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ANALYSIS OF CLIMATIC CONDITIONS AND PRELIMINARY ASSESSMENT OF ALTERNATIVE COOLING STRATEGIES FOR HOUSES IN CALIFORNIA TRANSITION CLIMATE ZONES

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ABSTRACT

This is a preliminary scoping study done as part of the "Alternatives to Compressive Cooling in California Transition Climates" project, which has the goal of demonstrating that houses in the transitional areas between the coast and the Central Valley of California do not require air-conditioning if they are properly designed and operated.

The first part of this report analyzes the climate conditions within the transitional areas, with emphasis on design rather than seasonal conditions. Transitional climates are found to be milder but more variable than those further inland. The design temperatures under the most stringent design criteria, e.g. 0.1% annual, are similar to those in the Valley, but significantly lower under more relaxed design criteria, e.g., 2% annual frequency. Transition climates also have large day-night temperature swings, indicating significant potential for night cooling, and wet-bulb depressions in excess of 25 F, indicating good potential for evaporative cooling.

The second part of the report is a preliminary assessment using DOE-2 computer simulations of the effectiveness of alternative cooling and control strategies in improving indoor comfort conditions in two conventional Title-24 houses modeled in various transition climate locations. The cooling measures studied include increased insulation, light colors, low-emissivity glazing, window overhangs, and exposed floor slab. The control strategies studied include natural and mechanical ventilation, and direct and two-stage (indirect/direct) evaporative cooling. The results indicate the cooling strategies all have limited effectiveness, and need to be combined to produce significant improvements in indoor comfort. Natural and forced ventilation provide similar improvements in indoor conditions, but during peak cooling periods, these will still be above the comfort zone. Two-stage evaporative coolers can maintain indoor comfort at all hours, but not so direct evaporative coolers.

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INTRODUCTION

Compressor-based cooling is growing rapidly in California as housing activity expands inland from the major coastal urban centers, while the public's demand for comfort remains high. The residential cooling load profiles in this "transition" climate zone are very disadvantageous for utility companies, with sporadic but sharp peaks on hot summer afternoons coincident with district peaks. The use of "alternative cooling" strategies in place of air-conditioning in these houses will greatly decrease this sporadic cooling load, thereby reducing peak electricity demands and total cooling electricity use.

"Alternative cooling" strategies refer to building designs that minimize unwanted heat gain into the building, or the use of naturally available sources of cooling such as the building mass, ground, outdoor air, or evaporative cooling to maintain indoor comfort. These strategies use very little energy, but they have limited cooling capacities and may increase the first costs. Therefore, careful analysis and planning are required to produce building designs and control systems that provide adequate comfort at the lowest additional cost.

In 1992, the California Institute for Energy Efficiency (CIEE) initiated the "Alternatives to Compressive Cooling in California Transition Climates" project to demonstrate that it is possible to construct houses in the transition climate zone that do not require air-conditioning. This report describes a preliminary scoping study completed in the first year of the CIEE project. The purpose of this scoping study is to present an overview of the climate conditions within what's termed as the "transition" climate zone, and make a preliminary assessment of the effectiveness of various alternative cooling strategies in improving indoor conditions in a conventional house built to the current Title-24 building energy standard. This study is not meant to be exhaustive, but to provide guidance for further research and design efforts to be carried out in the "Alternatives to Compressive Cooling" project.

ANALYSIS OF CALIFORNIA CLIMATE CONDITIONS

This climate analysis has three objectives : (1) define the extent and identify the distinctive climatic characteristics of inland areas of California popularly termed "transition" climates, (2) determine the design temperatures with this "transition" climate, and (3) assess the appropriateness of using California Energy Commission weather tapes for design as well as seasonal energy use calculations. This evaluation was done using weather data from the following sources : (1) design temperatures for 600 California locations published by the local ASHRAE chapter for Region X (ASHRAE 1982), (2) two sets of CTZ hourly weather tapes for 16 locations from the California Energy Commission, and (3) miscellaneous weather data for California locations from other sources.

Geographical Extent of Transition Climate Zone

It is impossible to provide a rigorous definition of the "Transition Climate", since there is a progression of mesoclimate variations from the coast inland. Furthermore, there are significant differences in climate between northern and southern California that are unrelated to the marine influence. For general purposes of discussion, the term "transition" climate can be used to refer to locations from 10 to 30 miles inland with climates intermediate between the marine-dominated coast and the more severe climate of the Central Valley or the semi-arid desert areas of southern California. Over the last decade, this "transition" climate zone has experienced a great deal of housing development due to the urban sprawl radiating out from San Francisco, Los Angeles, and San Diego.

ASHRAE Design Temperatures

Since the design data from the ASHRAE Region X publication are by far the most detailed in terms of geographical coverage, significant effort has been spent in analyzing them to determine the climate characteristics and geographical extent of the "transition" climate zone. A computer program was written using the *Disspla* software package to draw contour maps of the ASHRAE design data, including dry-bulb, wet-bulb, and coincident wet-bulb temperatures at three design criteria (0.1%, 0.5%, and 2% of the total annual hours), and daily temperature ranges (see Figs. 1 through 10). For brevity, this report focuses on the two areas with the most population and housing activity - a) San Francisco - Sacramento , and b) Los Angeles - San Diego. Table 1 lists ASHRAE Region X design temperatures for selected locations in the "transition" climate zone, with a few coastal locations such as Oakland and Central Valley locations such as Sacramento included for comparison.

Before proceeding to the climate analysis, some words of caution are needed regarding the data in the ASHRAE Region X publication. The apparent comprehensiveness of the data masks the uneven data quality among the 600 listed locations. Only 48 of these are based on full measured data, 332 are inferred from other data, and the remaining 220 completely interpolated from other sites (see ASHRAE 1982 for details). The three type of data points are identified in the maps in Appendix A. Despite these differences in data quality, all 600 data points are used in making the temperature contour maps. Another note concerning the 1982 ASHRAE Region X publication is that its design temperature criteria are 0.1%, 0.5%, and 2% *annual* frequencies, corresponding to 9, 44, and 175 hours. Traditionally, the ASHRAE *Handbook of Fundamentals* (ASHRAE 1993) have used design criteria of 1%, 2%, and 5% frequencies over four summer months (June to September), or 29, 59, and 146 hours. At the 1995 ASHRAE summer conference, the Weather Committee decided in future publications to use 0.4%, 1%, and 2% annual frequencies, which would be roughly equivalent to the current summer frequencies. The 0.1% annual design temperature in the ASHRAE Region X publication is more stringent than those typically used. For comparison, design temperatures from the *1993 Handbook of Fundamentals* for representative California "transition climates" are shown in Appendix B.

Figures 1 through 4 show the design dry-bulb and wet-bulb temperature contours at 0.1% and 2% design conditions for the San Francisco-Sacramento area, while Figures 5 through 8 show them for the Los Angeles-San Diego area. These contour maps not only interpolate between climate locations, but also adjust for the effect of adiabatic cooling on the design temperatures due to elevation changes. The terrain data was obtained from the Bay Area Air Quality Management District in San Francisco.

For design dry-bulb temperatures, the maps show the gradients for the 0.1% design condition to cluster closer to the coast than for the 2% condition. This is best illustrated in Figure 9, which shows the temperature *difference* between the two design conditions. The larger difference in the "transition" climate zone indicates that it has occasional episodes when temperatures are nearly as hot as in the Central Valley, but the frequency of these episodes is much less. There is relatively little difference in design wet-bulb temperatures between the coast, "transition" climate, and the inland parts of California. Compared to the Central Valley, wet- bulb temperatures in the "transition" climate zone are lower by 2 - 3°F at most for all three design criteria. Another climatic change from the coast to the Central Valley is an increase in the temperature range, or difference between daytime highs and nighttime lows. As shown in Figure 10, the summer temperature range is 23 - 26°F along the coast, 27 - 34°F in the "transition" climate zone, and over 34°F in the Central Valley.

In summary, the ASHRAE design temperature data indicate that a rough "transition" climate zone can be defined extending 10 miles to 30 miles inland from the coast. As suggested by its name, the climatic conditions in this region are intermediate between those of the coast and the Central Valley. The design dry-bulb temperatures in this zone vary from 94 to 100°F at the 0.1%, and from 83 to 88°F at the 2% design criterion. Compared to the Central Valley, the former is lower by 4 to 6°F, but the latter by almost 8°F. The design wet-bulb temperatures in the "transition" climate zone are 71 to 72°F at the 0.1% and 67 to 68°F at the 2% design criterion, nearly identical to those in the Central Valley (73°F and 68°F, respectively). This indicates that the "transition" climate zone is cooler and more humid than the Central Valley, with little difference in enthalpy. The relatively large temperature ranges and low nighttime temperatures in the "transition" climate zone indicate moderate to high potentials for utilizing night cooling with thermal mass to reduce daytime cooling needs. The sizable wet-bulb depression (difference between dry-bulb and wet-bulb temperatures) indicate that evaporative cooling would be another effective cooling strategy.

California Energy Commission Weather Tapes

Another purpose of the climate analysis is to evaluate the appropriateness of using annual weather tapes designed for annual energy simulations, i.e., the CTZ weather tapes produced by the California Energy Commission (CEC), for this preliminary evaluation and future design simulations. For the Title 24 building energy standard, the CEC divided the state into 16 climate zones and developed a set of standard weather tapes to represent these zones (see Figure 11, CEC 1980). These weather tapes are artificial years created by combining data from 12 months from different years, each selected as the most typical for that month.

Although the CTZ weather tapes are artificial years, they are based on historical data from actual meteorological sites. In 1992, the CEC modified these weather tapes to eliminate anomalies and adjust the temperatures to match the mean climate conditions within each climate zone (CEC 1992). For example, the average monthly temperatures on the weather tape for CTZ02 (Santa Rosa) were found to be higher than the average for Climate Zone 2 locations. To adjust for this difference, the dry-bulb temperatures on the weather tape were modified downwards to the mean of the CTZ02 locations. At the same time, the wet-bulb temperatures were also adjusted to maintain the same wet-bulb depression.[1] For some climate zones, these modifications produced major changes in the weather tapes, such as a 40% reduction in cooling degree-days for CTZ02 (original data Santa Rosa) and 4°F increases in both average summer dry-bulb and wet-bulb temperatures in CTZ04 (original data Sunnyvale). While these modified weather data may be more representative of average climatic conditions within each CEC climate zone, it is impossible to associate them with any specific location. Moreover, since the modifications were based solely on the recorded monthly dry-bulb temperatures within a climate zone, the resultant hourly profiles, wet-bulb temperatures, and humidity ratios have not been substantiated. Because of these unanswered questions, the modified CTZ weather data are regarded as questionable and to be used in this project only as a last resort.

To determine whether the CEC weather tapes should be used for assessing the performance of alternative cooling designs, the design dry-bulb, coincident wet-bulb, and design wet-bulb temperatures calculated from the two sets of CTZ weather tapes are compared to the design temperatures in the ASHRAE Region X publication. Table 2

1. Personal communications with Jim Augustyn of Augustyn + Company (Albany) and Chip Barnaby, now of XEnergy (Oakland), Fall 1992. Augustyn was the contractor for the CEC project, and Barnaby made the actual modification to the weather tapes.

shows that the design conditions calculated from the original CEC weather tapes are generally consistent with ASHRAE Region X design temperatures for the 2%, but not for the 0.1% annual criterion. This is unsurprising since the 0.1% criterion corresponds to only nine hours, so that the inclusion or removal of any one hot spell from the weather tape would significantly affect the resultant 0.1% design temperature. The CEC weather tapes are regarded as adequate for assessing the annual performance of alternative cooling strategies, but it is recommended that design calculations also be done using two- or three-day sequences of ASHRAE design-day values to cover hot spells that may be absent from the weather tapes.

Figures 12 through 15 show general climate statistics for the 16 climates zones from the original CTZ weather tapes. The figures are arranged with the hottest locations at the top to the coolest at the bottom. Three climate zones are in the Central Valley (11, 12, and 13), one in the desert (14), and one in the Imperial Valley (15). Six are coastal locations (1, 3, 4, 5, 6, and 7), and one represents the high mountains (16). The remaining four are moderately inland and are most representative of the "transition" climate zone : 2 (Santa Rosa), 8 (El Toro), 9 (Pasadena), and 10 (Riverside).

The five Southern California CTZ tapes provide a reasonable gradation from the coast (Climate Zones 6 and 7) to 10 miles (8 = El Toro), 20 miles (9 = Pasadena), and finally 30 miles inland (10 = Riverside). The weather statistics also indicate increasing maximum temperatures, temperature swings, and wet-bulb depressions, coupled with decreasing humidity, as one moves inland from the coast. Therefore, the three inland locations (El Toro, Pasadena, and Riverside) are selected as representative "transition climates" for use in the preliminary analysis of alternative cooling strategies.

The coverage of the CEC weather tapes is far less satisfactory for Northern California, where the Climate Zone 2 (Santa Rosa) is the only candidate "transition" climate, since Climate Zones 1 (Arcata), 3 (Oakland) and 4 (Sunnyvale) are all heavily marine-influenced (either coastal or Bay Area), and 11 (Red Bluff) and 12 (Sacramento) are in the Central Valley. Because of the significant differences between them, both the original and modified weather tapes for Climate Zone 2 are used in the preliminary analysis of alternative cooling strategies. The modified weather tape for Climate Zone 4 (originally Sunnyvale) was analyzed but not used because the adjusted wet-bulb temperatures are 5 to 7°F higher than in the original weather data, so that the design wet-bulb temperatures are higher than ASHRAE Region X values for any location in Climate Zone 4.

Figures 16 to 19 plot the hourly dry-bulb and wet-bulb temperatures for six cooling months for the four Southern California, and Figures 20 to 22 for the three Northern California, locations. Both sets show the daily temperature patterns as more erratic closer to the coast and regular in the inland areas. For example, Figure 17 for Climate Zone 8 (El Toro), a "transition" climate 10 miles from the coast, shows pronounced "heat waves" in mid-May and late September. Figure 19 for Climate Zone 10 (Riverside), which is 30 miles inland, however, shows a more regular pattern of day/night temperatures.

Other Weather Tapes

Inquiries with the Climatic Data Center and the CEC revealed an absence of stations in the "transition" climate zone collecting hourly data beyond those that have been already turned into CEC weather tapes. Phone conversations with Woody Whitlatch, staff meteorologist at PG&E, indicates that PG&E has ten years of hourly data from Travis Air Force Base, from which it may be possible to generate a weather tape. Collaboration with PG&E in such a task will be explored in later phases of this project.

HOUSING CHARACTERISTICS

A reasonable characterization of the current housing stock is needed for determining the annual and peak cooling loads of a typical house in the "transition" climate zone. The following information sources were used to characterize the current housing being built in the "transition" climate zone : (1) typical conservation "packages" suggested by the CEC's Title 24 Building Energy Standard, (2) results from a recent project for CEC's Demand Forecasting Office to develop building prototypes using statistical housing data such as Association of Homebuilder's builder's survey, F.W. Dodge building permit data, and Residential Appliance Saturation Survey (RASS) results from five California utility companies, and (3) a CEC report by the Buildings Office describing new residential building prototypes used in Title 24 energy calculations.

Tables 3 and 4 show typical conservation packages that meet the 1992 Title 24 Energy Standard for the five climate zones identified as "transition climates" (2 and 12 in the north; 8, 9, and 10 in the south). Package A for typical wood-frame construction is similar for all five climate zones, consisting of R-30 ceilings, R-13 walls, and single-pane windows. The required window shading coefficients are either unrestricted for Zone 2 or 0.40 for the south- and west-facing windows in the other four zones.

A recent CEC study (Byrne, Huang, and Cunningham 1992) used survey data to derive average house sizes and construction practices by Demand Forecast Office (DFO) Zones. These DFO zones follow utility district boundaries and are different from the CTZ zones defined for Title 24 calculations (see Figure 23). The "transition" climate zone falls within DFO Zone 4 in the northern part of the state, and Zones 8, 9, and 10 in the southern part of the state (by coincidence, some of these DFO zone numbers correspond to those for CTZ climate zones, but their zone boundaries are different). Excerpts from the unpublished draft final report for that project indicate current construction in the DFO zones follow closely Title 24 packages, with slightly less than R-30 in the ceilings, R-13 in the walls in the north and R-11 in the south, no slab insulation, and single-pane windows with a 0.89 shading coefficient (see Table 5). The ratios of roof to floor area (73% in the north and 70% in the south) indicate that the housing stock is divided equally between one- and two-story houses. The utility surveys indicate an average of three to four occupants per house, and an average house size of 1900 ft^2 in the north and 1790-2330 ft^2 in the south (see Table 6).

In an unrelated project, CEC's Building Energy Standards office conducted various studies of the current housing stock and developed a prototypical house for use in their Title 24 energy calculations (Salazar and Ware 1990). As shown in Figure 24, this building is a two-story house, with a floor area of 1761 ft^2 (925 ft^2 on the ground floor and 836 ft^2 on the second floor), a window area of 352 ft^2, and an attached garage.

PROTOTYPICAL BUILDINGS

After reviewing the above information, two prototypical buildings have been developed for the "transition" climate zone and used in this preliminary assessment of alternative cooling strategies. The first prototype is a large two-story 2200 ft^2 house with a narrow frontage indicative of the smaller lot sizes in the state today (see Figure 25). The architectural details are modified from actual house plans for a housing development in West Covina by Lewis Homes. The second prototype is a one-story 1544 ft^2 ranch house more representative of a starter home (see Figure 26). The architectural details are taken from an actual 1980's vintage house in Sacramento monitored in an earlier CIEE project (Akbari et al. 1992).

Both houses have slab-on-grade foundations, and conservation levels required by the Title 24 energy standards (see Table 7). Neither building has significant exterior shading, but are modeled with similar neighboring buildings on the adjoining lots. Prototype 1 has an an attic only over the bedrooms, but Prototype 2 has a full attic over the entire living area. Attic ventilation is modeled using the Sherman-Grimsrud Infiltration Model, with a leakage area adjusted to produce peak attic temperatures that correspond roughly with measured data.[2]

The internal load conditions of the two prototypical houses are based on previous LBL work and assumes energy use intensities derived from PG&E metered data (PGE 1987). Prototype 1 is modeled with three, and Prototype 2 with two occupants. The windows are modeled with medium density drapes partially closed (shading coefficient of 0.60) throughout the summer. An internal "furniture weight" of 5.5 lb/ft^2 is modeled based on information obtained from two local moving companies.[3]

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2. Measured peak attic temperatures in California houses are typically 125 to 140°F. (personal communication, Mark Modera, LBL, 1992).
3. We called a local and a long-distance moving company about the amount of furnishings in a typical house. The estimate by the long-distance moving company was more helpful since they charge by weight, while local companies charge by the hour (personal communications, North America Moving Co., 1993).

PRELIMINARY ASSESSMENT OF ALTERNATIVE COOLING STRATEGIES

DOE-2.1E

The 2.1E version of DOE-2 is used for the simulations to take advantage of its better modeling of window glazing properties and summer solar heat gains. This new version of DOE-2 has an extensive window library with the solar-optical and thermal properties of 200 different glazings, including low-E, gas-filled, heat mirror, superwindows, and electrochromics. In addition, the WINDOW-4 calculation for window conduction and solar gain has been integrated into the program. DOE-2.1E also has improved calculations of the outside air film conductance, and the long-wave radiation from the surface. These improvements produced a 50% decrease in the outside air film U-value compared to the earlier 2.1D program, and significantly greater heat gains through the building shell during the summer.

PARAMETRIC SIMULATIONS

Simulations are done for the two prototypical new houses with CTZ weather tapes for the following three "transition climates" : CTZ02 (Santa Rosa), CTZ09 (Pasadena), CTZ10 (Riverside). In addition, simulations are also done for CTZ12 (Sacramento) to provide comparisons to a Central Valley climate. For each building/climate combination, the simulations are done for the base case building, and then repeated for the following single shell improvements :

Case 1	increased ceiling and wall insulation
Case 2	selective low-emissivity glazing
Case 3	light-colored surfaces
Case 4	half-exposed floor slab
Case 5	window overhangs

and finally for the following combined shell improvements :

Case 1+2	added insulation and low-E glazing
Case 1+2+3	add light-color surfaces
Case 1+2+3+4	add half-exposed floor slab
Case 1+2+3+4+5	add window overhangs

The results from the single building shell improvements indicate the effect of each individual strategy on improving the indoor conditions of the prototypical buildings in different climates. The results from the combined shell improvements indicate how well do the various measures work in combination. The combined strategies are neither inclusive nor optimized for the building design and climate condition. The ordering of the measures is by their perceived obtrusiveness or public acceptance, rather than by their energy performance. For example, insulation measures are considered first because they are invisible to the occupants, while the exposed floor slab is considered last because it is very visible and may entail some change in the occupant lifestyle.

For each configuration, the prototypical houses are simulated with the following modes of operation : (a) standard air-conditioning, (b) no cooling and windows closed all day, (c) no cooling but window venting when beneficial, and (d) no cooling but mechanical venting providing a steady 20 air-changes per hour when beneficial. For the base case building, additional simulations are done with a direct and a two-stage evaporative cooler. For the final package, henceforth referred to as the "improved case" for convenience, three evaporative cooling options are simulated : direct, two-stage, and an indirect-only evaporative cooler.

The purpose of most building energy simulations is to determine the total or savings in space-conditioning energy use for a particular conservation strategy. Such an emphasis, however, is not appropriate for this project which has the goal of eliminating the air-conditioning system. Although a compressorless house can be expected to produce dramatic savings in cooling energy use, their success and public acceptance depend more on their ability to maintain indoor comfort during peak summer conditions. Therefore, the emphasis in this scoping study has been placed on evaluating the "comfort performance" of the house and cooling system. This comfort performance is evaluated by studying the hourly temperatures and humidity ratios in the living space for two peak and two typical summer periods of five days each. The conditions within the occupied space are assumed to be uniform and temperature gradients or asymmetries in mean radiant temperatures have been ignored. The simulations with an air-conditioner are done primarily to determine the building's cooling load. However, the simulated electricity consumption for the air-conditioner or evaporative cooler are still reported for reference purposes.

Building Shell Improvements :

1. *Increase ceiling and wall insulation.* The insulation level of the ceiling is increased from R-30 to R-38, and that of the wall from R-11 or R-13 to R-19. The R-19 wall assumes a change from standard 2x4 16" on-center to 2x6 24" on-center construction.

2. *Selective low-emissivity glazing.* Replace the base case double-pane clear glazing (U-value 0.49 Btu/ft^2·h·°F, shading coefficient 0.89) with argon-filled selective low-E glazing. Selective low-E glazings are effective in cooling climates because they are transparent in the visible spectrum, but reflect most of the other parts of the solar spectrum. Such low-E glazings have a U-value of 0.24, a low shading coefficient of 0.50, and an emissivity of 0.04. In contrast, typical double-pane low-E windows have a U-value of 0.30, but a shading coefficient of 0.86 and a emissivity of 0.20.[4] Initial simulations with standard low-E windows showed slight increases in cooling loads compared to the base case double-pane windows.

4. Personal communications with Dariush Arasteh, LBL, Fall 1993.

3. *Increase albedo of the wall and roof.* The base case buildings are assumed to have a roof albedo of 0.16 and a wall albedo of 0.50, corresponding to dark shingles and medium-colored walls. For the parametric analysis, the albedo of the roof and the walls is increased to 0.75, corresponding to either a white roof or walls with off-white color paint.

4. *Exposed floor slab.* The base case buildings are assumed to be carpeted. To increase the thermal stability and the capacity of the floor slab to store night-time cooling, half of the floor is modeled as exposed. Only half of the floor is modeled as exposed because in all likelihood much of the floor will be covered by either area rugs or furniture. The exposed floor slab can be either bare concrete, or more likely, a ceramic tile floor.

5. *Window overhangs.* The base case buildings do not have any overhangs over the windows. For the parametric analysis, one foot overhangs are added over the south, east, and west windows. Since the Prototype 1 house has large west windows, one foot vertical fins are also added to those windows.

System and Control Options :

a. *Air-Conditioner.* For Prototype 1, the air-conditioner is modeled as a 3-ton unit with a 1050 CFM fan and an COP of 2.7. For Prototype 2, a 2½ ton unit with a 1060 CFM fan and an COP of 2.1 has been modeled. Natural ventilation is assumed if it can meet the building loads; otherwise, the windows are closed and the A/C is turned on. The ducts are assumed to be insulated and located in the attic. The efficiency of the air distribution system is modeled as varying with the attic temperature, and based on regression analyses of detailed simulations provided by Mark Modera of LBL (for details, see Byrne et al. 1992).

b. *Windows closed.* The building is modeled with windows closed at all hours and no cooling system of any kind. This condition provides the worst case condition against which the effectiveness of other system and control options can be compared.

c. *Window venting.* The building is modeled with natural ventilation through open windows if the building is overheating and the enthalpy of outside air is lower than that inside. The amount of natural ventilation is calculated using the Sherman-Grimsrud infiltration model for a "leakage area" 1/4 of the total window area, and a discharge coefficient of 0.60. Inside-film coefficients for still air are used for these simulations.

d. *Forced venting.* To model mechanical venting, a function has been added to the DOE-2 Systems program to introduce 20 air changes per hour of outside air whenever the outside air temperature is lower than the indoor air temperature the previous hour, and still above 65°F to avoid overcooling the inside space. To account for the better thermal coupling between the air and the building mass due to this air flow rate, inside-film coefficients for 20 ach of air motion are used for these simulations.[5]

e. *Evaporative cooler.* The evaporative cooler is modeled using a heat- and mass-transfer model developed at LBL and installed in a developmental version of the DOE-2 program (Chen et al. 1992, Huang et al. 1992). Both the direct and two-stage units are modeled with a primary fan size of 3500 CFM, and a 7% duct loss estimated assuming 25 ft. of ducts. The evaporative cooler is modeled with a thermostatic control set at the same 78°F as assumed for the air-conditioner. As in the case of the A/C, natural ventilation is assumed if it can meet the building load. Furthermore, the two-stage unit is assumed to operate only in the direct stage if possible, and switches to two-stage only as required to maintain the indoor set temperature.

SIMULATION RESULTS

The following DOE-2 simulation results are saved : (1) total, latent, and peak cooling loads (for A/C only), vented cooling load (for A/C and evaporative cooling) , electricity use (for A/C or evaporative cooling), and water use (for evaporative cooling only); (2) number of hours and average humidity ratio above 78°F binned by temperature; and (3) hourly data of indoor and outdoor conditions (temperatures and humidity ratio), electricity use (for A/C or evaporative cooling), and water use (for evaporative cooling only) for two peak and two average cooling periods.

The results for Prototype 1 in CTZ02 (Santa Rosa) and CTZ09 (Pasadena), and Prototype 2 in CTZ10 (Riverside) and CTZ12 (Sacramento), are presented in various tables and figures. Tables 8 through 11 show the cooling loads in MBtu's and cooling electricity use in kWh for the various cases if the house had air-conditioning. In addition, the energy consumptions for the "base case" and "improved case" with an evaporative cooler are also shown. Tables 12 through 15 show the number of overheated hours for one degree F temperature bins above 78°F under three operating conditions - windows closed, window or natural ventilation, and mechanical or forced ventilation. For the "base case" and "improved case", the number of overheated hours by temperature bin are also shown for the houses with evaporative cooling. For the mechanical venting and

5. More details on the impact of different inside-film coefficients from air motion on thermal storage effects and building energy performance are presented in a separate project report (Winkelmann and Huang 1995).

evaporative cooling options, the numbers in parenthesis on Tables 12 through 15 give the average indoor humidity ratios (x 1000) during the overheated hours.

Plots of the hourly indoor and outdoor temperatures are shown in Figures 27 through 66. Figures 27 through 58 are in sets of four for different building types, weather conditions, and locations : Figs. 27-30 for the Prototype 1 house in Santa Rosa during two peak summer periods and Figs. 31-34 during two average summer periods, Figs. 35-38 for the Prototype 1 house in Pasadena during two peak summer periods and Figs. 39-42 during two average summer periods. Figs. 43-46 the Prototype 2 house in Riverside during two peak summer periods, and Figs. 47-50 during two average summer periods, and finally Figs. 51-54 the Prototype 2 house in Sacramento during two peak summer periods, and Figs. 55-58 during two average summer periods.

The first figure of each set, e.g., Figure 27, shows the indoor, attic, and outdoor temperatures for the base case building with A/C, then with no cooling and either windows closed, window opened, or mechanical venting, and finally with direct and indirect/direct evaporative cooling. The second figure of each set, e.g., Figure 28, shows indoor temperatures for the single shell measures with no cooling and either windows closed, window opened, or mechanical venting. The third figure of each set, e.g., Figure 29, shows indoor temperatures for combined shell measures, also assuming no cooling and either windows closed, window opened, or mechanical venting. The last figure of each set, e.g., Figure 30, has the same format as the first figure and shows the indoor, attic, and outdoor temperatures for the "improved case" building with A/C, then with no cooling and either windows closed, window opened, or mechanical venting, and finally with direct and indirect/direct evaporative cooling.

Figures 59 and 60 show the decreases in indoor temperature for the Prototype 1 house in Santa Rosa and Figures 61 and 62 for the Prototype 2 house in Riverside during two typical summer periods with window venting due to single and then incremental shell improvements. Figures 63 through 66 repeat the same plots for two peak summer periods.

DISCUSSION

Ventilation Controls

The hourly temperature plots show large differences in the houses between having the windows closed all day or opened to provide natural ventilation. For the base case Prototype 1 in Santa Rosa, natural ventilation reduces peak indoor temperatures by 4.5°F, nighttime temperatures by as much as 10°F (see Figs. 27 and 31), and the number of overheated hours above 78°F by 63% from 1917 to 705 (see Table 12). The temperature reductions for Prototype 1 in Pasadena are similar, with the number of hours above 78°F decreasing by 68% from 2012 to 641 (see Table 13). For Prototype 2 in Riverside and Sacramento, the reductions in peak and minimum temperatures are 4 to 5°F and 8 to 9°F (see Figs. 43, 47, 51, and 55). The slightly smaller temperature reductions are due to the greater thermal coupling to the floor slab in an one-story building. The number of overheated hours above 78°F decreases by 62% from 1928 to 733 in Riverside and 72% from 1394 to 386 in Sacramento (see Tables 14 and 15). Since nighttime temperatures in the "transition climates" fall to the comfort zone even on the hottest days, natural ventilation is nearly always beneficial and effective. The benefits shown for window venting should be regarded as the maximum theoretical potentials since the simulations assume that the occupants are both intelligent (opening windows only when outside enthalpy is lower than that indoor) and diligent (opening windows on all days and at all hours).

Compared to the optimal window operations just described, mechanical ventilation providing 20 air changes per hour produces only slight further improvements in indoor comfort. In the Prototype 1 house, both the indoor peak and minimum temperatures are lowered by another 1.5 to 2°F compared to when natural ventilation is used. In the Prototype 2 house, the reductions are slightly greater, about 3°F. The reason that the minimum temperatures are not further reduced is that mechanical ventilation is stopped at 65°F to avoid overcooling the house at night. Because of this constraint, the improvement in indoor comfort going from natural to mechanical ventilation is relatively small. However, on a practical level the comfort benefits of mechanical ventilation are more achievable since it does not depend on occupant management of windows, nor does it present security risks as with windows left open at night.

It is quite apparent from the hourly temperature plots on Figs. 27 to 58 that, in the "transition climates", keeping the windows closed all day incurs large penalties in terms of either energy use or thermal comfort. For example, Figure 31 shows that, for a closed house on typical summer days in Santa Rosa, the outdoor temperatures are lower than that indoor for 19 hours out of the day, and also lower than 78°F for 14 of those hours. The effectiveness of ventilation in the "transition climates" is also apparent on Tables 8 through 11, which show that the "vented" cooling loads are from two to five times that of the remaining cooling load. These imply that natural or mechanical ventilation should always be utilized as a comfort or energy managing strategy in such climates. Because of its greater reliability, the following discussion on shell improvements assumes mechanical ventilation is used.

Single Shell Improvements

The parametric study of single shell improvements indicates that individually they produce only moderate reductions in peak indoor temperatures and cooling loads. For the Prototype 1 house in CTZ02 (Santa Rosa) with mechanical ventilation, selective low-E glazing reduces peak indoor temperatures by 3.5°F, light-colored surfaces by around 2°F, and half-exposed floor slab by 2.5°F, and overhangs by 2°F (see Table 18, Figs. 28, 32 and 59). The temperature reductions in CTZ09 (Pasadena) have the same trends but are smaller by 30% due to the lower air temperatures (see Table 19, Figs. 36 and 40). If the two-story house is equipped with an air-conditioner, its cooling loads will be reduced from 21 to 43%, with selective low-E glazing having the largest effect - 42% in CTZ02 and 43% in CTZ09. The cooling load reductions are 33% and 35% for overhangs, 28% and 26% for light-colored roof and walls, and 21% in both climates for a half-exposed floor slab (see Tables 8 and 9).

For the Prototype 2 house in CTZ10 (Riverside) with mechanical ventilation, selective low-E glazing reduces peak indoor temperatures by 1.5°F, light-colored surfaces by 2 to 2.5°F, half-exposed floor slab by 1.8 to 3°F, and overhangs by less than 1°F (see Table 20, Figs. 44 and 48). The temperature reductions in CTZ12 (Sacramento) are similar except for a larger effect from low-E glazing (see Table 21, Figs. 52 and 56). If the one-story house is operated with an A/C, the cooling loads will be reduced from 13 to 43%, with light-colored roof and walls having the largest effect - 42% in CTZ10 and 43% in CTZ12. The reductions are 27% and 39% for half-exposed floor slab, 26% and 35% for selective low-E windows, and 13% and 18% for window overhangs (see Tables 10 and 11). Compared to the Prototype 1 house, selective low-E glazing and overhangs are less effective simply because the Prototype 2 house has fewer windows.

Overall, the comfort improvements for light-colored roof and walls are significant for all buildings and climates studied. Selective low-E glazing and window overhangs are particularly effective in houses like Prototype 1 that have large amounts of windows. Exposed floor slabs are more effective in one-story houses like Prototype 2 or in climates with large day-time temperature swings.

Combined Shell Improvements

The parametric study of combined shell measures indicate the effects of individual shell measures are additive and can produce much greater improvements in indoor comfort when applied in unison.

For the Prototype 1 house in CTZ02 (Santa Rosa) with mechanical ventilation, the peak indoor temperature on the hottest day can be reduced 9°F from an unbearable 94°F in the base case to 85°F in the "improved case", but still 7° above the comfort zone. The average indoor temperature over the two five-day peak periods falls 3°F from 76.5°F in the base case to 73.5°F in the "improved case" (see Table 18, Figs. 27, 30, and 64). Over the entire cooling season, the number of overheated hours above 78°F drops from 572 to 73 hours, and the number of hours over 82°F from 337 to just 16 hours (see Table 12). Expressed in terms of annual frequencies, 73 and 16 hours correspond to 0.8% and 0.2%, satisfactory for the lenient 2% or 0.5% design criteria, but not the more stringent 0.1% design criterion.

If the house is air-conditioned, its cooling loads will drop by 86% from 7.7 to 1.1 MBtu, of which 3.2 MBtu of the reduction can be attributed to selective low-E glazings, 0.7 MBtu to increased insulation, 1.3 MBtu to light-colored roof and walls, 0.7 MBtu to exposing half of the floor slab, and 0.6 MBtu to window overhangs. The corresponding cooling electricity use with an air-conditioner will fall from 1400 to 300 kWh (see Table 8).

The results are similar for the same Prototype 1 house in CTZ09 (Pasadena), with maximum indoor temperatures dropping 7°F from 88°F to 81°F, and average temperatures dropping 2½°F from 74.5°F to 72°F (see Table 19, Figs. 35 and 38). The number of overheated hours above 78°F drops from 508 to 59 (0.7%), and the number of hours above 82°F from 228 to 0 (see Table 13). If the house had air-conditioning, the cooling loads will decrease 87% from 6.4 MBtu in the base case to just 0.8 MBtu in the "improved case".

For the Prototype 2 house in CTZ10 (Riverside), the peak indoor temperature on the hottest day can be reduced 7°F from 88°F to 80°F, only slightly above the comfort zone. The average indoor temperature over the two peak cooling periods is reduced 3°F to 72.4°F. (see Table 20, Figs. 35, 38, and 66). Over the cooling season, the number of overheated hours over 78°F falls from 336 hours to 35 hours, and the number of hours over 82°F from 146 to 0 hours (see Table 14). Since this represents an annual frequency of only 0.4%, the "improved case" Prototype 2 house in Riverside will be very close to not requiring an air-conditioner.

If the Prototype 2 house is air-conditioned, the cooling loads will drop by 84% from 4.1 to 0.7 MBtu, with selective low-E glazings, increased insulation, and light-colored roof and walls each saving about 1 MBtu. The cooling reductions from exposing half of the floor slab and window overhangs are much less. The corresponding air-conditioning electricity use will be reduced from 1130 to only 190 kWh (see Table 10).

The results are similar for the Prototype 2 house in CTZ12 (Sacramento), with the peak indoor temperature dropping 8°F and the average dropping 2.5°F (see Table 21, Figs. 51 and 54). The number of overheated hours above 78°F dropped from 228 to 12, with no hours above 80°F (see Table 15). If the house had air-conditioning, the cooling loads will drop from 2.48 MBtu to practically nil (0.25 MBtu). Both the paucity of overheated hours and the tiny cooling load indicate that the Prototype 2 house does not require air-conditioning in Sacramento.

Evaporative Cooling :

Since mechanical ventilation alone cannot completely eliminate overheating in the Prototype 1 house (particularly in Santa Rosa, see Figs. 34 and 42), evaporative cooling may be needed as an alternative cooling strategy to meet the residual load. The simulations show that a direct evaporative cooler on the "improved case" house will leave 26 hours (0.3%) of overheating in CTZ02 (Santa Rosa, see Table 12). An indirect-only unit will be worse, leaving 91 overheated hours (1.0%) but maintaining the indoor humidity at a low level. A two-stage indirect/direct cooler will be able to maintain the house at 78°F at all times of the year, with a moderate increase in the indoor humidity. The results for

Pasadena are similar, except that a direct evaporative cooling will leave only 9 hours of overheating, equivalent to a 0.1% design criterion (see Table 13).

Mechanical ventilation also does not eliminate overheating in the smaller Prototype 2 house in CTZ10 (Riverside) and CTZ12 (Sacramento), but the numbers of overheated hours are smaller (35 in Riverside, 12 in Sacramento). Surprisingly, direct evaporative cooling is still not able to eliminate overheating completely, possibly because of the high coincident wet-bulb temperatures. As in the Prototype 1 house, two-stage indirect/direct evaporative coolers will have no difficulty in maintaining indoor temperatures at 78°F (see Tables 14 and 15).

In terms of energy consumption, two-stage evaporative coolers in the "improved case" houses use half the energy of standard air-conditioning, but both are minimal (as much as 300 kWh for A/C, 150 kWh for E/C). In terms of peak electricity consumption, there is little difference between the two options (up to 2.5 kW for A/C, 1.7 kW for EC). However, it is premature to conclude there's no peak savings in switching from air-conditioning to evaporative cooling since the analysis does not investigate the possibility of downsizing the evaporative cooling system.

CONCLUSIONS

The objective of this report is to make a preliminary assessment of alternative cooling strategies for houses in California "transition climates", but not to provide specific design guidelines or identify optimum combinations of strategies. Based on the simulation results, the following observations can be made :

1. All the shell strategies studied are effective to some degree depending on the building and climate characteristics, with none that is clearly more effective. The effectiveness of a single strategy is limited and at most lowers indoor peak temperatures by no more than 3°F.
2. Other than low-E windows and window overhangs, the effects of individual cooling measures are additive and can produce significant improvements in indoor comfort when used in combination. Peak indoor temperatures can be reduced by up to 9°F, and cooling loads reduced by over 80%. However, during occasional peak periods, temperatures will rise above the ASHRAE comfort zone. Guidelines are needed on the appropriate design criteria to prevent overdesign while still maintaining an acceptable level of comfort.
3. The use of either natural or mechanical ventilation is highly effective in improving indoor comfort. In terms of temperature control, mechanical ventilation is only marginally better, unless building occupants are willing to tolerate temperatures below 65°F at night. The choice of ventilation strategy should be based on other factors such as noise (street noise through windows or fan noise), security, and convenience. The last consideration is important since the simulations assume optimal

window operations at all times.

4. Ventilation alone cannot prevent overheating during peak summer conditions even in the "improved case" buildings. In one instance (two-story house in Santa Rosa), there is some overheating even on typical summer days.
5. Two-stage evaporative coolers can keep indoor temperatures at 78°F in all house types and climates studied. However, direct and indirect-only evaporative coolers are problematic because their poor performance during peak summer conditions resulted in indoor temperatures rising up to 80°F.
6. It is important to select the appropriate low-E glazing for the climate. Low-E glazings that maximize R-value are effective in cold or very hot climates with large indoor-outdoor temperature differences, but not in mild sunny California climates. The simulations show that high R-value low-E glazing reduce cooling loads in the four California "transition climates" by only 4 to 8%, while selective low-E glazing reduce them by 25 to 40%. Another LBL researcher has pointed out that in some instances low window U-values can actually increase cooling loads by trapping heat in the house during morning and evening hours (Sullivan et al. 1993).
7. The shell and ventilation methods investigated can greatly reduce, but in most cases not eliminate entirely, the building cooling load. The reductions in annual loads are greater than in peak cooling loads. Comparing the "base case" to the "improved case" Prototype 1 house in Santa Rosa, annual cooling loads decreased by 86%, while the peak loads dropped by 35% from 3.8 to 2.5 kW.
8. The evaluation of indoor comfort has been based primarily on the indoor air temperature and, to a limited extent, on humidity. In future work, more investigation is needed on the effects of the mean radiant temperature and humidity on human comfort. The simulations indicate that while two-stage evaporative coolers can maintain temperatures at 78°F, the resultant relative humidity of 70 to 80% is outside the current ASHRAE comfort zone. The relationship of humidity to comfort is examined in a related report by UC Berkeley (Arens et al. 1994).

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Table 1. ASHRAE Design Temperatures for Selected Locations in the Transition Climate
(from *Climatic Data for Region X*, by the Golden Gate and S. Calif. Chapter, ASHRAE,1982)

				Design DBT/Coinc. WBT			Temp	Design WBT		
Location	Lat	Lon	Alt	0.1%	0.5%	2.0%	Range	0.1%	0.5%	2.0%
NORTHERN CALIFORNIA										
Climate Zone 2										
Duttons Landg	122.3	38.2	20	96/68	91/66	84/64	31	70	68	66
Graton	122.9	38.4	200	95/68	91/67	82/64	34	70	68	65
Lakeport	122.9	39.0	1347	97/67	93/66	88/63	41	69	67	64
Napa	122.3	38.3	60	94/67	91/67	86/66	29	71	70	68
Petaluma	122.6	38.2	16	98/69	92/67	85/66	31	72	69	67
Rohnert Park	122.7	38.4	106	99/69	96/68	92/66	33	71	69	67
Santa Rosa	122.7	38.5	167	99/69	96/68	92/66	35	71	69	67
Sonoma	122.5	38.3	70	101/70	96/69	90/67	40	72	70	68
St. Helena	122.5	38.5	225	102/70	98/69	93/67	40	72	70	68
Ukiah	123.2	39.2	623	100/70	97/69	92/68	42	72	71	69
Willits	123.3	39.4	1350	95/66	89/65	82/62	38	68	66	63
Climate Zone 3										
Mill Valley	122.6	37.9	80	97/68	91/66	84/64	28	70	68	66
Oakland	122.2	37.8	6	91/66	84/64	77/62	20	67	65	62
San Francisco AP	122.4	37.6	8	89/66	83/64	74/61	20	67	64	61
Climate Zone 4										
Gilroy	121.6	37.0	194	101/70	93/68	86/65	25	72	69	66
King City	121.1	36.2	320	94/67	90/65	85/64	36	70	68	65
Milpitas	121.9	37.4	15	94/68	87/65	79/63	27	70	67	64
Morgan Hill	121.6	37.1	350	100/69	92/68	85/66	25	71	69	67
San Jose	121.9	37.4	67	94/68	86/66	78/64	26	70	68	65
Saratoga	122.0	37.3	500	96/67	88/66	80/65	31	70	68	66
Sunnyvale	122.0	37.4	97	96/68	88/66	80/64	26	70	68	65
Climate Zone 12										
Antioch	121.8	38.0	60	102/70	97/68	91/66	34	70	69	67
Benicia	122.2	38.1	55	99/69	93/67	87/65	30	70	68	65
Concord	122.1	38.0	195	102/70	97/68	89/65	34	71	68	66
Crockett	122.2	38.0	9	96/68	90/66	85/64	23	70	67	65
Davis	121.8	38.5	60	103/72	99/70	93/68	41	74	71	69
Dixon	121.8	38.5	100	104/72	99/70	93/68	36	74	71	69
Dublin	121.9	37.7	200	99/69	93/67	86/65	35	70	68	66
Fairfield	122.0	38.3	38	103/69	98/68	91/66	34	73	71	68
Lafayette	122.1	37.9	535	100/69	94/67	87/66	32	71	69	67
Livermore	121.8	37.7	490	100/69	95/68	88/67	35	71	70	68
Martinez	122.1	38.0	40	99/67	94/66	88/65	36	71	69	67
Moraga	122.1	37.8	600	99/68	93/66	86/64	27	70	68	65
Orinda	122.2	37.9	550	99/68	93/66	86/64	32	70	68	65
Pittsburg	121.9	38.0	50	102/70	97/68	90/67	34	72	70	68
Pleasant Hill	122.1	38.0	102	96/68	93/67	88/65	34	70	68	65
Pleasanton	121.9	37.7	350	97/68	94/67	89/65	35	70	68	66
Sacramento	121.5	38.5	17	104/72	100/70	94/68	35	74	71	69
Travis AFB	121.9	38.3	72	103/71	98/69	91/66	35	73	70	67
Vacaville	122.0	38.4	105	103/71	100/70	94/68	40	73	71	69
Walnut Creek	122.0	37.9	245	100/69	94/67	87/66	32	71	69	67

Table 1. ASHRAE Design Temps. for Selected Locations in the Transition Climate (Cont.)
(from *Climatic Data for Region X*, by the Golden Gate and S. Calif. Chapter, ASHRAE, 1982)

Location	Lat	Lon	Alt	Design DBT/Coinc. WBT 0.1%	0.5%	2.0%	Temp Range	Design WBT 0.1%	0.5%	2.0%
SOUTHERN CALIFORNIA										
Climate Zone 6										
Los Angeles AP	118.4	33.9	97	91/67	84/67	79/66	14	71	69	67
Long Beach AP	118.2	33.8	34	97/70	88/68	82/65	21	73	71	68
Climate Zone 8										
Anaheim	117.9	33.8	158	99/69	92/68	85/67	26	73	71	69
Cerritos	118.1	33.9	34	99/71	92/69	85/68	23	73	71	69
Commerce	118.2	34.0	175	98/69	92/68	86/67	23	72	70	68
Culver City	118.4	34.0	106	96/70	88/69	83/67	18	72	70	68
Downey	118.1	33.9	110	98/71	90/70	84/68	21	73	71	69
El Toro	117.7	33.7	380	96/69	89/69	82/68	26	73	71	69
Fullerton	118.0	33.9	340	100/70	94/69	87/68	26	73	71	69
Garden Grove	117.9	33.8	85	98/70	91/68	84/67	23	72	70	68
Mission Viejo	117.7	33.6	350	95/67	87/66	81/63	22	71	67	64
Orange	117.9	33.8	194	99/70	92/68	85/67	27	72	70	68
Placentia	117.9	33.9	323	101/69	93/68	87/67	28	73	71	69
Climate Zone 9										
Alhambra	118.2	34.1	483	100/71	96/70	90/68	25	73	71	69
Arcadia	118.0	34.1	475	100/69	96/68	91/67	30	73	71	69
Azusa	117.9	34.1	605	101/70	97/69	91/68	36	74	72	70
Beverly Hills	118.4	34.1	268	94/69	88/68	83/66	20	71	69	67
Burbank	118.4	34.2	699	101/70	96/68	90/67	28	72	70	68
Claremont	117.7	34.1	1201	101/69	97/68	91/66	34	73	71	69
Diamond Bar	117.8	34.0	880	101/69	97/68	92/66	33	73	71	69
El Monte	118.0	34.1	271	101/71	97/70	91/68	30	73	71	69
Glendale	118.3	34.2	563	101/70	96/68	90/67	28	73	71	69
Los Angeles	118.2	34.1	270	99/69	92/68	86/67	21	72	70	68
Monterey Park	118.1	34.1	380	99/69	94/68	87/67	23	72	70	68
N. Hollywood	118.4	34.2	619	102/70	97/69	91/67	31	73	71	69
Ojai	119.2	34.5	750	102/71	97/69	91/68	38	73	71	69
Pasadena	118.2	34.2	864	99/69	94/68	88/67	30	73	71	69
Pomona	117.8	34.1	740	102/70	98/69	93/67	36	74	72	70
Rosemead	118.1	34.1	275	98/70	90/69	84/67	27	72	70	68
San Fernando	118.5	34.3	977	104/71	99/70	94/68	37	74	72	70
San Gabriel	118.1	34.1	450	99/70	94/69	88/68	30	73	71	69
Simi Valley	118.8	34.3	500	98/70	93/68	87/66	30	73	71	69
Walnut	117.9	34.0	550	101/70	97/69	92/69	30	74	72	70
West Covina	118.0	34.1	365	102/70	98/69	92/68	34	74	72	70
Whittier	118.0	34.0	320	99/69	90/68	84/67	24	72	70	68
Climate Zone 10										
El Cajon	117.0	32.8	525	96/70	91/69	87/67	30	72	70	68
Escondido	117.1	33.1	660	97/69	90/68	84/67	29	72	70	68
Ontario	117.6	34.1	934	105/70	101/69	95/66	34	74	72	70
Redlands	117.2	34.1	1318	106/70	102/69	98/67	34	74	72	70
Riverside	117.4	34.0	840	104/70	100/69	95/65	37	74	72	68
San Bernardino	117.3	34.1	1125	106/70	102/69	98/68	39	75	72	69

Table 2. Comparison of Design Temperatures for CEC Climate Zones

Climate Zone	Unrevised weather data 0.1%	0.5%	2.0%	Revised weather data 0.1%	0.5%	2.0%	ASHRAE Design Data 0.1%	0.5%	2.0%
	Design Drybulb and Mean Coincident Wet Bulb Temperatures								
1 Arcata	72/61	66/58	63/58	74/66	72/65	68/63	75/61	69/59	65/58
2 Santa Rosa	102/69	98/67	94/67	99/66	95/65	90/63	99/69	96/68	92/66
3 Oakland	81/61	77/62	73/62	88/66	83/65	77/66	91/66	84/64	77/62
4 Sunnyvale	91/66	83/64	76/65	95/69	89/71	84/70	96/68	88/66	80/64
5 Santa Maria	95/63	84/60	75/62	88/75	83/65	78/63	90/66	83/64	78/61
6 Long Beach*	93/61	89/64	83/70	85/71	82/68	78/67	99/71	90/69	84/66
7 San Diego	91/59	83/63	77/69	87/67	85/69	80/70	88/70	83/69	78/68
8 El Toro	95/66	90/68	86/67	94/72	91/69	87/68	96/69	89/69	82/68
9 Pasadena	95/66	93/68	88/71	101/71	96/70	91/71	99/69	94/68	88/67
10 Riverside	105/68	100/64	95/65	102/65	99/66	94/69	104/70	100/69	95/65
11 Red Bluff	114/72	106/67	99/68	102/63	100/64	95/67	107/70	104/69	98/66
12 Sacramento	102/73	99/68	93/70	102/70	98/67	93/67	104/72	100/70	94/68
13 Fresno	103/67	101/68	97/69	104/69	102/69	98/70	104/73	101/71	97/68
14 China Lake	109/67	107/66	103/67	104/63	102/63	98/62	112/70	108/69	104/68
15 El Centro	115/68	112/71	108/72	114/70	112/71	107/70	115/74	111/73	107/73
16 Mt. Shasta	97/65	91/62	85/63	93/64	91/64	86/66	93/62	89/61	84/59
	Mean Coincident Dry Bulb and Design Wetbulb Temperatures								
1 Arcata	70/62	66/60	63/58	72/68	70/66	67/63	61	60	58
2 Santa Rosa	98/73	96/70	99/67	92/69	89/67	90/65	71	69	67
3 Oakland	77/65	73/64	73/62	81/70	80/68	83/65	67	65	62
4 Sunnyvale	92/70	79/68	76/65	84/76	84/74	89/71	70	68	65
5 Santa Maria	81/65	79/64	76/62	81/72	77/68	78/65	67	65	62
6 Long Beach*	85/73	83/70	82/68	82/72	79/70	80/67	73	71	68
7 San Diego	85/72	76/71	77/68	84/77	81/74	79/70	72	70	68
8 El Toro	89/73	86/71	84/69	88/75	86/73	87/70	73	71	69
9 Pasadena	89/73	87/71	85/69	94/76	91/74	89/71	73	71	69
10 Riverside	89/72	92/71	93/68	93/72	91/71	96/68	74	72	68
11 Red Bluff	101/73	99/71	97/69	96/70	95/69	91/66	73	71	68
12 Sacramento	97/74	95/71	99/68	96/72	95/70	93/68	74	71	69
13 Fresno	98/73	95/72	99/69	102/75	96/73	99/70	75	73	70
14 China Lake	105/69	103/68	104/66	99/65	99/64	100/62	74	72	70
15 El Centro	95/78	99/76	104/75	105/76	101/75	110/73	81	79	77
16 Mt. Shasta	84/68	86/66	86/64	86/71	87/68	84/65	65	63	60

* Los Angeles Airport data used on revised weather tape.

