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Simulated Performance of CIEE's "Alternatives to Compressive Cooling" Prototype House Under Design Conditions in Various California Climates

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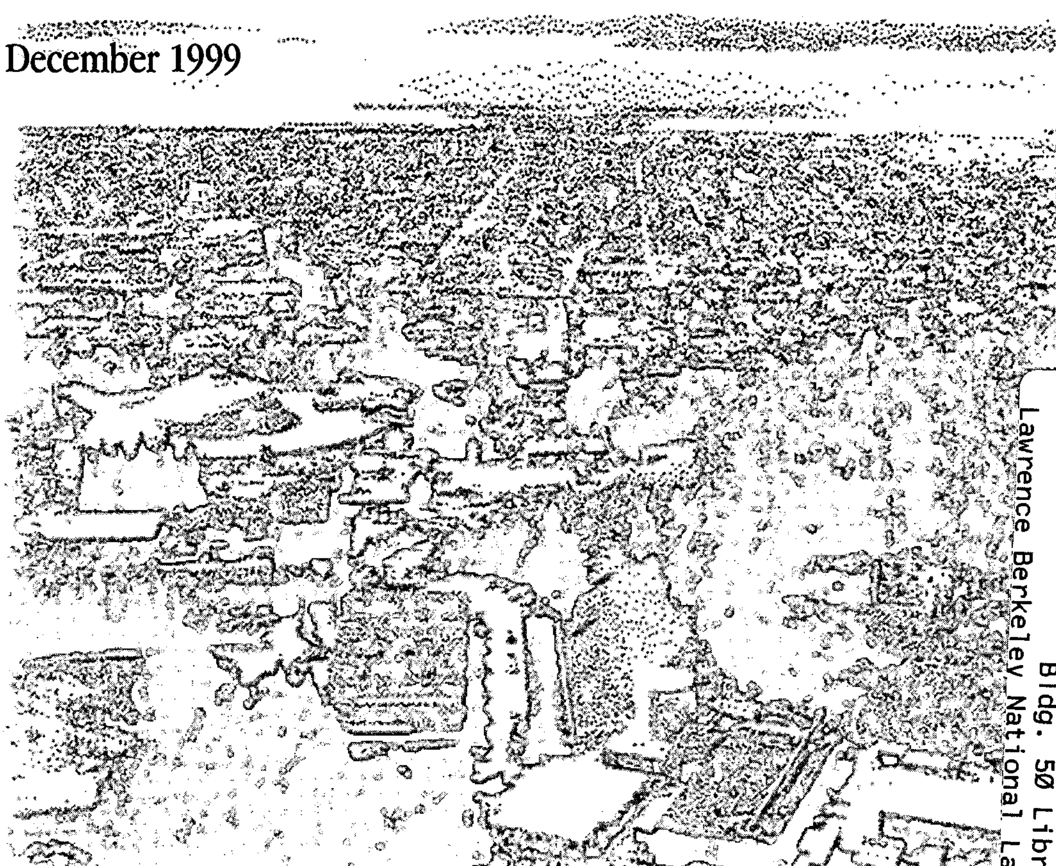

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SIMULATED PERFORMANCE OF CIEE'S "ALTERNATIVES TO COMPRESSIVE COOLING" PROTOTYPE HOUSE UNDER DESIGN CONDITIONS IN VARIOUS CALIFORNIA CLIMATES

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ABSTRACT

To support the design development of a "compressorless" house that does not rely on mechanical air-conditioning, the author carried out detailed computer analysis of a prototypical house design to determine the indoor thermal conditions during peak cooling periods for over 170 California locations. The peak cooling periods are five-day sequences at 2% frequency determined through statistical analysis of long-term historical weather data. The DOE-2 program was used to simulate the indoor temperatures of the house under four operating options: windows closed, with mechanical ventilation, evaporatively-cooled mechanical ventilation, or a conventional 1½-ton air conditioner. The study found that with a 1500 CFM mechanical ventilation system, the house design would maintain comfort under peak conditions in the San Francisco Bay Area out to Walnut Creek, but not beyond. In southern California, the same system and house design would maintain adequate comfort only along the coast. With the evaporatively-cooled ventilation system, the applicability of the house design can be extended to Fairfield and Livermore in northern California, but in southern California a larger 3000 CFM system would be needed to maintain comfort conditions over half of the greater Los Angeles area, the southern half of the Inland Empire, and most of San Diego county. With the 1½-ton air conditioner, the proposed house design would perform satisfactorily through most of the state, except in the upper areas of the Central Valley and the hot desert areas in southern California. In terms of energy savings, the simulations showed that the prototypical house design would save from 0.20 to 0.43 in northern California, 0.20 to 0.53 in southern California, and 0.16 to 0.35 in the Central Valley, the energy used by the same house design built to Title-24 requirements.

