      Y = 8.75       AZ = 0.0
                               HEIGHT = 6.8          WIDTH = 3
                               NEXT-TO = ROOM2        INT-WALL-TYPE  =  AIR
                                SOLAR-FRACTION = (0.03,0.03)
                               CONSTRUCTION = AIRWALL  ..

IWAL2A = INTERIOR-WALL         X = -7.35      Y = 8.75       AZ = 0.0
                               HEIGHT = 1.2   Z = 6.8        WIDTH = 3
                               NEXT-TO = ROOM2        INT-WALL-TYPE  =  STANDARD
                                SOLAR-FRACTION = (0.01,0.01)
                               CONSTRUCTION = IWAL_A  ..

IWAL3A = INTERIOR-WALL         X = -10.35     Y = 8.75       AZ = 0.0
                               HEIGHT = 8.0   WIDTH = 6.35
                               NEXT-TO = ROOM2        INT-WALL-TYPE  =  STANDARD
                                SOLAR-FRACTION = (0.07,0.07)
                               CONSTRUCTION = IWAL_A  ..

WWALL1_I = EXTERIOR-WALL       LIKE NWALL_I
                               X = 0.00       Y = 0.00       AZ = 90
                                SOLAR-FRACTION = 0.08
                               WIDTH = 7.00 ..

  WWIND1 = WINDOW              LIKE EWIND1
                               X = 3.35       Y = 3.67
                               HEIGHT = 2.2   WIDTH = 1.38  ..

WWALL1_F = EXTERIOR-WALL       LIKE NWALL_F
                               X = 0.00       Y = 7.00       AZ = 90
                                SOLAR-FRACTION = 0.02
                               WIDTH = 1.75    ..

FND1 = UNDERGROUND-FLOOR       $ Slab floor
                               X = -16.7      Y = 0.00       Z = 0
                               HEIGHT = 8.75  WIDTH = 16.7
                               TILT = 180     CONSTRUCTION = FLORCON
                                SOLAR-FRACTION = 0.21
                               U-EFFECTIVE = 0.110
                               FUNCTION =(*NONE*,*FNDQ*)   ..
CEILING1 = INTERIOR-WALL
                               X = 0.00       Y = 8.75       Z = WALLHT
                               HEIGHT = 8.75  WIDTH = 16.7
                               TILT = 0
                               SOLAR-FRACTION = (0.21,0.43)
                               NEXT-TO = ATTIC        CONSTRUCTION = CEILCON       ..

ROOM2   =   SPACE              X = 0.00       Y = -8.75      Z = 0   AZ = 180
                               SPACE-CONDITIONS = ROOMCOND
                               AREA = FLRAREA
                               VOLUME = HOUSVOL ..

EWALL2_I = EXTERIOR-WALL       LIKE EWALL1_I
                               X = -16.7      Y = 8.75       AZ = 270  ..

  EWIND2 = WINDOW              LIKE EWIND1
                               X = 3.30  ..

EWALL2_F = EXTERIOR-WALL       LIKE EWALL1_F
                               X = -16.7      Y = 1.75       AZ = 270  ..

SWALL_F = EXTERIOR-WALL               LIKE NWALL_F
                               X = 0.0        Y = 8.75       AZ = 0
                               HEIGHT = WALLHT        WIDTH = SWALLWD TIMES 0.2  ..

SWALL_I = EXTERIOR-WALL               LIKE NWALL_I
                               X = -3.34      Y = 8.75       AZ = 0
                               HEIGHT = WALLHT        WIDTH = 13.36  ..

SWIND = WINDOW                        LIKE NWIND
                               X = 3.16  ..

WWALL2_I = EXTERIOR-WALL       LIKE WWALL1_I
                               X = 0.0        Y = 0.00       AZ=90  ..

  WWIND2 = WINDOW              LIKE WWIND1
```

```
                             X = 3.45  ..

WWALL2_F = EXTERIOR-WALL     LIKE WWALL1_F  ..


FND2 = U-F                   LIKE FND1  ..

CEILING2 = INTERIOR-WALL     LIKE CEILING1  ..