Table 3. Alternative Component Packages from CEC Title-24 for Northern California Transition Climates (envelope section only)

Component	Package A	B	C	D	E
Climate Zone 2 :					
BUILDING ENVELOPE					
Insulation Minimums					
Ceiling	R30	R30	R49	R30	R30
Wall[1]	R13	R19	R29	R13	R13
"Heavy" Walls	(R2.3)	(R2.2)	NA	(R2.44)	(R2.44)
"Light Mass" Walls	[R4.5]	[R4.5]	NA	NA	NA
Slab Floor Perimeter	R7	R7	R7	NR	NR
Raised Floor	R13	R19	R30	R19[3]	R19
GLAZING					
Maximum U-value[12]	1.10	0.65	0.40	0.65	0.65
Maximum Total Area	NR	14%	16%	16%	16%
Maximum Total Nonsouth Facing Area	9.6%	NR	NR	NR	NR
Minimum South Facing Area	6.4%	NR	NR	NR	NR
SHADING COEFFICIENT					
South Facing Glazing	NR	NR	0.66	0.66	0.66
West Facing Glazing	NR	NR	0.66	0.66	0.66
East Facing Glazing	NR	NR	0.66	0.66	0.66
North Facing Glazing	NR	NR	0.66	0.66	0.66
THERMAL MASS[5]	REQ	NR	REQ	20%	5%
INFILTRATION CONTROL					
Continuous Barrier	NR	NR	NR	NR	NR
Air-to-Air Heat Exchanger	NR	NR	NR	NR	NR
Climate Zone 12 :					
BUILDING ENVELOPE					
Insulation Minimums					
Ceiling	R30	R30	R49	R38	R38
Wall[1]	R13	R19	R29	R19	R19
"Heavy" Walls	(R3.5)	(R3.5)	NA	(R4.76)	(R4.76)
"Light Mass" Walls	[R5.0]	[R5.5]	NA	NA	NA
Slab Floor Perimeter	NR	R7	R7	NR	NR
Raised Floor	R13	R19	R30	R19[3]	R19
GLAZING					
Maximum U-value[12]	0.65	0.65	0.40	0.65	0.65
Maximum Total Area	NR	14%	16%	16%	16%
Maximum Total Nonsouth Facing Area	9.6%	NR	NR	NR	NR
Minimum South Facing Area	6.4%	NR	NR	NR	NR
SHADING COEFFICIENT					
South Facing Glazing	0.40	0.40	0.66	0.66	0.66
West Facing Glazing	0.40	0.40	0.40	0.40	0.40
East Facing Glazing	NR	NR	0.40	0.40	0.40
North Facing Glazing	NR	NR	0.66	0.66	0.66
THERMAL MASS[5]	REQ	NR	REQ	20%	5%
INFILTRATION CONTROL					
Continuous Barrier	NR	NR	NR	NR	NR
Air-to-Air Heat Exchanger	NR	NR	NR	NR	NR

Table 4. Alternative Component Packages from CEC Title-24 for Southern California Transition Climates (envelope section only)

Component	Package A	Package B	Package C	Package D	Package E
Climate Zone 8 :					
BUILDING ENVELOPE					
Insulation Minimums					
Ceiling	R30	R30	R38	R30	R30
Wall[1]	R13	R19	R21	R13	R13
"Heavy" Walls	(R1.6)	(R1.5)	NA	(R2.44)	(R2.44)
"Light Mass" Walls	[R4.0]	[R4.5]	NA	NA	NA
Slab Floor Perimeter	NR	R7	R7	NR	NR
Raised Floor	R13	R19	R21	R19[3]	R19
GLAZING					
Maximum U-value[12]	1.10	0.65	0.50	0.75	0.75
Maximum Total Area	NR	14%	14%	20%	20%
Maximum Total Nonsouth Facing Area	9.6%	NR	NR	NR	NR
Minimum South Facing Area	6.4%	NR	NR	NR	NR
SHADING COEFFICIENT					
South Facing Glazing	NR	NR	0.66	0.66	0.66
West Facing Glazing	NR	NR	0.40	0.40	0.40
East Facing Glazing	NR	NR	0.40	0.40	0.40
North Facing Glazing	NR	NR	0.66	0.66	0.66
THERMAL MASS[5]	REQ	NR	REQ	20%	5%
INFILTRATION CONTROL					
Continuous Barrier	NR	NR	NR	NR	NR
Air-to-Air Heat Exchanger	NR	NR	NR	NR	NR
Climate Zone 9 :					
BUILDING ENVELOPE					
Insulation Minimums					
Ceiling	R30	R30	R38	R30	R30
Wall[1]	R13	R19	R21	R13	R13
"Heavy" Walls	(R1.4)	(R1.5)	NA	(R2.44)	(R2.44)
"Light Mass" Walls	[R4.0]	[R4.0]	NA	NA	NA
Slab Floor Perimeter	R7	R7	R7	NR	NR
Raised Floor	R13	R19	R21	R19[3]	R19
GLAZING					
Maximum U-value[12]	1.10	0.65	0.50	0.75	0.75
Maximum Total Area	NR	14%	14%	20%	20%
Maximum Total Nonsouth Facing Area	9.6%	NR	NR	NR	NR
Minimum South Facing Area	6.4%	NR	NR	NR	NR
SHADING COEFFICIENT					
South Facing Glazing	0.40	0.40	0.66	0.66	0.66
West Facing Glazing	0.40	0.40	0.40	0.40	0.40
East Facing Glazing	NR	NR	0.40	0.40	0.40
North Facing Glazing	NR	NR	0.66	0.66	0.66
THERMAL MASS[5]	REQ	NR	REQ	20%	5%
INFILTRATION CONTROL					
Continuous Barrier	NR	NR	NR	NR	NR
Air-to-Air Heat Exchanger	NR	NR	NR	NR	NR

Table 4. Alternative Component Packages from CEC Title-24 for Southern California Transition Climates (continued)

Component	Package A	B	C	D	E
Climate Zone 10 :					
BUILDING ENVELOPE					
Insulation Minimums					
Ceiling	R30	R30	R49	R30	R30
Wall[1]	R13	R19	R25	R13	R13
"Heavy" Walls	(R1.9)	(R2.0)	NA	(R2.44)	(R2.44)
"Light Mass" Walls	[R4.5]	[R4.5]	NA	NA	NA
Slab Floor Perimeter	R7	R7	R7	NR	NR
Raised Floor	R13	R19	R30	R19[3]	R19
GLAZING					
Maximum U-value[12]	1.10	0.65	0.40	0.75	0.75
Maximum Total Area	NR	16%	16%	20%	20%
Maximum Total Nonsouth Facing Area	9.6%	NR	NR	NR	NR
Minimum South Facing Area	6.4%	NR	NR	NR	NR
SHADING COEFFICIENT					
South Facing Glazing	0.40	0.40	0.66	0.66	0.66
West Facing Glazing	0.40	0.40	0.40	0.40	0.40
East Facing Glazing	NR	NR	0.40	0.40	0.40
North Facing Glazing	NR	NR	0.66	0.66	0.66
THERMAL MASS[5]	REQ	NR	REQ	20%	5%
INFILTRATION CONTROL					
Continuous Barrier	NR	NR	NR	NR	NR
Air-to-Air Heat Exchanger	NR	NR	NR	NR	NR

(from *Energy Efficiency Standards for Residential and Nonresidential Buildings,* California Energy Commission, July 1992)

LEGEND : NR = Not Required; NA = Not Applicable; REQ = Required

Notes :

1. The value in parentheses is the minimum R-value for the entire wall assembly if the wall weight exceeds 40 pounds per square foot. The value in brackets is the minimum R-value for the entire assembly if the heat capacity of the wall meets or exceeds the result of multiplying the bracketed minimum R-value by 0.65. The insulation must be integral with or installed on the outside of the exterior mass. The inside surface of the thermal mass, including plaster or gypsum board in direct contact with the masonry wall, shall be exposed to the room air. The exterior wall used to meet the R-value in parentheses cannot also be used to meet the thermal requirement.

5. If the package requires thermal mass, meet the requirements of Section 1451(f)4. When using the performance approach, the mass requirement for Package D is based on having 20 percent of the ground floor slab area exposed to conditioned space with no thermal resistance material on the surface. The remaining 90 percent of the ground floor slab area has a surface R-value of 2.0. The slab is composed of concrete at least 3.5 inches thick with 1a volumetric heat capacity of 29, a conductivity of 0.98, and a surface conductance of 1.3.

12. The glazing U-value rating procedures and labeling requirement of Section 116(a)2. go into effect on July 1, 1992, for all fenestration products except dual-pane, aluminum-frame fenestration products, for which the procedures and requirements are optional until July 1, 1993. During this one-year period: (1) if prescriptive package D or E is used, dual-pane, aluminum-frame glazing may be assumed to meet the U-value specified in the package used; (2) if a performance method is used, dual-pane, aluminum-frame glazing may be assumed to have the U-value specified in the package (D or E) on which the performance budget is based.

Table 5. Average Conservation Levels in 1983-1991 Vintage Single-family Houses by DFO Zones Based on Housing Stock Data

DFO	Roof R-value		Wall R-value		Slab	Glass	
Zone	Elec	Non-Elec	Cavity	Sheath	R-val	U-val	S-C
1	28.9	21.8	12.7	4.2	7	0.79	0.88
2	29.9	26.9	13.4	0.7	0	0.89	0.90
3	26.6	26.6	13.8	2.0	0	0.86	0.89
4	**28.5**	**24.7**	**13.2**	**1.6**	**0**	**0.82**	**0.89**
5	25.9	24.1	11.1	1.5	0	0.82	0.89
6	30.0	29.4	11.2	2.6	0	0.90	0.88
7	26.0	24.5	13.0	0.6	0	0.89	0.90
8	**28.0**	**24.7**	**11.2**	**1.9**	**0**	**1.24**	**0.99**
9	**28.2**	**27.9**	**11.2**	**2.4**	**0**	**0.98**	**0.92**
10	**30.0**	**23.2**	**12.0**	**0.8**	**0**	**1.06**	**0.94**
11	28.0	24.7	11.2	1.9	0	1.24	0.99
12	**28.2**	**27.9**	**11.3**	**2.4**	**0**	**0.98**	**0.92**
13	24.0	23.6	11.3	1.0	0	1.14	0.96
14	29.9	27.1	13.5	6.3	7	0.81	0.89
15	30.3	26.9	11.5	3.7	0	1.10	0.95
16	28.2	27.9	11.3	2.4	0	0.98	0.92

Table 6. Average Characteristics of 1983-1991 Vintage Single-family Houses by DFO Zones Based on Housing Stock Data

DFO Zone	Floor Area (ft^2)	Area (% of floor area) Roof	Wall	Glass	AC EER	Furn SE	HP COP	No. of People
1	1868	70.9	58.0	19.6	8.2	0.72	2.78	3.1
2	1813	83.1	70.8	10.0	8.2	0.72	2.78	3.2
3	1626	80.2	69.0	11.9	8.2	0.72	2.78	3.3
4	**1900**	**73.4**	**64.2**	**12.6**	**8.2**	**0.72**	**2.78**	**3.4**
5	1925	74.3	64.8	10.0	8.2	0.72	2.78	3.4
6	1792	86.4	76.8	10.0	8.2	0.72	2.78	3.0
7	1723	90.3	70.1	13.4	8.2	0.72	2.78	2.4
8	**2328**	**61.6**	**64.3**	**19.9**	**8.2**	**0.72**	**2.78**	**3.2**
9	**1924**	**69.6**	**71.5**	**10.0**	**8.9**	**0.78**	**2.78**	**3.3**
10	**1793**	**76.0**	**69.3**	**19.8**	**8.9**	**0.78**	**2.78**	**2.9**
11	2718	61.6	64.3	19.9	8.9	0.72	2.78	3.7
12	**2458**	**69.9**	**71.5**	**10.0**	**8.9**	**0.78**	**2.78**	**3.7**
13	1975	65.1	61.8	19.5	8.9	0.78	2.78	3.1
14	1868	78.1	68.6	10.0	8.9	0.78	2.78	3.1
15	1793	81.6	67.9	18.4	8.9	0.78	2.78	2.9
16	2458	69.9	71.5	10.3	8.9	0.78	2.78	3.7

Table 7. Summary of Prototype House Characteristics

	Prototype 1	Prototype 2
Foor area (ft^2)	2160	1544
No. of floors	2	1
House volume (ft^3)	16,320	13,896
Perimeter length (ft)	166	192
Roof area (ft^2)	1528	1544
Roof albedo	0.16	0.16
Ceiling R-value	R-30	R-30
Wall area (ft^2)		
Gross	2207	1264
Net	1894	1098
Wall R-value	R-13	R-11
Wall construction	Stucco	Stucco
Wall albedo	0.50	0.50
Window area		
(ft^2)	274 (18)	146 (8)
(% of floor)	12.7%	9.5%
Window glass layers	2-pane	2-pane
Window glass type	clear (SC=0.89)	clear (SC=0.89)
Window shading schedule	0.60 summer	0.60 summer
Door area (ft^2)	37.6 (2)	19.5 (1)
Internal wall area (ft^2)	1500	1480
Internal loads (Btu/day)		
sensible	41,083	41,083
latent	6,532	6,532
No. of occupants	3	2
Leakage fraction	0.0005	0.0005
Cooling control	78°F all day	78F all day
Air conditioner		
Capacity (Btu/hr)	36,000	29,000
Efficiency (COP)	2.70	2.10
Fan size (cfm)	1,050	1,060
Evaporative cooler fan size (cfm)	3,500	3,500
Window venting	Whenever enthalpy of outside air is less than that of indoor air, provided that temperature does not drop below 65°F. Amount of airflow calculated using Sherman-Grimsrud infiltration model.	
Forced venting	Whenever enthalpy of outside air is less than that of indoor air, provided that temperature does not drop below 65°F. Amount of airflow set at 20 air changes per hour.	

Table 8. Prototype 1 in CTZ02c (Santa Rosa)

	Total Cool. Load (MBtu)	Latent Cool. Load (MBtu)	Vented Cool. Load (MBtu)	Peak Cool. Load (kBtu)	Hours Cool. Load	Cool. Energy (kWh)	Fan. Energy (kWH)	Peak Cool. Energy (kW)
Base Case								
AC	7.65	0.22	12.58	20.06	840	1350.3	52.4	3.81
Direct EC	-	-	12.62	-	-	108.0	213.2	0.65
Two-stage EC	-	-	12.60	-	-	120.2	443.2	1.76
Single measures (all with AC)								
Select. Low-E glazing	4.46	0.15	11.37	16.75	663	884.9	35.2	3.25
Light colors	5.52	0.19	11.31	19.13	710	1024.8	41.0	3.59
1/2 Exp. slab	6.07	0.18	13.60	19.58	759	1126.9	42.1	3.71
Overhangs	5.15	0.16	11.24	18.27	703	988.1	40.1	3.50
Multiple measures (all with AC)								
+ Insul & Select. Low-E glazing	3.72	0.13	11.44	15.72	615	772.4	29.9	3.08
+ Lt. colors	2.38	0.09	10.02	14.28	479	539.7	23.1	2.81
+ 1/2 Exp. slab	1.66	0.07	10.74	13.50	403	416.5	17.4	2.69
+ Overhangs	1.05	0.05	9.63	12.11	269	279.6	15.1	2.46
Improved case (same as last step of multiple measures)								
AC	1.05	0.05	9.63	12.11	269	279.6	15.1	2.46
Two-stage EC	-	-	9.64	-	-	43.0	114.0	1.67
Indirect EC	-	-	9.67	-	-	57.3	274.1	1.56
Direct EC	-	-	9.60	-	-	39.9	58.5	0.65

Table 9. Prototype 1 in CTZ09c (Pasadena)

	Total Cool. Load (MBtu)	Latent Cool. Load (MBtu)	Vented Cool. Load (MBtu)	Peak Cool. Load (kBtu)	Hours Cool. Load	Cool. Energy (kWh)	Fan. Energy (kWH)	Peak Cool. Energy (kW)
Base Case								
AC	6.40	0.42	13.51	18.26	804	1093.6	38.7	2.95
Direct EC	-	-	13.98	-	-	70.5	160.1	0.65
Two-stage EC	-	-	13.91	-	-	77.9	333.9	1.76
Single measures (all with AC)								
Select. Low-E glazing	3.62	0.28	12.10	13.57	634	703.5	24.1	2.27
Light colors	4.77	0.37	12.04	16.91	713	861.4	29.8	2.66
1/2 Exp. slab	5.04	0.35	14.57	16.73	730	908.7	30.6	2.72
Overhangs	4.13	0.31	12.00	14.85	662	775.4	27.3	2.46
Multiple measures (all with AC)								
+ Insul & Select. Low-E glazing	3.09	0.25	12.09	12.82	589	622.4	20.6	2.15
+ Lt. colors	2.03	0.19	10.60	11.60	468	443.6	14.9	1.95
+ 1/2 Exp. slab	1.42	0.15	11.35	10.45	363	328.7	10.8	1.84
+ Overhangs	0.85	0.10	10.15	8.78	256	215.4	8.1	1.63
Improved case (same as last step of multiple measures)								
AC	0.85	0.10	10.15	8.78	256	215.4	8.1	1.63
Two-stage EC	-	-	10.30	-	-	18.3	76.3	1.69
Indirect EC	-	-	10.40	-	-	31.4	207.4	1.56
Direct EC	-	-	10.31	-	-	16.2	37.0	0.65

Table 10. Prototype 2 in CTZ10c (Riverside)

	Total Cool. Load (MBtu)	Latent Cool. Load (MBtu)	Vented Cool. Load (MBtu)	Peak Cool. Load (kBtu)	Hours Cool. Load	Cool. Energy (kWh)	Fan. Energy (kWH)	Peak Cool. Energy (kW)
Base Case								
AC	4.12	0.04	9.61	12.74	827	1130.7	56.3	3.47
Direct EC	-	-	9.77	-	-	76.9	161.8	0.65
Two-stage EC	-	-	9.80	-	-	84.0	336.3	1.76
Single measures (all with AC)								
Select. Low-E glazing	3.03	0.04	9.28	12.67	709	871.2	42.9	3.46
Light colors	2.41	0.04	8.28	11.66	599	582.2	26.7	3.11
1/2 Exp. slab	3.00	0.03	10.83	12.68	702	878.5	42.2	3.46
Overhangs	3.59	0.04	9.32	12.72	770	1005.3	50.1	3.46
Multiple measures (all with AC)								
+ Insul & Select. Low-E glazing	2.20	0.03	9.46	10.45	601	670.9	32.1	3.46
+ Lt. colors	1.17	0.03	7.95	8.53	396	322.8	14.3	2.37
+ 1/2 Exp. slab	0.77	0.02	8.87	7.73	279	222.4	9.7	2.19
+ Overhangs	0.65	0.01	8.60	6.70	244	190.6	8.7	1.87
Improved case (same as last step of multiple measures)								
AC	0.65	0.01	8.60	6.70	244	190.6	8.7	1.87
Two-stage EC	-	-	8.71	-	-	29.0	99.3	1.51
Indirect EC	-	-	0.00	-	-	0.0	0.0	0.00
Direct EC	-	-	8.67	-	-	26.9	47.8	0.65

Table 11. Prototype 2 in CTZ12c (Sacramento)

	Total Cool. Load (MBtu)	Latent Cool. Load (MBtu)	Vented Cool. Load (MBtu)	Peak Cool. Load (kBtu)	Hours Cool. Load	Cool. Energy (kWh)	Fan. Energy (kWH)	Peak Cool. Energy (kW)
Base Case								
AC	2.48	0.00	11.09	11.76	541	712.7	37.0	3.35
Direct EC	-	-	11.32	-	-	59.4	121.7	0.65
Two-stage EC	-	-	11.25	-	-	67.4	258.6	1.76
Single measures (all with AC)								
Select. Low-E glazing	1.62	0.00	10.33	10.36	409	490.2	26.5	3.26
Light colors	1.41	0.00	9.62	11.13	358	353.3	19.3	2.71
1/2 Exp. slab	1.52	0.00	12.45	10.30	383	468.6	23.9	3.25
Overhangs	2.03	0.00	10.53	11.56	450	589.2	31.9	3.35
Multiple measures (all with AC)								
+ Insul & Select. Low-E glazing	1.04	0.00	10.29	9.10	308	336.9	18.2	3.10
+ Lt. colors	0.55	0.00	8.71	7.83	191	159.0	10.1	2.03
+ 1/2 Exp. slab	0.30	0.00	9.79	6.00	112	91.4	6.5	1.66
+ Overhangs	0.25	0.00	9.32	5.70	99	78.3	6.3	1.54
Improved case (same as last step of multiple measures)								
AC	0.25	0.00	9.32	5.70	99	78.3	6.3	1.54
Two-stage EC	-	-	9.46	-	-	20.2	56.3	1.48
Indirect EC	-	-	9.55	-	-	23.8	112.7	1.56
Direct EC	-	-	9.48	-	-	18.0	27.1	0.65

Table 12. Number of Hours Above 78 F with Non-A/C Operation for Prototype 1 (2200 ft^2 two-story house) in CTZ02c (Santa Rosa)
(numbers in parentheses are average humidity ratios x 1000)

			No. of Overheated Hours per °F Temperature Bin											
Bldg Shell	Operating Mode	Tot	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	over 90
Base case	Wind.closed	1917	198	172	180	179	154	145	130	128	129	116	98	288
	Wind. Vent	705	83	84	87	65	76	71	67	53	33	31	23	32
	Forced Vent	572	80	63	92	70	63	59	39	32	30	15	10	19
		(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(7)	(8)	(9)	(9)
	Direct EC	93	29	27	20	8	5	3	1					
		(14)	(14)	(14)	(15)	(15)	(15)	(16)	(16)					
	Two-stage EC	4	4											
		(13)	(13)											
Selective Low-E glaz.	Wind.closed	1598	209	195	174	166	143	149	133	102	81	73	52	121
	Wind. Vent	531	90	94	77	83	50	45	35	23	10	8	8	8
	Forced Vent	376	76	96	51	42	34	34	15	8	9	7	3	1
Lt. colors	Wind.closed	1563	199	170	192	147	137	128	132	106	97	65	57	133
	Wind. Vent	602	100	75	84	82	66	63	39	35	23	11	9	15
	Forced Vent	463	77	88	74	66	40	38	31	17	10	11	5	6
1/2 Exp. slab	Wind.closed	1804	209	192	192	181	165	147	150	127	118	85	73	165
	Wind. Vent	640	94	90	79	99	73	67	43	39	20	12	10	14
	Forced Vent	457	82	95	83	59	42	32	23	13	11	11	2	4
Overhangs	Wind.closed	1518	197	176	167	156	135	138	130	100	79	65	51	124
	Wind. Vent	560	80	88	83	81	64	50	33	32	19	10	6	14
	Forced Vent	458	76	85	76	67	38	37	31	18	9	9	6	6
+ Insul & Select. Low-E	Wind.closed	1617	220	217	166	173	172	148	113	103	82	68	51	104
	Wind. Vent	478	85	94	85	68	46	36	23	14	12	7	4	4
	Forced Vent	323	96	60	48	36	34	19	9	11	6	2	2	
+ Lt. colors	Wind.closed	1180	183	178	171	143	118	103	89	60	48	33	23	31
	Wind. Vent	338	89	68	62	44	28	17	11	10	2	4	3	
	Forced Vent	205	65	49	37	15	12	15	4	5	3			
+ 1/2 Exp.slab	Wind.closed	1058	206	178	156	148	105	93	60	43	33	16	10	10
	Wind. Vent	259	81	65	37	28	16	15	8	6	3			
	Forced Vent	119	51	16	17	18	9	4	4					
+ Overhangs	Wind.closed	791	181	149	141	103	75	55	33	26	13	8	6	1
	Wind. Vent	163	56	32	31	15	17	3	5	4				
	Forced Vent	73	19	16	22	7	5	4						
		(9)	(9)	(9)	(9)	(10)	(8)	(11)						
	Direct EC	26	14	6	2	3	1							
		(15)	(15)	(15)	(16)	(16)	(16)							
	Indirect EC	91	36	23	13	10	4	4	1					
		(9)	(8)	(9)	(9)	(9)	(9)	(10)	(12)					
	Two-stage EC	0												

Table 13. Number of Hours Above 78 F with Non-A/C Operation for Prototype 1 (2200 ft^2 two-story house) in CTZ09c (Pasadena)
(numbers in parentheses are average humidity ratios x 1000)

			No. of Overheated Hours per °F Temperature Bin											
Bldg Shell	Operating Mode	Tot	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	over 90
Base case	Wind.closed	2012	233	221	202	195	211	176	157	168	110	95	87	157
	Wind. Vent	641	89	104	107	90	52	59	43	35	28	21	8	5
	Forced Vent	508	96	91	87	66	49	42	25	26	19	5	2	
		(9)	*(9)*	*(9)*	*(10)*	*(9)*	*(9)*	*(10)*	*(9)*	*(10)*	*(9)*	*(9)*	*(4)*	
	Direct EC	45	18	21	5	1								
		(16)	*(15)*	*(16)*	*(17)*	*(18)*								
	Two-stage EC	2	2											
		(16)	*(16)*											
Selective Low-E glaz.	Wind.closed	1714	257	247	221	208	191	168	131	97	77	63	33	21
	Wind. Vent	462	98	102	79	51	48	38	28	15	2	1		
	Forced Vent	304	88	60	51	42	34	19	10					
Lt. colors	Wind.closed	1679	237	217	215	199	167	178	124	100	87	67	49	39
	Wind. Vent	546	105	107	93	57	57	38	44	28	10	7		
	Forced Vent	402	100	80	58	56	38	34	20	14	2			
1/2 Exp. slab	Wind.closed	1904	260	236	221	235	195	188	161	126	98	77	57	50
	Wind. Vent	576	107	120	99	62	60	45	41	29	9	4		
	Forced Vent	394	103	90	57	47	42	26	23	6				
Overhangs	Wind.closed	1585	228	224	217	190	179	152	116	91	74	61	31	22
	Wind. Vent	503	106	105	79	65	42	44	30	20	9	3		
	Forced Vent	386	101	82	50	51	41	32	19	8	2			
+ Insul & Select. Low-E	Wind.closed	1777	283	264	233	223	207	171	120	105	76	54	34	7
	Wind. Vent	424	101	98	75	48	41	31	20	8	2			
	Forced Vent	254	72	62	44	40	24	12						
+ Lt. colors	Wind.closed	1366	286	227	240	183	133	116	84	58	29	10		
	Wind. Vent	306	97	66	54	44	27	15	2	1				
	Forced Vent	165	56	43	34	27	5							
+ 1/2 Exp.slab	Wind.closed	1192	280	269	208	153	128	81	54	19				
	Wind. Vent	223	75	68	45	24	9	2						
	Forced Vent	103	47	38	17	1								
+ Overhangs	Wind.closed	840	275	190	151	114	61	41	8					
	Wind. Vent	149	71	37	29	9	3							
	Forced Vent	59	34	24	1									
		(11)	*(11)*	*(11)*	*(10)*									
	Direct EC	9	8	1										
		(17)	*(17)*	*(18)*										
	Indirect EC	47	31	14	2									
		(11)	*(11)*	*(11)*	*(12)*									
	Two-stage EC	0												

Table 14. Number of Hours Above 78 F with Non-A/C Operation for Prototype 2 (1544 ft^2 one-story house) in CTZ10c (Riverside)

(numbers in parentheses are average humidity ratios x 1000)

			No. of Overheated Hours per °F Temperature Bin											
Bldg Shell	Operating Mode	Tot	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	over 90
Base case	Wind.closed	1928	208	213	224	217	212	198	177	138	121	87	62	71
	Wind. Vent	733	148	120	116	108	75	56	41	37	14	11	5	2
	Forced Vent	336	83	61	46	55	28	22	24	7	7	3		
		(9)	*(8)*	*(9)*	*(9)*	*(9)*	*(9)*	*(10)*	*(10)*	*(10)*	*(10)*	*(7)*		
	Direct EC	66	35	22	6	1	2							
		(15)	*(14)*	*(14)*	*(15)*	*(14)*	*(14)*							
	Two-stage EC	1	1											
		(16)	*(16)*											
Selective Low-E glaz.	Wind.closed	1818	219	243	239	233	219	189	142	129	81	71	23	30
	Wind. Vent	581	118	128	107	70	56	41	34	13	10	4		
	Forced Vent	261	70	63	40	29	23	21	11	4				
Lt. colors	Wind.closed	1483	247	234	241	196	171	135	103	73	48	15	15	5
	Wind. Vent	493	128	112	84	59	44	36	15	11	4			
	Forced Vent	219	70	52	28	25	26	8	8	2				
1/2 Exp. slab	Wind.closed	1773	254	264	260	253	222	179	133	93	72	22	14	7
	Wind. Vent	604	153	133	114	63	57	43	23	12	6			
	Forced Vent	216	76	36	32	45	12	13	2					
Overhangs	Wind.closed	1816	221	214	232	227	205	192	151	127	93	72	43	39
	Wind. Vent	661	136	141	100	93	57	46	42	25	10	8	3	
	Forced Vent	301	75	58	61	33	23	22	17	8	4			
+ Insul & Select. Low-E	Wind.closed	1951	271	279	255	270	252	193	158	106	93	42	19	13
	Wind. Vent	485	133	117	71	59	42	36	19	7	1			
	Forced Vent	190	74	30	24	39	11	10	2					
+ Lt. colors	Wind.closed	1390	291	289	257	185	151	99	74	26	14	4		
	Wind. Vent	302	105	72	41	48	24	10	2					
	Forced Vent	100	31	39	16	14								
+ 1/2 Exp.slab	Wind.closed	1114	360	272	213	134	92	34	9					
	Wind. Vent	200	71	62	38	26	3							
	Forced Vent	50	24	26										
+ Overhangs	Wind.closed	989	340	264	176	124	58	23	4					
	Wind. Vent	171	65	53	32	20	1							
	Forced Vent	35	18	17										
		(10)	*(10)*	*(11)*										
	Direct EC	16	13	3										
		(15)	*(15)*	*(14)*										
	Indirect EC	126	58	32	23	9	4							
		(10)	*(9)*	*(10)*	*(10)*	*(9)*	*(8)*							
	Two-stage EC	0												

Table 15. Number of Hours Above 78 F with Non-A/C Operation for Prototype 2 (1544 ft^2 one-story house) in CTZ12c (Sacramento)
(numbers in parentheses are average humidity ratios x 1000)

			No. of Overheated Hours per °F Temperature Bin											
Bldg Shell	Operating Mode	Tot	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	over 90
Base case	Wind.closed	1394	236	218	197	177	144	114	89	76	56	30	31	26
	Wind. Vent	386	99	78	57	47	40	18	21	11	10	5		
	Forced Vent	228	60	41	41	25	22	15	14	10				
		(9)	*(9)*	*(8)*	*(8)*	*(9)*	*(8)*	*(9)*	*(9)*	*(11)*				
	Direct EC	53	18	16	9	7	3							
		(15)	*(14)*	*(15)*	*(15)*	*(17)*	*(16)*							
	Two-stage EC	1	1											
		(15)	*(15)*											
Selective Low-E glaz.	Wind.closed	1182	227	217	188	157	106	96	74	44	35	25	12	1
	Wind. Vent	271	82	58	48	27	20	13	14	7	2			
	Forced Vent	155	51	33	18	22	14	15	2					
Lt. colors	Wind.closed	964	216	197	150	117	87	79	43	35	26	14		
	Wind. Vent	235	63	54	42	27	18	15	11	5				
	Forced Vent	148	52	26	24	16	18	12						
1/2 Exp. slab	Wind.closed	1198	268	233	196	155	115	93	58	40	29	11		
	Wind. Vent	256	80	57	47	23	23	17	9					
	Forced Vent	115	29	29	20	22	15							
Overhangs	Wind.closed	1202	220	208	174	155	124	90	79	.58	33	33	18	10
	Wind. Vent	320	87	62	52	44	26	18	12	11	8			
	Forced Vent	193	50	41	37	17	19	13	15	1				
+ Insul & Select. Low-E	Wind.closed	1192	249	224	212	153	112	100	52	41	34	15		
	Wind. Vent	201	69	46	27	26	15	11	7					
	Forced Vent	99	30	22	16	19	12							
+ Lt. colors	Wind.closed	754	218	174	127	93	66	35	37	4				
	Wind. Vent	108	37	25	18	16	10	2						
	Forced Vent	60	23	19	17	1								
+ 1/2 Exp.slab	Wind.closed	535	206	146	85	55	39	4						
	Wind. Vent	70	26	29	15									
	Forced Vent	20	20											
+ Overhangs	Wind.closed	435	180	113	78	39	25							
	Wind. Vent	60	25	24	11									
	Forced Vent	12	12											
		(10)	*(10)*											
	Direct EC	14	9	5										
		(16)	*(16)*	*(16)*										
	Indirect EC	36	18	18										
		(10)	*(9)*	*(10)*										
	Two-stage EC	0												

Table 16. Temperature Reductions for Shell Measures from Base Case Prototype 1 House in CTZ02C(Santa Rosa)

Prototype and Measure	Window Venting Max. (F)	Window Venting Avg. (F)	Window Venting Min. (F)	Mechanical Venting Max. (F)	Mechanical Venting Avg. (F)	Mechanical Venting Min. (F)
Typical Summer Days						
Single Measures						
Low-E Glazing only	-3.3	-1.2	0.1	-3.5	-1.2	0.0
Light-colored surfaces only	-2.2	-0.8	-0.1	-2.2	-0.8	0.0
1/2 Exposed floor slab only	-2.3	-0.4	0.1	-2.7	-0.8	0.0
Overhangs only	-2.6	-1.0	-0.1	-2.2	-0.8	0.0
Combined Measures						
Low-E Glazing + Insulation	-4.2	-1.4	0.1	-4.6	-1.4	0.0
+ Light-colored surfaces	-6.2	-2.1	0.1	-6.4	-2.2	0.0
+ 1/2 Exposed floor slab	-7.7	-2.4	0.1	-8.3	-2.6	0.2
+ Overhangs	-9.1	-3.0	0.1	-9.4	-3.1	0.2
Peak Summer Days						
Single Measures						
Low-E Glazing only	-3.0	-1.2	0.0	-3.4	-1.2	0.0
Light-colored surfaces only	-1.7	-0.7	0.0	-1.9	-0.7	-0.1
1/2 Exposed floor slab only	-2.2	-0.3	0.0	-2.7	-0.4	0.4
Overhangs only	-2.0	-0.9	0.0	-2.0	-0.7	0.0
Combined Measures						
Low-E Glazing + Insulation	-3.9	-1.3	0.0	-4.5	-1.4	0.0
+ Light-colored surfaces	-5.6	-2.1	0.0	-6.2	-2.1	-0.1
+ 1/2 Exposed floor slab	-7.4	-2.4	0.0	-8.1	-2.4	0.2
+ Overhangs	-8.6	-3.0	0.0	-9.2	-2.9	0.2

Table 17. Temperature Reductions for Shell Measures from Base Case Prototype 1 House in CTZ09C(Pasadena)

Prototype and Measure	Window Venting Max. (F)	Window Venting Avg. (F)	Window Venting Min. (F)	Mechanical Venting Max. (F)	Mechanical Venting Avg. (F)	Mechanical Venting Min. (F)
Typical Summer Days						
Single Measures						
Low-E Glazing only	-2.9	-0.8	0.0	-2.8	-0.7	0.0
Light-colored surfaces only	-1.9	-0.5	0.0	-1.7	-0.4	0.0
1/2 Exposed floor slab only	-2.2	-0.2	0.0	-2.2	-0.3	-1.3
Overhangs only	-2.3	-0.6	0.0	-1.8	-0.4	0.0
Combined Measures						
Low-E Glazing + Insulation	-3.6	-0.9	0.0	-3.6	-0.8	0.1
+ Light-colored surfaces	-5.2	-1.3	0.0	-4.7	-1.2	0.1
+ 1/2 Exposed floor slab	-6.8	-1.4	0.0	-6.4	-1.6	-1.4
+ Overhangs	-8.0	-1.8	0.0	-7.4	-1.9	-1.4
Peak Summer Days						
Single Measures						
Low-E Glazing only	-2.4	-0.7	0.0	-2.9	-1.0	1.0
Light-colored surfaces only	-1.6	-0.3	0.0	-1.7	-0.5	0.9
1/2 Exposed floor slab only	-1.9	-0.1	0.0	-2.0	-0.4	0.2
Overhangs only	-2.0	-0.6	0.0	-1.7	-0.6	1.0
Combined Measures						
Low-E Glazing + Insulation	-3.0	-0.8	0.0	-3.8	-1.2	1.1
+ Light-colored surfaces	-4.4	-1.4	0.0	-5.1	-1.7	0.9
+ 1/2 Exposed floor slab	-6.0	-1.7	0.0	-6.4	-2.0	0.1
+ Overhangs	-7.3	-2.1	0.0	-7.3	-2.3	1.1

Table 18. Temperature Reductions for Shell Measures from Base Case Prototype 2 House in CTZ10C(Riverside)

Prototype and Measure	Window Venting Max. (F)	Window Venting Avg. (F)	Window Venting Min. (F)	Mechanical Venting Max. (F)	Mechanical Venting Avg. (F)	Mechanical Venting Min. (F)
Typical Summer Days						
Single Measures						
Low-E Glazing only	-1.1	-0.6	0.0	-1.3	-0.5	0.0
Light-colored surfaces only	-2.2	-1.1	0.0	-2.2	-0.9	0.0
1/2 Exposed floor slab only	-1.7	-0.3	0.0	-1.8	-0.5	0.1
Overhangs only	-0.6	-0.4	0.0	-0.7	-0.4	0.0
Combined Measures						
Low-E Glazing + Insulation	-1.9	-0.9	0.0	-2.4	-1.1	0.1
+ Light-colored surfaces	-3.9	-2.0	0.0	-4.2	-1.9	0.0
+ 1/2 Exposed floor slab	-5.1	-2.1	0.0	-5.2	-2.4	0.1
+ Overhangs	-5.5	-2.3	0.0	-5.5	-2.6	0.1
Peak Summer Days						
Single Measures						
Low-E Glazing only	-1.7	-0.7	0.0	-1.7	-0.7	0.0
Light-colored surfaces only	-2.5	-1.3	0.0	-2.4	-1.0	0.0
1/2 Exposed floor slab only	-2.7	-0.5	0.0	-3.1	-0.7	0.3
Overhangs only	-0.7	-0.4	0.0	-0.7	-0.3	0.0
Combined Measures						
Low-E Glazing + Insulation	-3.3	-1.1	0.0	-3.3	-1.2	0.0
+ Light-colored surfaces	-5.4	-2.1	0.0	-5.4	-2.2	0.0
+ 1/2 Exposed floor slab	-6.9	-2.4	0.0	-7.7	-2.8	0.0
+ Overhangs	-7.3	-2.6	0.0	-8.1	-3.0	0.0

Table 19. Temperature Reductions for Shell Measures from Base Case Prototype 2 House in CTZ12C(Sacramento)

Prototype and Measure	Window Venting Max. (F)	Window Venting Avg. (F)	Window Venting Min. (F)	Mechanical Venting Max. (F)	Mechanical Venting Avg. (F)	Mechanical Venting Min. (F)
Typical Summer Days						
Single Measures						
Low-E Glazing only	-1.6	-0.6	0.0	-1.6	-0.7	-0.1
Light-colored surfaces only	-1.7	-0.7	0.0	-1.7	-0.6	0.0
1/2 Exposed floor slab only	-1.5	-0.3	0.0	-1.9	-0.7	0.2
Overhangs only	-0.8	-0.4	0.0	-0.8	-0.4	-0.1
Combined Measures						
Low-E Glazing + Insulation	-2.7	-0.9	0.0	-2.7	-1.0	0.0
+ Light-colored surfaces	-4.0	-1.5	0.0	-4.0	-1.5	0.0
+ 1/2 Exposed floor slab	-4.8	-1.6	0.0	-5.1	-2.0	0.2
+ Overhangs	-5.2	-1.8	0.0	-5.4	-2.2	0.1
Peak Summer Days						
Single Measures						
Low-E Glazing only	-1.7	-0.7	0.0	-1.8	-0.7	-0.1
Light-colored surfaces only	-2.4	-0.8	-0.3	-2.4	-0.8	-0.1
1/2 Exposed floor slab only	-2.7	-0.4	0.3	-3.4	-0.6	0.4
Overhangs only	-0.8	-0.4	-0.1	-0.8	-0.4	-0.1
Combined Measures						
Low-E Glazing + Insulation	-3.3	-1.1	0.3	-3.4	-1.1	0.0
+ Light-colored surfaces	-5.4	-1.9	0.2	-5.5	-1.9	-0.1
+ 1/2 Exposed floor slab	-7.3	-2.2	0.3	-7.9	-2.4	0.2
+ Overhangs	-7.7	-2.4	0.3	-8.3	-2.6	0.2