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1.0 INTRODUCTION

Since 1993, the author has been involved with a team of researchers, engineers, and architects in the "Alternatives to Compressive Cooling" project sponsored by the California Institute for Energy Efficiency (CIEE) with the goal to design and construct a house for California Transition Climates that would not require mechanical air-conditioning. There is no rigorous definition of the Transition Climates, but they can be roughly delineated as the area between the coast and the Central Valley or Southern desert where the climates are alternately affected by cooler marine or warmer inland influences. The rationale for the project is that as urbanization expands into the Transition Climates, new housing is being constructed with central air-conditioning systems that operate for a limited number of days and add an extremely disadvantageous electricity load to the utility district on hot summer afternoons. The project aims to provide a counter-example by demonstrating that it is possible to build a relatively conventional house in such locations that does not require, or at least minimizes, the use of air-conditioning.

In July 1995, the project team held a design charette in San Francisco with invited architects and builders that resulted in four concept house plans of varying degrees of conventionality. The project designer, George Loisos, selected one of the house plans with the most immediate market appeal and buildability, refined it into working drawings, and gave it the title of the "Summer Comfort House". At the same time, other members of the team, especially the Davis Energy Group, worked with consultant engineers to design possible alternative cooling systems such as a mechanical ventilation system, an indirect evaporatively-cooled ventilation system, or a small air-conditioner should that prove necessary. More detailed descriptions of the "Summer Comfort House" and cooling system can be found in other project reports (Loisos and Ubbelohde 1996, Bourne et al. 1998).

To support the design development and evaluate the performance of the "Summer Comfort House" and the proposed cooling systems, the author carried out the DOE-2 (Winkelman et al. 1993) computer analysis described in this report. This analysis differs from standard building energy simulations in two ways : (1) the focus is on the building performance during peak design periods rather than over an average year, and (2) the performance evaluation is measured in terms of indoor thermal conditions rather than building energy use. The reason for this perspective is that public acceptability of the house will depend much more on whether it can provide satisfactory comfort on the hottest days, rather than on its energy performance. Therefore, the key issue being addressed by the DOE-2 analysis is to determine how the "Summer Comfort House" performs under design conditions in various California Transition Climates. Only after this analysis was completed was a secondary task added to simulate the building's annual energy performance in the 16 climate zones designated by the California Energy Commission for Title-24 compliance.

This use of DOE-2 to analyze design performance opens up the issue of how to define appropriate outdoor design conditions. Since the "Summer Comfort House" is designed to use thermal mass and/or night venting to moderate daytime temperatures, the simulations need to be done not for a single design day, but for a heat wave of several days duration. Such design climatic data are not readily available. Typical engineering references such as the ASHRAE *Handbook of Fundamentals* provide only single peak design temperatures with no information about the preceding or subsequent temperature history (ASHRAE 1997). A recently completed ASHRAE Research Project compiled 5-day design sequences for 216 U.S. locations, of which only five were located in California, too sparse to distinguish between coastal, transition, and inland climates (Colliver et al. 1996). The 16 California Energy Commission Title 24 hourly weather tapes (California Energy Commission 1980, 1992) have a similar problem in geographical coverage. Furthermore, all such "typical year" weather data are suspect because by design they omit extreme climatic conditions.

Because of the clear need for better weather data for this and similar projects, the author obtained funding from the University of California Energy Institute (UCEI) in 1996 to develop 5-day sequences at various design frequencies for 171 California locations based on 10 to 30 years of historical weather data for each location. Each design sequence consists of the maximum and minimum dry-bulb and coincident wet-bulb temperatures for each day of the 5-day design sequence (Zhang and Huang 1999).