 $ Attic    assume 1 ft2 of vents per 450 ft2 of attic space area,
 $ Attic    ELF  =  75% of vent area

ATTIC = SPACE                AZ = 180
                             AREA = FLRAREA TIMES 2  VOLUME = FLRAREA TIMES 2.90  $ avg height
                             INF-METHOD = S-G       FRAC-LEAK-AREA =  .00243
                             FLOOR-WEIGHT = 0       ZONE-TYPE = UNCONDITIONED
                             T = (80)  ..

  SROOF = ROOF               X = 0.0        Y = 17.5       Z = ROOFZ
                             HEIGHT = ROOFHT        WIDTH = ROOFWD
                             SOLAR-FRACTION = 0.43
                             TILT = 19      CONSTRUCTION = ROOFCON  ..

  NROOF = ROOF               LIKE SROOF
                             X = -16.7      Y = 0.0        AZIMUTH = 180  ..

  GABLEW = EXTERIOR-WALL     LIKE WWALL1_I  Z = ROOFZ
                               CONSTRUCTION = GABLCON
                             SOLAR-FRACTION = 0.07
                             WIDTH = 17.5   HEIGHT = 1.35  ..

  GABLEE = EXTERIOR-WALL     LIKE EWALL2_I
                               CONSTRUCTION = GABLCON
                             Y = 17.5       Z = ROOFZ
                             SOLAR-FRACTION = 0.07
                             WIDTH = 17.5   HEIGHT = 1.35  ..

REPSCH_0        = SCHEDULE  THRU DEC 31 (ALL) (1,24) VALUES=(0) ..
REPSCH          = SCHEDULE  THRU DEC 31 (ALL) (1,24) VALUES=(1) ..

RB-GL    = REPORT-BLOCK
           VARIABLE-TYPE   = GLOBAL
           VARIABLE-LIST   = (13,14,15,20,21,22,36,37)   ..

RB-00    = REPORT-BLOCK
           VARIABLE-TYPE   = NWIND
           VARIABLE-LIST   = (11,12) ..

RB-01    = REPORT-BLOCK
           VARIABLE-TYPE   = NWALL_I
           VARIABLE-LIST   = (16)  ..

RB-02    = REPORT-BLOCK
           VARIABLE-TYPE   = WWIND1
           VARIABLE-LIST   = (11,12) ..

RB-03    = REPORT-BLOCK
           VARIABLE-TYPE   = WWALL1_I
           VARIABLE-LIST   = (16)  ..

RB-04    = REPORT-BLOCK
           VARIABLE-TYPE   = EWIND1
           VARIABLE-LIST   = (11,12) ..

RB-05    = REPORT-BLOCK
           VARIABLE-TYPE   = EWALL1_I
           VARIABLE-LIST   = (16)  ..

RB-06    = REPORT-BLOCK
           VARIABLE-TYPE   = SWIND
           VARIABLE-LIST   = (11,12,13) ..

RB-07    = REPORT-BLOCK
           VARIABLE-TYPE   = SWALL_I
           VARIABLE-LIST   = (16,17)  ..
```

```
HR_REP   = HOURLY-REPORT
           REPORT-SCHEDULE = REPSCH_0
           REPORT-BLOCK    = (RB-GL) ..

END ..