Figure 1
0.1% Annual Design Dry-bulb Temperatures (F)
San Francisco-Sacramento

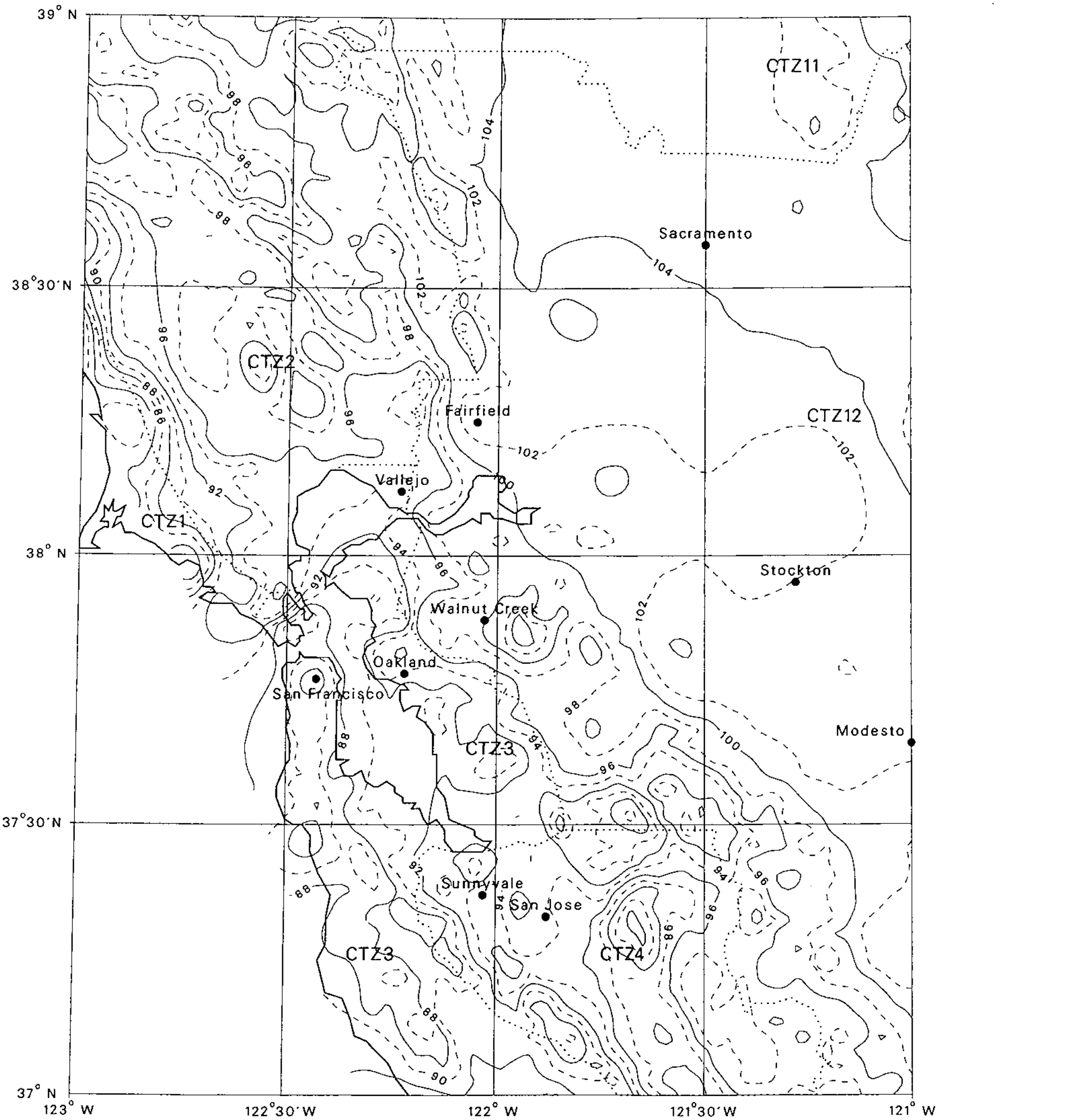


Figure 2
2.0% Annual Design Dry-bulb Temperatures (F)
San Francisco-Sacramento

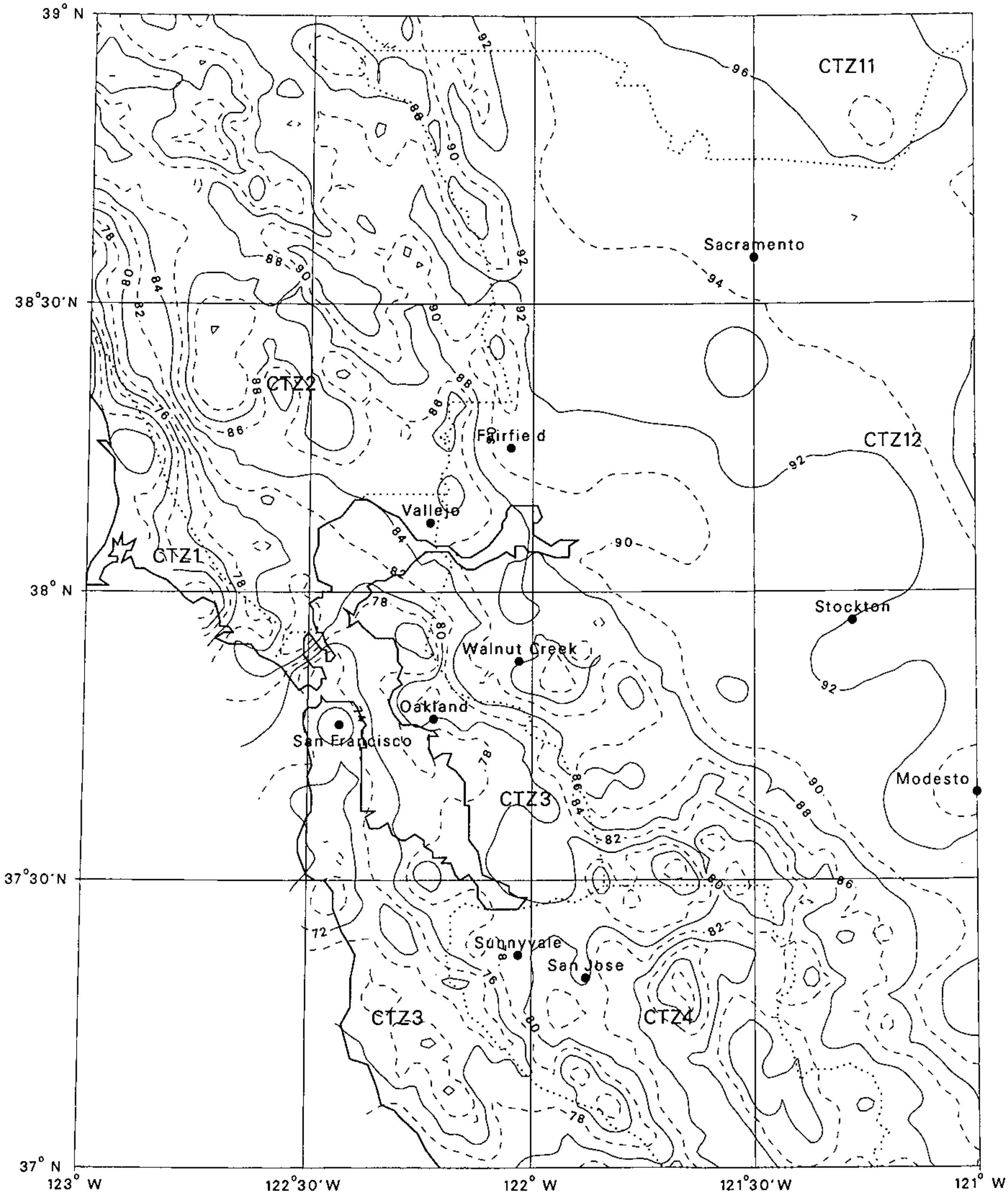


Figure 3
0.1% Coincident Wet-bulb Temperatures (F)
San Francisco-Sacramento

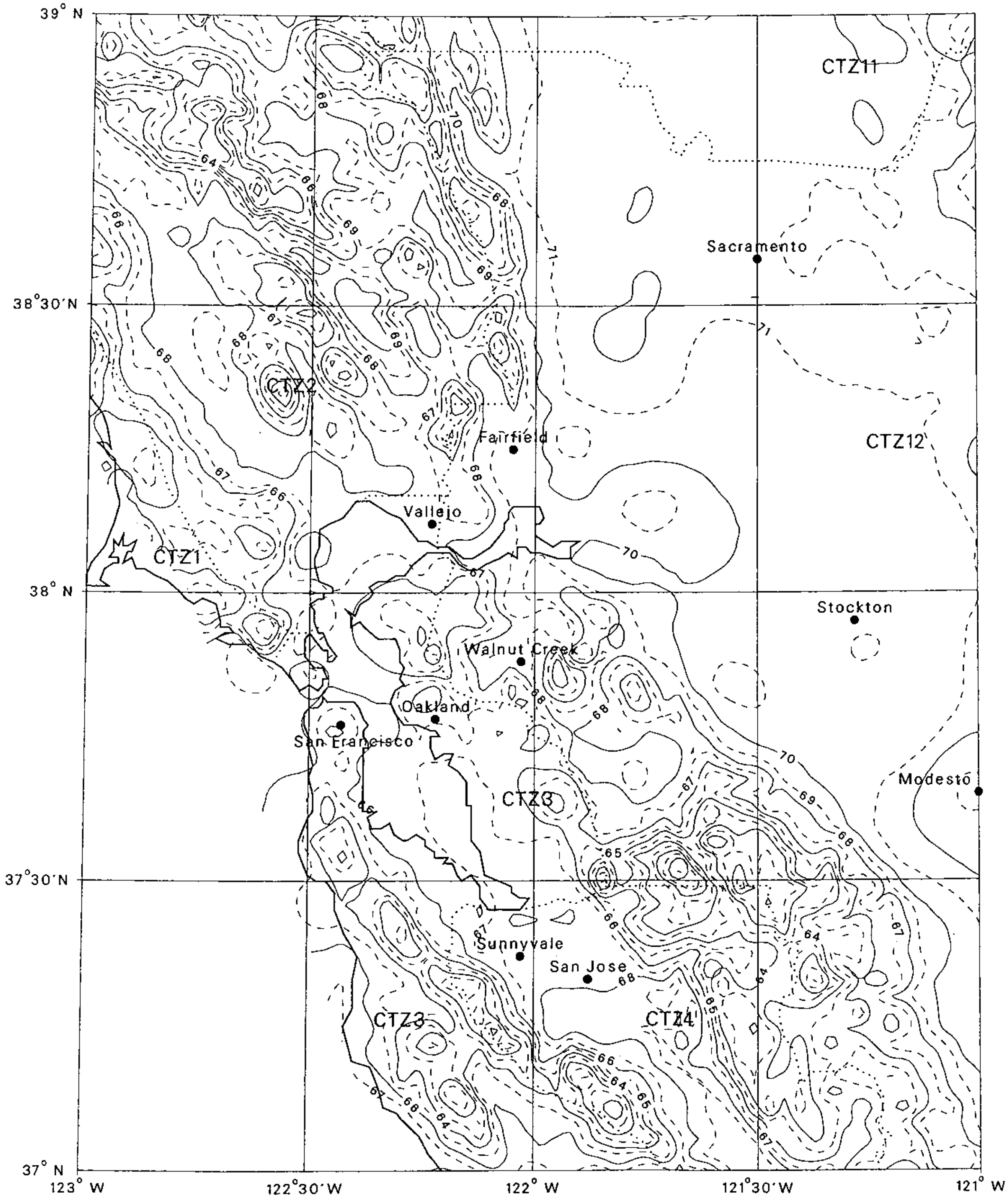


Figure 4
2.0% Coincident Wet-bulb Temperatures (F)
San Francisco-Sacramento

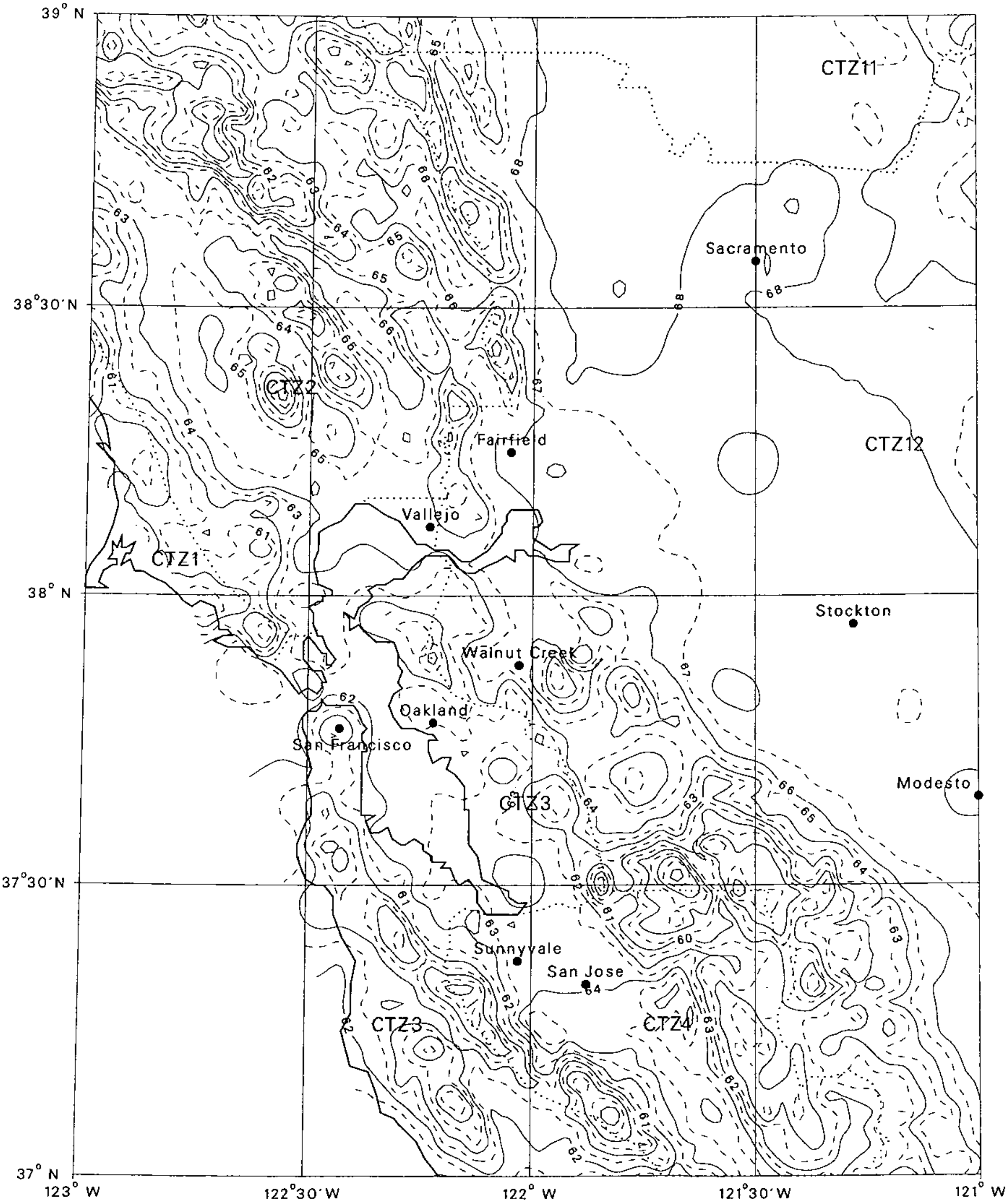


Figure 5
0.1% Annual Design Dry-bulb Temperatures (F)
Los Angeles-San Diego

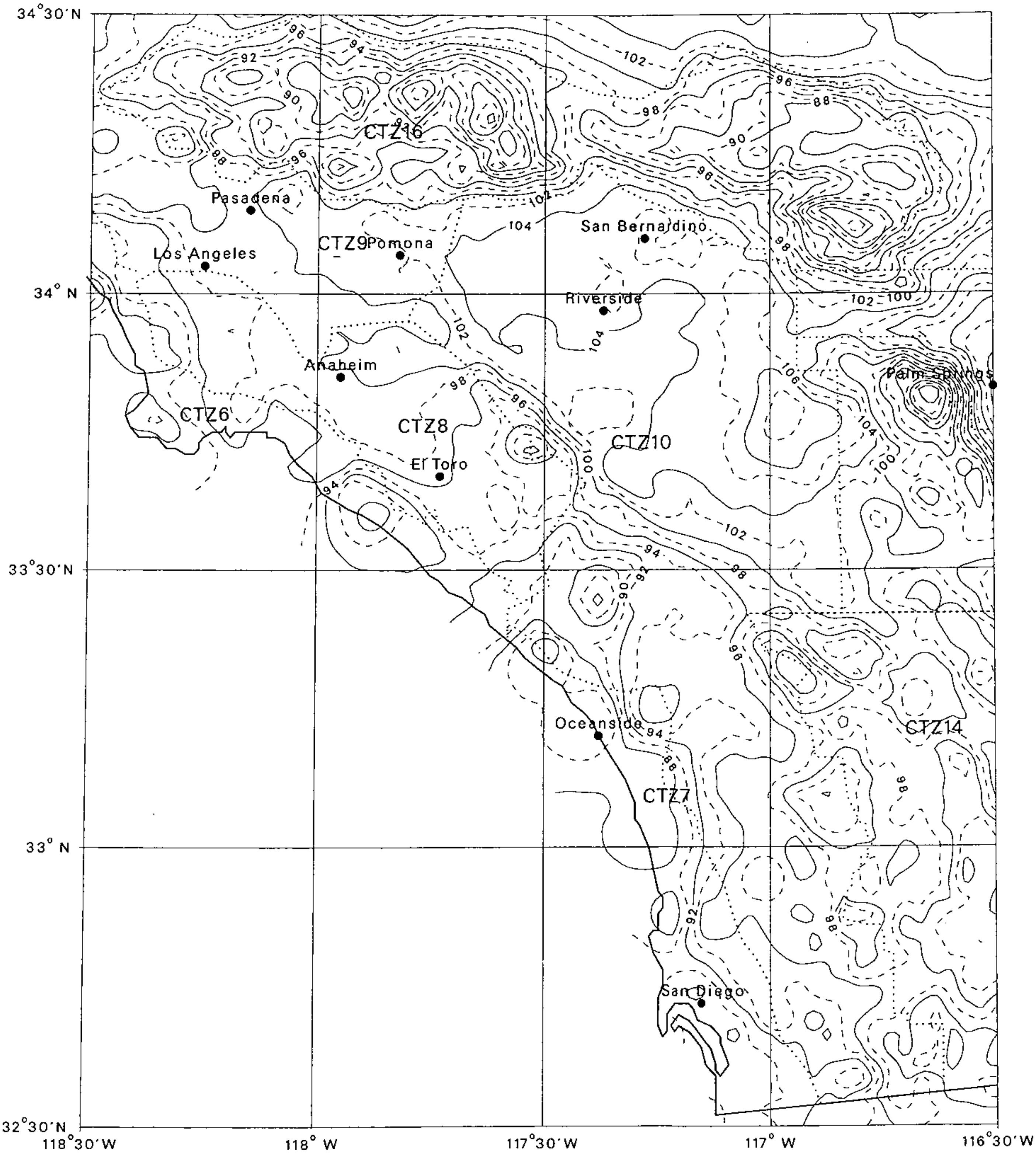


Figure 6
2.0% Coincident Wet-bulb Temperatures (F)
Los Angeles-San Diego

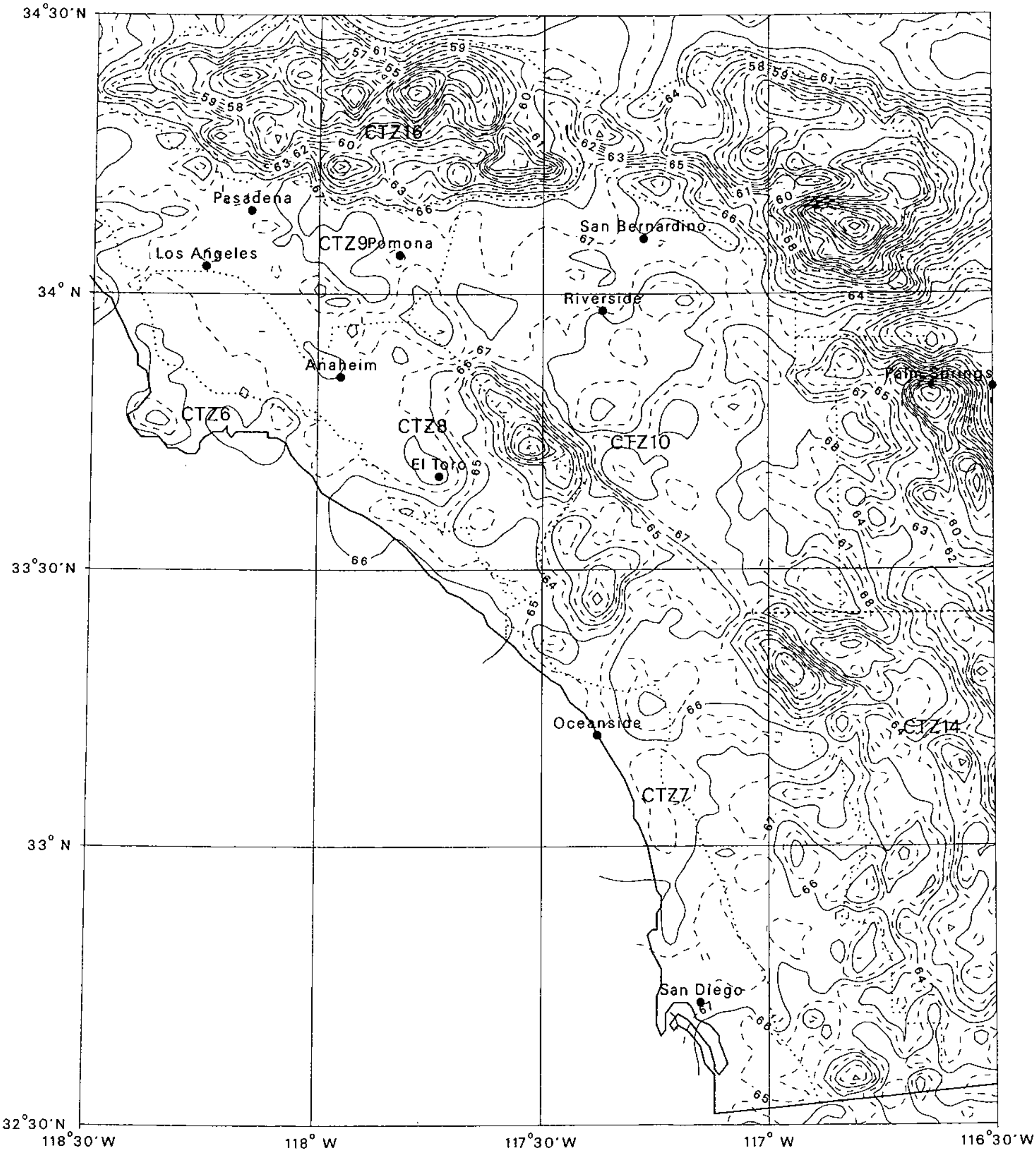


Figure 7
0.1% Coincident Wet-bulb Temperatures (F)
Los Angeles-San Diego

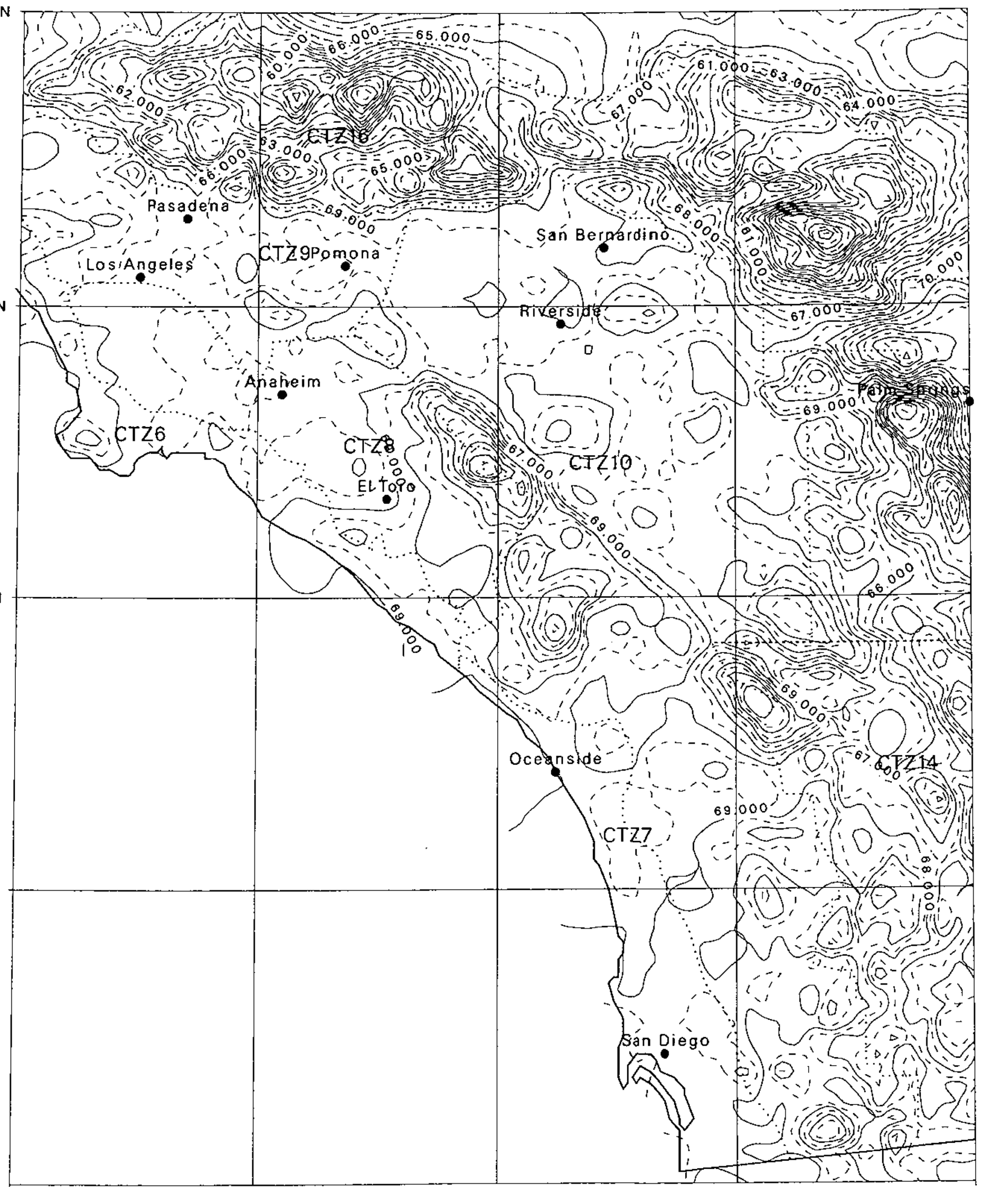


Figure 8
2.0% Coincident Wet-bulb Temperatures (F)
Los Angeles-San Diego

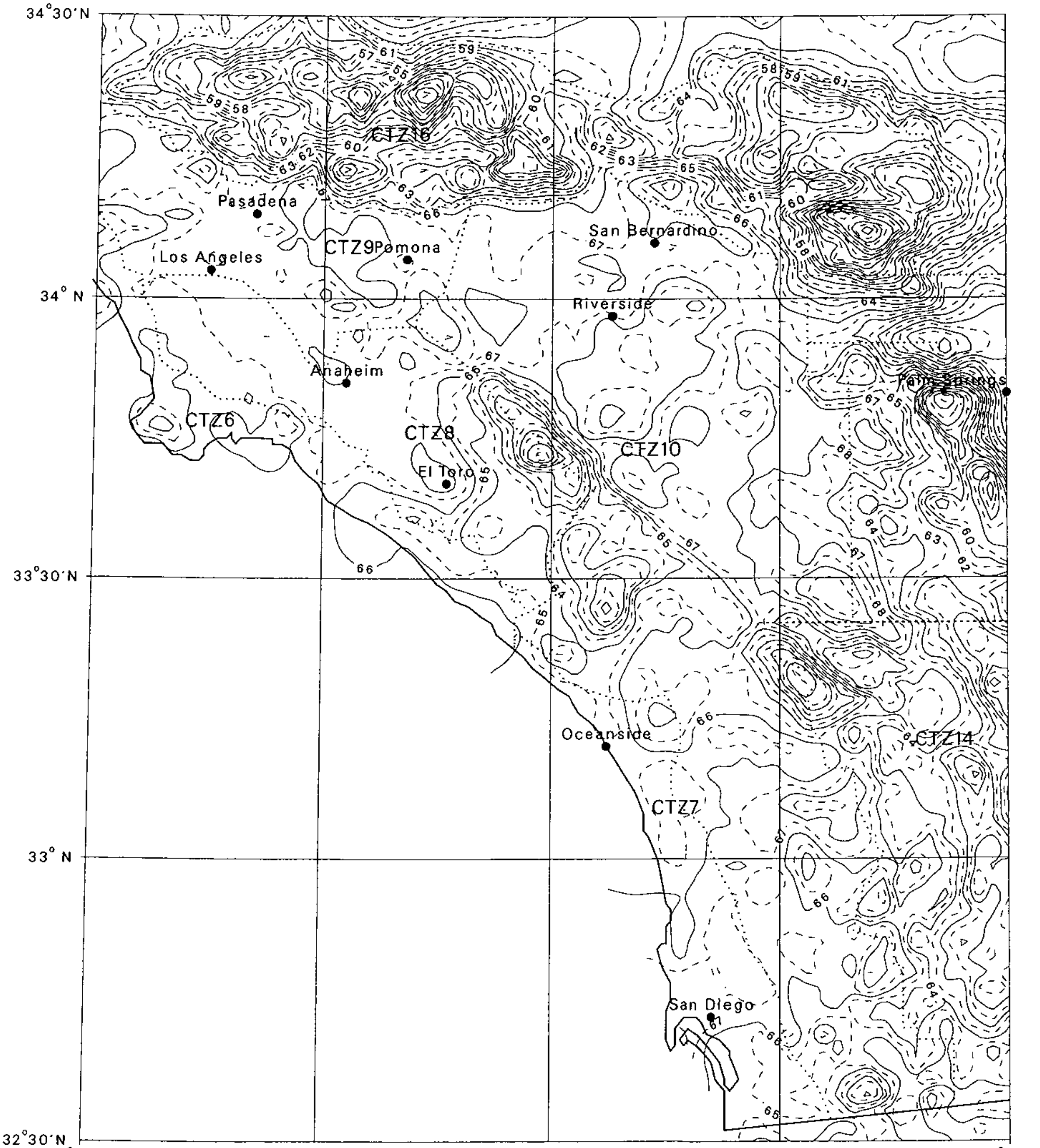


Figure 9
Difference in Design Dry-bulb Temperatures (0.1%-2%)
California

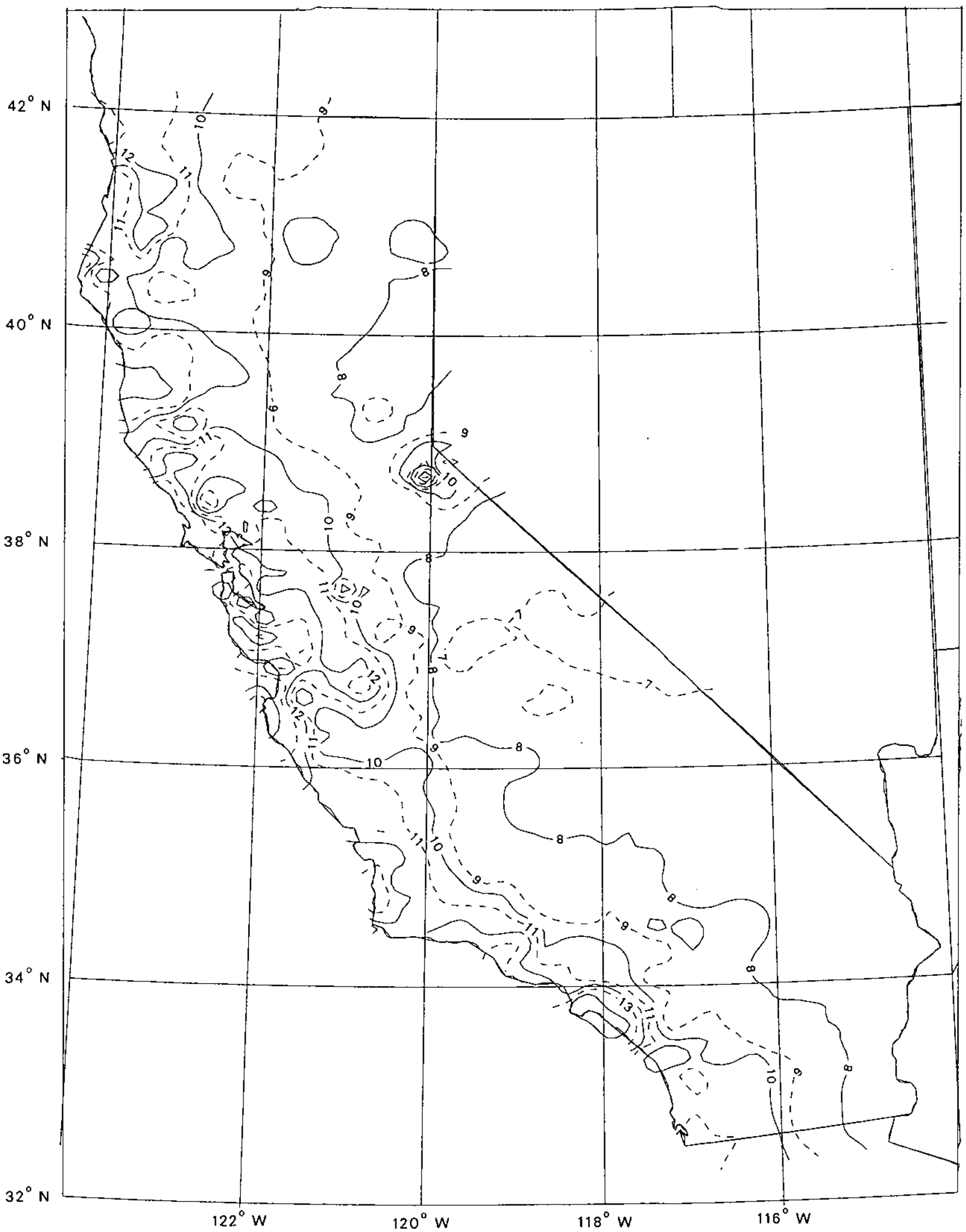


Figure 10
Daily Temperature Ranges
California

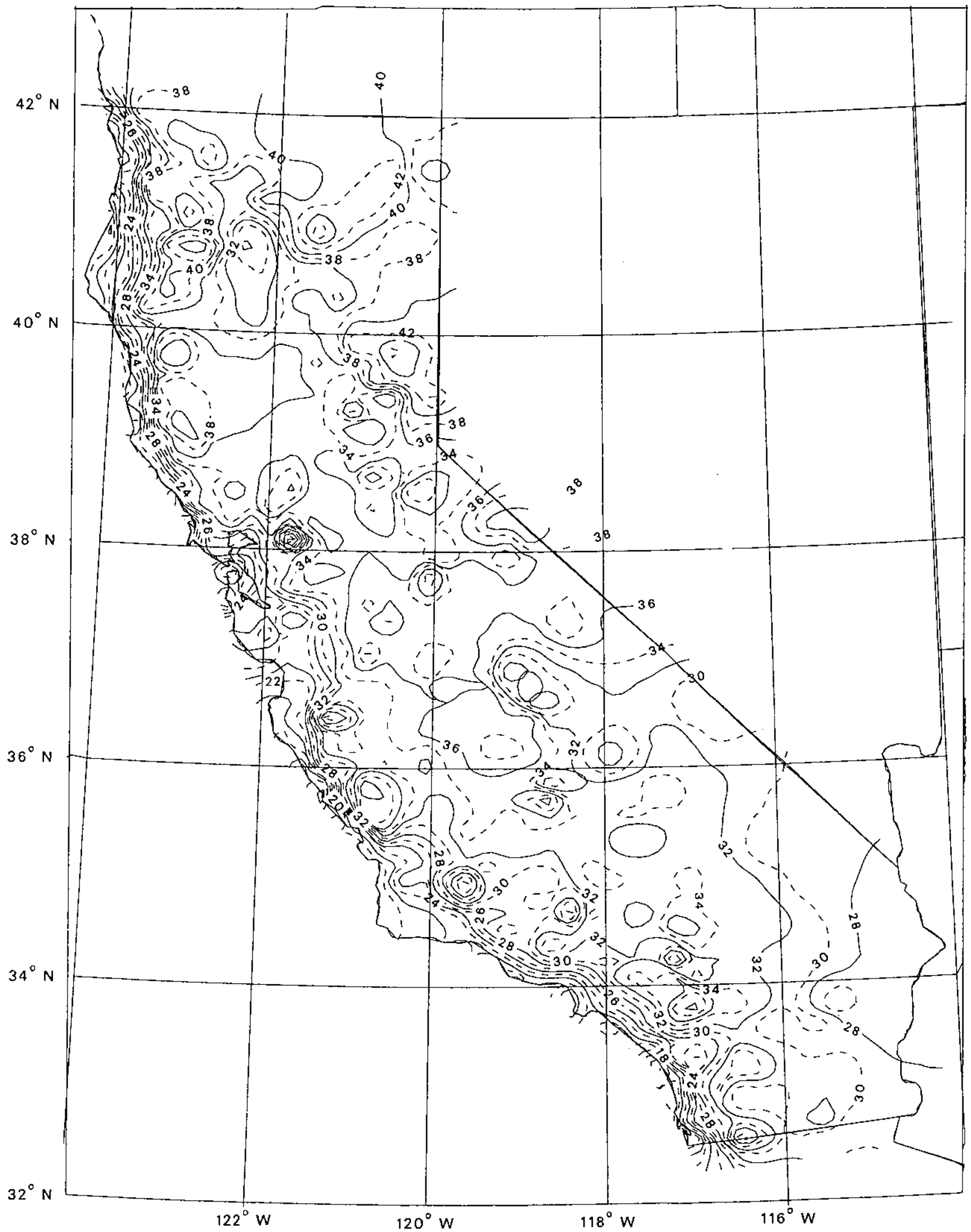
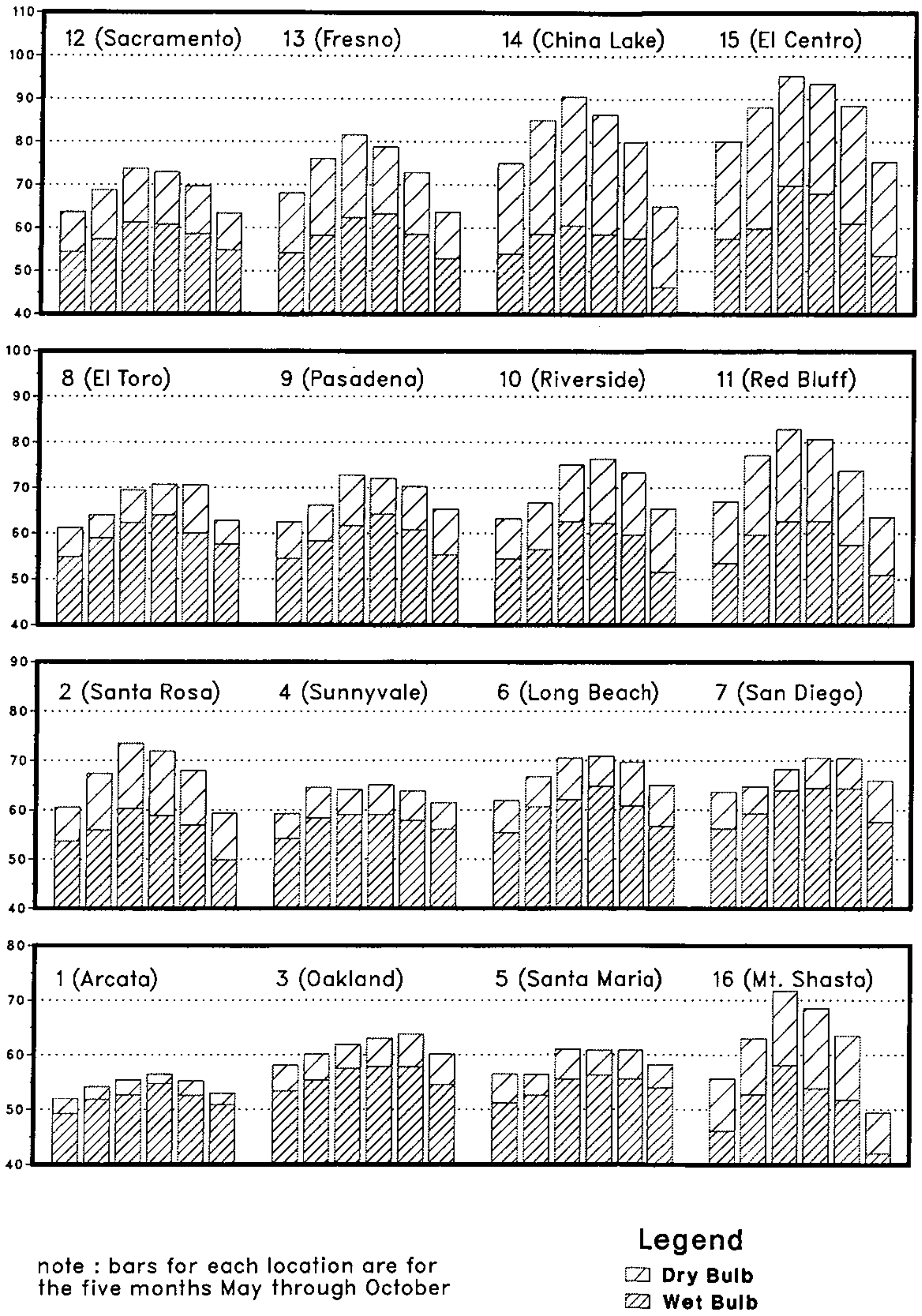


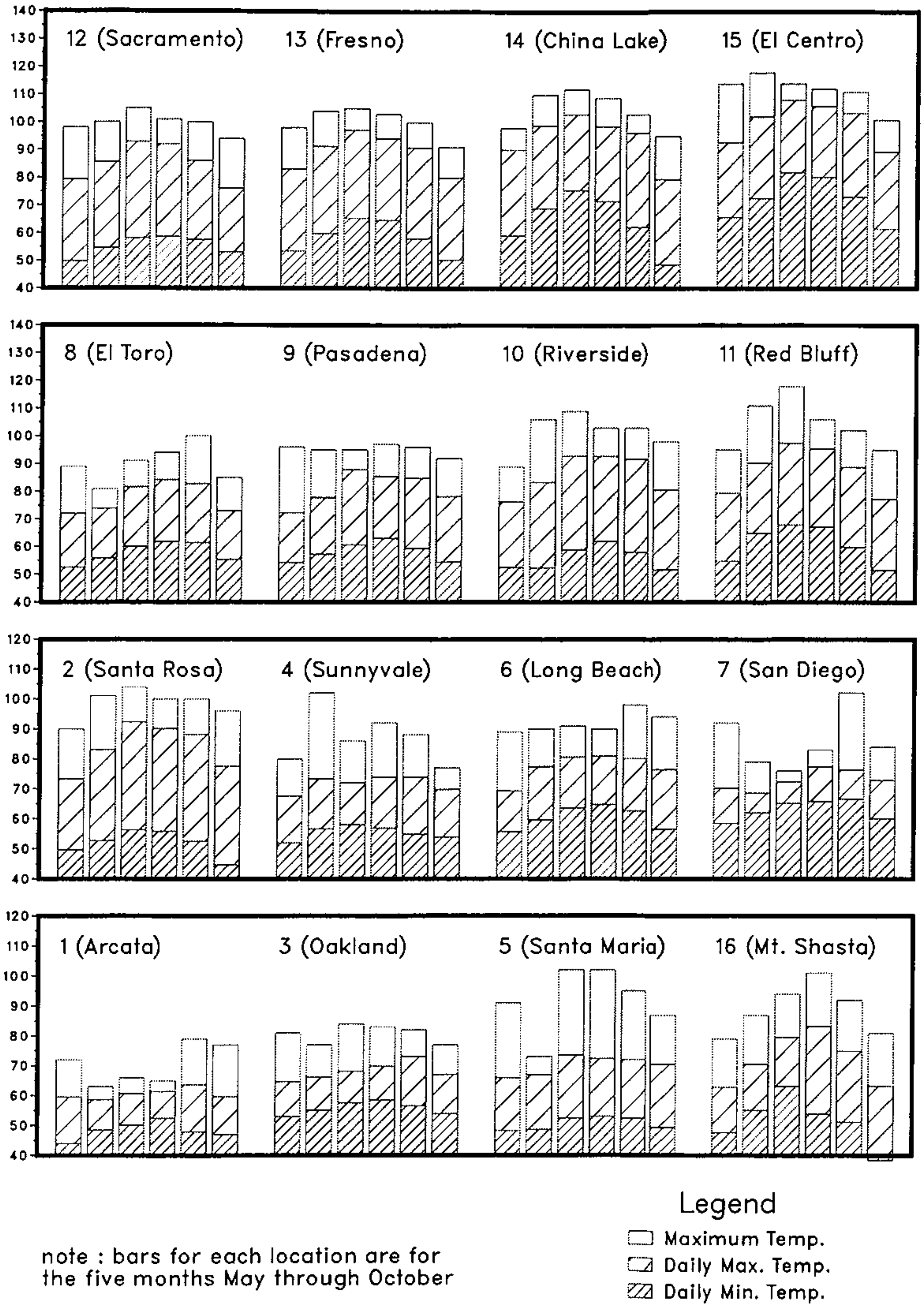
Figure 11.
Building Energy Standard (Title-24) Climate Zones

Figure 12
Average Monthly Dry Bulb and Wet Bulb Temperatures (F)



note : bars for each location are for the five months May through October

Figure 13
Daily Maximum/Minimum and Peak Monthly Temperatures (F)



note : bars for each location are for the five months May through October

Figure 14
Cooling Degree-Days Base 65 and Degree-Hours/24 Base 75

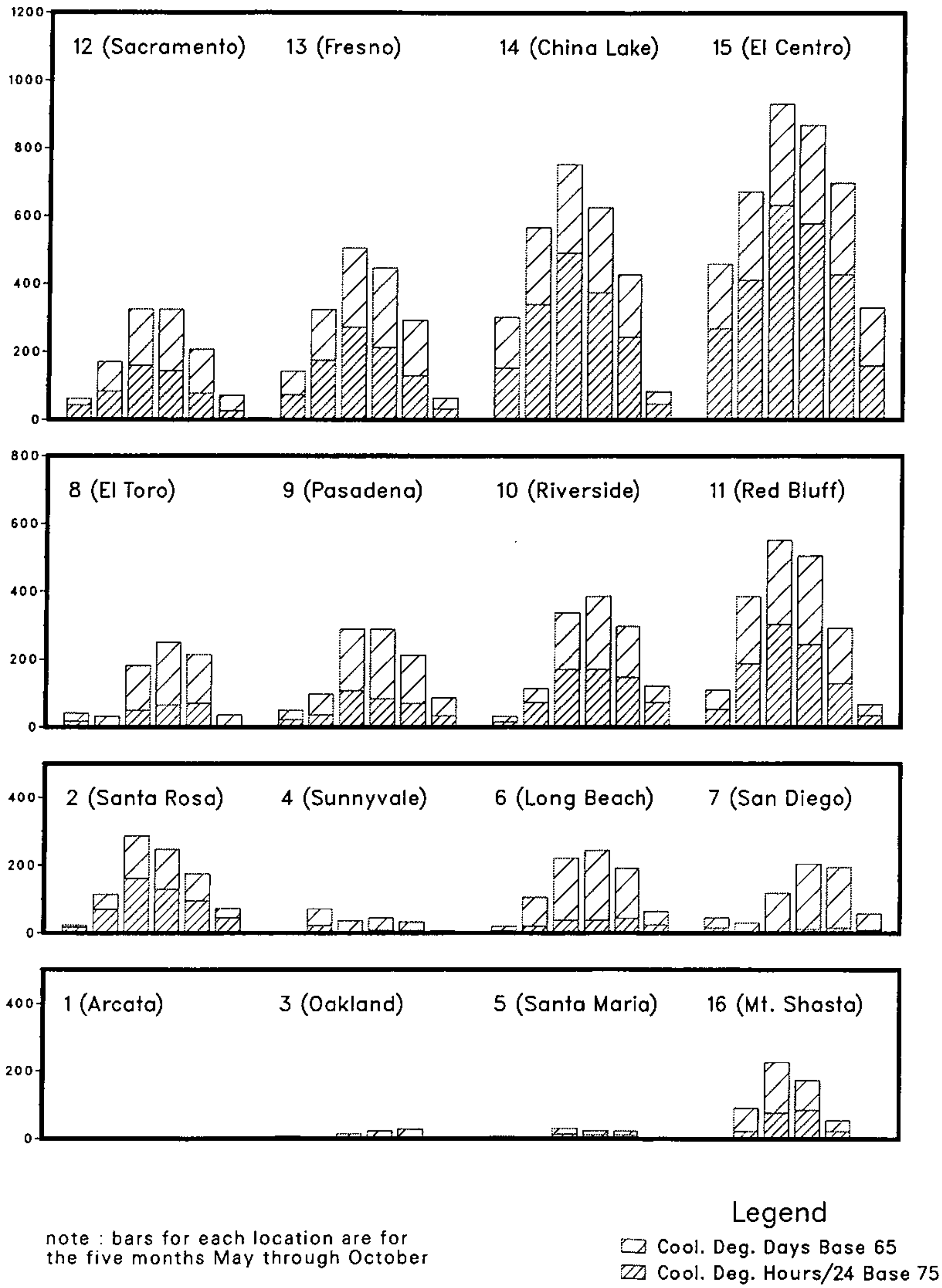
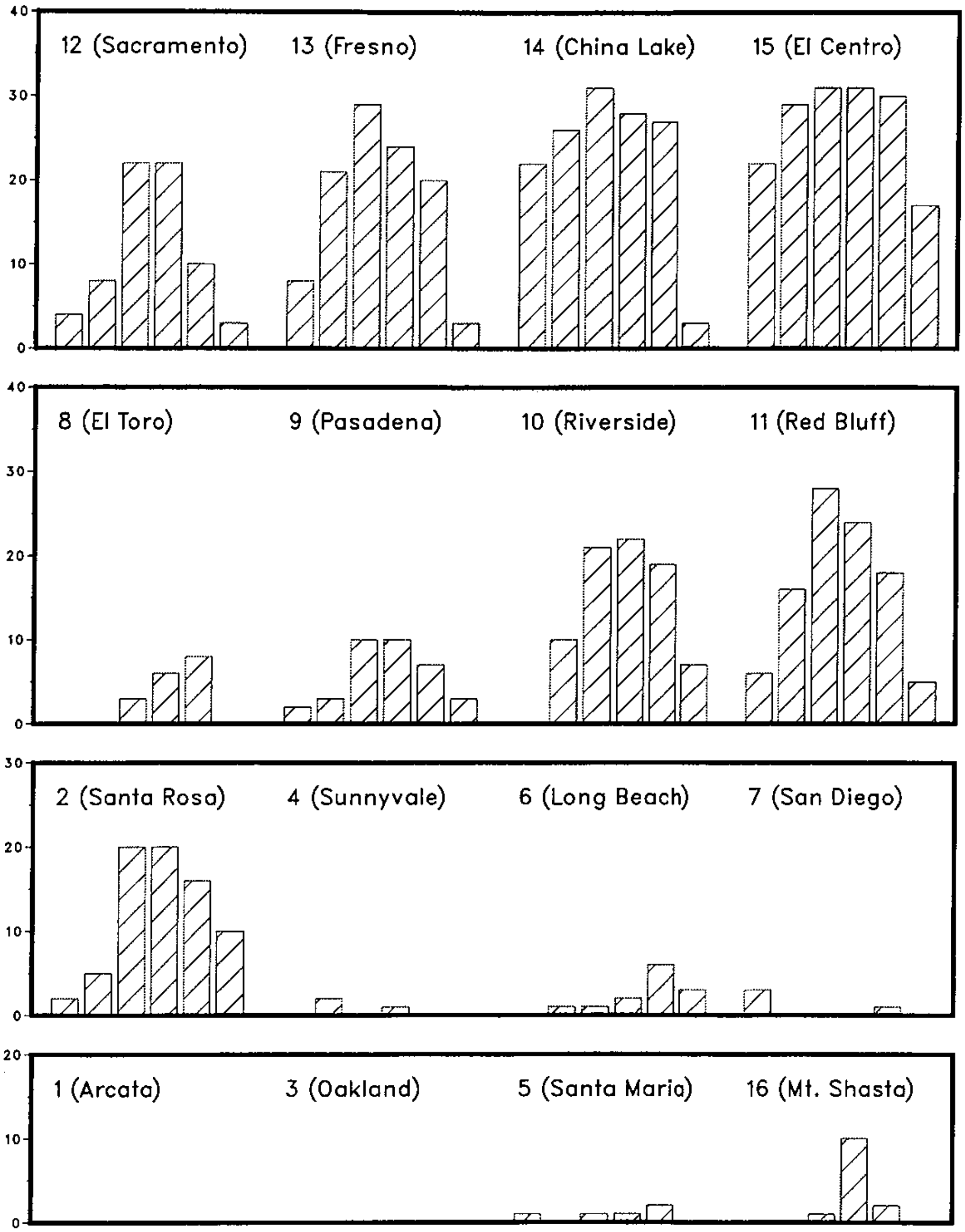
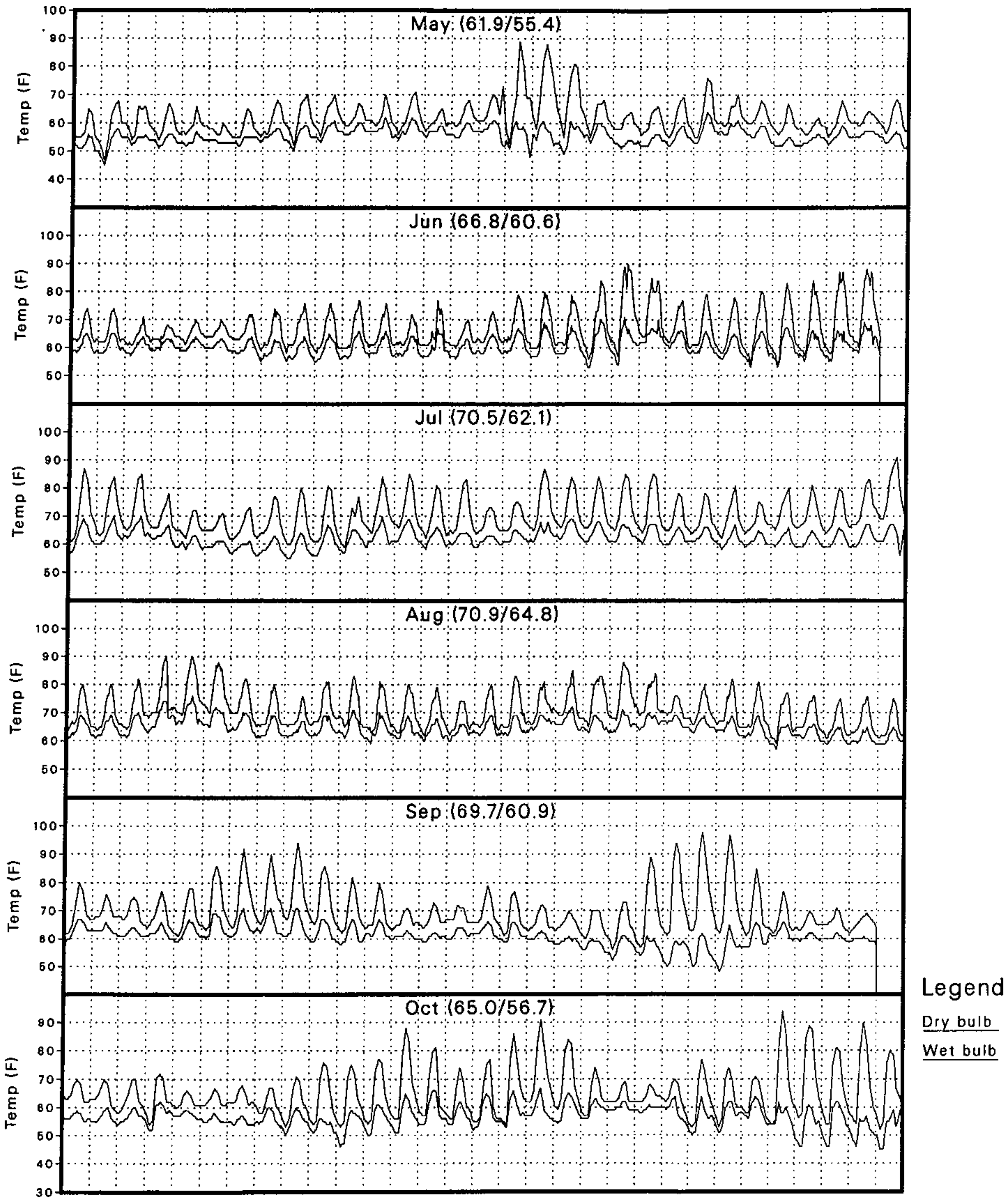


Figure 15
Days With Above 90 F Temperatures



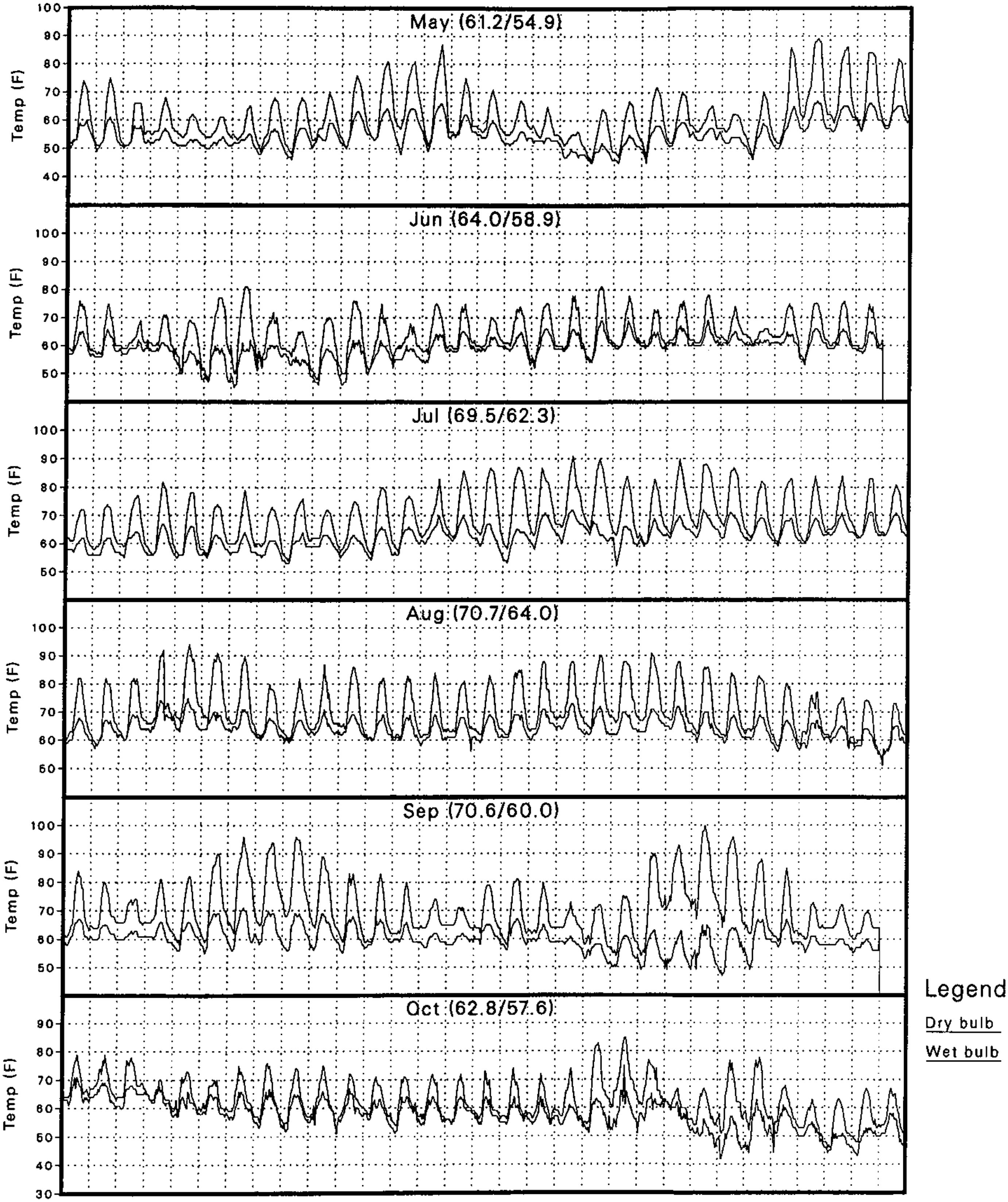
note : bars for each location are for the five months May through October

Figure 16. CTZ06C (Long Beach) Weather Tape



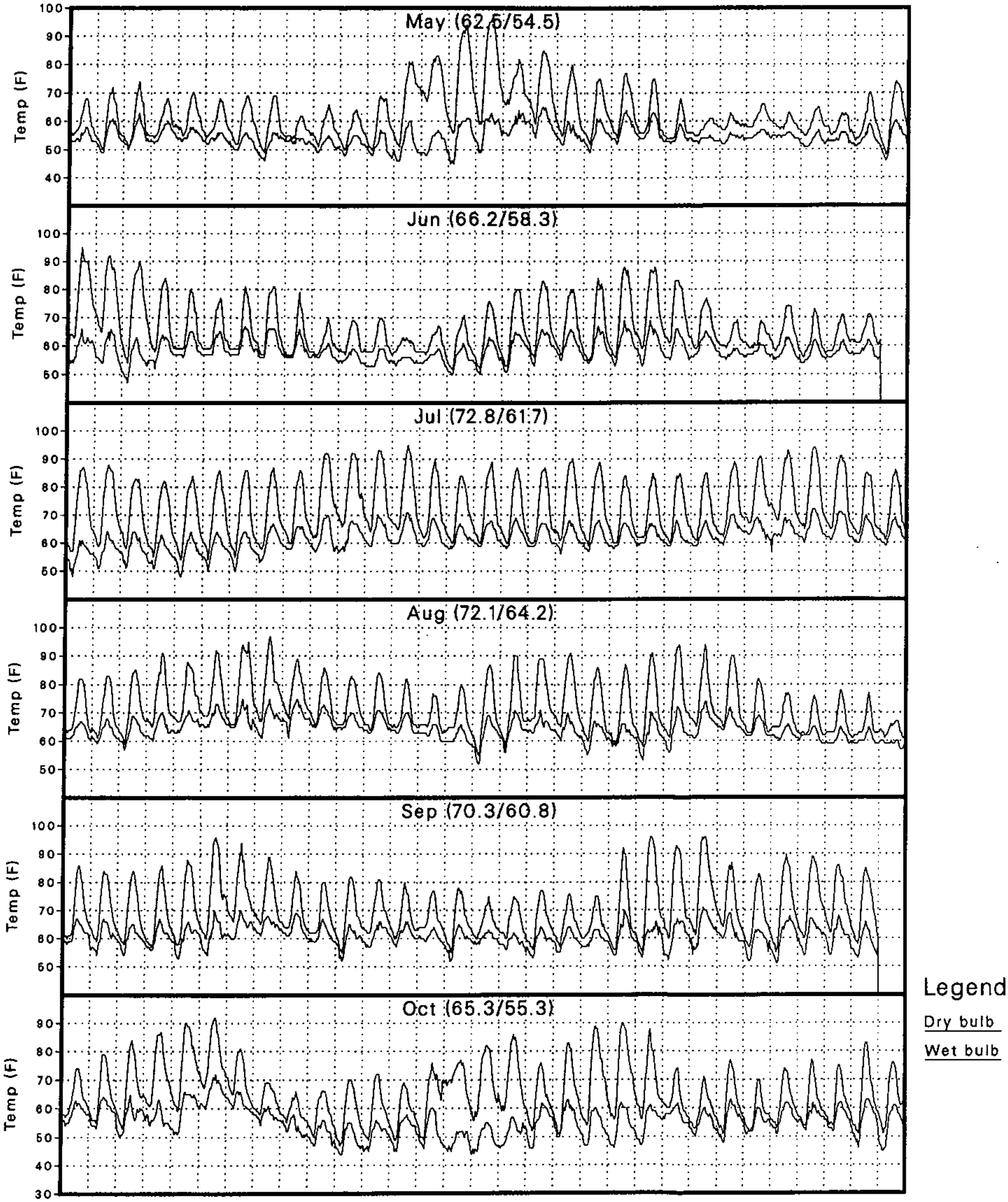
note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 17. CTZ08C (El Toro) Weather Tape



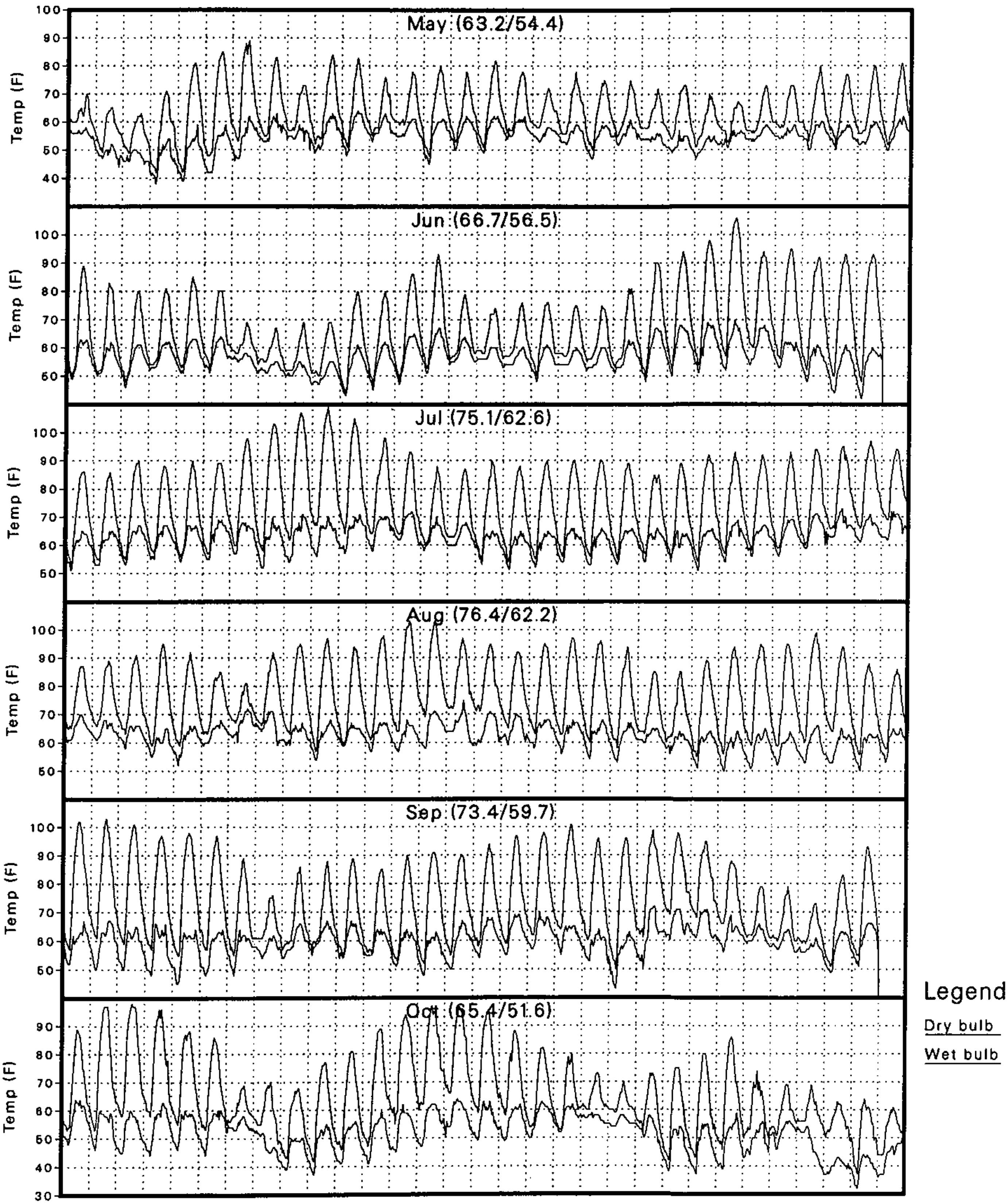
note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 18. CTZ09C (Pasadena) Weather Tape



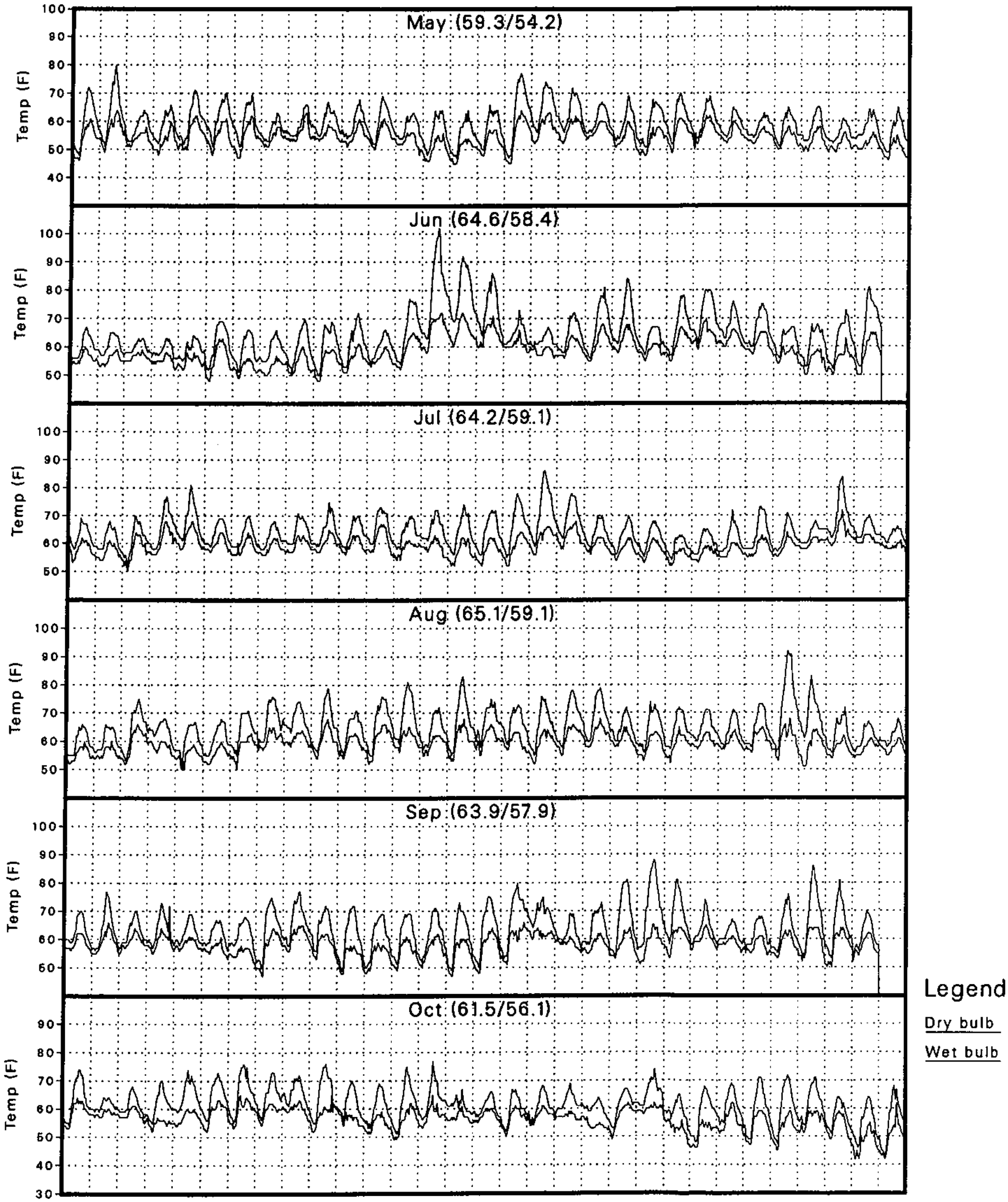
note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 19. CTZ10C (Riverside) Weather Tape



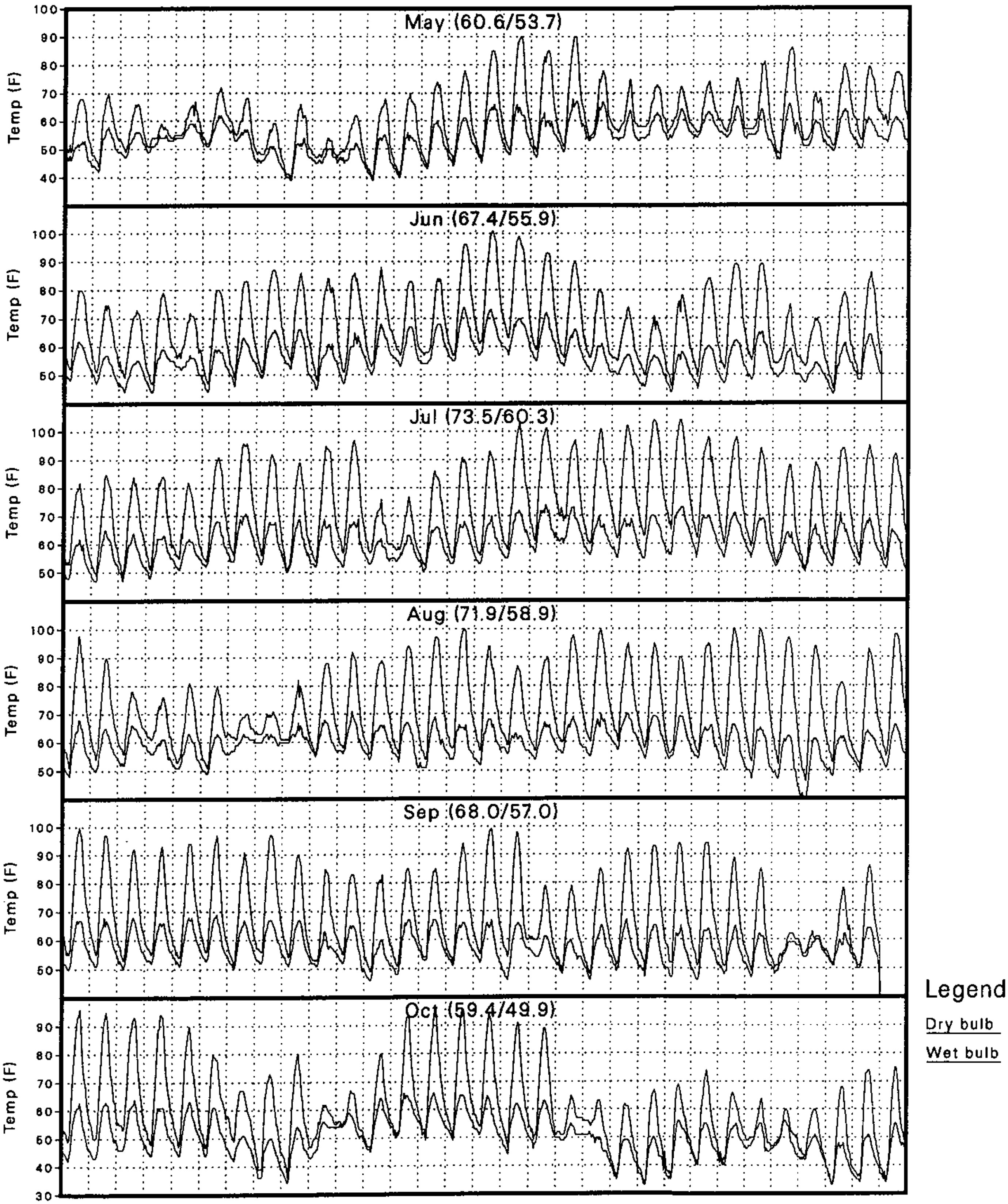
note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 20. CTZ04C (Sunnyvale) Weather Tape



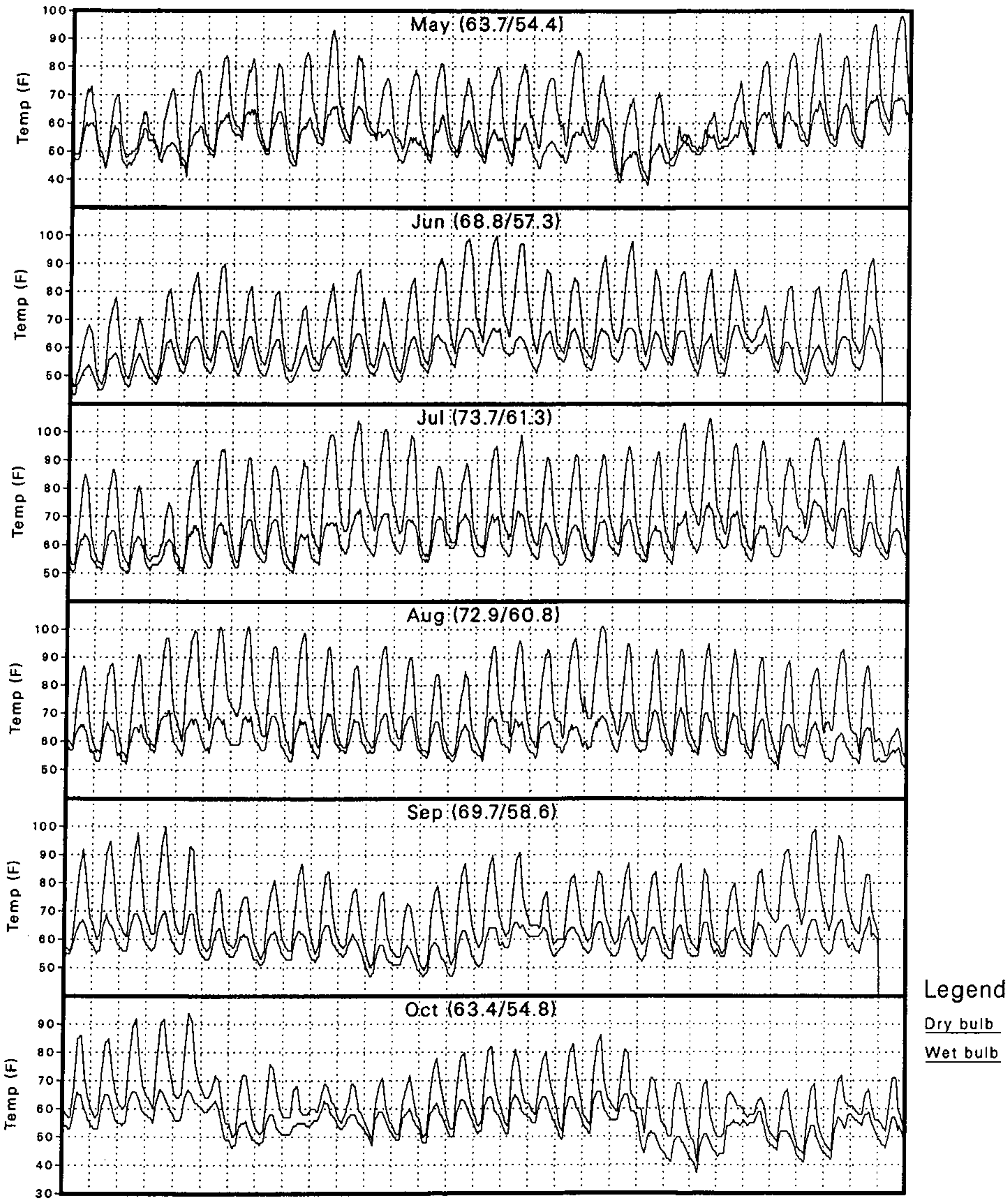
note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 21. CTZ02C (Santa Rosa) Weather Tape



note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 22. CTZ12C (Sacramento) Weather Tape



note : numbers in parenthesis are average dry and wet bulb temperatures by month

Figure 23.
CEC Demand Forecasting Zones

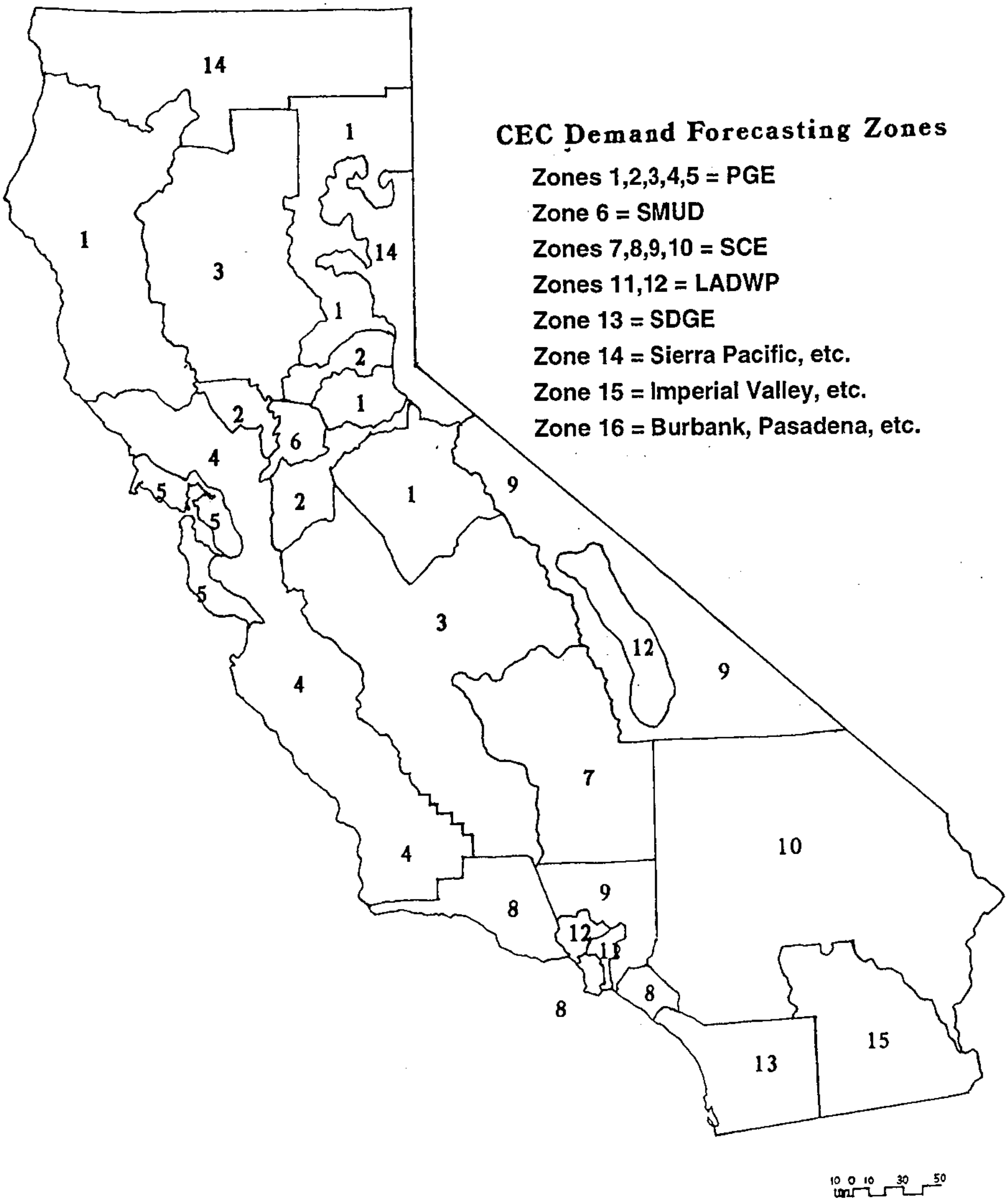
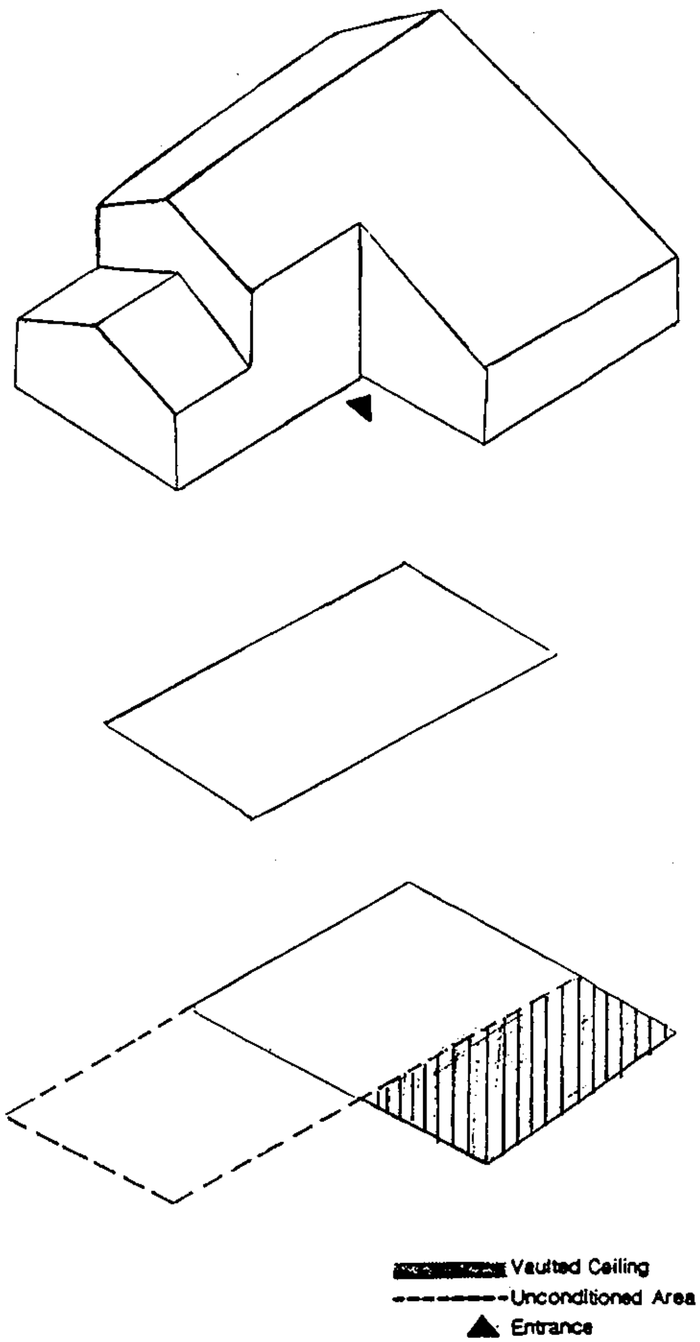


Figure 24.
Prototypical Single-family House used in 1990 Title-24 Building Energy Calculations



from R.M. Salazar and D. Ware 1990, "Residential Building Prototypes for Analyzing the 1992 Standards", Staff Report, California Energy Commission, Sacramento CA.

Figure 25.
Prototype 1 House (2200 ft^2, 2-story, 4 Bedrooms)

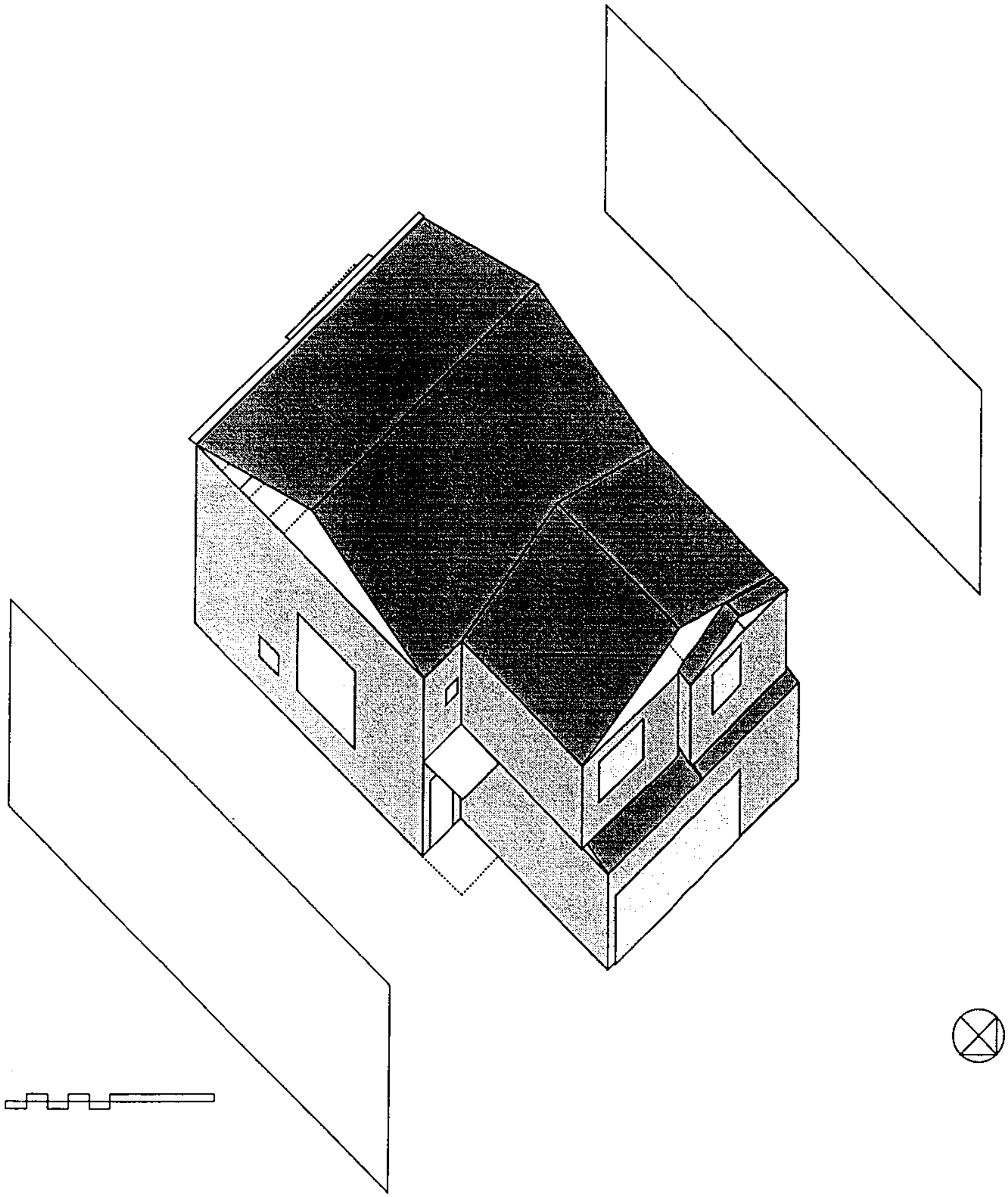


Figure 26.
Prototype 2 House (1544 ft^2, 1-story, 3 Bedrooms)