$ Foundation fluxes for Pala from Y.J. Huang using Huang/Chen model.
$ FdnL= 16.0 FdnW= 16.0 ICorner=4
$ U-EFFECTIVE= 0.110
FUNCTION NAME = FNDQ
         LEVEL = UNDERGROUND-WALL  ..
ASSIGN   DOY=IDOY UGFQ=QUGF UGWQ=QUGW ..
ASSIGN   QTABL = TABLE
(  1,  -169.2)(  2,  -166.6)(  3,  -164.5)(  4,  -171.2)(  5,  -166.8)
(  6,  -146.8)(  7,  -150.4)(  8,  -157.2)(  9,  -162.6)( 10,  -178.7)
( 11,  -187.7)( 12,  -190.4)( 13,  -186.2)( 14,  -181.9)( 15,  -188.4)
( 16,  -192.8)( 17,  -195.2)( 18,  -194.2)( 19,  -201.6)( 20,  -209.2)
( 21,  -217.4)( 22,  -210.8)( 23,  -181.8)( 24,  -174.1)( 25,  -171.4)
( 26,  -166.6)( 27,  -164.5)( 28,  -164.7)( 29,  -167.0)( 30,  -180.1)
( 31,  -185.6)( 32,  -178.8)( 33,  -173.6)( 34,  -168.5)( 35,  -165.3)
( 36,  -162.8)( 37,  -164.2)( 38,  -149.8)( 39,  -147.4)( 40,  -144.3)
( 41,  -142.4)( 42,  -138.3)( 43,  -141.0)( 44,  -134.1)( 45,  -128.3)
( 46,  -126.2)( 47,  -123.8)( 48,  -124.7)( 49,  -125.8)( 50,  -125.5)
( 51,  -124.6)( 52,  -121.7)( 53,  -123.5)( 54,  -129.2)( 55,  -111.8)
( 56,  -106.0)( 57,  -101.2)( 58,   -96.3)( 59,   -94.6)( 60,   -89.0)
( 61,   -88.6)( 62,   -88.8)( 63,   -89.9)( 64,   -87.6)( 65,   -85.5)
( 66,   -86.5)( 67,   -87.7)( 68,   -89.5)( 69,   -92.7)( 70,   -91.8)
( 71,   -90.0)( 72,   -81.7)( 73,   -75.5)( 74,   -72.4)( 75,   -73.8)
( 76,   -76.9)( 77,   -85.0)( 78,   -86.8)( 79,   -87.4)( 80,   -85.2)
( 81,   -77.1)( 82,   -77.1)( 83,   -71.9)( 84,   -67.3)( 85,   -66.0)
( 86,   -68.2)( 87,   -76.7)( 88,   -89.2)( 89,   -98.2)( 90,  -101.6)
( 91,   -89.5)( 92,   -76.0)( 93,   -73.5)( 94,   -80.2)( 95,   -86.7)
( 96,   -91.3)( 97,   -98.7)( 98,  -110.2)( 99,  -114.2)(100,  -113.0)
(101,  -117.5)(102,  -121.2)(103,  -123.0)(104,  -128.1)(105,  -140.2)
(106,  -148.2)(107,  -161.8)(108,  -174.8)(109,  -176.9)(110,  -175.0)
(111,  -163.8)(112,  -155.7)(113,  -146.1)(114,  -134.8)(115,  -150.2)
(116,  -162.2)(117,  -173.9)(118,  -186.3)(119,  -191.3)(120,  -181.2)
(121,  -171.3)(122,  -167.7)(123,  -163.1) ..
      CALCULATE ..
      WEEK = (DOY/3.0) + 1.0
      UGWQ = 0.0
      UGFQ = PWL(QTABL, WEEK)
      END-FUNCTION ..

COMPUTE LOADS ..

INPUT SYSTEMS  .. $ all rooms unconditioned: no heating or cooling

SYSTEMS-REPORT  SUMMARY=(SS-A,SS-J)
                HOURLY-DATA-SAVE=FORMATTED ..

$ SYSTEMS SCHEDULES

FAN-0        =DAY-SCHEDULE     (1,24) (-1)   ..
FAN-1        =DAY-SCHEDULE     (1,6)(0)(7,18)(1)(19,24)(0)   ..
FAN-SCHED    =SCHEDULE         THRU DEC 31 (WD) FAN-1 (WEH) FAN-0  ..
FAN-NUL      =SCHEDULE         THRU DEC 31 (ALL) FAN-0 ..

HEAT-0       =DAY-SCHEDULE     (1,24) (0)  ..
HEAT-1       =DAY-SCHEDULE     (1,8) (55)   (9,18) (71)   (19,24) (55)  ..
HEAT-2       =DAY-SCHEDULE     (1,24) (55)   ..
HEAT-WEEK    =WEEK-SCHEDULE    (MON,FRI) HEAT-0   (WEH)  HEAT-0   ..
HEAT-SCHED   =SCHEDULE         THRU DEC 31   HEAT-WEEK   ..

COOL-0       =DAY-SCHEDULE     (1,24) (150)  ..
COOL-1       =DAY-SCHEDULE     (1,8) (99)   (9,18) (75)   (19,24) (99)  ..
COOL-2       =DAY-SCHEDULE     (1,24) (99)   ..
COOL-WEEK    =WEEK-SCHEDULE    (MON,FRI) COOL-0   (WEH)  COOL-0   ..
COOL-SCHED   =SCHEDULE         THRU DEC 31   COOL-WEEK   ..