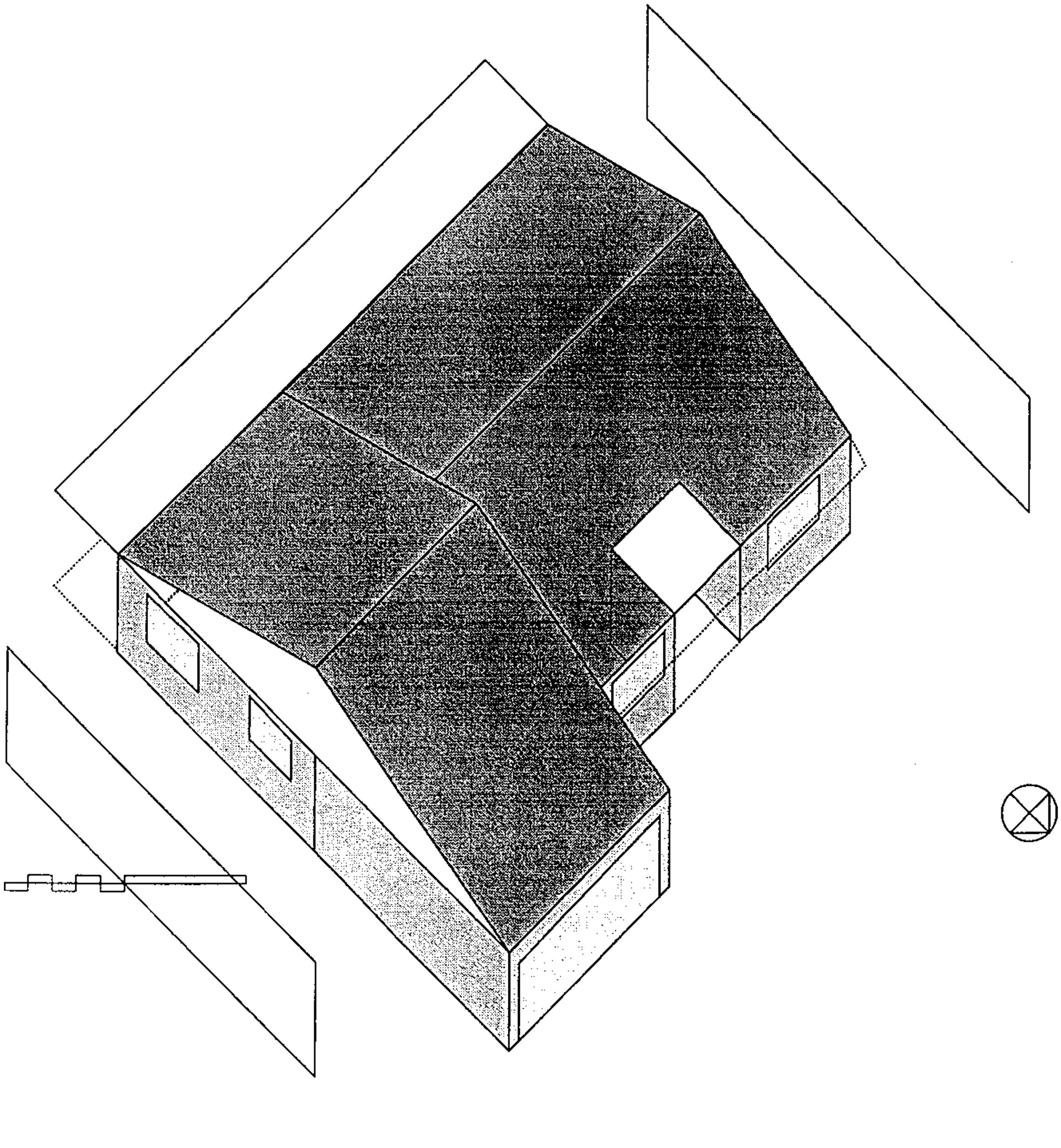


Figure 27
Prototype 1 Base Case in CTZ02C (Santa Rosa) on Peak Summer Days

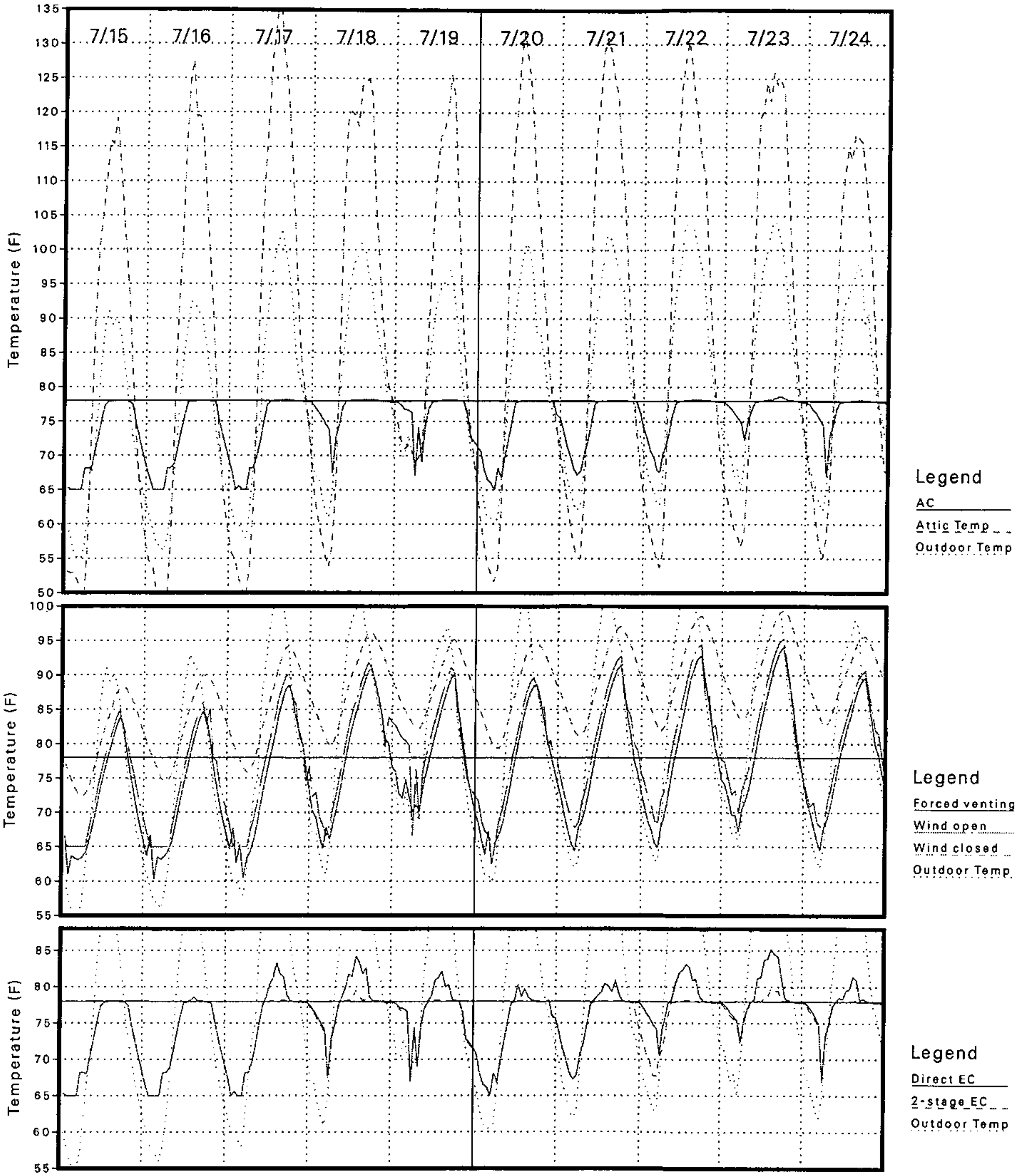


Figure 28
Single Measures for Prototype 1 in CTZ02C on Peak Summer Days

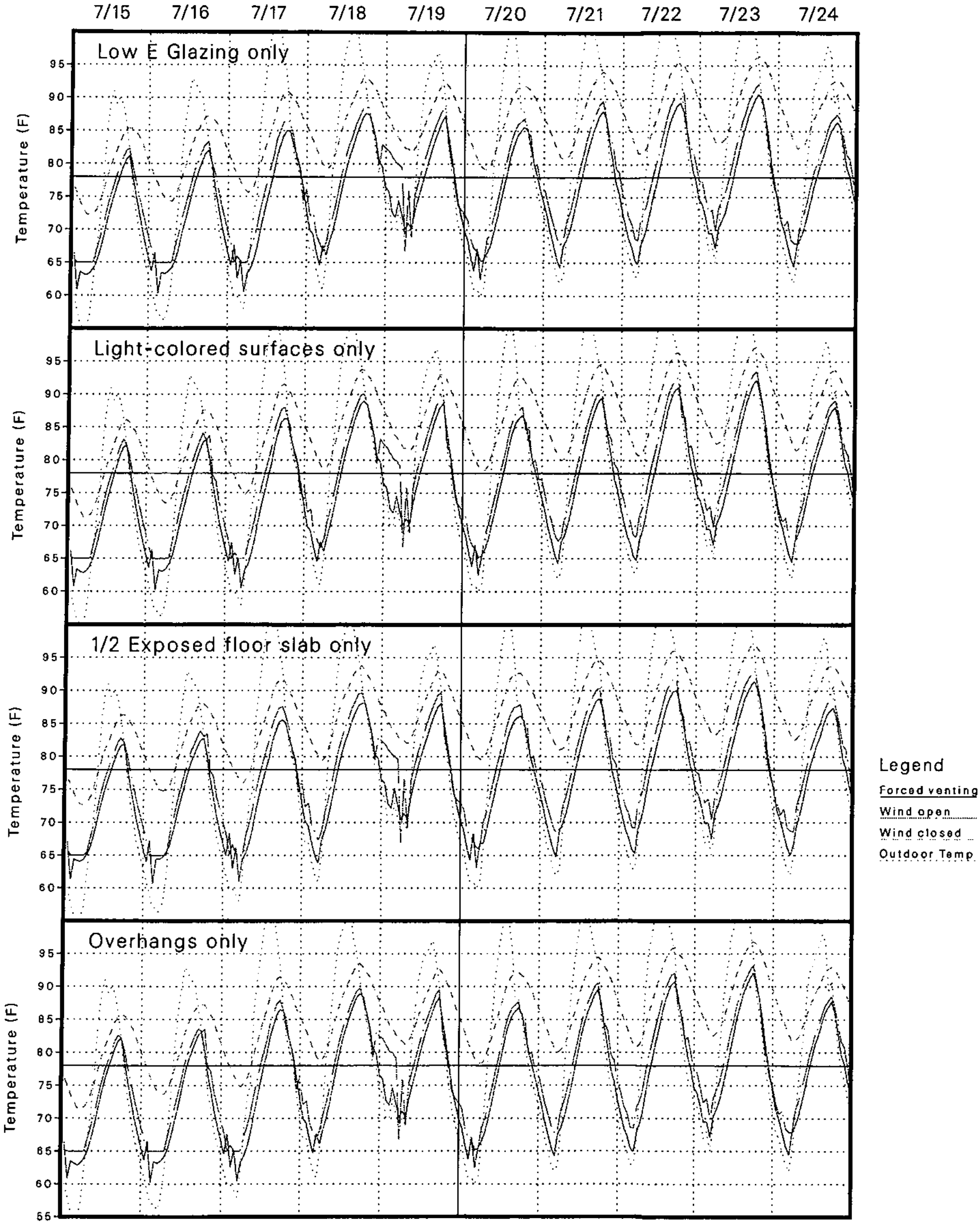


Figure 29
Combined Measures for Prototype 1 in CTZ02C on Peak Summer Days

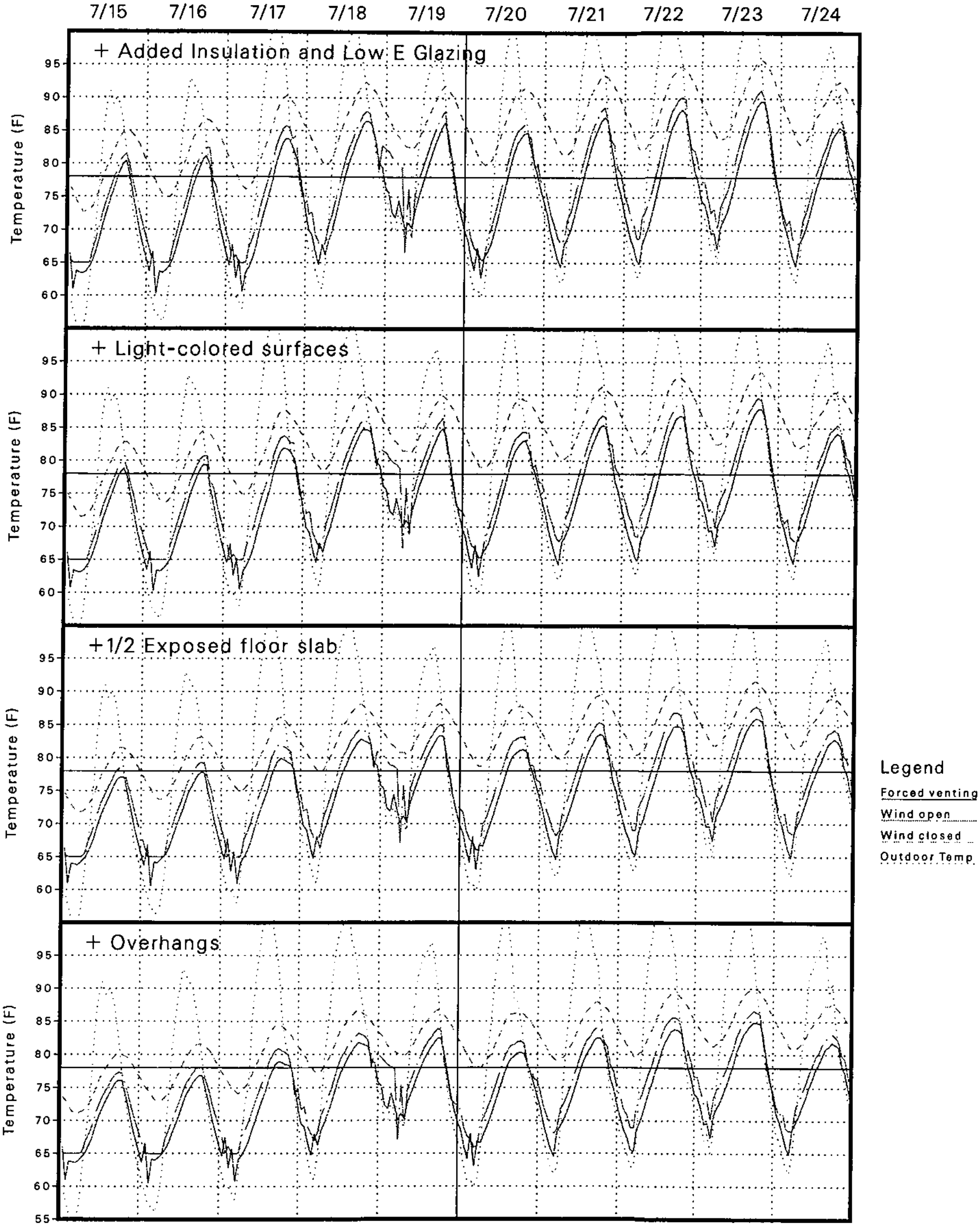


Figure 30
Prototype 1 Improved Case in CTZ02C (Santa Rosa) on Peak Summer Days

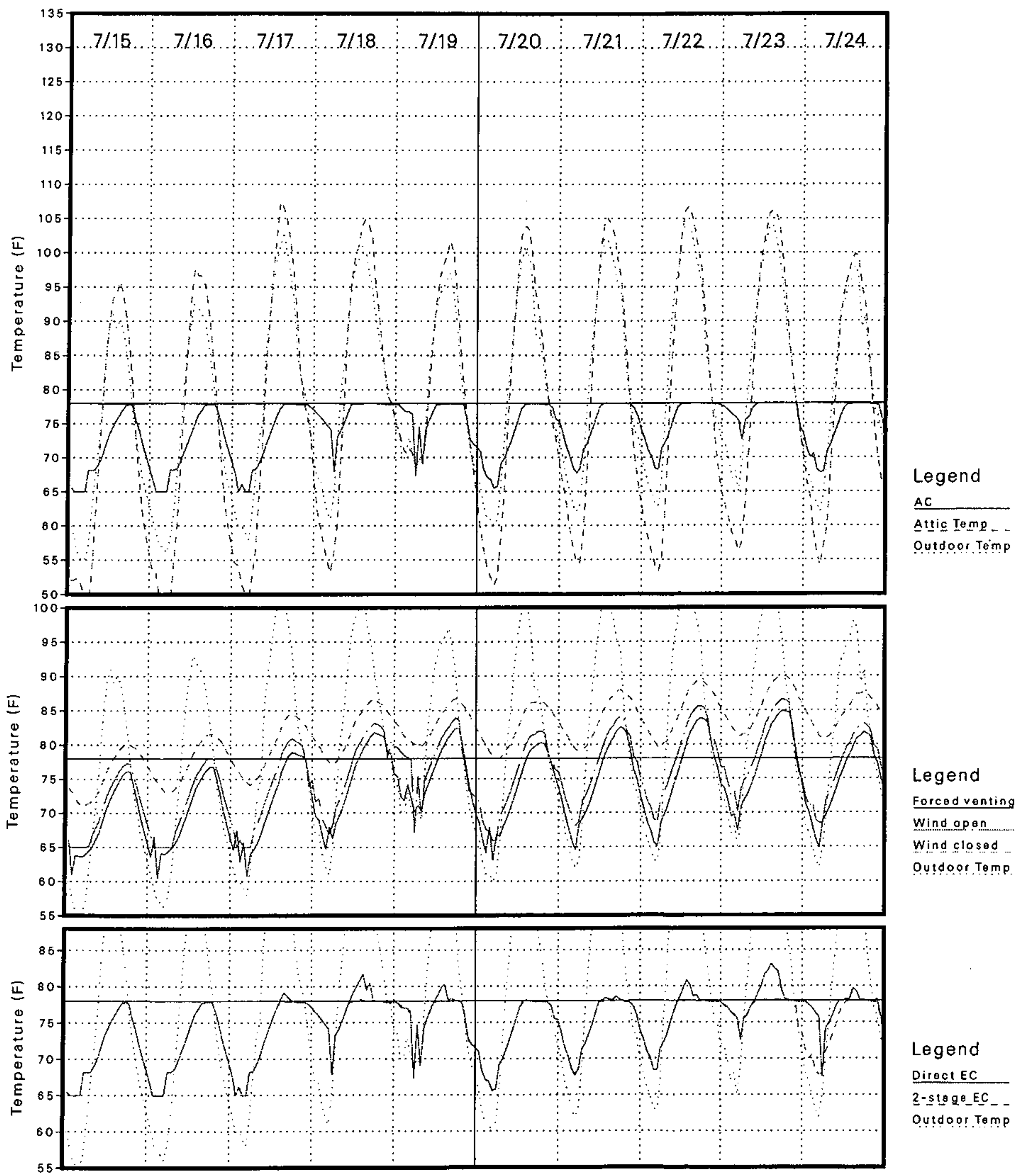


Figure 31
Prototype 1 Base Case in CTZ02C (Santa Rosa) on Typical Summer Days

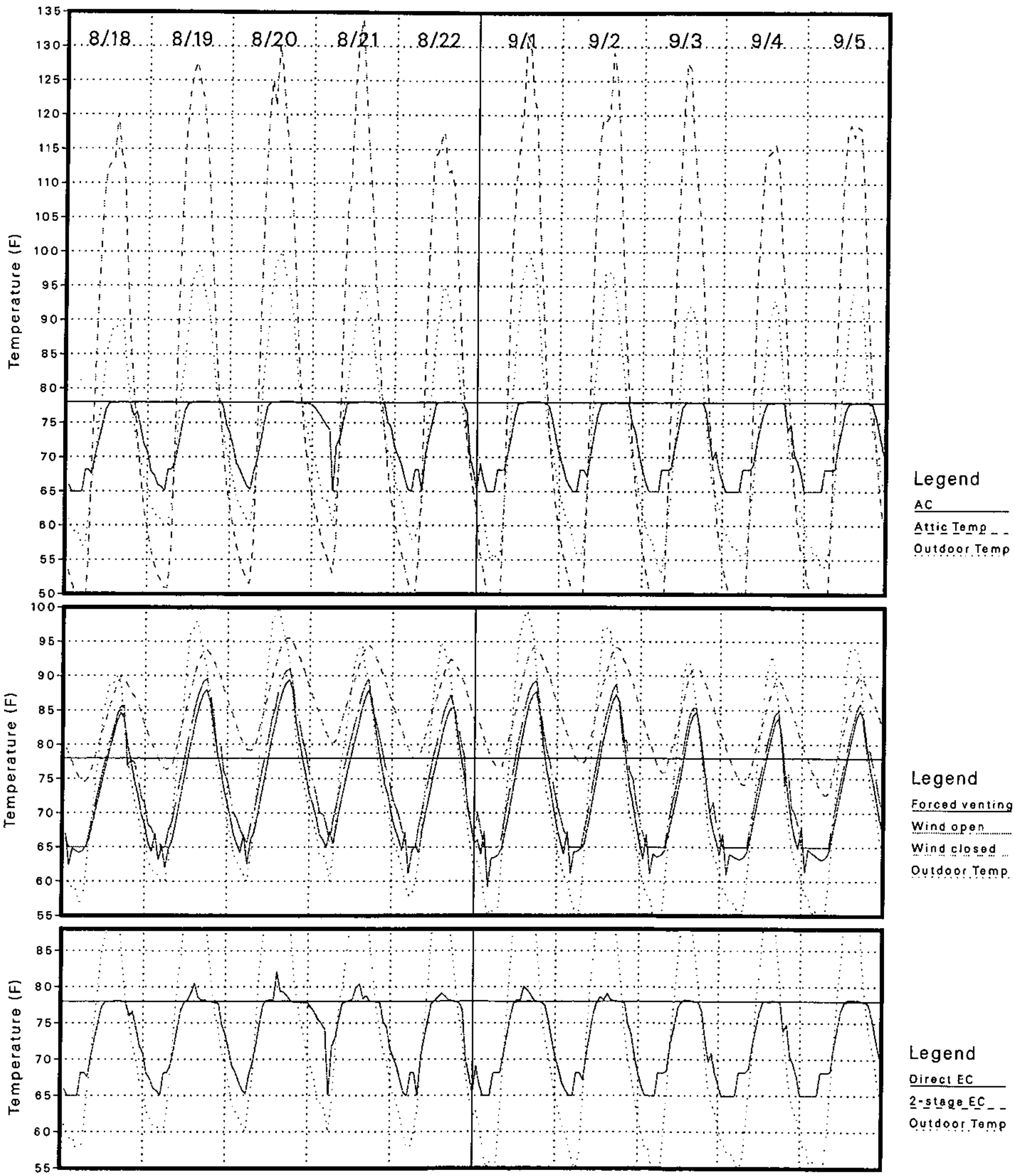


Figure 32
Single Measures for Prototype 1 in CTZ02C on Typical Summer Days

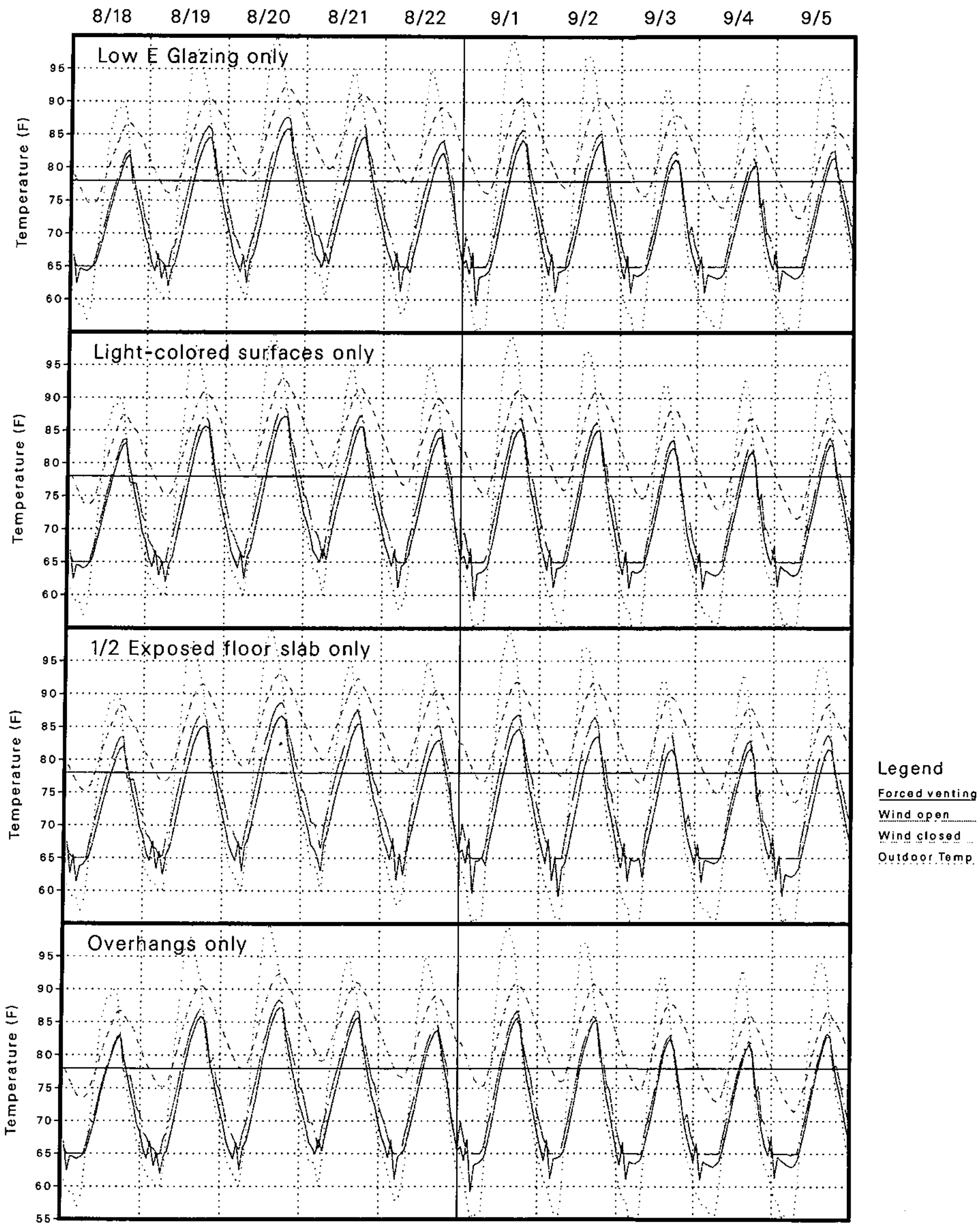


Figure 33
Combined Measures for Prototype 1 in CTZ02C on Typical Summer Days

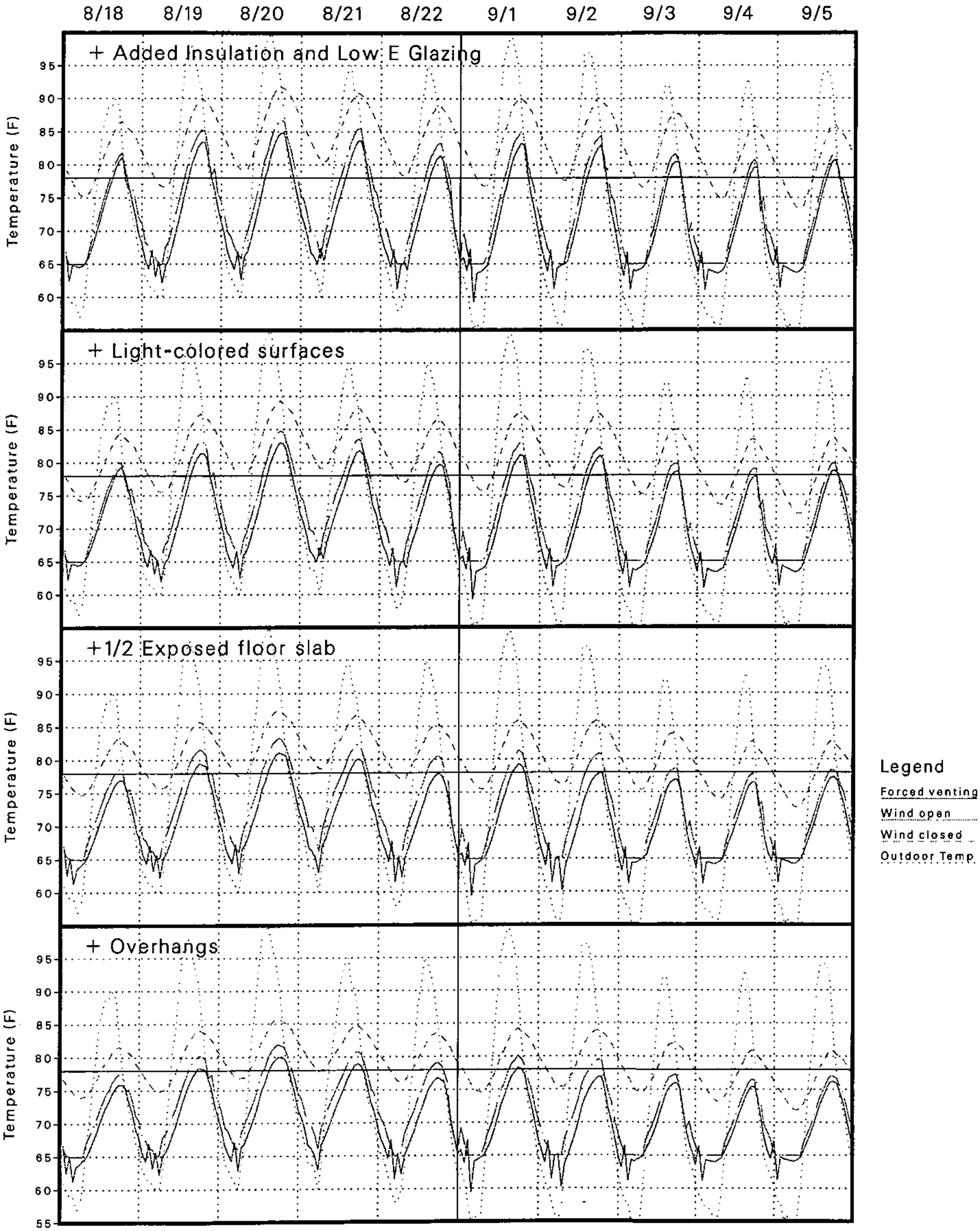


Figure 34
Prototype 1 Improved Case in CTZ02C (Santa Rosa) on Typical Summer Days

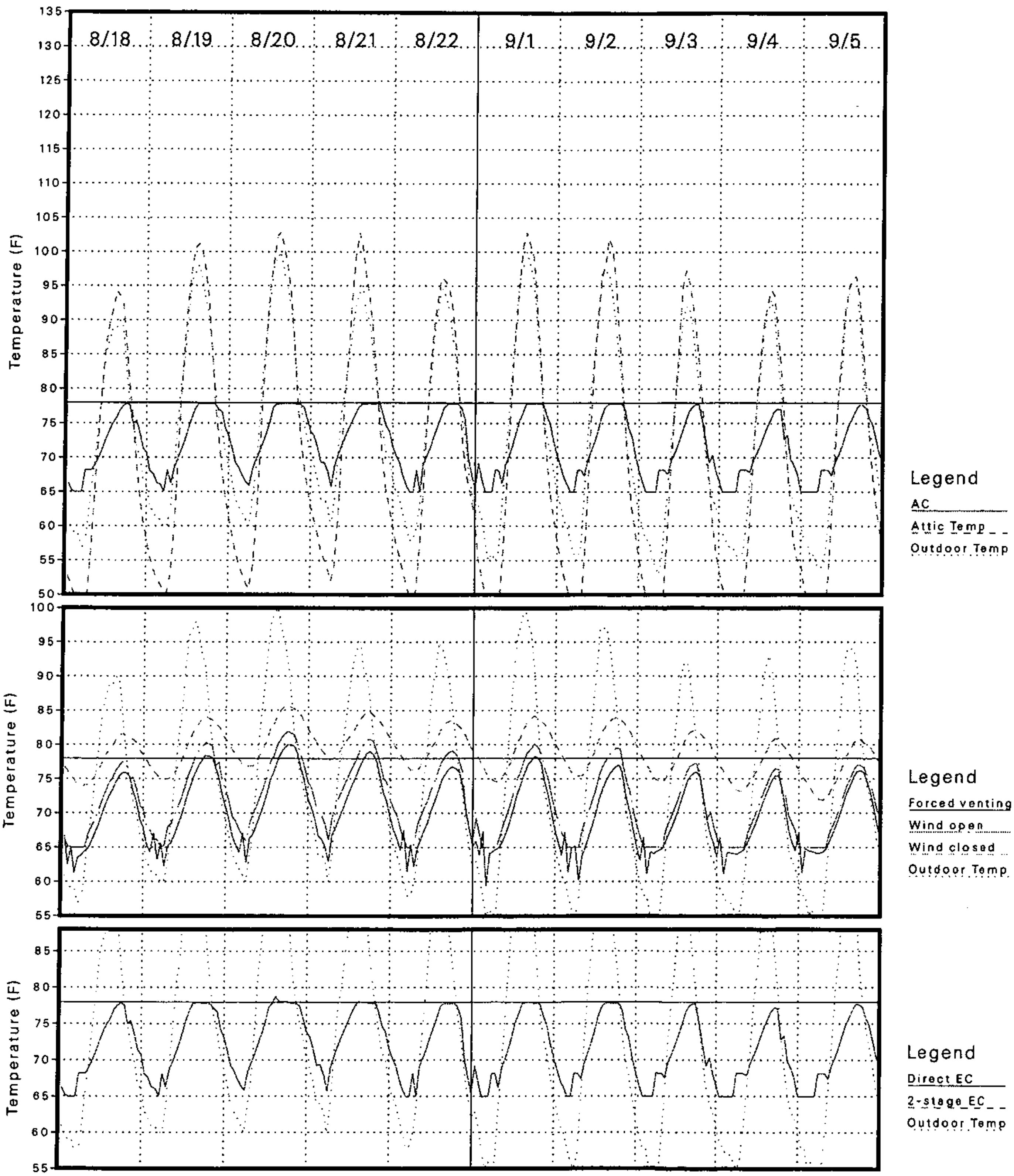


Figure 35

Prototype 1 Base Case in CTZ09C (Pasadena) on Peak Summer Days

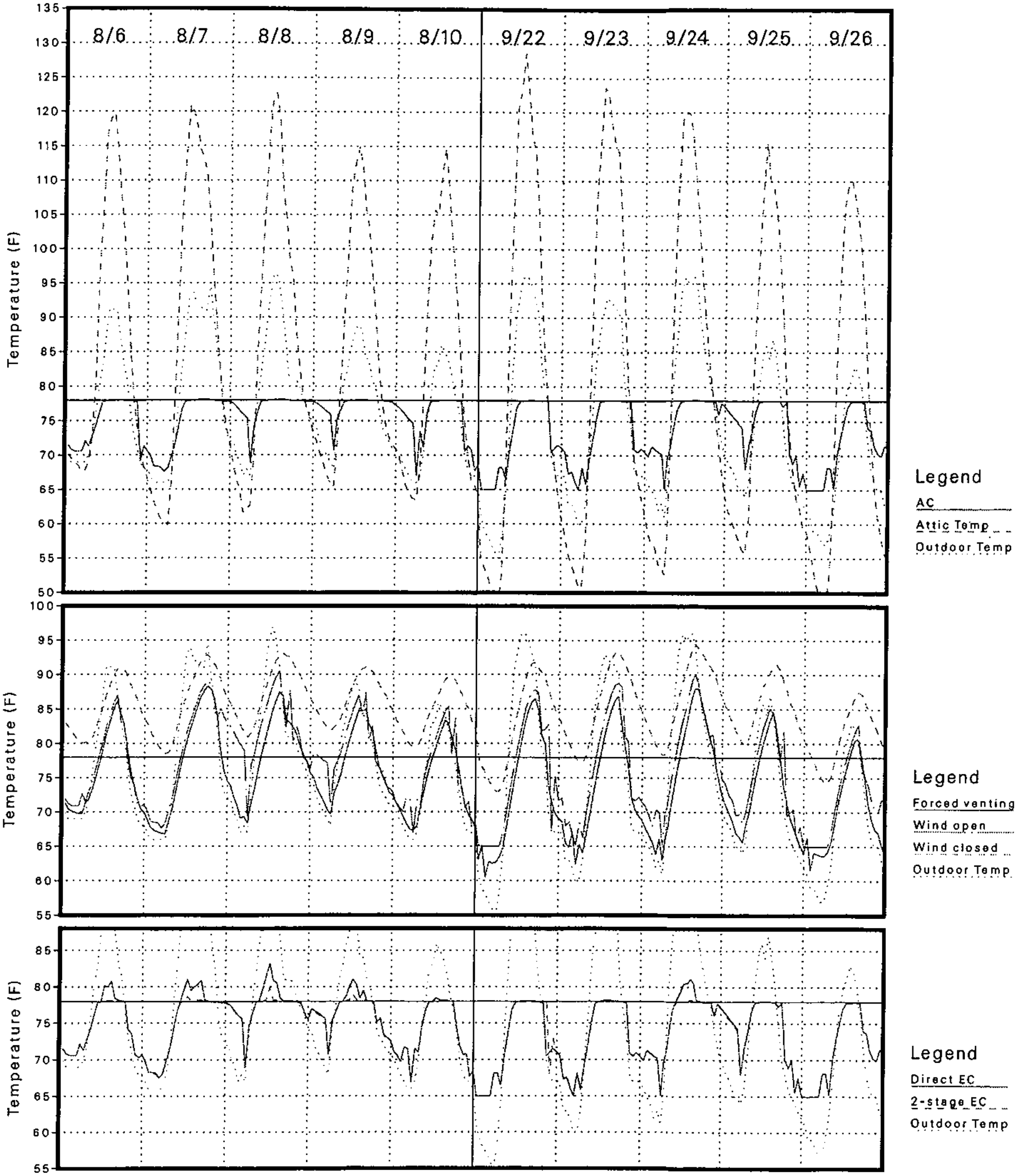


Figure 36
Single Measures for Prototype 1 in CTZ09C on Peak Summer Days

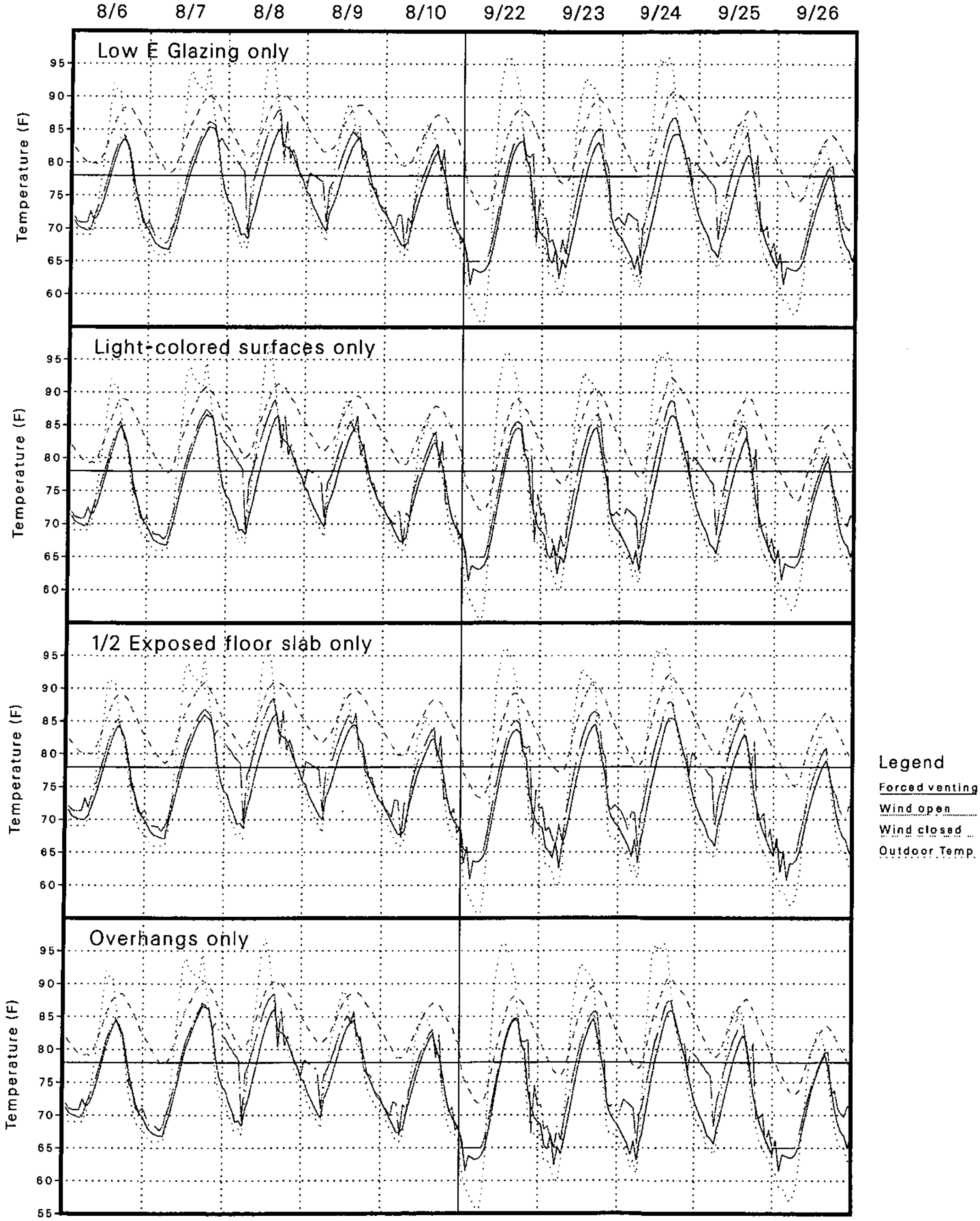


Figure 37
Combined Measures for Prototype 1 in CTZ09C on Peak Summer Days

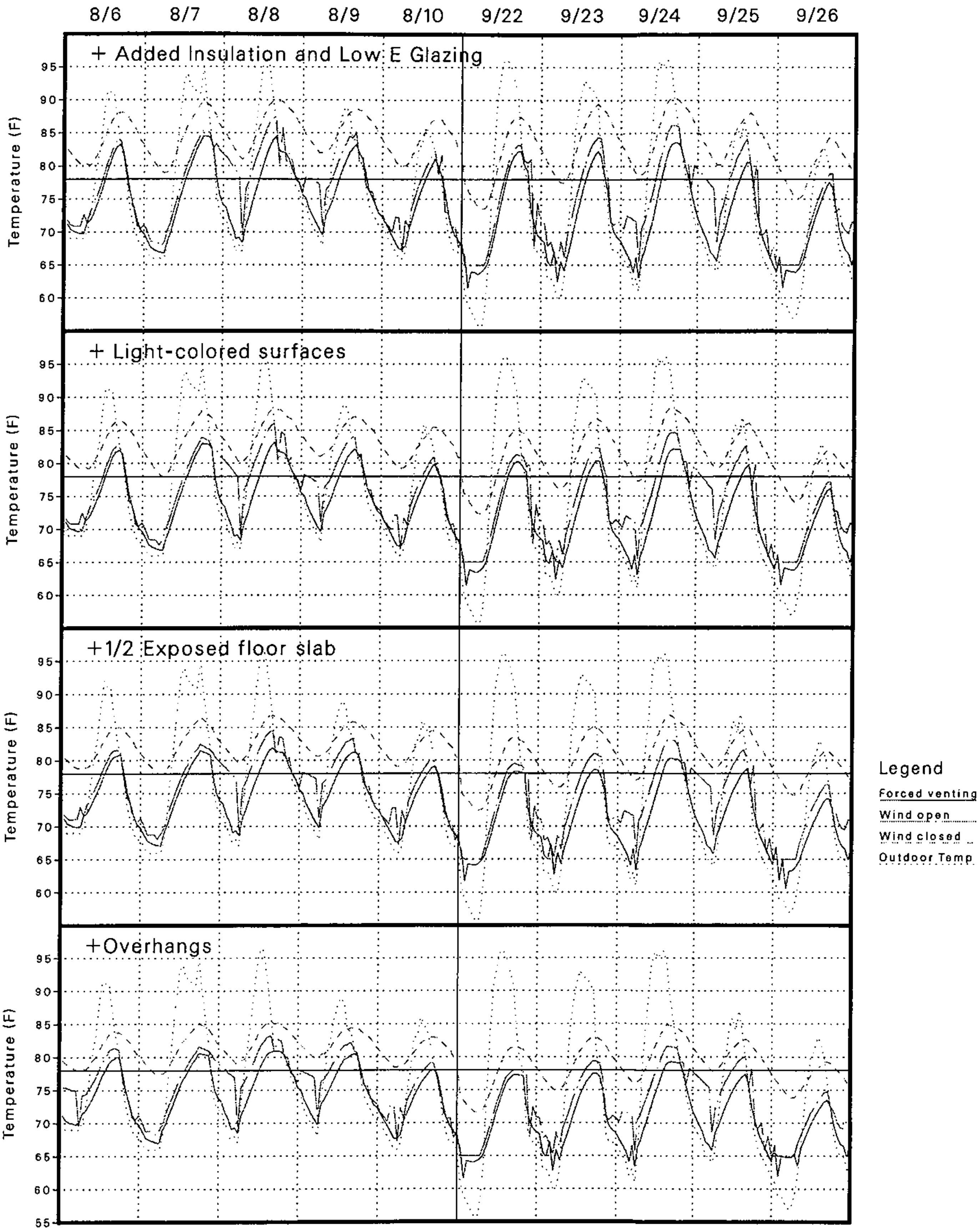


Figure 38
Prototype 1 Improved Case in CTZ09C (Pasadena) on Peak Summer Days

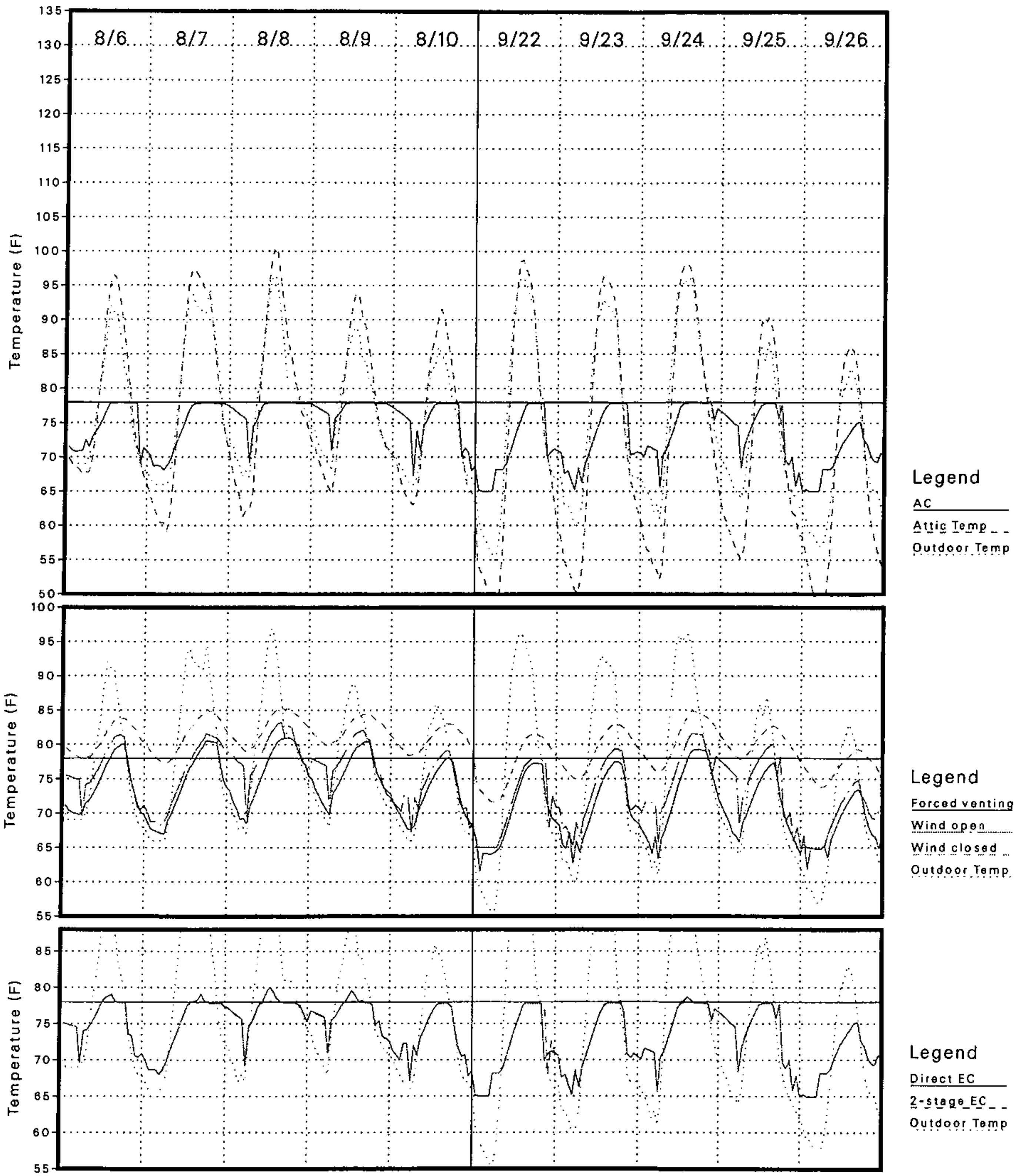


Figure 39
Prototype 1 Base Case in CTZ09C (Pasadena) on Typical Summer Days

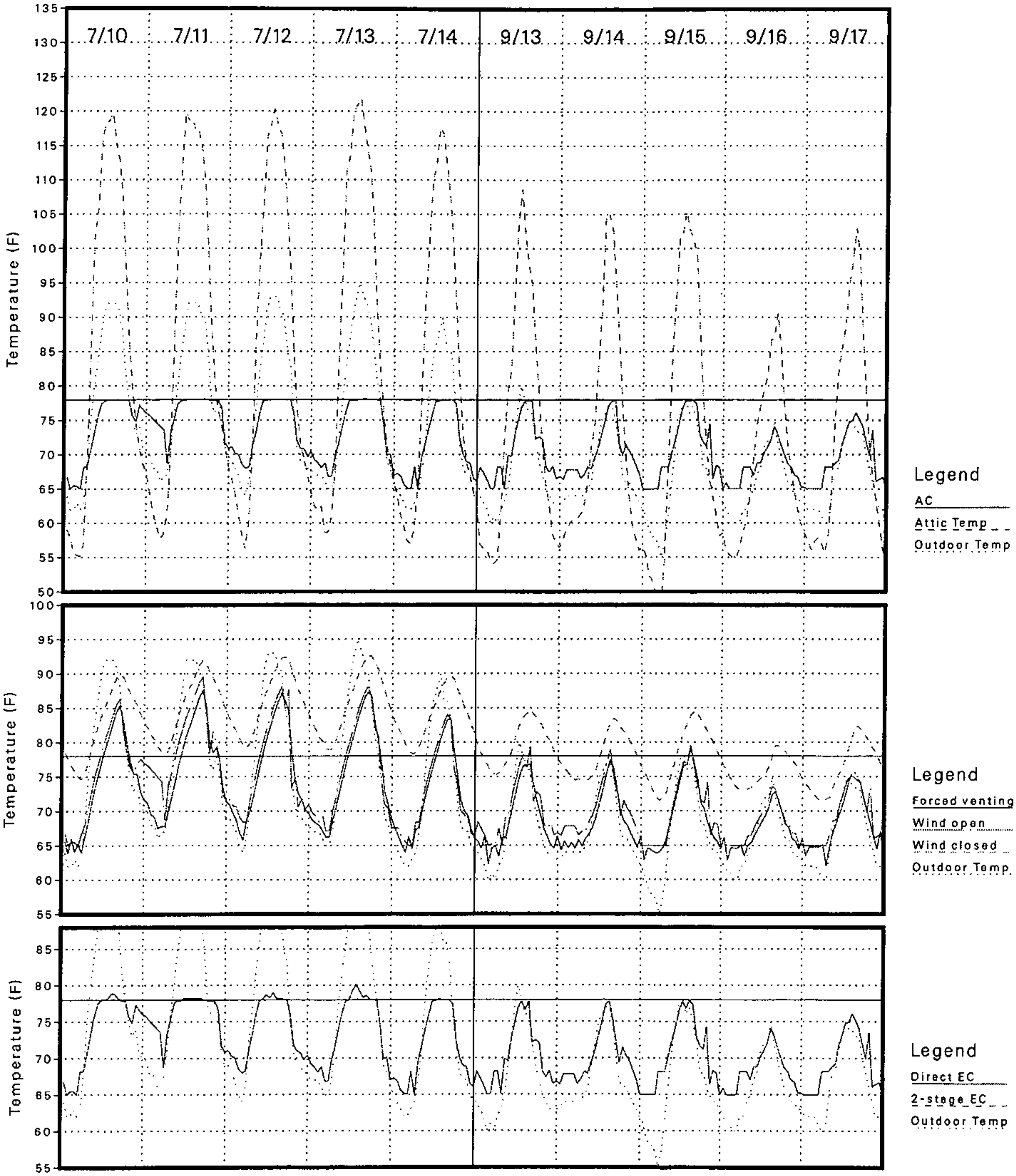


Figure 40
Single Measures for Prototype 1 in CTZ09C on Typical Summer Days

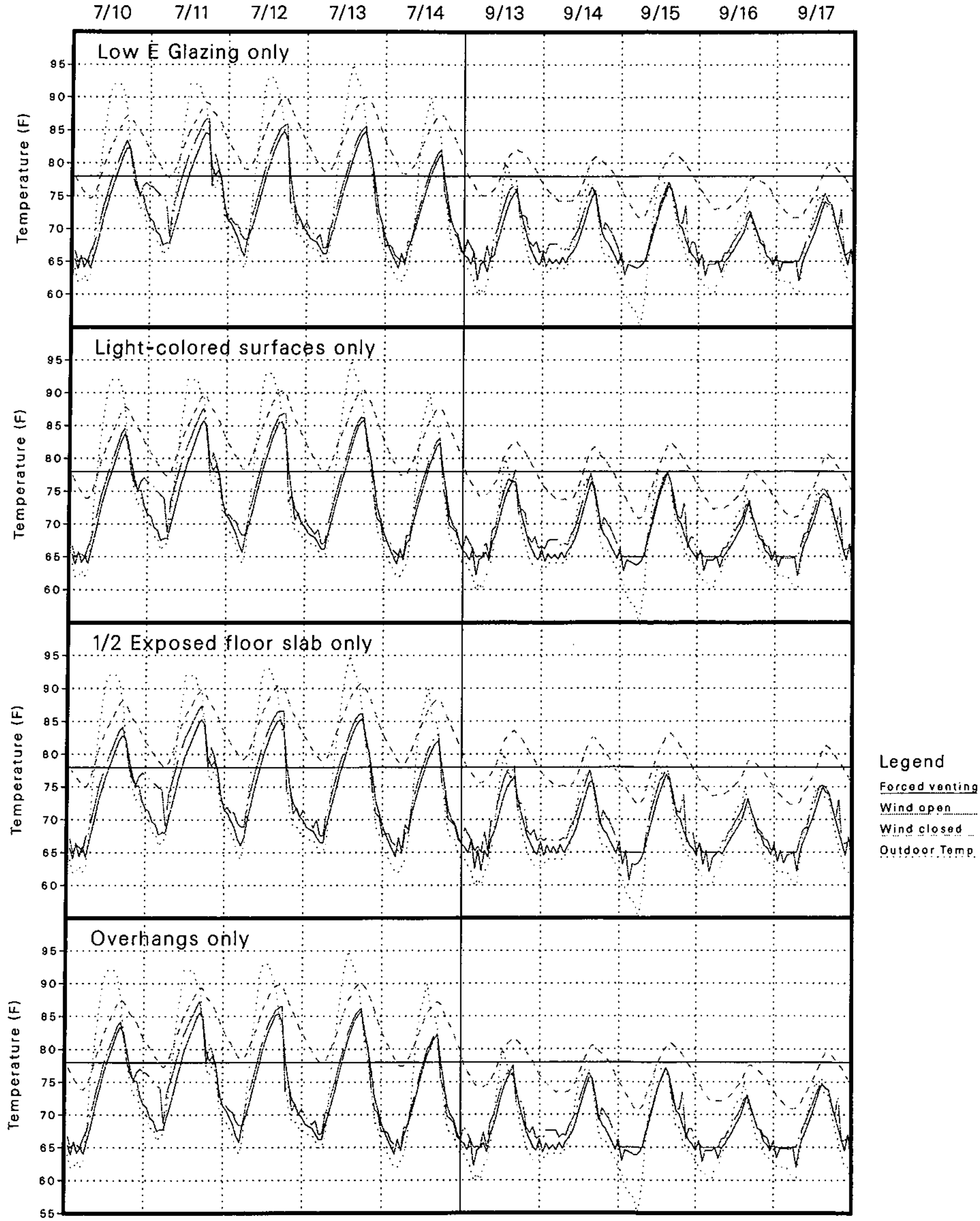


Figure 41
Combined Measures for Prototype 1 in CTZ09C on Typical Summer Days

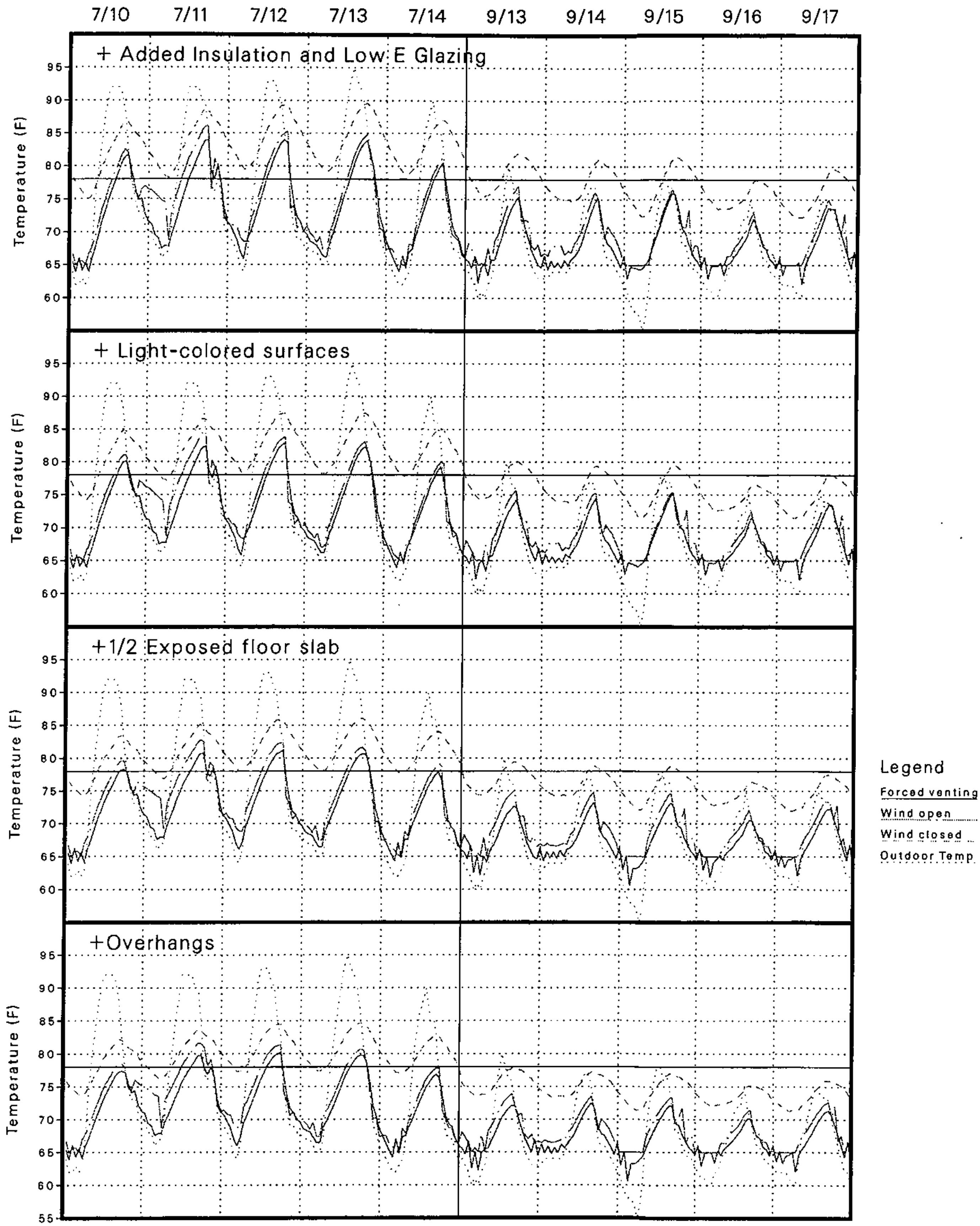


Figure 42
Prototype 1 Improved Case in CTZ09C (Pasadena) on Typical Summer Days

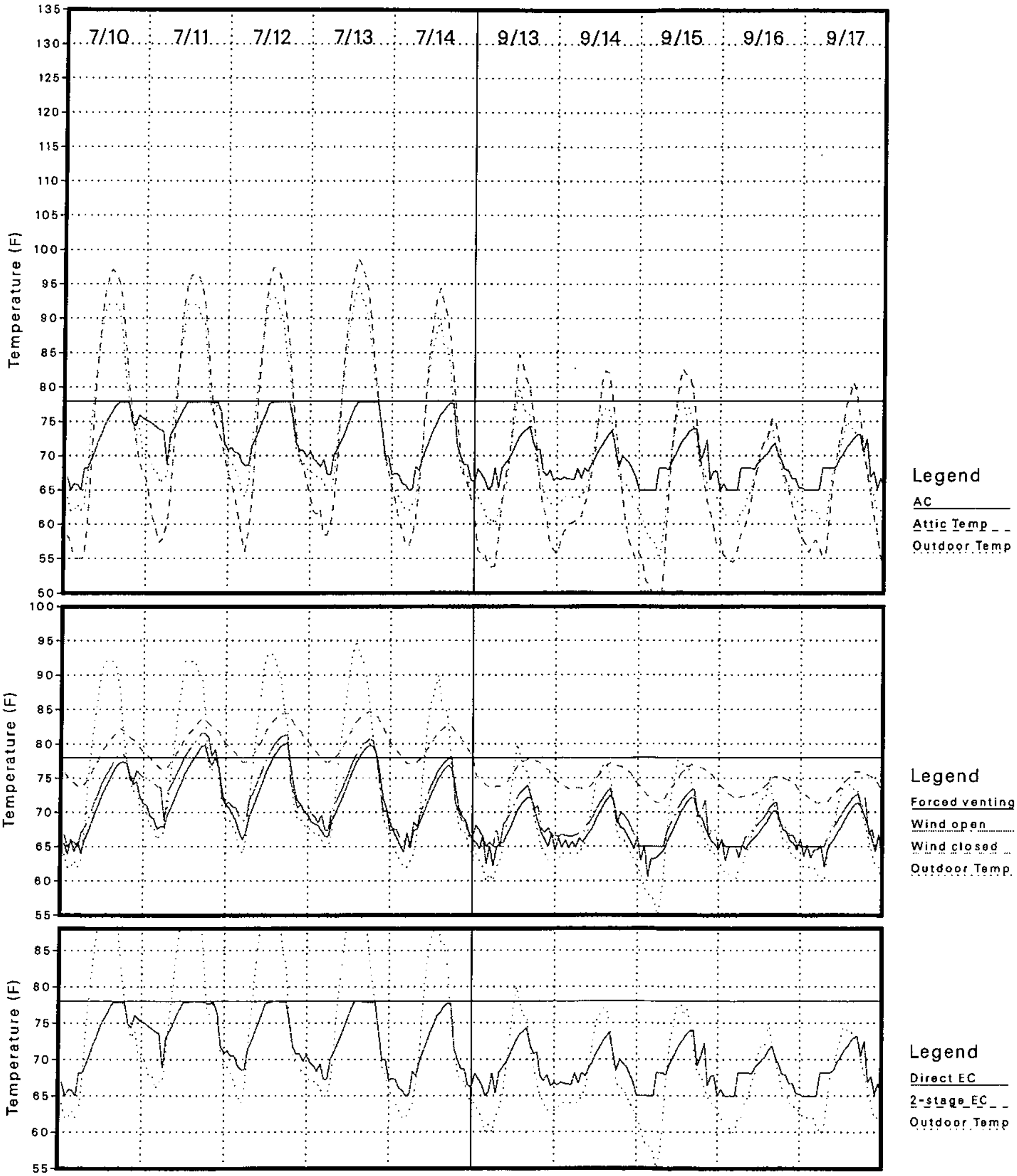


Figure 43
Prototype 2 Base Case in CTZ10C (Riverside) on Peak Summer Days

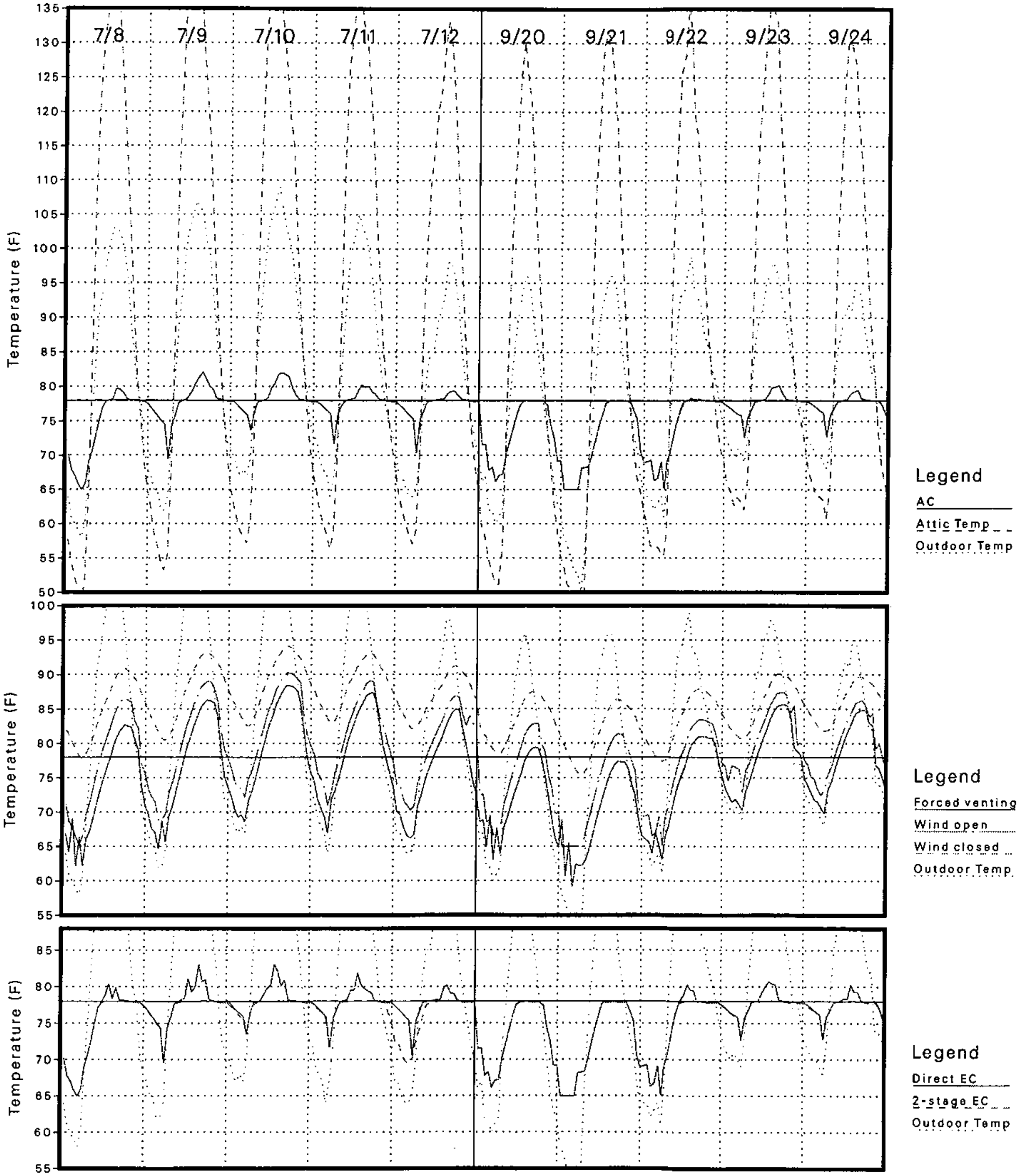


Figure 44
Single Measures for Prototype 2 in CTZ10C on Peak Summer Days

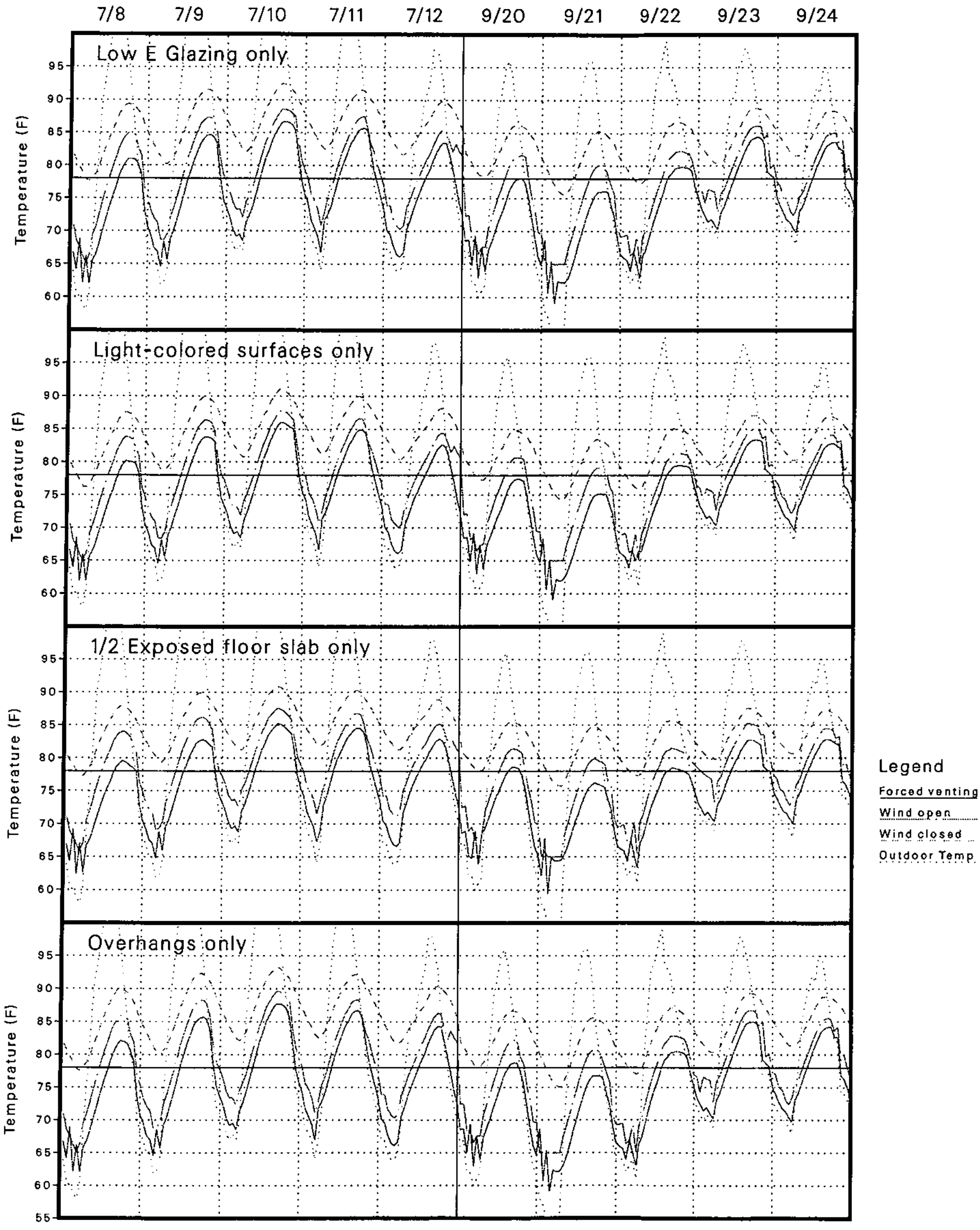


Figure 45
Combined Measures for Prototype 2 in CTZ10C on Peak Summer Days

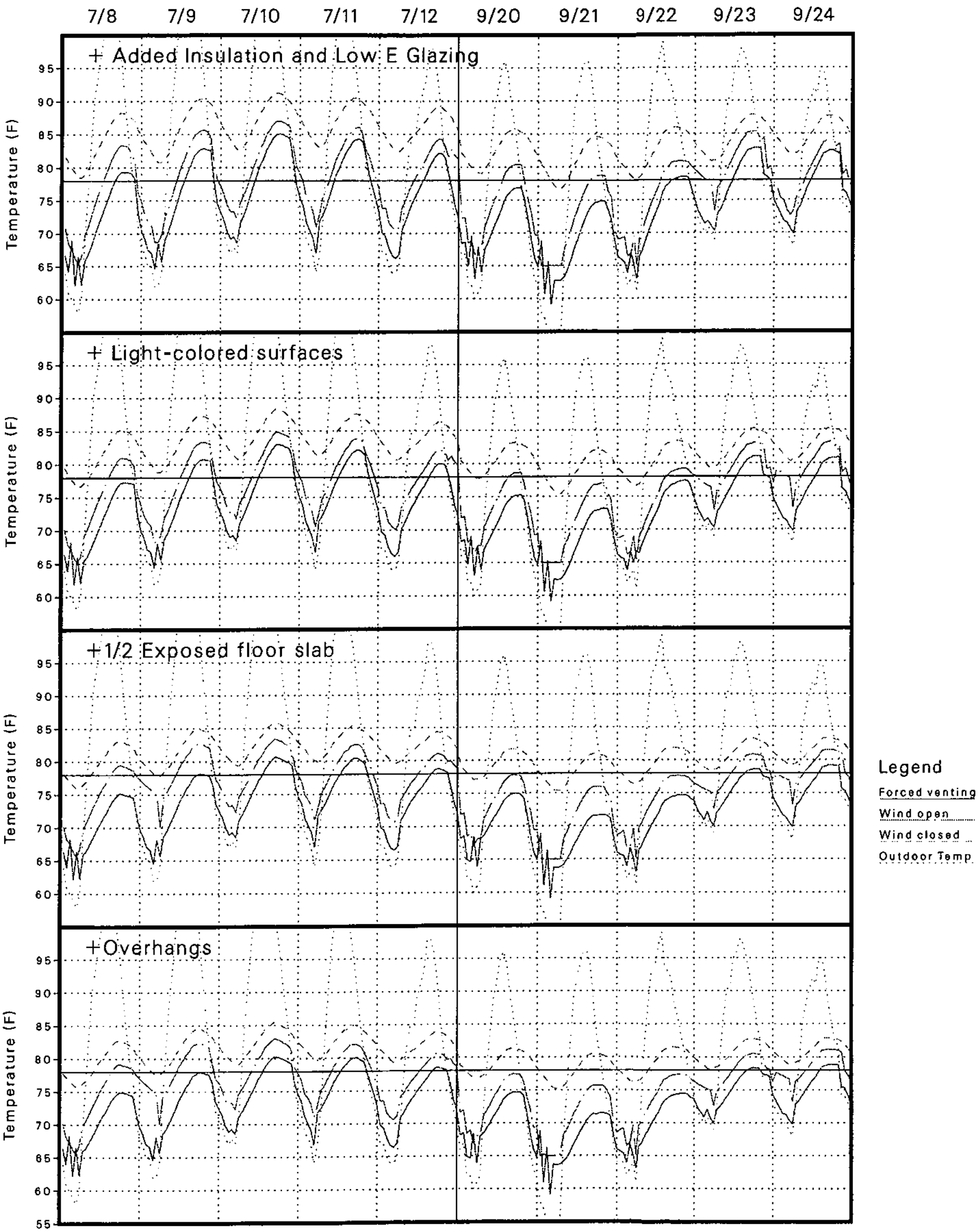


Figure 46
Prototype 2 Improved Case in CTZ10C (Riverside) on Peak Summer Days

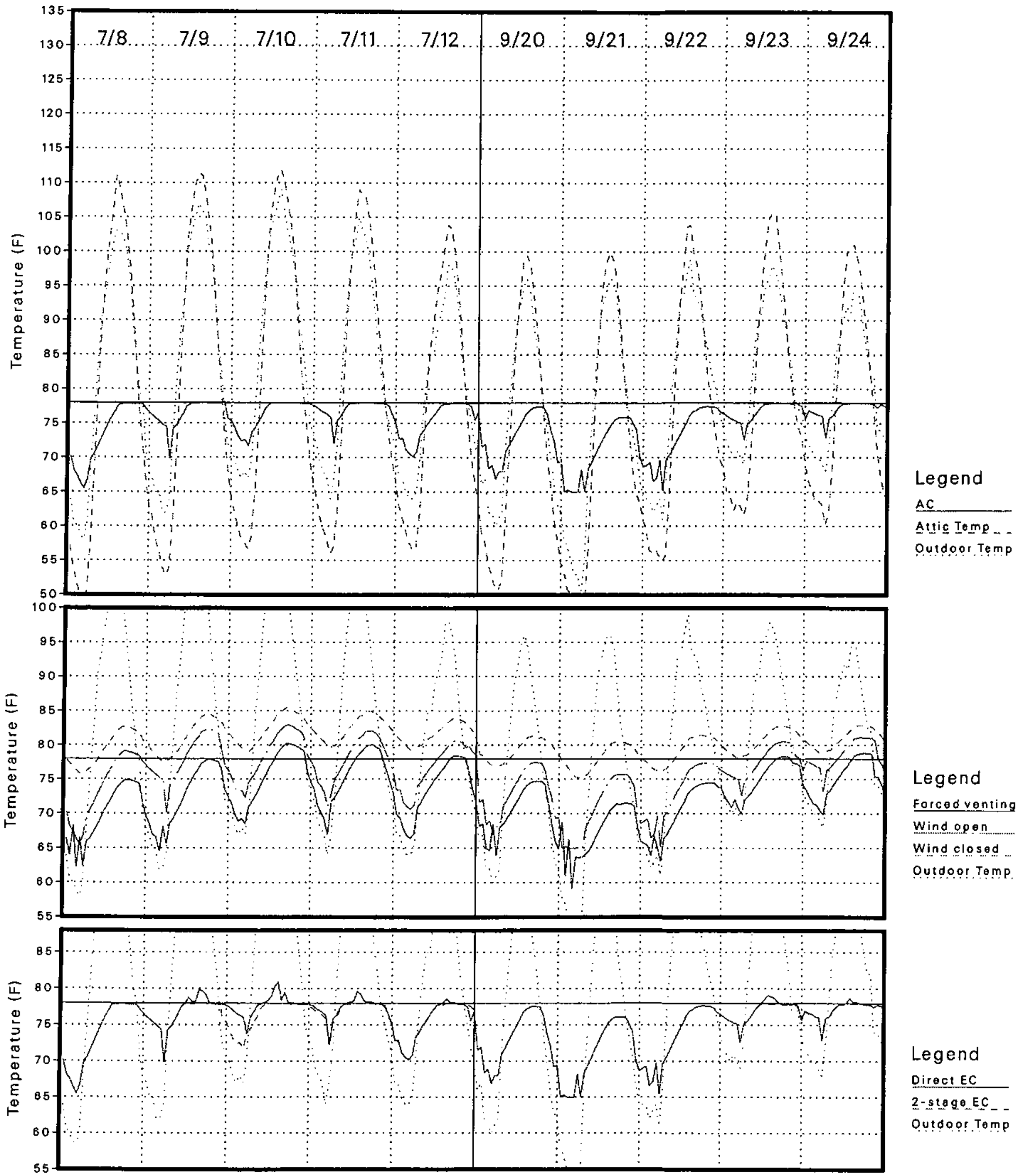


Figure 47
Prototype 2 Base Case in CTZ10C (Riverside) on Typical Summer Days

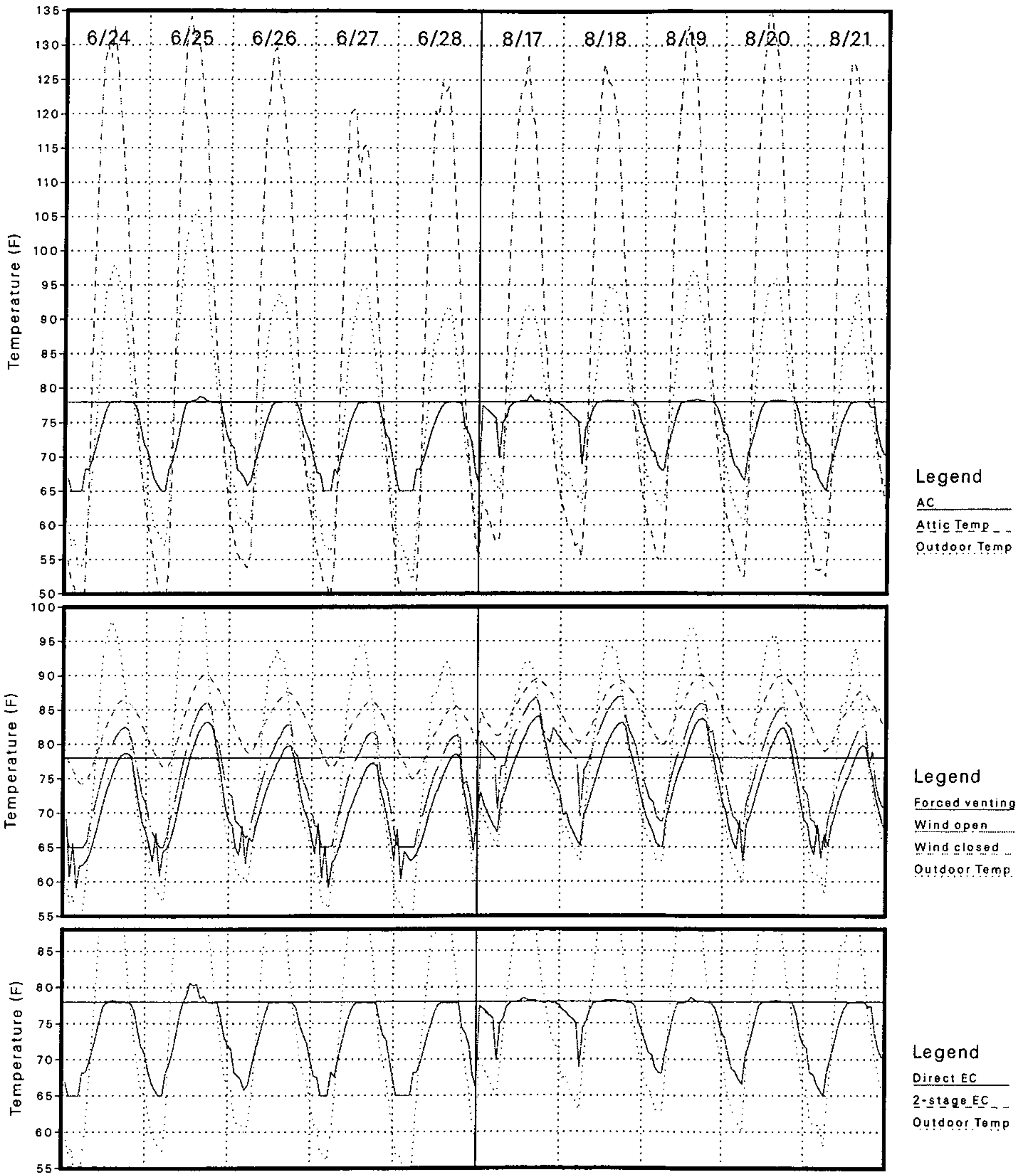


Figure 48
Single Measures for Prototype 2 in CTZ10C on Typical Summer Days

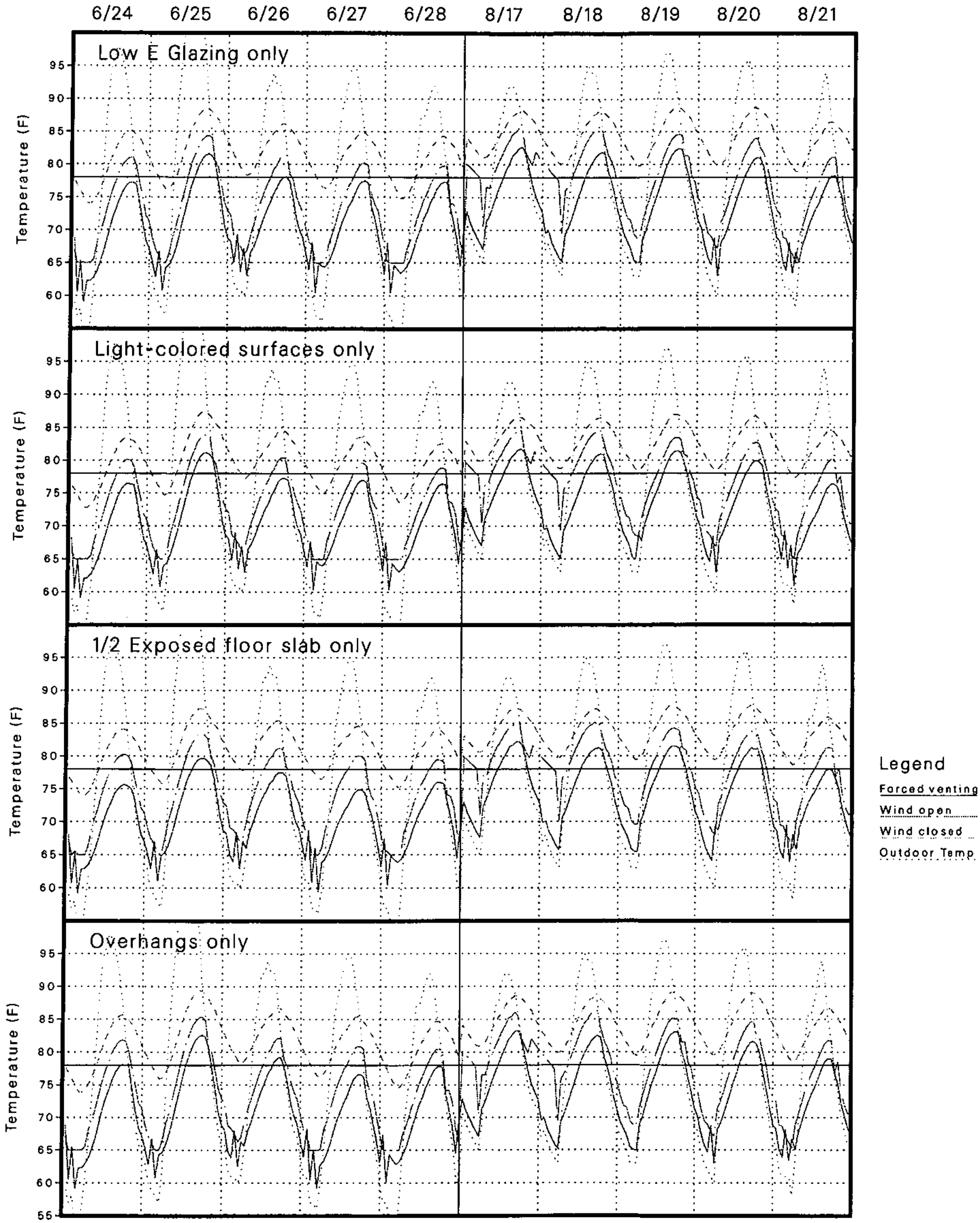


Figure 49
Combined Measures for Prototype 2 in CTZ10C on Typical Summer Days

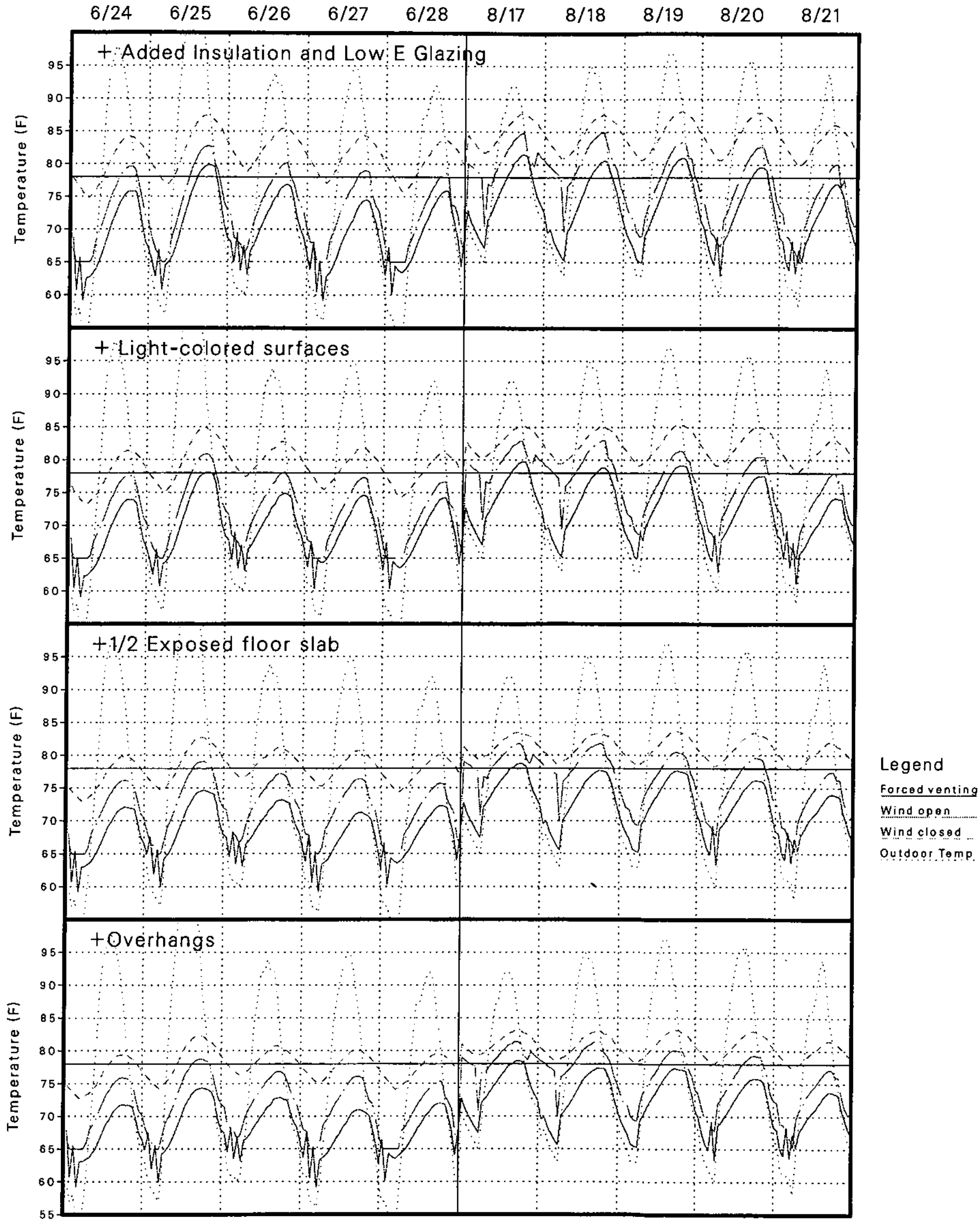


Figure 50
Prototype 2 Improved Case in CTZ10C (Riverside) on Typical Summer Days

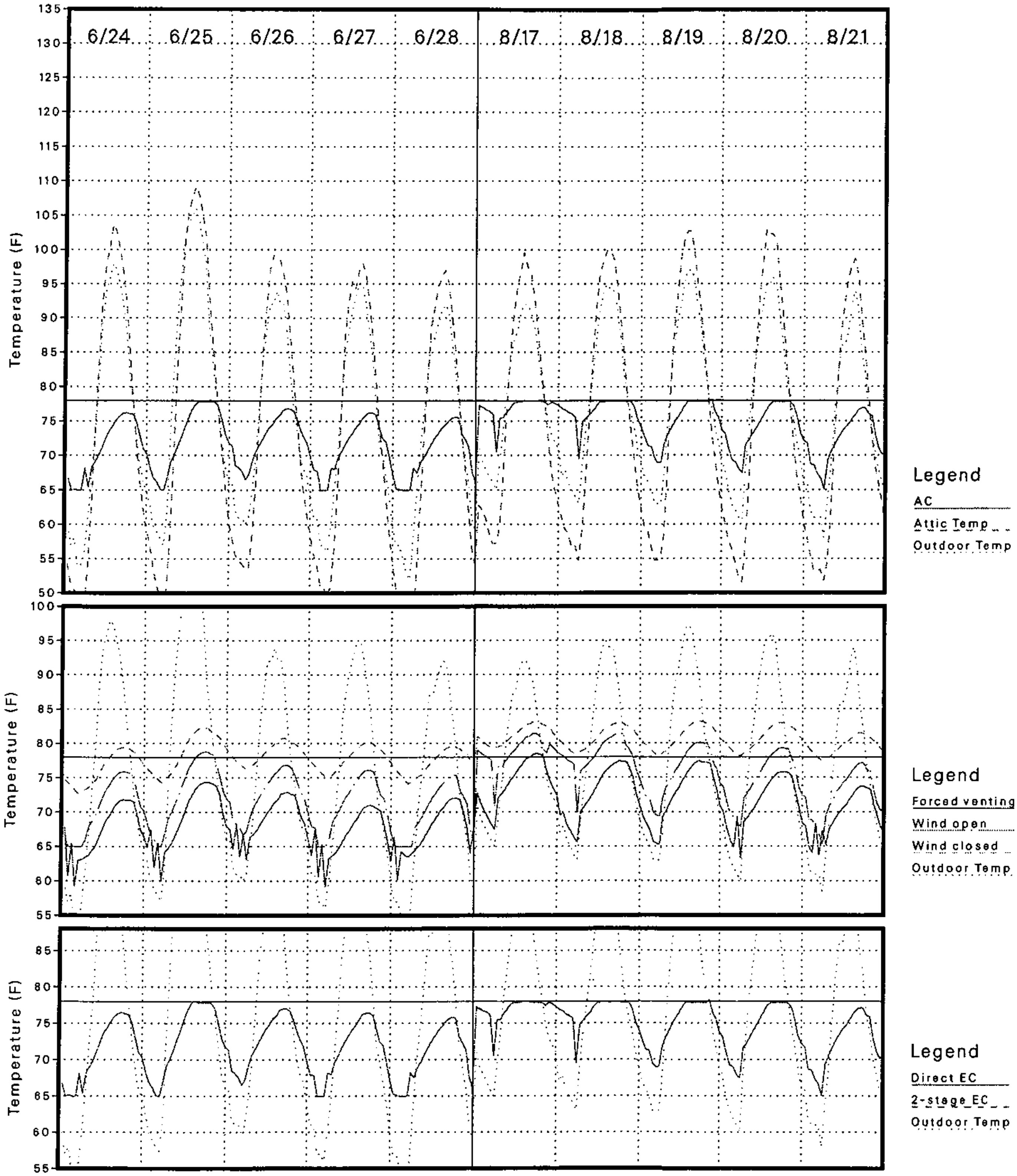


Figure 51
Prototype 2 Base Case in CTZ12C (Sacramento) on Peak Summer Days

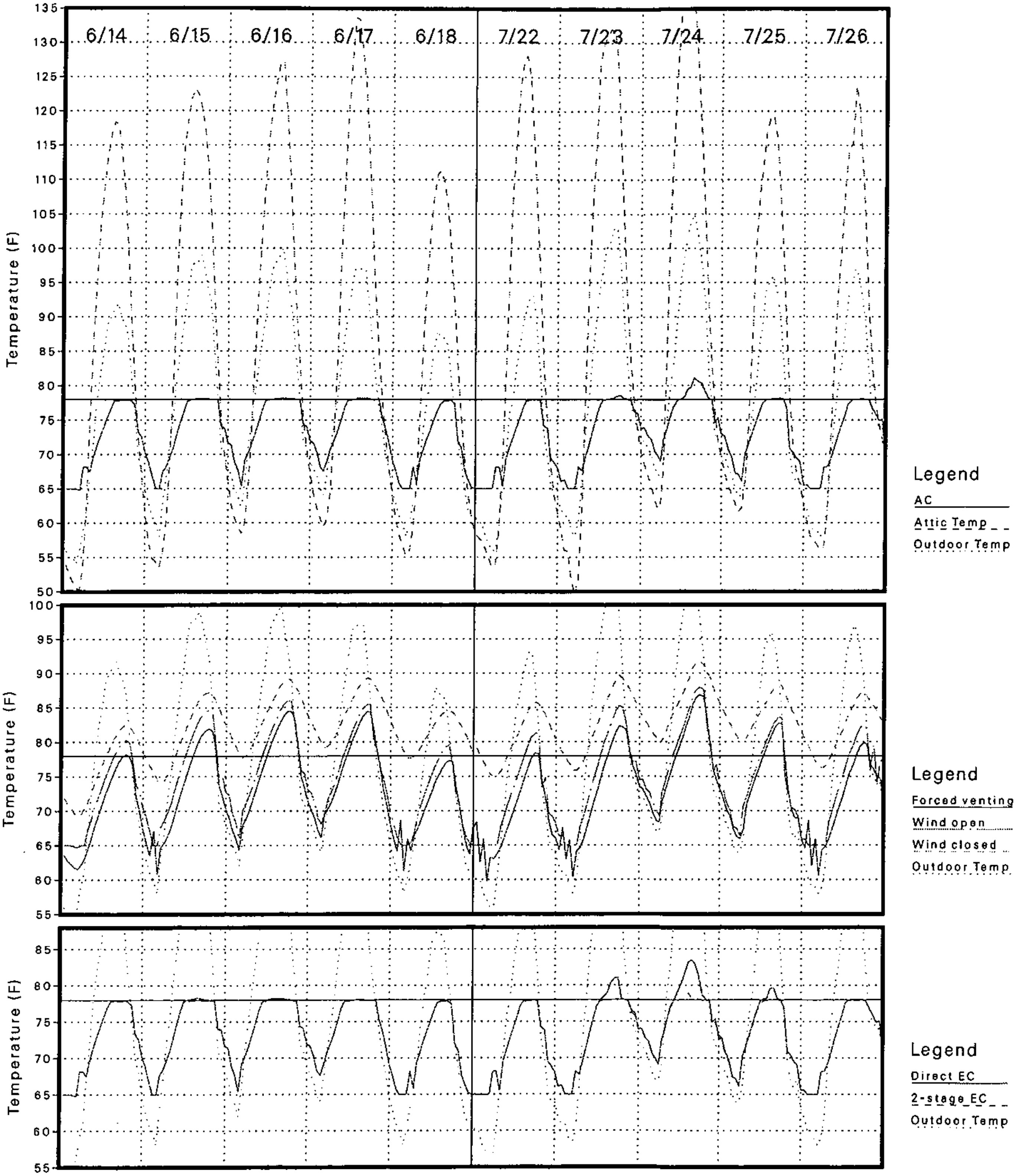


Figure 52
Single Measures for Prototype 2 in CTZ12C on Peak Summer Days

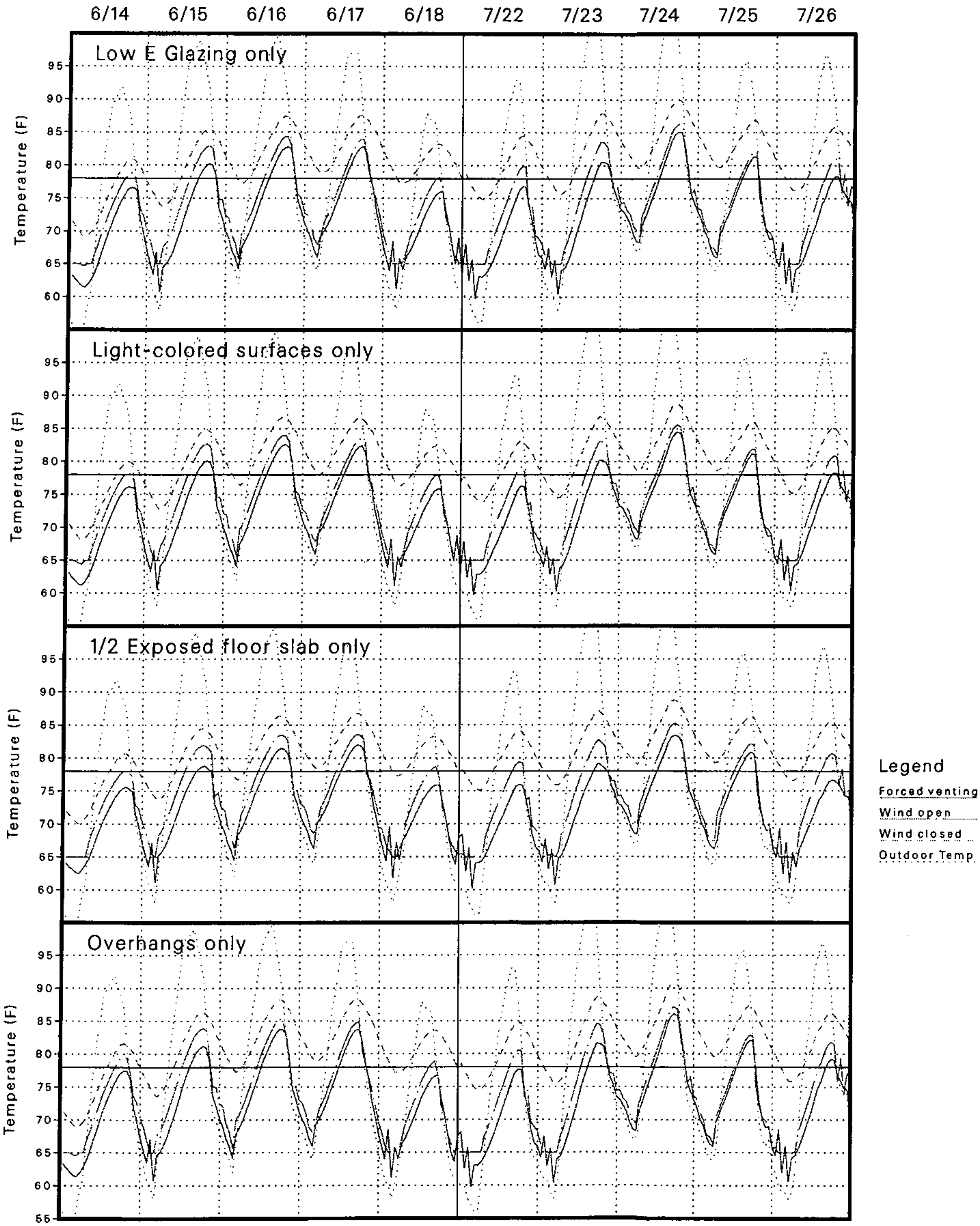


Figure 53
Combined Measures for Prototype 2 in CTZ12C on Peak Summer Days