R1           =DAY-RESET-SCH    SUPPLY-HI=60
                               SUPPLY-LO=52
                               OUTSIDE-LO=30
                               OUTSIDE-HI=75  ..
```

```
SAT-RESET    =RESET-SCHEDULE   THRU DEC 31 (ALL) R1  ..

$ SYSTEM DESCRIPTION (FLOATING TEMPERATURES: NO HEATING OR COOLING)

ZAIR         =ZONE-AIR         OA-CFM/PER=20  ..

CONTROL      =ZONE-CONTROL     DESIGN-HEAT-T=72
                               DESIGN-COOL-T=74
                               HEAT-TEMP-SCH= HEAT-SCHED
                               COOL-TEMP-SCH= COOL-SCHED
                               THERMOSTAT-TYPE=PROPORTIONAL ..

ROOM1        =ZONE             ZONE-AIR=ZAIR
                               SIZING-OPTION=ADJUST-LOADS
                               ZONE-CONTROL=CONTROL  ..

ROOM2        =ZONE             ZONE-AIR=ZAIR
                               SIZING-OPTION=ADJUST-LOADS
                               ZONE-CONTROL=CONTROL  ..

ATTIC        =ZONE             ZONE-TYPE = UNCONDITIONED  ..
ROOMGND-1    =ZONE             ZONE-TYPE = UNCONDITIONED  ..

S-CONT       =SYSTEM-CONTROL   COOLING-SCHEDULE= COOL-SCHED
                                       HEATING-SCHEDULE= HEAT-SCHED
                                       HEAT-SET-T=65
                                       COOL-CONTROL=CONSTANT
                                       MIN-SUPPLY-T=60 ..

S-AIR        =SYSTEM-AIR               OA-CONTROL=FIXED  ..

S-FAN        =SYSTEM-FANS      FAN-SCHEDULE=FAN-NUL
                               FAN-CONTROL=SPEED
                                       SUPPLY-STATIC=5.5
                               SUPPLY-EFF=.55
                                       NIGHT-CYCLE-CTRL=STAY-OFF  ..

S-TERM       =SYSTEM-TERMINAL  REHEAT-DELTA-T=58
                                       MIN-CFM-RATIO=0.3   ..

SYST-1       =SYSTEM           SYSTEM-TYPE=SZRH
                                       SYSTEM-CONTROL= S-CONT
                                       SYSTEM-FANS= S-FAN
                                       SYSTEM-AIR= S-AIR
                                       SYSTEM-TERMINAL= S-TERM
                                       ECONO-LIMIT-T=65
                                       ZONE-NAMES=(ROOM1,ROOM2,ATTIC,ROOMGND-1)  ..

REPSCH_0          = SCHEDULE  THRU DEC 31 (ALL) (1,24) VALUES=(0) ..

REPSCH_UC94       = SCHEDULE  THRU APR 03 (ALL) (1,24) VALUES=(0)
                              THRU APR 30 (ALL) (1,24) VALUES=(1)
                              THRU JUN 05 (ALL) (1,24) VALUES=(0)
                              THRU JUN 18 (ALL) (1,24) VALUES=(1)
..
RB-GL     = REPORT-BLOCK
            VARIABLE-TYPE    = GLOBAL
            VARIABLE-LIST    = (8)   ..

RB-01     = REPORT-BLOCK
            VARIABLE-TYPE    = ROOM1
            VARIABLE-LIST    = (6)  ..

RB-02     = REPORT-BLOCK
            VARIABLE-TYPE    = ROOM2
            VARIABLE-LIST    = (6)  ..

RB-03     = REPORT-BLOCK
            VARIABLE-TYPE    = ATTIC
            VARIABLE-LIST    = (6)  ..

RB-04     = REPORT-BLOCK
            VARIABLE-TYPE    = SYST-1
            VARIABLE-LIST    = (1,2,3,4,5,6,7,10,14,17,18,19,20,30,31,33,39)  ..
```

```
HR_REP   = HOURLY-REPORT
           REPORT-SCHEDULE = REPSCH_UC94
           REPORT-BLOCK    = (RB-GL,RB-01,RB-02,RB-03) ..
END ..
COMPUTE SYSTEMS  ..
STOP ..
```