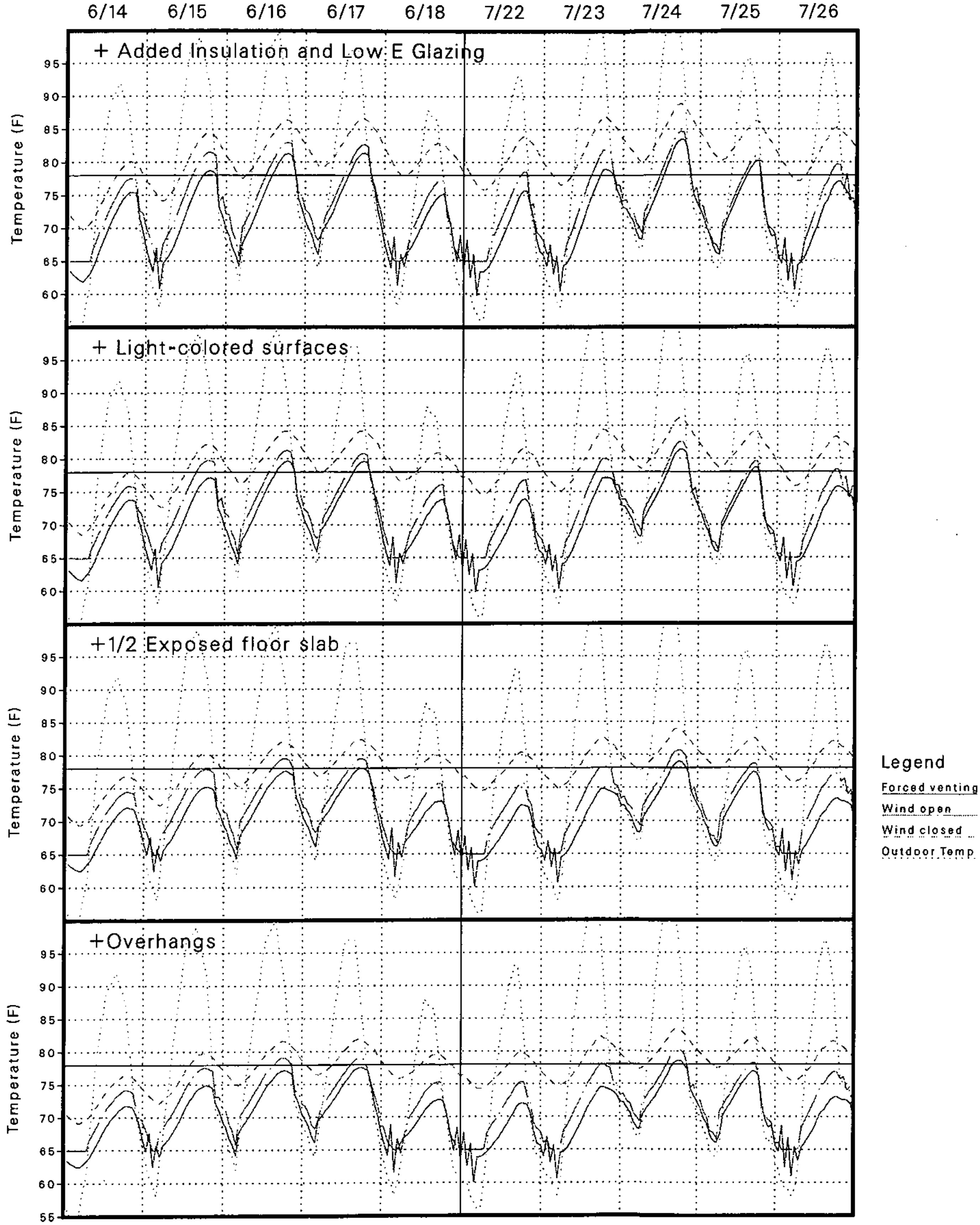


Figure 54
Prototype 2 Improved Case in CTZ12C (Sacramento) on Peak Summer Days

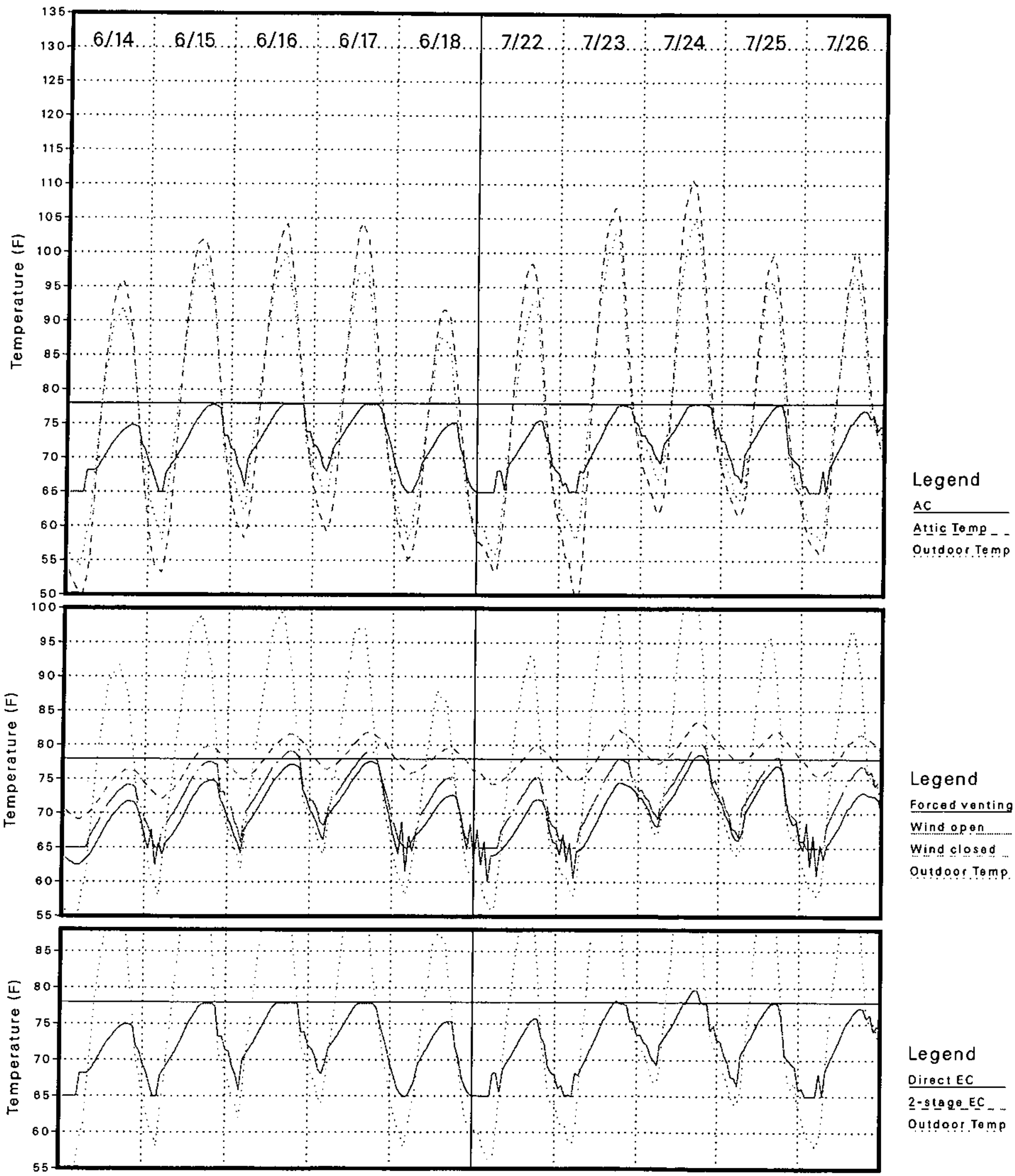


Figure 55
Prototype 2 Base Case in CTZ12C (Sacramento) on Typical Summer Days

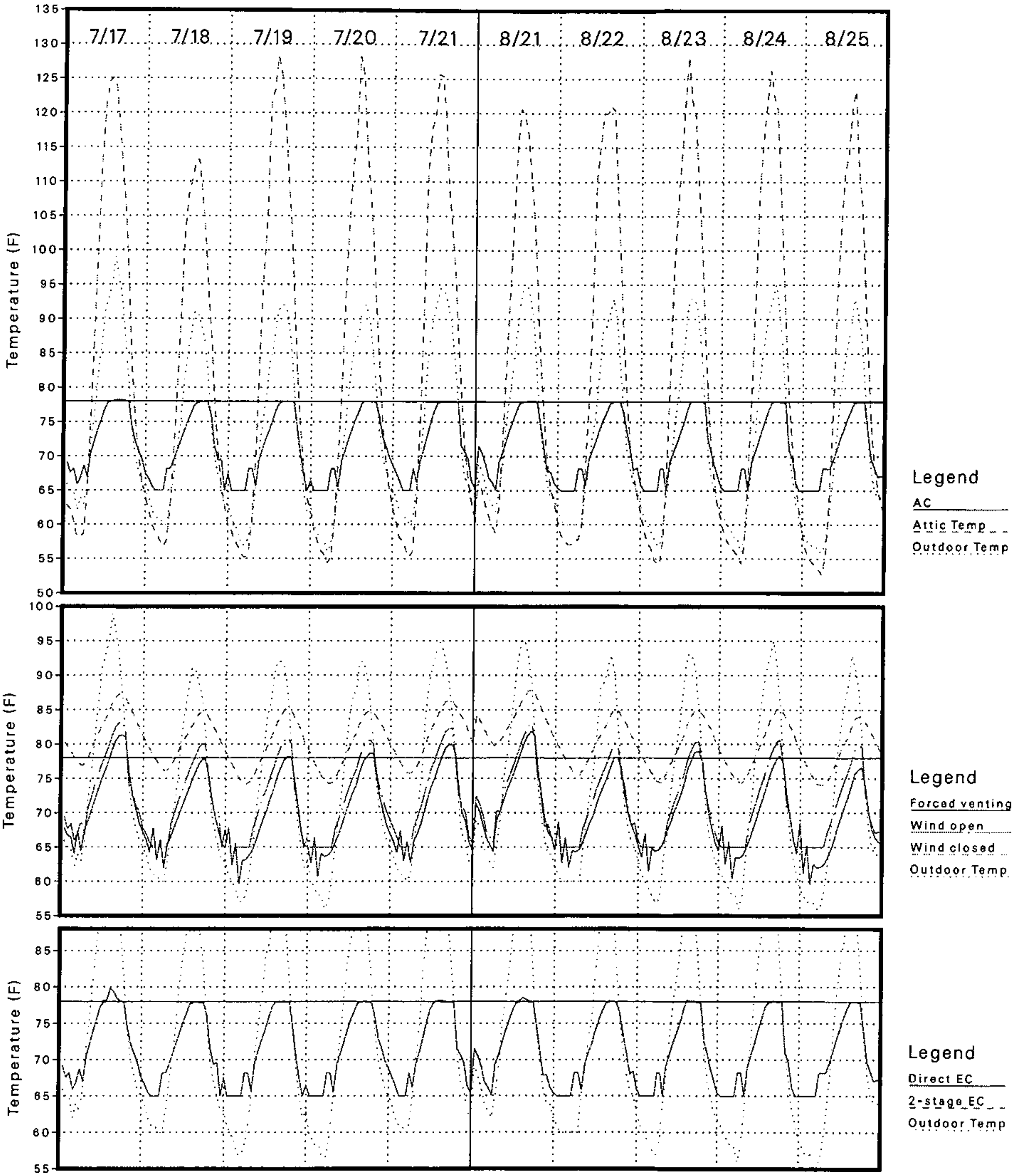


Figure 56
Single Measures for Prototype 2 in CTZ12C on Typical Summer Days

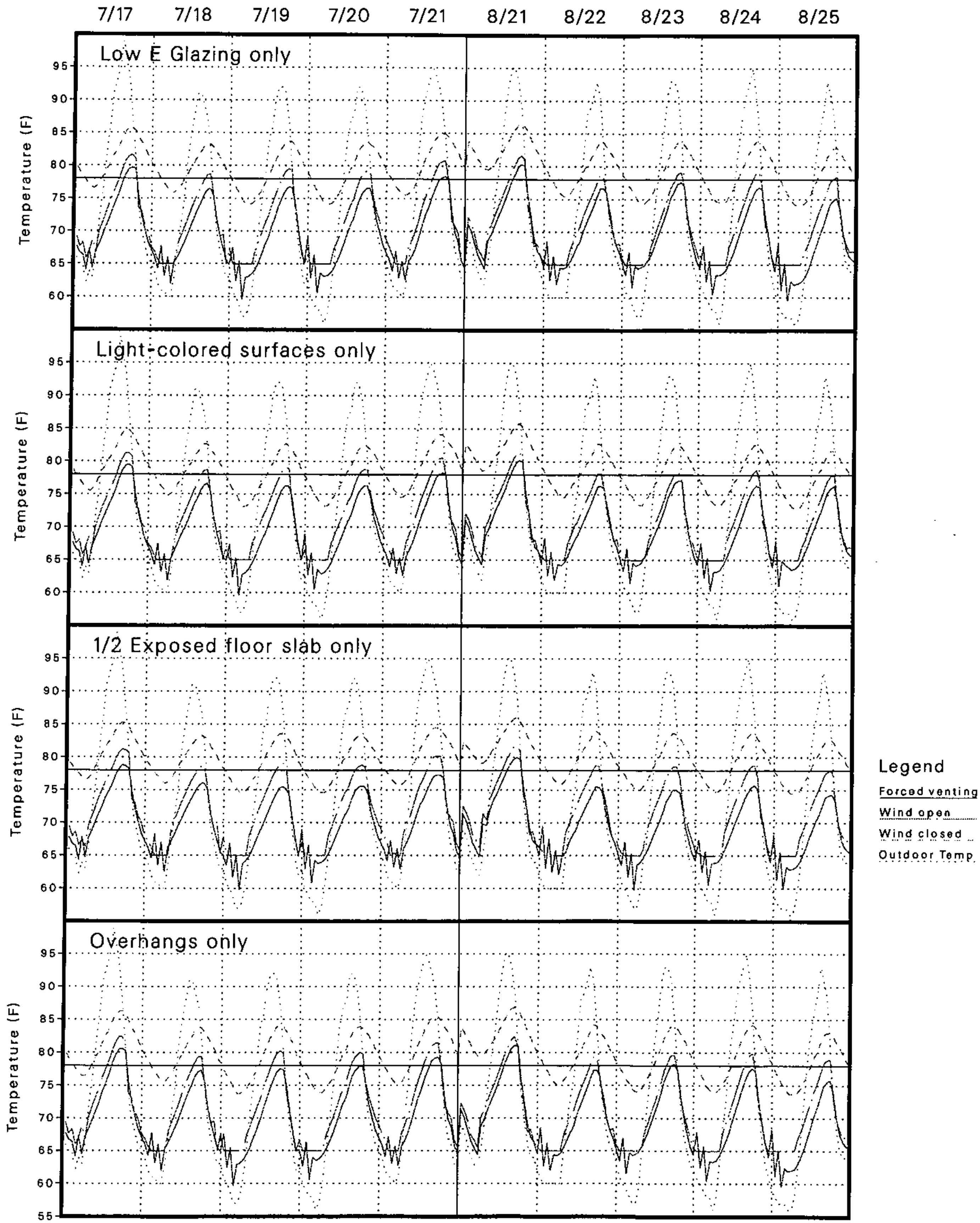


Figure 57
Combined Measures for Prototype 2 in CTZ12C on Typical Summer Days

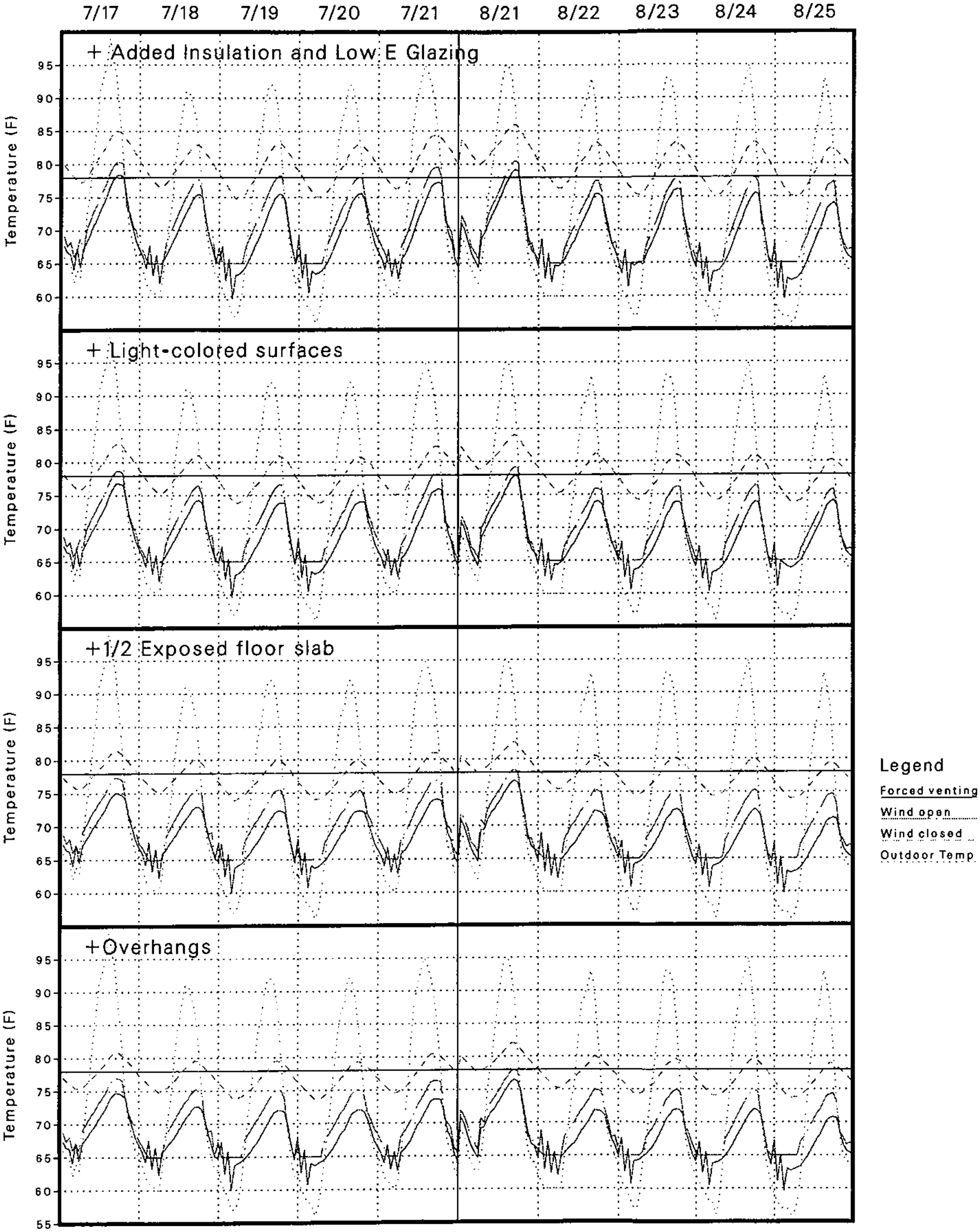


Figure 58
Prototype 2 Improved Case in CTZ12C (Sacramento) on Typical Summer Days

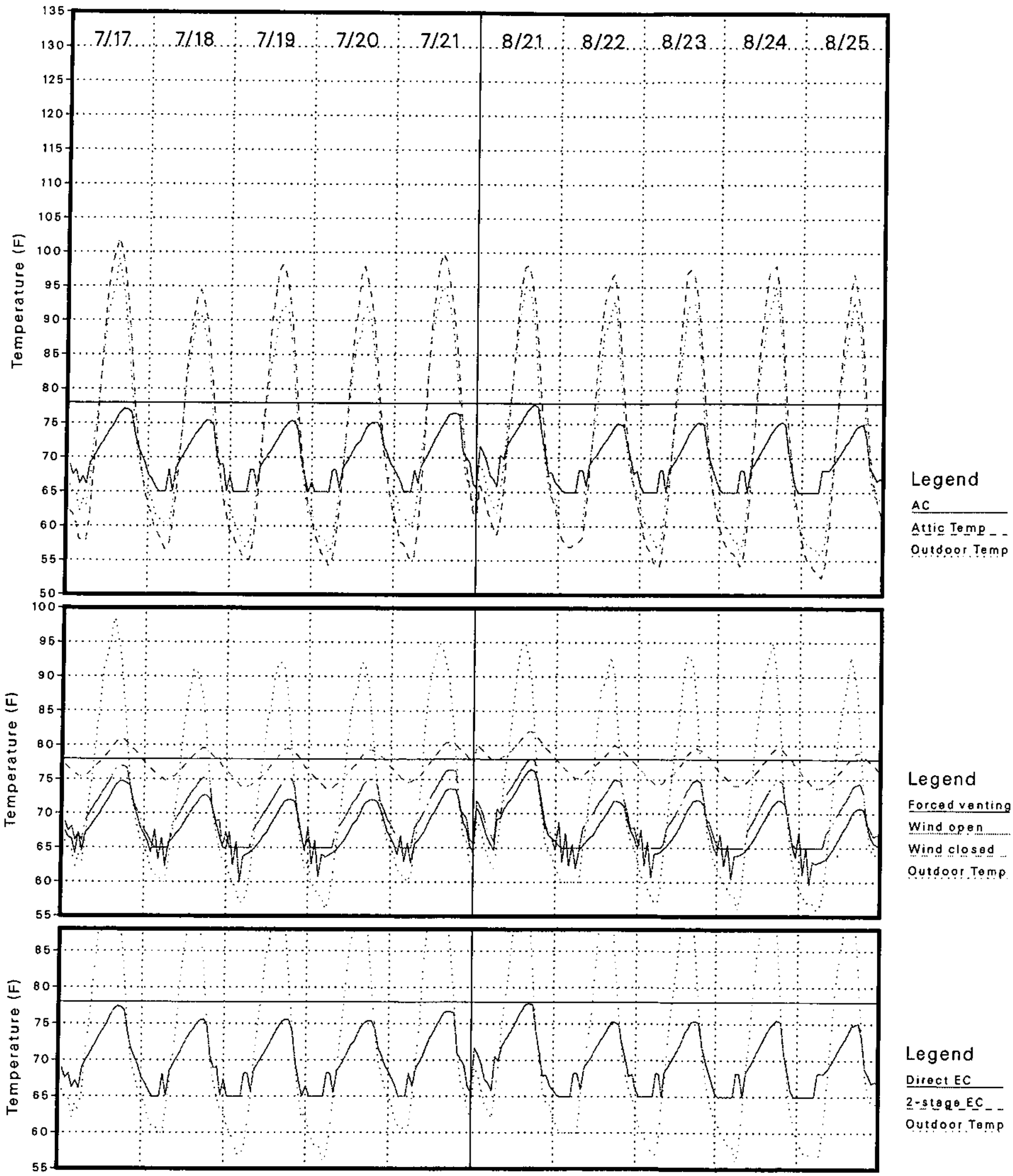


Figure59

Indoor Temperatures with Single Measures in Prototype 1 House during Typical Summer Days in CTZ02C (Santa Rosa) with Window Venting

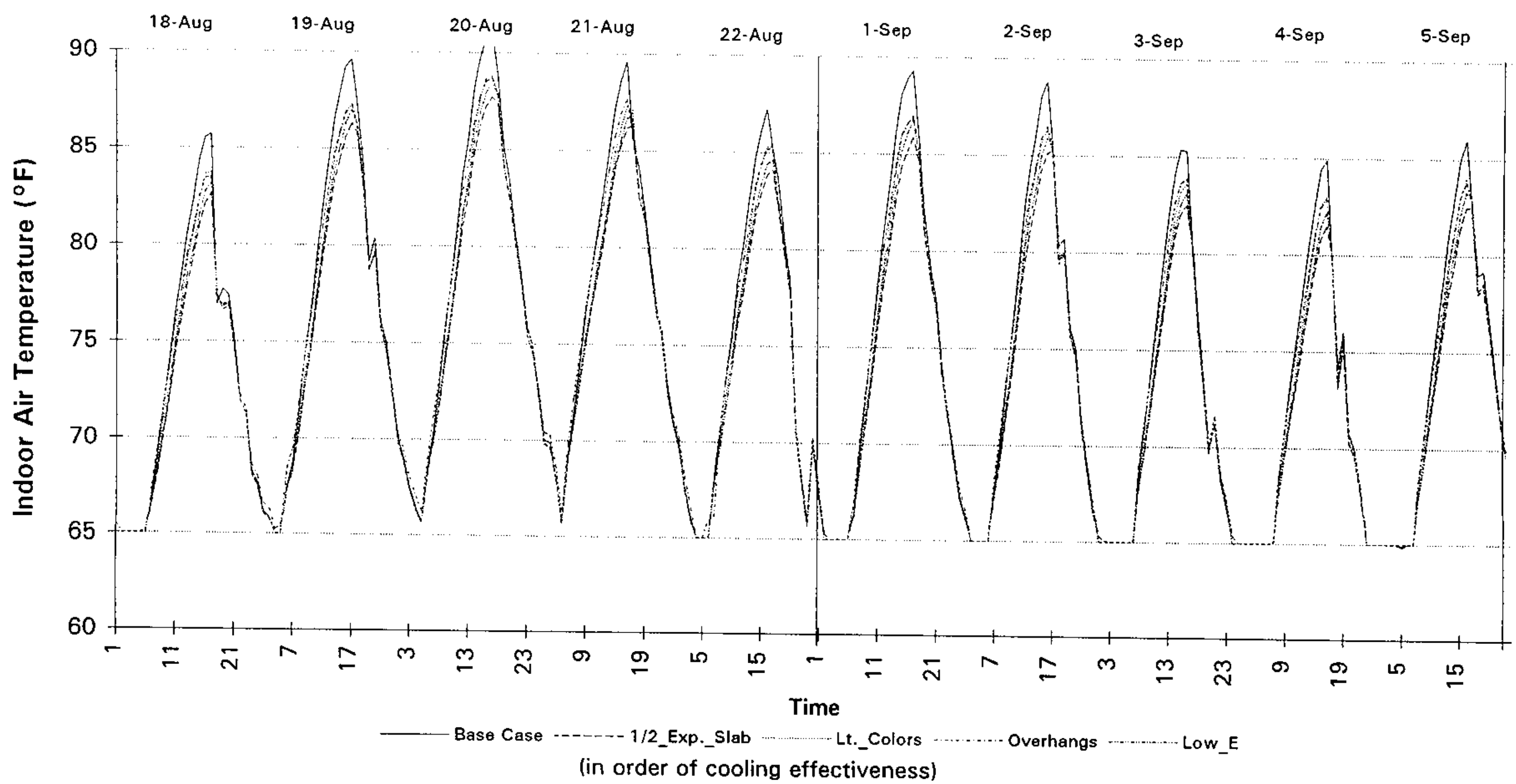


Figure 60

Indoor Temperatures with Combined Measures in Prototype 1 House during Typical Summer Days in CTZ02C (Santa Rosa) with Window Venting

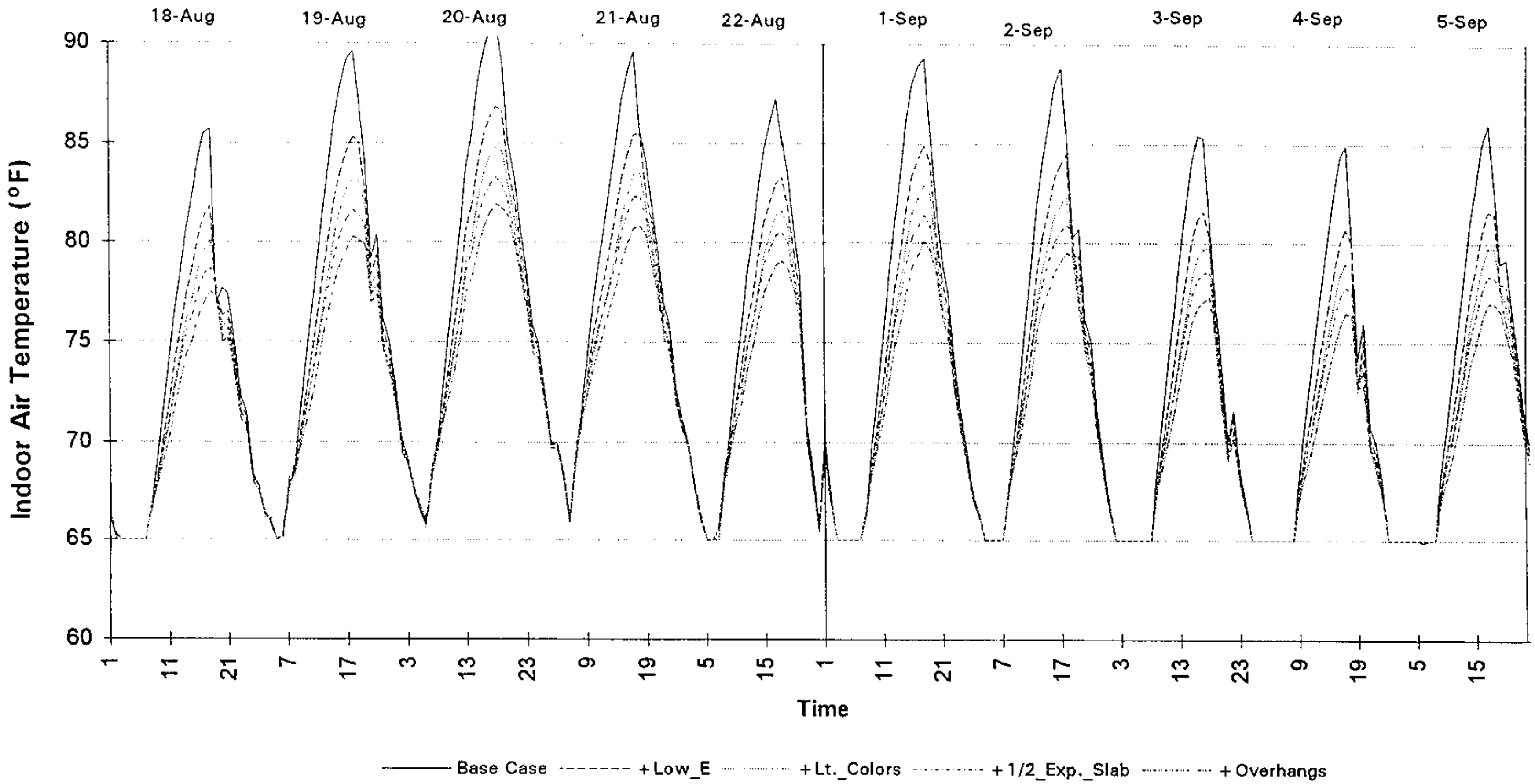


Figure 61

Indoor Temperatures with Single Measures in Prototype 2 House during Typical Summer Days in CTZ10C (Riverside) with Window Venting

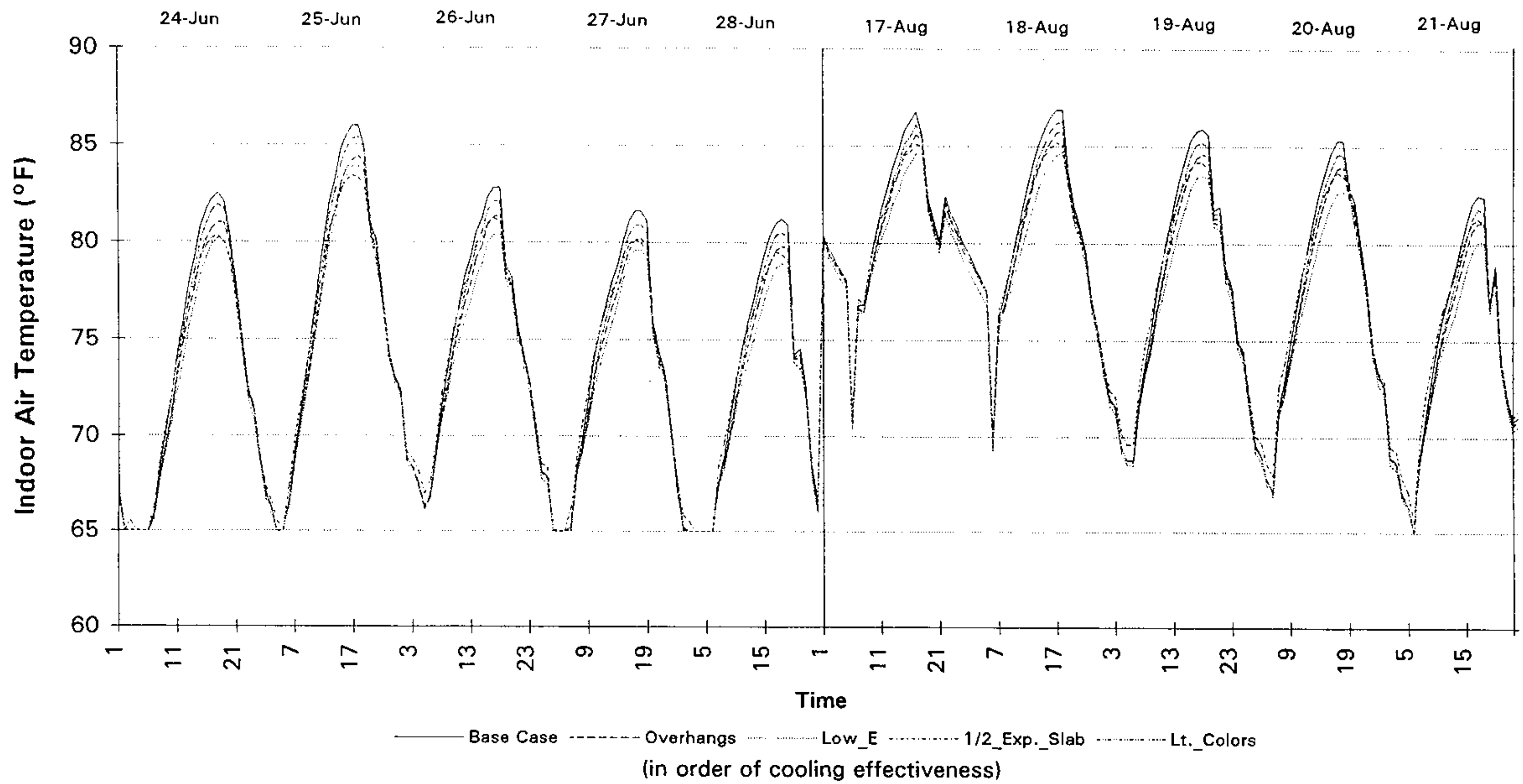


Figure 62

Indoor Temperatures with Combined Measures in Prototype 2 House during Typical Summer Days in CTZ10C (Riverside) with Window Venting

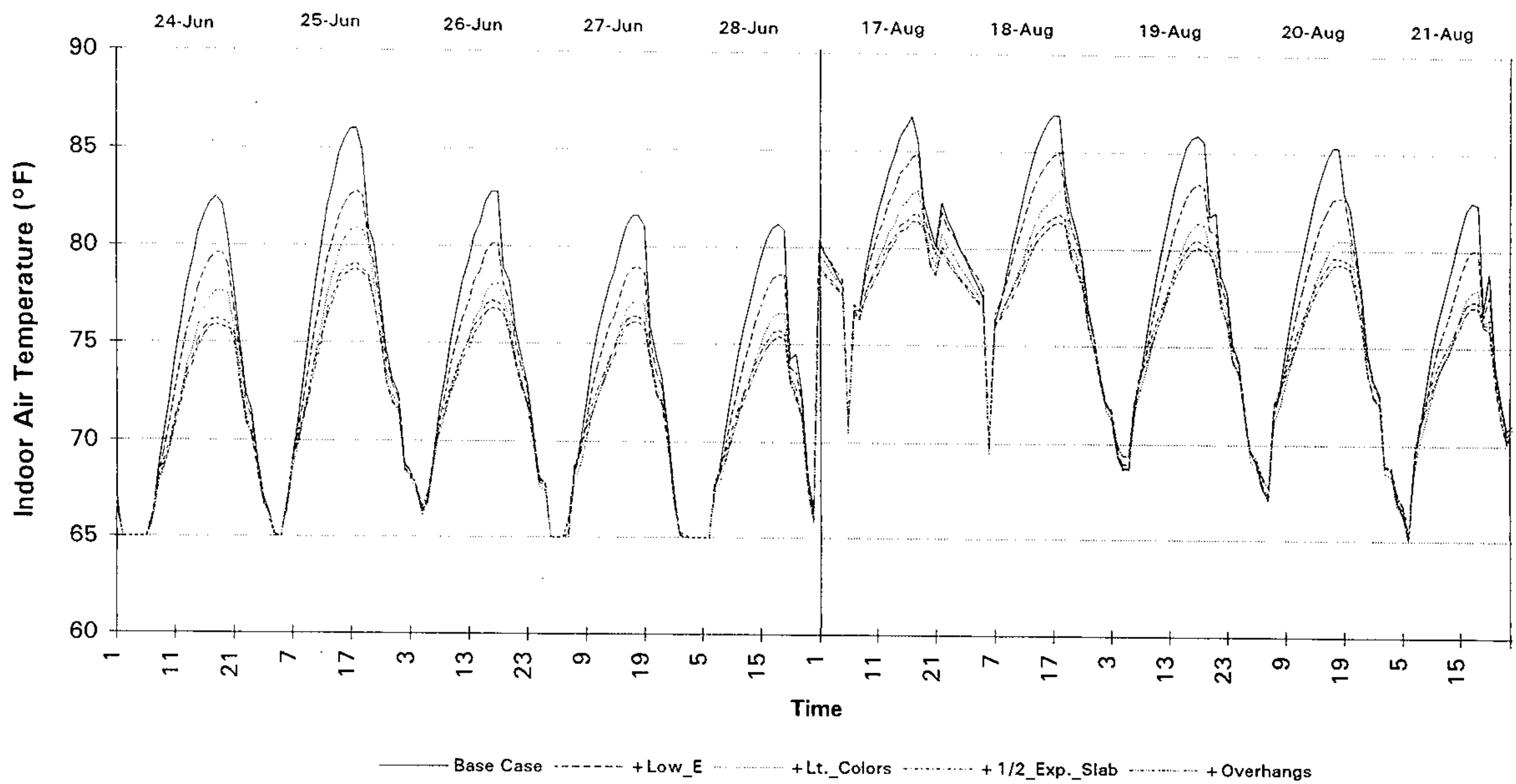
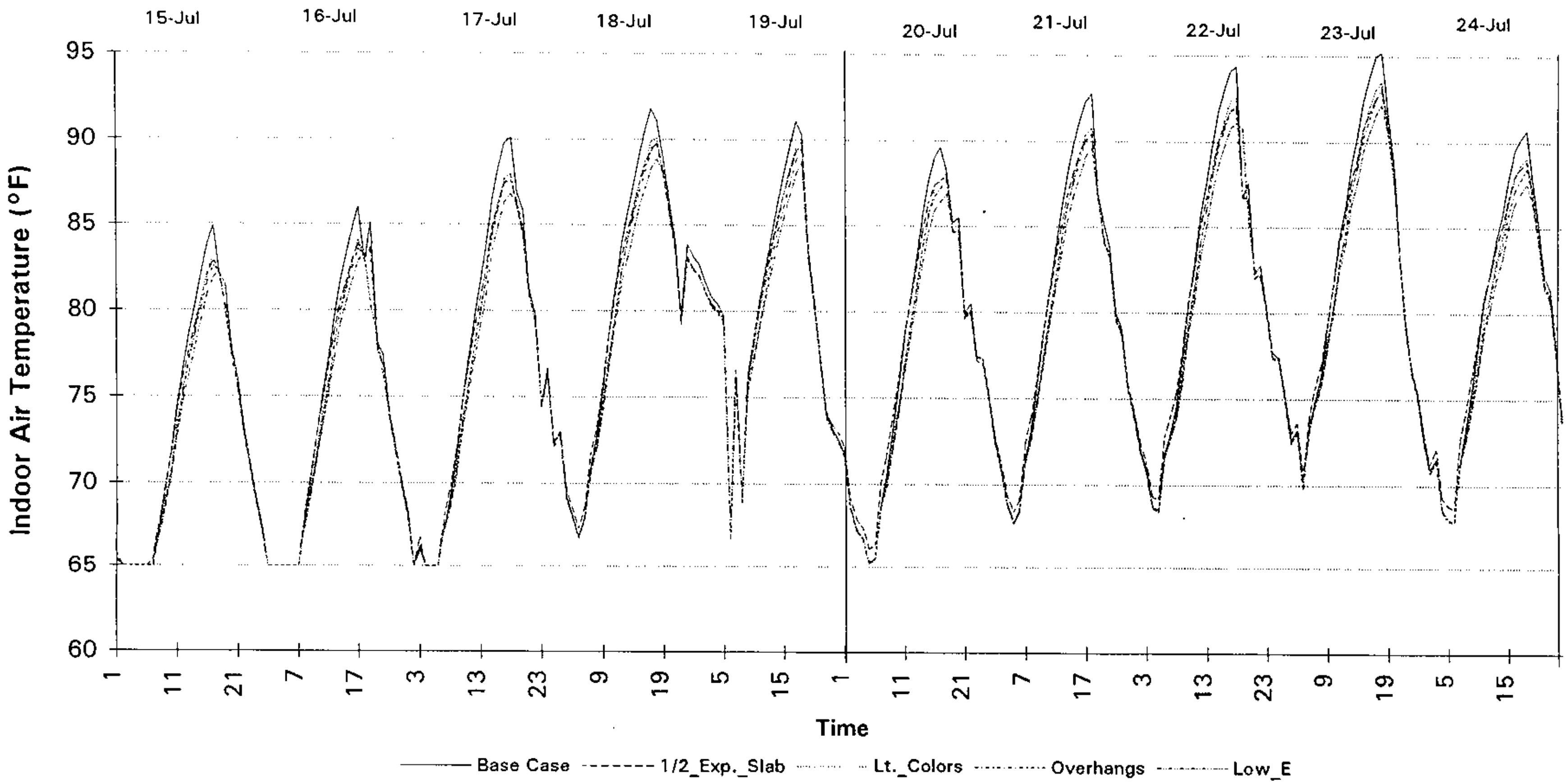


Figure 63
Indoor Temperatures with Single Measures in Prototype 1 House during Peak Summer Days in CTZ02C (Santa Rosa) with Window Venting



(in order of cooling effectiveness)

Figure 64

Indoor Temperatures with Combined Measures in Prototype 1 House during Peak Summer Days in CTZ02C (Santa Rosa) with Window Venting

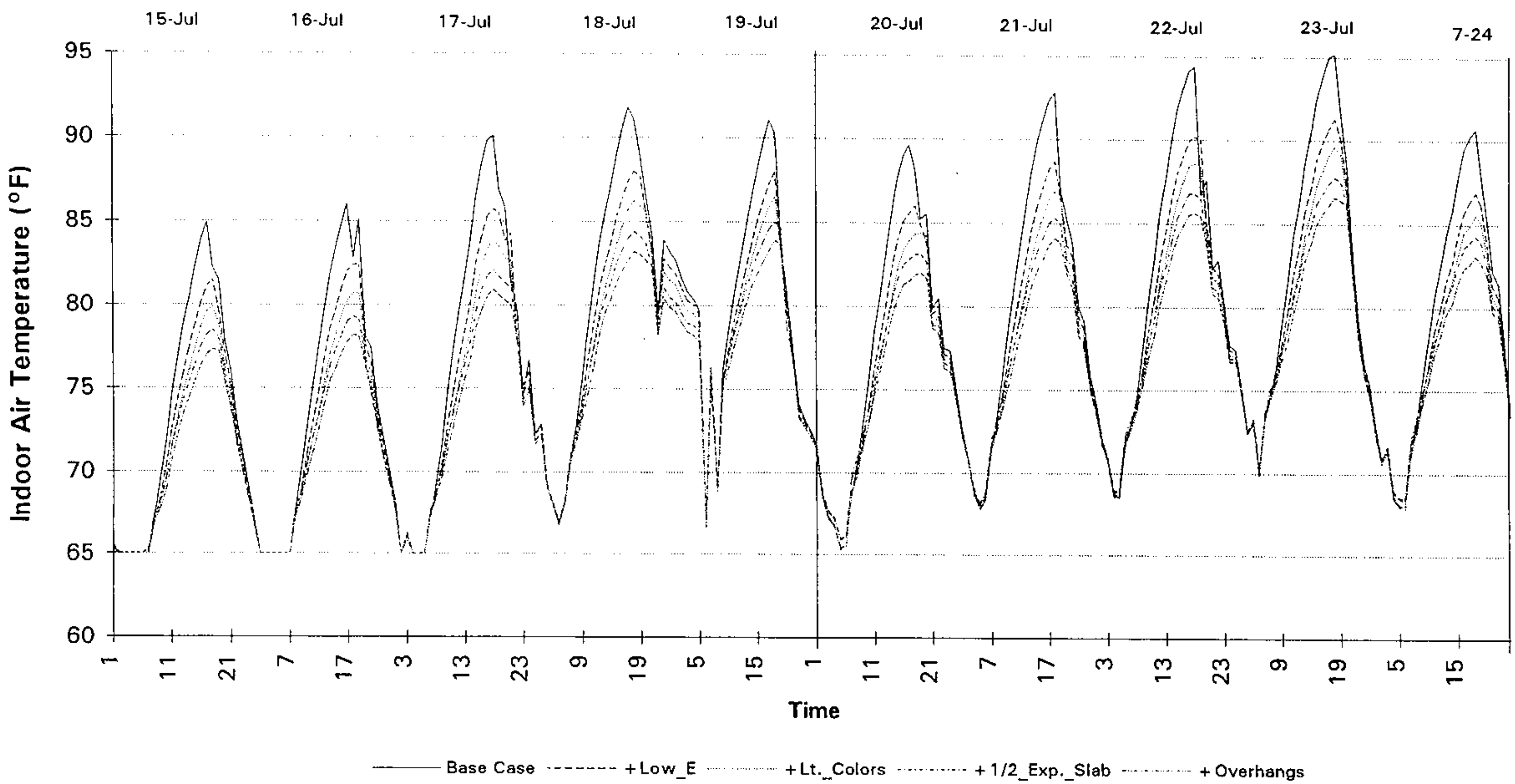


Figure 65

Indoor Temperatures with Single Measures in Prototype 2 House during Peak Summer Days in CTZ10C (Riverside) with Window Venting

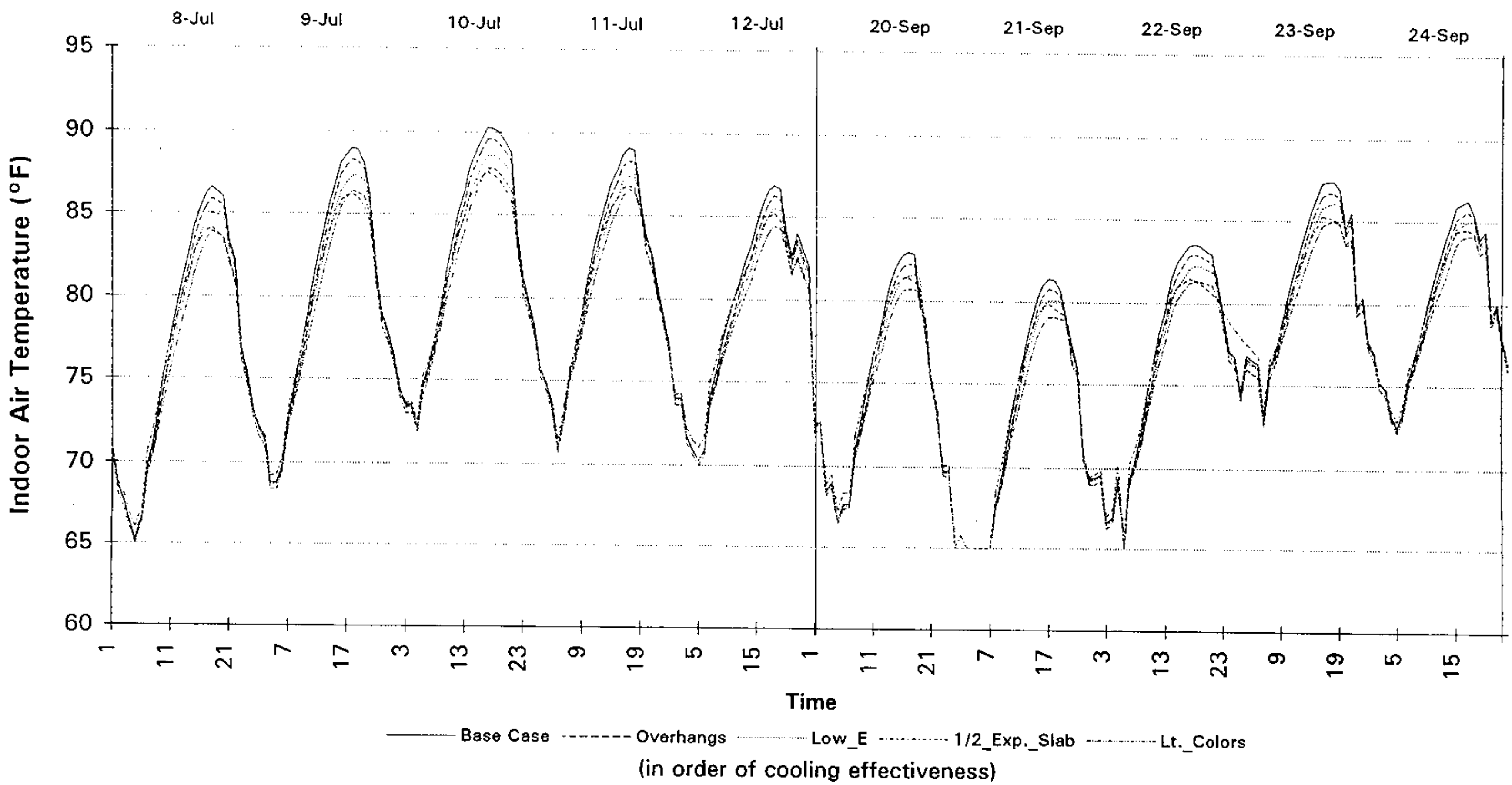
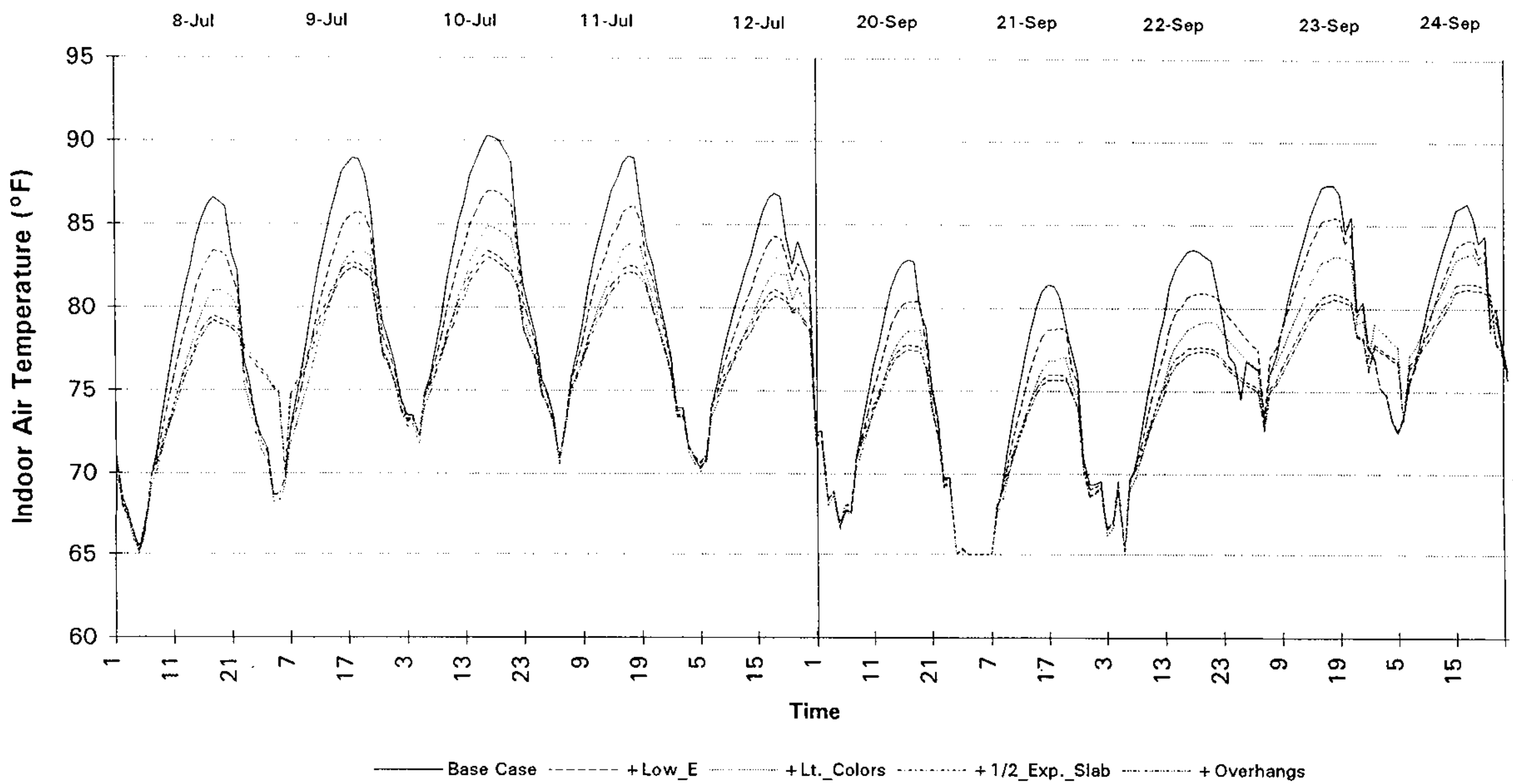


Figure 66

Indoor Temperatures with Combined Measures in Prototype 2 House during Peak Summer Days in CTZ10C (Riverside) with Window Venting



Appendix A. Plots of California Design Temperatures
(based on *Climatic Data for Region X*, ASHRAE 1982.)

● = A stations (full meteorological measurements)
○ = B stations (partial measurements and inferred data)
\+ = C stations (totally interpolated)

Ref: American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) 1982. *Climatic Data for Region X (Arizona, California, Hawaii, and Nevada)*, Golden Gate Chapter and Southern California Chapter, ASHRAE.

Figure A1
Locations
California

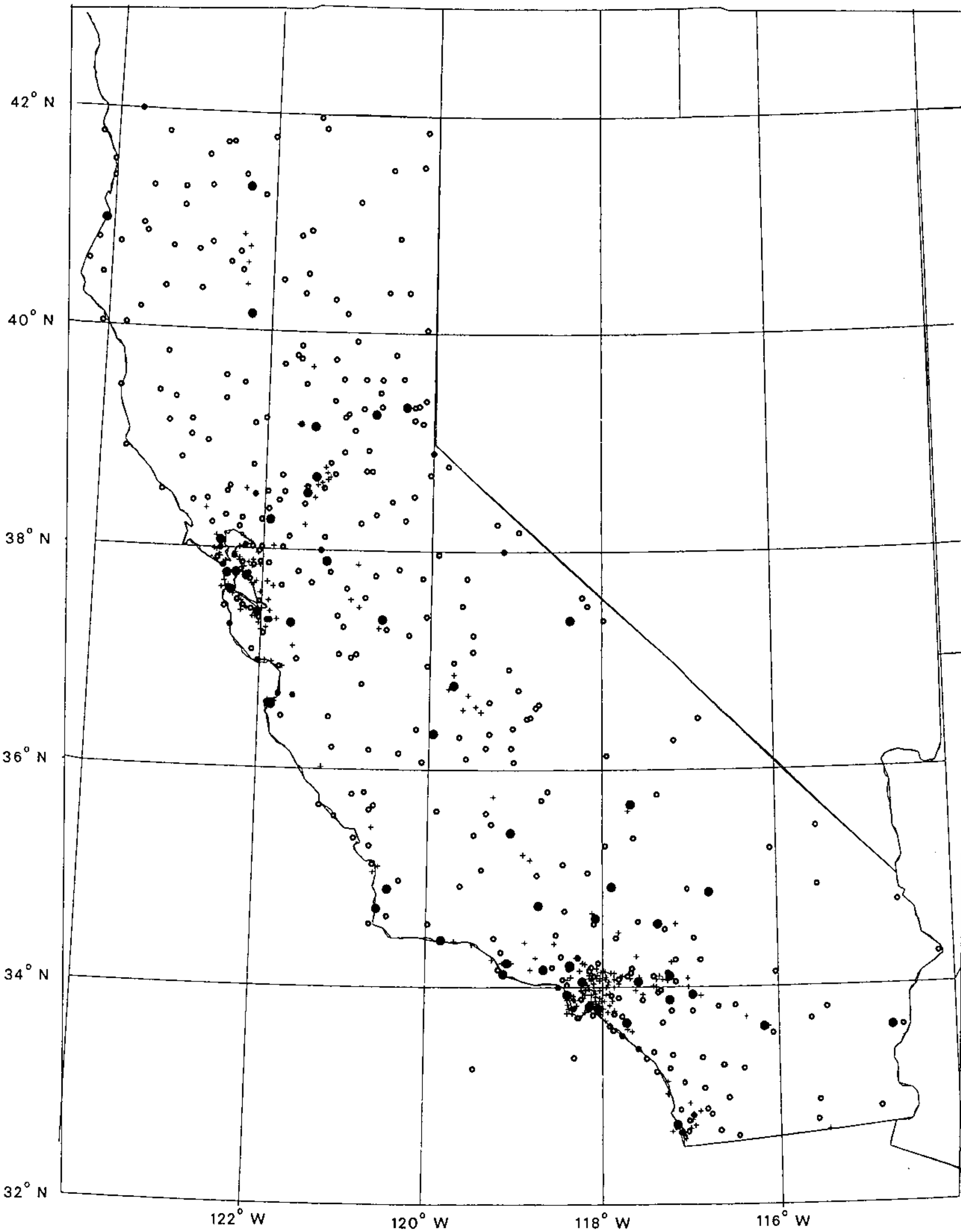


Figure A2
Locations
San Francisco-Sacramento

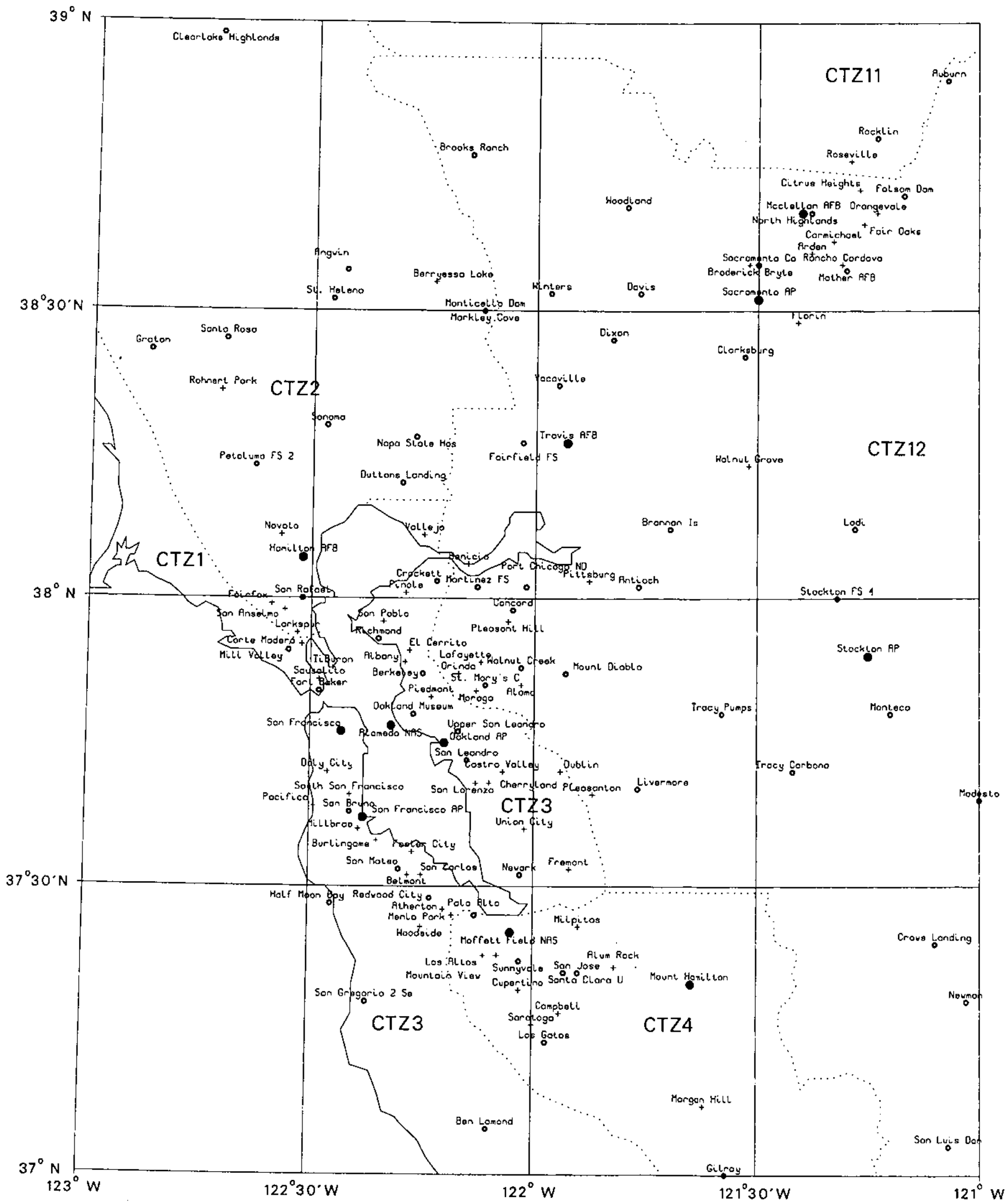


Figure A3
0.1% Annual Design Drybulb Temperature
San Francisco-Sacramento

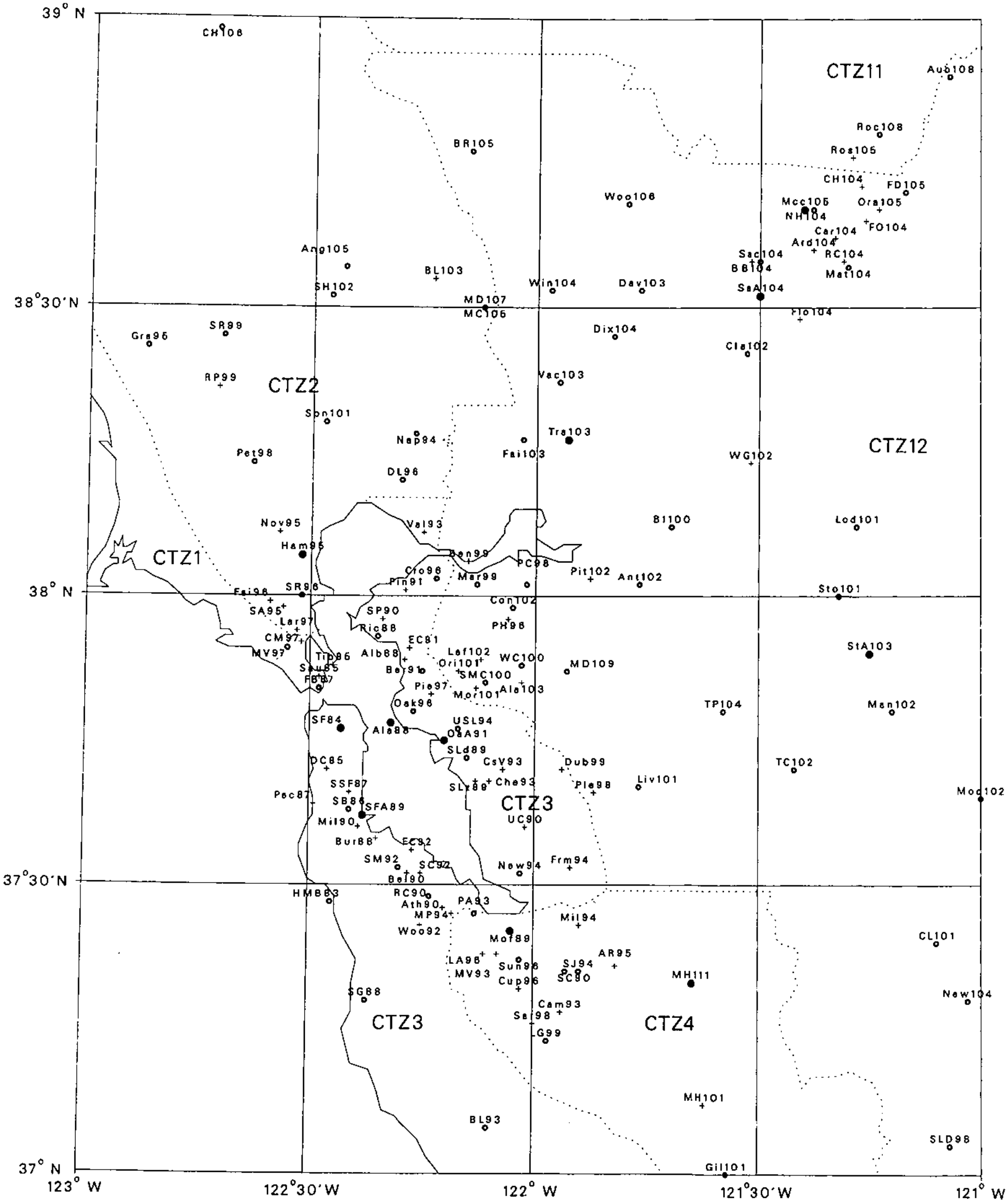


Figure A4
0.5% Annual Design Drybulb Temperature
San Francisco-Sacramento

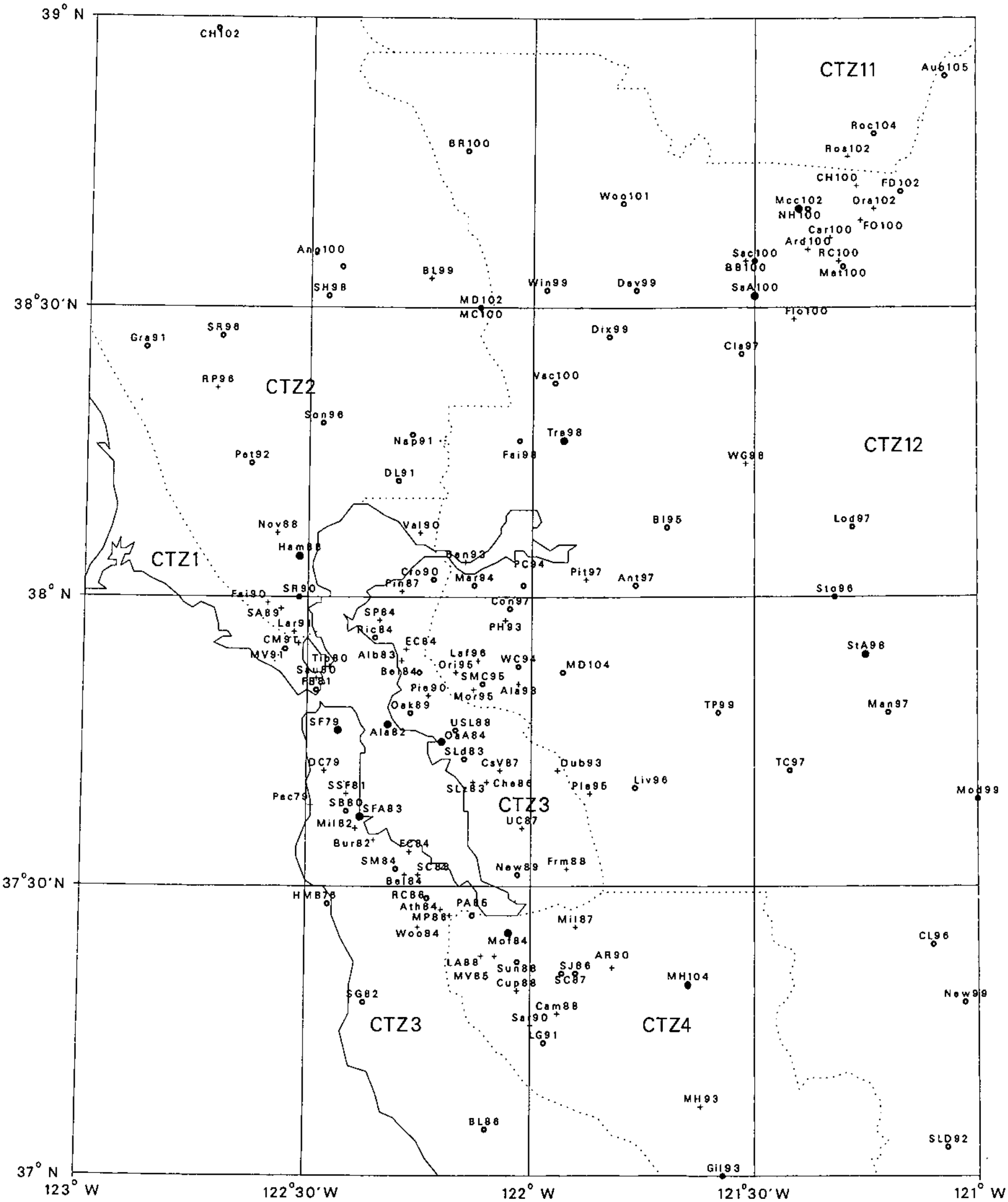


Figure A5
2.0% Annual Design Drybulb Temperature
San Francisco-Sacramento

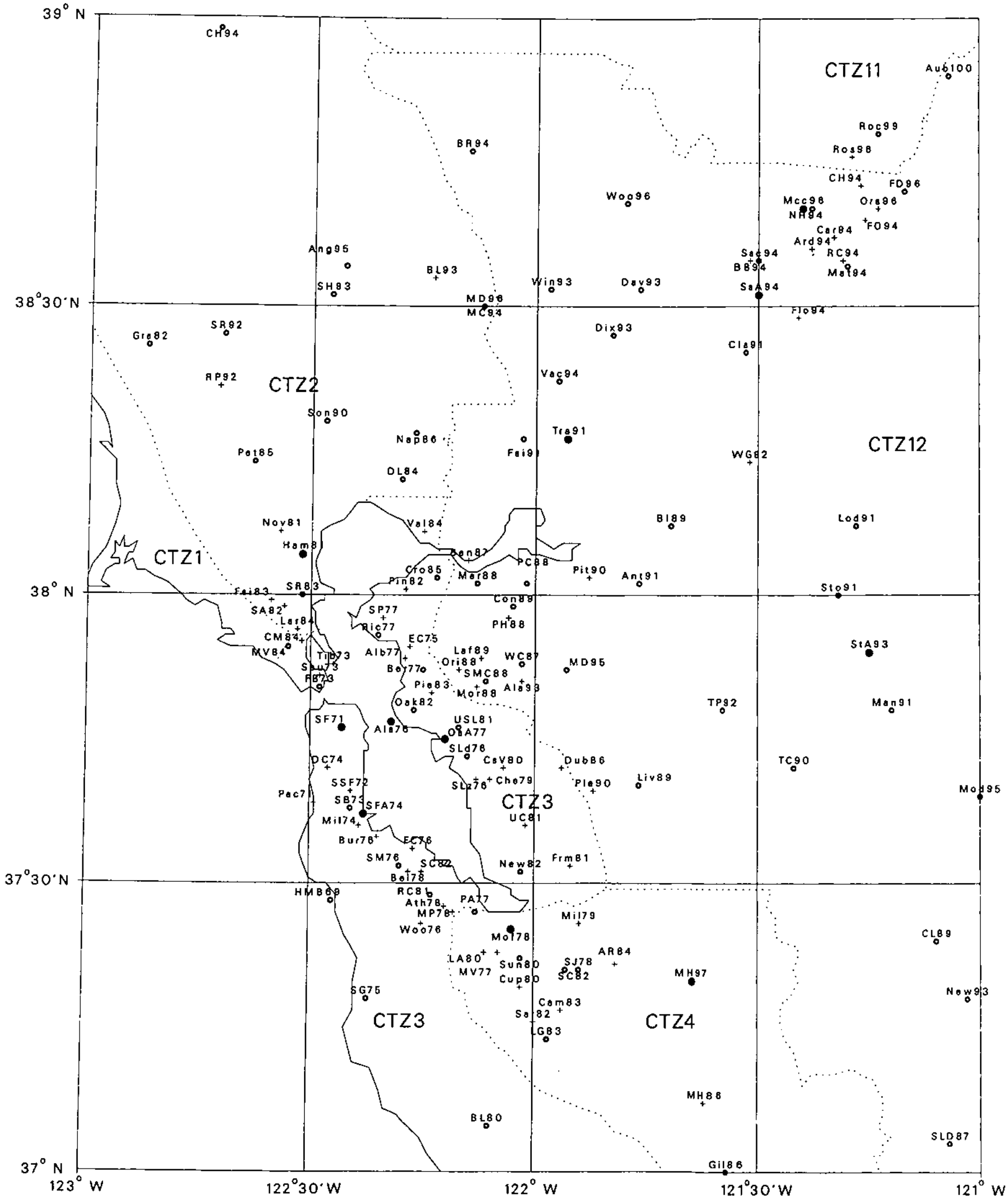


Figure A6
Locations
Los Angeles-San Diego

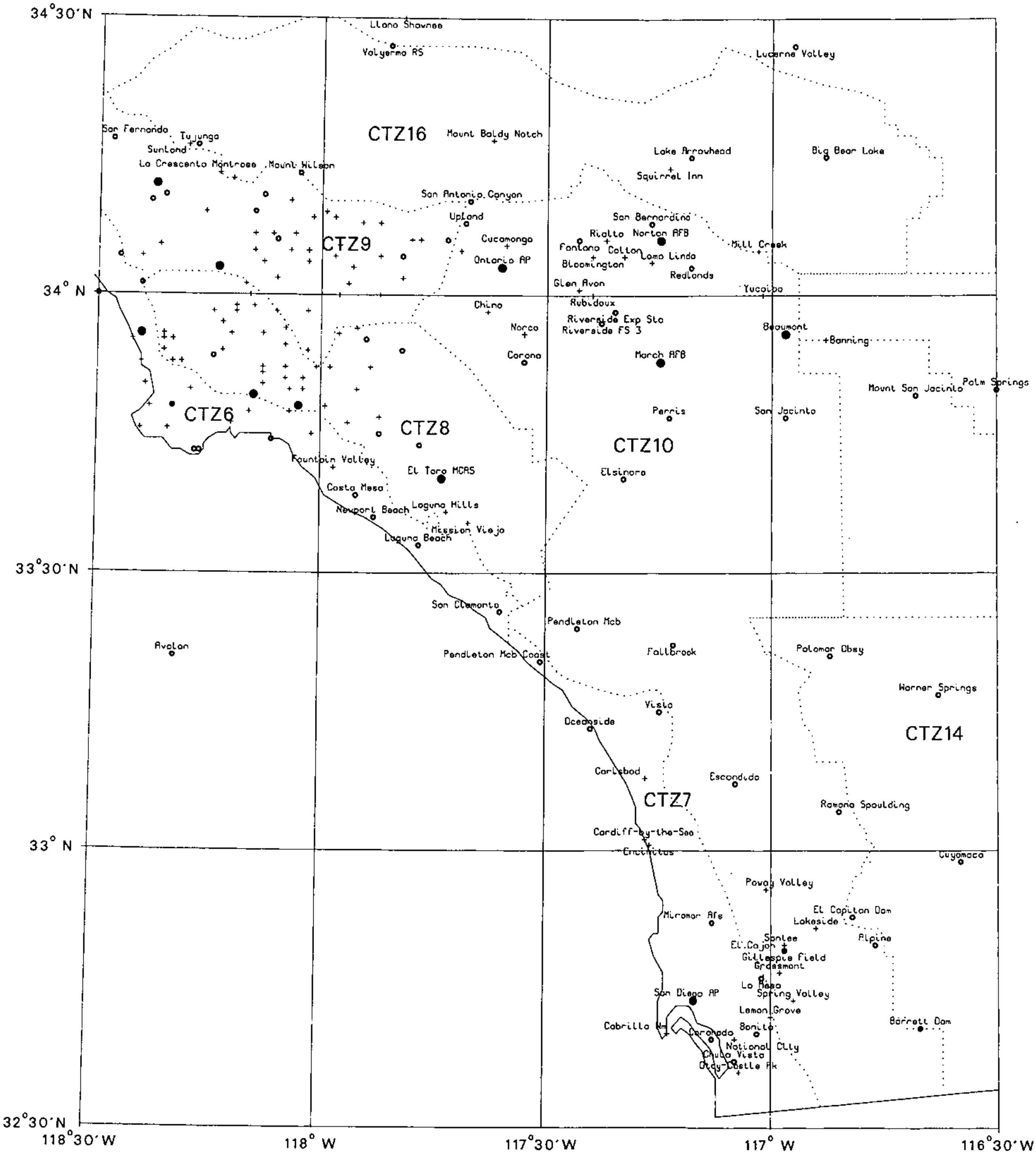


Figure A7
Locations
Los Angeles Area

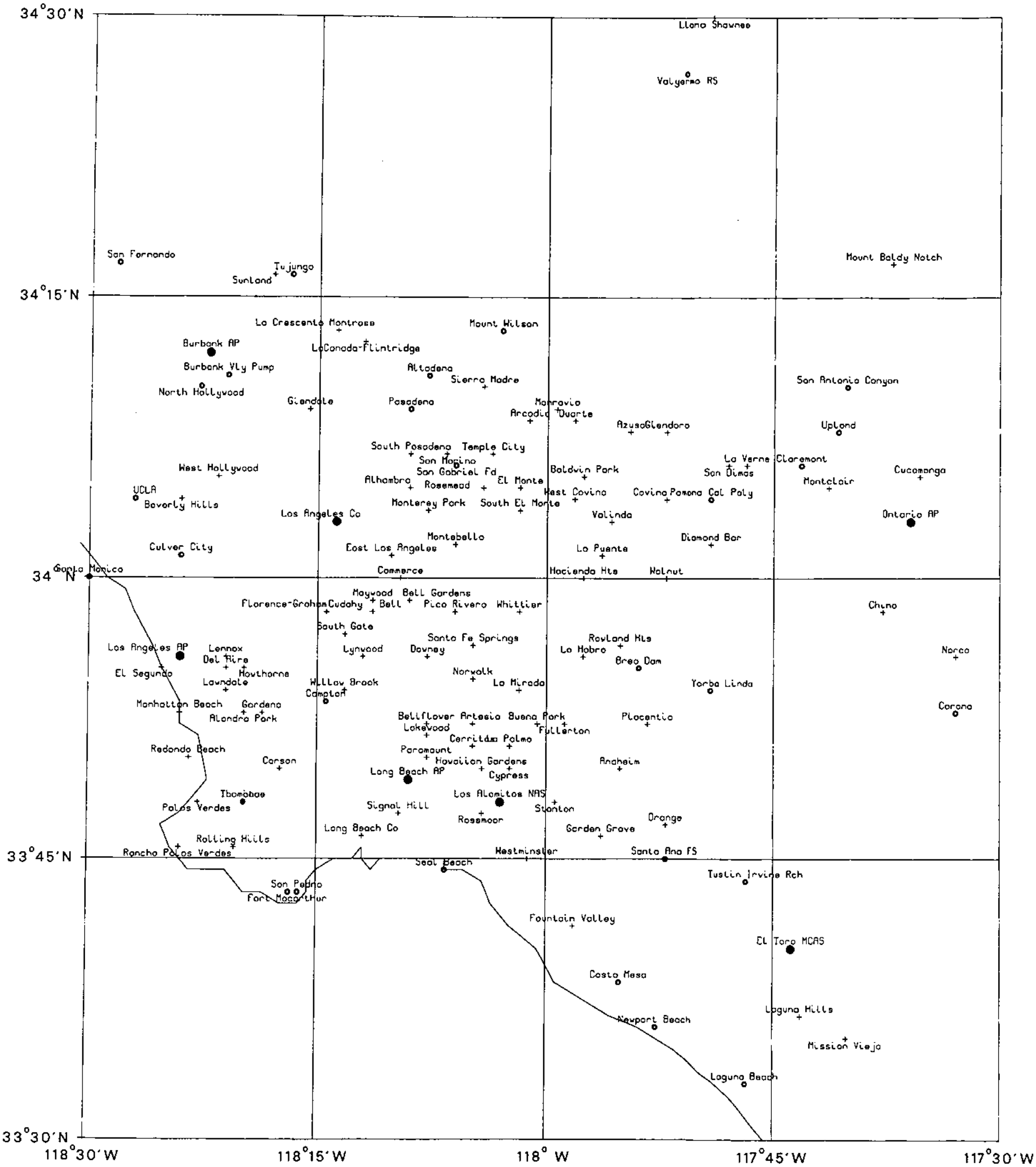


Figure A8
0.1% Annual Design Drybulb Temperature
Los Angeles-San Diego

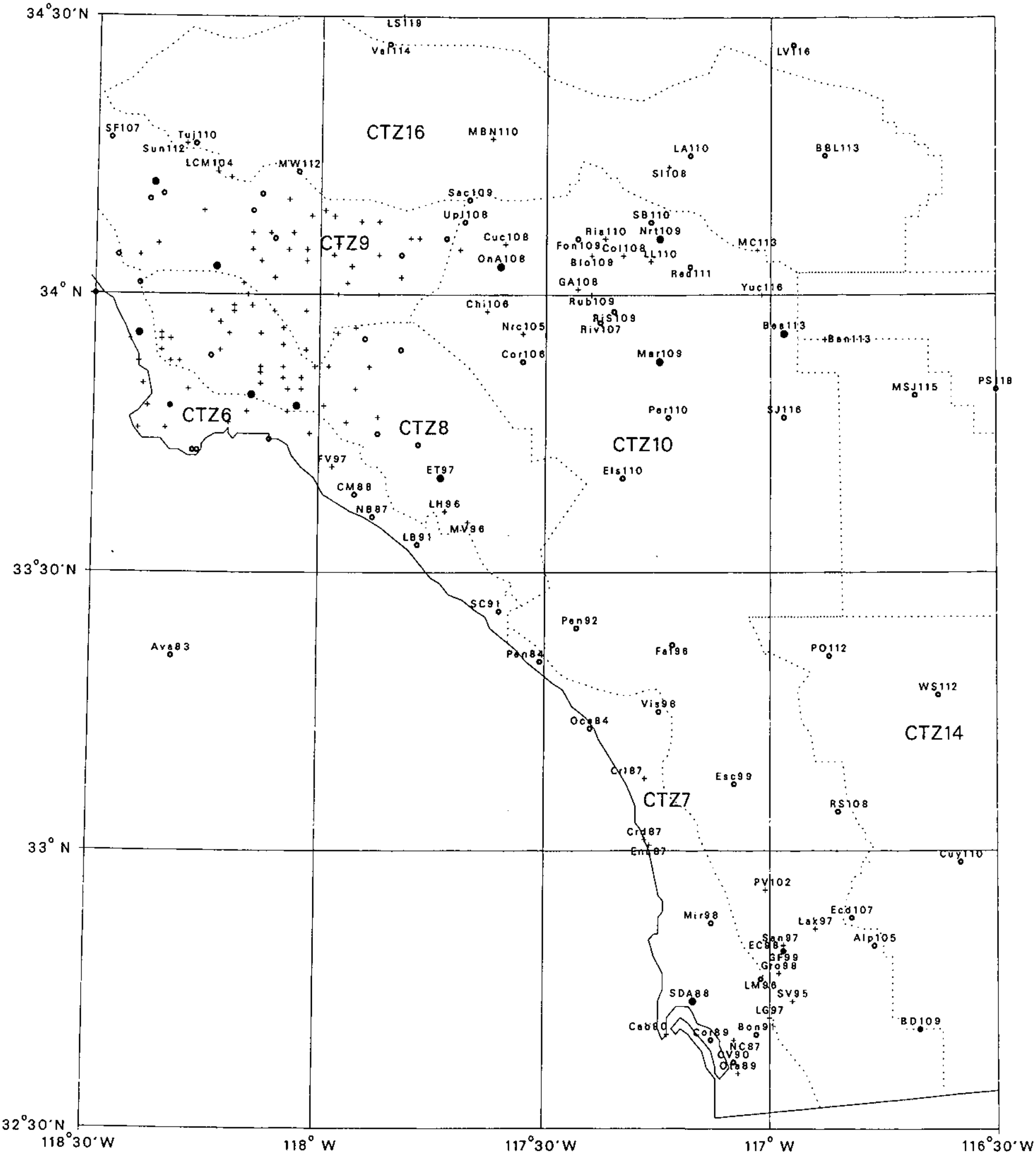


Figure A9
2.0% Annual Design Drybulb Temperature
Los Angeles-San Diego

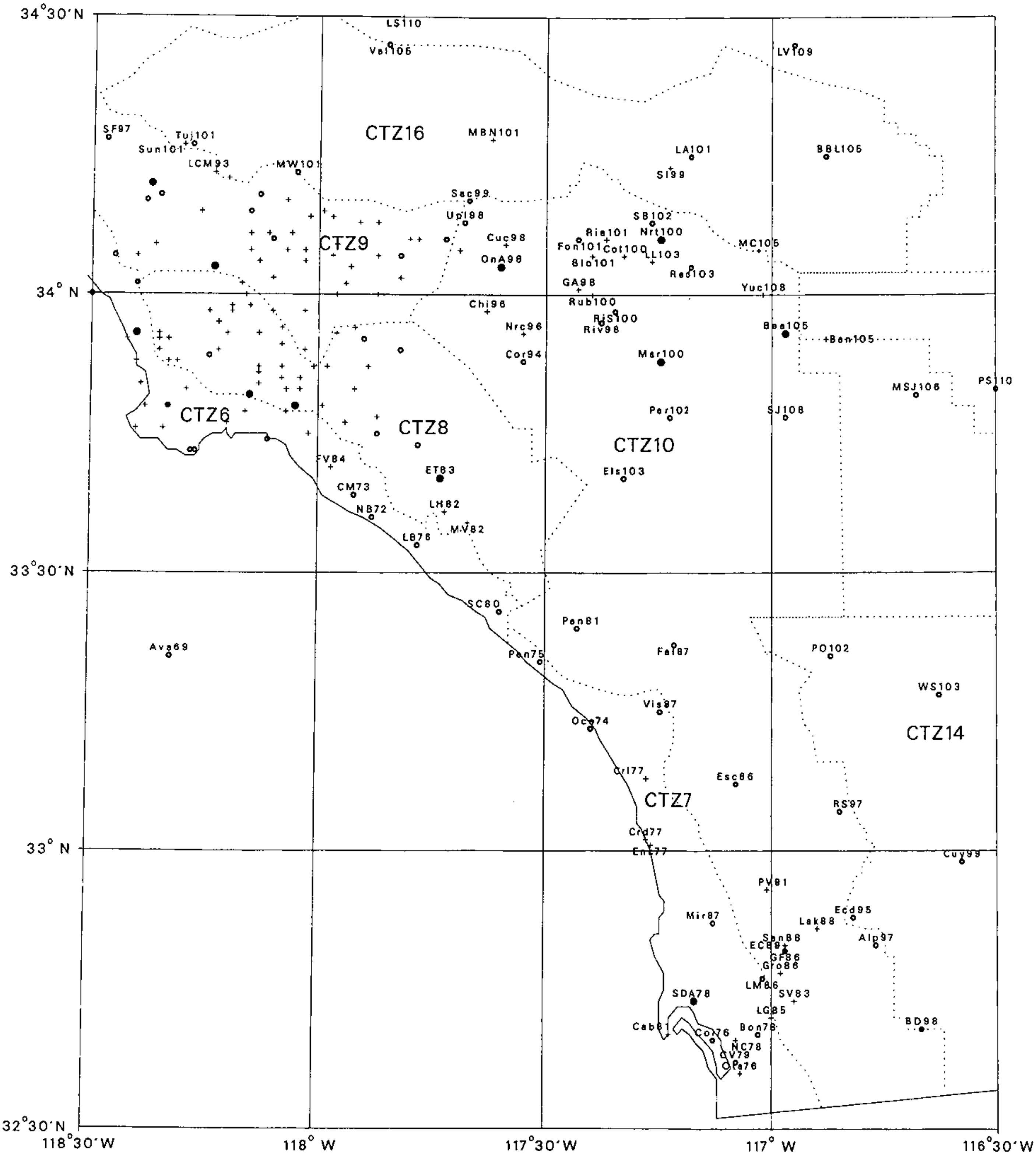


Figure A10
0.1% Annual Design Drybulb Temperature
Los Angeles Area

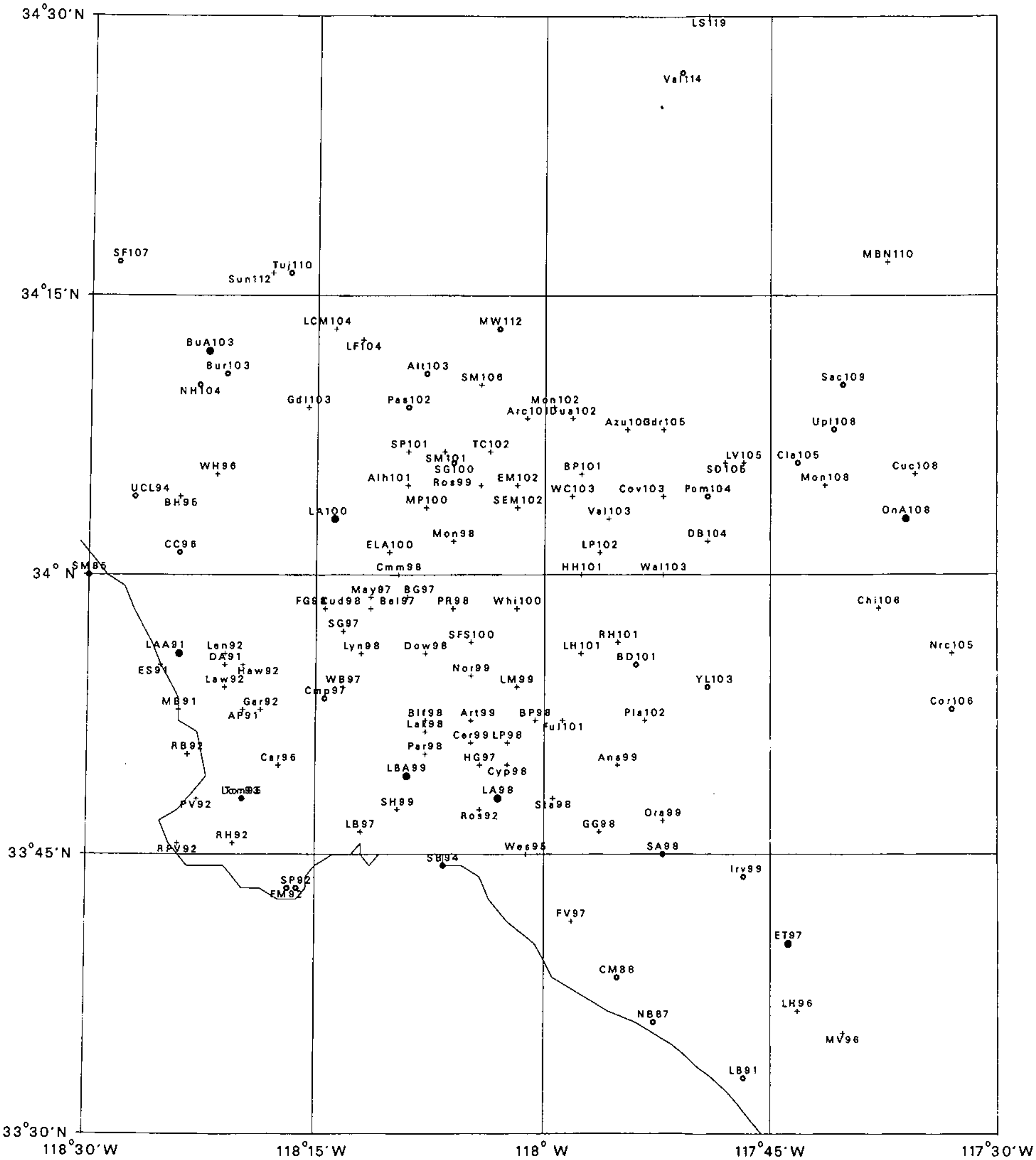
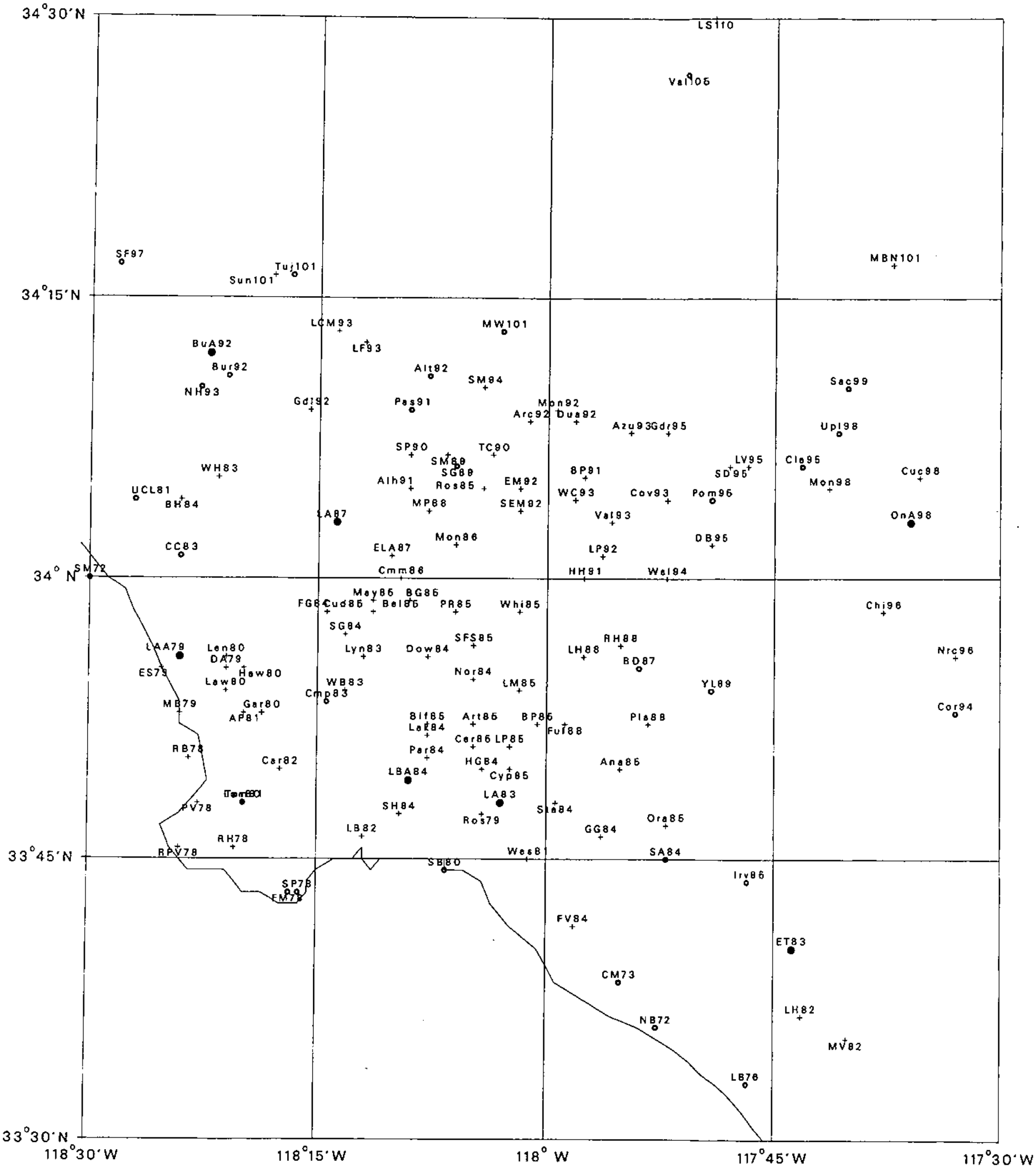


Figure A11
2.0% Annual Design Drybulb Temperature
Los Angeles Area



Appendix B. Summer Climate Climate Conditions for California

(abridged from *1993 ASHRAE Handbook : Fundamentals*, p. 24.4-24.5, ASHRAE 1993)

Station	Lat.	Long.	Elev.	Design Dry-Bulb and Mean Coincident Wet-bulb			Mean Daily	Design Wet-Bulb			Prev.Wind		Median of Annual Extr
			Ft	1%	2.5%	5.%	Range	1%	2.5%	5%	knots	summer	Max.
Bakersfield AP	35.25	119.03	475	104/70	101/69	98/68	32	73	71	70	5	WNW	109.8
Barstow AP	34.51	116.47	1927	106/68	104/68	102/67	37	73	71	70	7	W	110.4
Blythe AP	33.37	114.43	395	112/71	110/71	108/70	28	75	75	74			116.8
Burbank AP	34.12	118.21	775	95/68	91/68	88/67	25	71	70	69	3	S	
Chico	39.48	121.51	238	103/69	101/68	98/67	36	71	70	68	5	SSE	109.0
Concord	37.58	121.59	200	100/69	97/68	94/67	32	71	70	68	5	NW	
Covina	34.05	117.52	575	98/69	95/68	92/67	31	73	71	70			
Crescent City AP	41.46	124.12	40	68/60	65/59	63/58	18	62	60	59			
Downey	33.56	118.08	116	93/70	89/70	86/69	22	72	71	70			
El Cajon	32.49	116.58	367	83/69	80/69	78/68	30	71	70	68			
El Centro AP(S)	32.49	115.40	-43	112/74	110/74	108/74	34	81	80	78	6	SE	
Escondido	33.07	117.05	660	89/68	85/68	82/68	30	71	70	69			
Eureka/Arcata AP	40.59	124.06	218	68/60	65/59	63/58	11	62	60	59	5	NW	75.8
Fairfield-Travis AFB	38.16	121.56	62	99/68	95/67	91/66	34	70	68	67	5	WSW	
Fresno AP (S)	36.46	119.43	328	102/70	100/69	97/68	34	72	71	70	4	WNW	108.7
Hamilton AFB	38.04	122.30	3	89/68	84/66	80/65	28	72	69	67	4	SE	
Laguna Beach	33.33	117.47	35	83/68	80/68	77/67	18	70	69	68			
Livermore	37.42	121.57	545	100/69	97/68	93/67	24	71	70	68	4	NW	
Lompoc, Vandenberg AFB	34.43	120.34	368	75/61	70/61	67/60	20	63	61	60	5	NW	
Long Beach AP	33.49	118.09	30	83/68	80/68	77/67	22	70	69	68	4	WNW	
Los Angeles AP (S)	33.56	118.24	97	83/68	80/68	77/67	15	70	69	68	4	WSW	
Los Angeles Co (S)	34.03	118.14	270	93/70	89/70	86/69	20	72	71	70	4	NW	98.1
Merced, Castle AFB	37.23	120.34	188	102/70	99/69	96/68	36	72	71	70	4	NW	
Modesto	37.39	121.00	91	101/69	98/68	95/67	36	71	70	69			105.8
Monterey	36.36	121.54	39	75/63	71/61	68/61	20	64	62	61	4	NW	
Napa	38.13	122.17	56	100/69	96/68	92/67	30	71	69	68			103.1
Needles AP	34.46	114.37	913	112/71	110/71	108/70	27	75	75	74			116.4
Oakland AP	37.49	122.19	5	85/64	80/63	75/62	19	66	64	63	5	W NW	93.0
Oceanside	33.14	117.25	26	83/68	80/68	77/67	13	70	69	68			
Ontario	34.03	117.36	952	102/70	99/69	96/67	36	74	72	71	4	WSW	
Oxnard	31.12	119.11	49	83/66	80/64	77/63	19	70	68	67			
Palmdale AP	31.38	118.06	2542	103/65	101/65	98/64	35	69	67	66	5	WSW	
Palm Springs	33.49	116.32	411	112/71	110/70	108/70	35	76	74	73			
Pasadena	31.09	118.09	864	98/69	95/68	92/67	29	73	71	70			102.8
Petaluma	38.14	122.38	16	94/68	90/66	87/65	31	72	70	68			102.0
Pomona Co	34.03	117.45	934	102/70	99/69	95/68	36	74	72	71	4	W	105.7
Redding AP	40.31	122.18	495	105/68	102/67	100/66	32	71	69	68			109.2
Redlands	34.03	117.11	1318	102/70	99/69	96/68	33	74	72	71			106.7
Richmond	37.56	122.21	55	85/64	80/63	75/62	17	66	64	63			
Riverside-March AFB (S)	33.54	117.15	1532	100/68	98/68	95/67	37	72	71	70	4	NW	107.6
Sacramento AP	38.31	121.30	17	101/70	98/70	44/69	36	72	71	70	6	SW	105.1
Salinas AP	36.40	121.36	75	74/61	70/60	67/59	24	62	61	59			
San Bernandino, Norton AFB	31.08	117.16	1125	102/70	99/69	96/68	38	74	72	71	3	W	109.3
San Diego AP	32.44	117.10	13	83/69	80/69	7X/68	12	71	70	68	3	WNW	91.2
San Fernando	34.17	118.28	965	95/68	91/68	88/67	38	71	70	69			
San Francisco AP	37.37	122.23	8	82/64	77/63	73/62	20	65	64	62	5	NW	
San Francisco Co	37.16	122.26	72	74/63	71/62	69/61	14	61	62	61	5	W	91.3
San Jose AP	37.22	171.56	56	85/66	81/65	77/64	26	68	67	65	4	NNW	98.6
San Luis Obispo	35.20	120.43	250	92/69	88/70	84/69	26	73	71	70	4	W	99.8
Santa Ana AP	33.45	117.52	115	89/69	85/68	82/68	28	71	70	69	3	SW	101.0
Santa Barbara MAP	31.26	119.50	10	81/67	77/66	75/65	24	68	67	66	3	SW	97.1
Santa Cruz	36.59	122.01	125	75/63	71/61	68/61	28	64	62	61			97.5
Santa .Maria AP (S)	34.54	120.27	236	81/64	76/63	73/62	23	65	64	63	1	WNW	
Santa Monica Co	34.01	118.29	64	83/68	80/68	77/67	16	70	69	68			
Santa Paula	34.21	119.05	263	90/68	86/67	84/66	36	71	69	68			
Santa Rosa	38.31	122.49	125	99/68	95/67	91/66	34	70	68	67	5	SE	102.5
Stockton AP	37.54	121.15	22	100/69	97/68	94/67	37	71	70	68	4	NW	104.1
Ukiah	39.09	123.12	623	99/69	95/68	91/67	40	70	68	67			108.1
Visalia	36.20	119.18	325	102/70	100/69	97/68	38	72	71	70			108.4
Yreka	41.43	122.38	2625	95/65	92/64	89/63	38	67	65	64			102.8
Yuba City	39.08	121.36	80	104/68	101/67	99/66	36	71	69	68			