2.0 METHODOLOGY

2.1 Design Climate Sequences

The UCEI Weather Project produced design weather sequences for 171 California locations at 4 design criteria of 0.4%, 1%, 2%, and 10% annual frequency. 15 stations have hourly dry-bulb and wet-bulb temperatures. The remaining 156 have only max/min dry-bulb temperatures. The same search method was used on both sets of data to identify 5-day sequences with average temperatures corresponding to the four design criteria mentioned. For the stations with only max/min dry-bulb temperatures, the coincident wet-bulb temperatures at the daily maxima were interpolated based on the relationship between the peak dry-bulb and coincident wet-bulb design temperatures given in the ASHRAE Region X weather data for the same locations (ASHRAE 1982). The coincident wet-bulb temperatures at the daily minima were estimated using the average wet-bulb depressions during peak cooling periods in the 16 California Energy Commission Title 24 weather tapes. The 156 stations were then grouped into the 16 climate zones according to the Title 24 climate zone boundaries, with some adjustments to avoid large discontinuities when crossing climate zone boundaries (Zhang and Huang 1999).

Correlating the design frequencies for the 5-day sequences to conventional design temperatures is more complex than meets the eye. We found that the peak temperature during a 5-day design sequence was significantly higher than the design temperature of the same design frequency, e.g., 0.4%, 1%, etc. This is not unexpected since the peak temperature within a 5-day sequence introduces a further frequency probability, but relating the combined frequency to conventional hourly frequencies is difficult. Empirical comparisons to ASHRAE design temperatures indicate that the maximum temperature during a 2% design sequence corresponded closest to 0.1% summer/0.4% annual temperatures. Since these design temperatures are the most stringent design criteria, we selected the 2% design sequence for use in this analysis. One interpretation of this design frequency is that it would occur once every 250 days, or slightly more than once in a typical year. The average and peak temperatures of the 2% design sequences for the 171 California locations are listed in Appendix B. The maximum and minimum daily temperatures for each of the 5 days are listed on the first line for each city in Table 1, preceded by the temperatures for the warm-up period.

The warm-up period refers to the days before each five-day design sequence. Since DOE-2 initializes the house conditions for 7 days or 168 hours before each simulation period, the assumed weather conditions of the warm-up period can have a significant impact on the thermal conditions of the building during the design sequence. For this analysis, the temperatures for the warm-up period are taken as the average of the five-day sequence at the 10% design frequency. This criteria corresponds roughly to using the average maximum and minimum temperatures from the hottest month of the year.

The design sequences are incorporated into the DOE-2 simulations by a procedure that creates a pseudo-yearly weather file with the 5-day design sequence repeated twice, once beginning on July 1 and the other on September 15, and filling the remaining 355 days each with a repetition of the warm-up day.

2.2 DOE-2 Model of Prototype House

A general description and architectural drawings of the "Summer Comfort House" are available in other project reports (Loisos et al. 1997). The house is a Mediterrean-style 2-story building of conventional wood-frame construction with a floor area of 2190 ft^2. Following an earlier DOE-2 analysis effort, the insulation levels of the building were selected as R-40 roof, R-33 walls, and R-5 slab edge. The building window area (glazing only) is 293 ft^2 (13.8% of floor area), all consisting of double-pane low-E windows with a U-factor of 0.31 and a Solar Heat Gain Factor of 0.37 (Shading Coefficient 0.43). A shading multiplier of 0.60 on solar heat gain is added to account for drapes or blinds half closed during the cooling season.

The building is modeled with the front facing west and the courtyard opening to the south. For solar protection, the building has 3 ft. roof overhangs on all sides. Additional shading is provided to the front of the building by a large entry porch, and by identical neighboring buildings located 10 ft. away on both the north and south sides of the house.

To enhance the building's thermal mass, the insides of the exterior walls are finished with ¾ in. gypsum board, the interior walls are made of 3¼ in. of solid gypsum, and the floor slab is assumed to be 50% exposed tile and 50% carpeted. The infiltration rate of the building is modeled with an Effective-Leakage-Fraction of 0.0006, reflecting a relatively tight construction given this building's large surface-to-volume ratio. Both the roof and walls are modeled with albedos of 0.65 indicating off-white to light colors.

Although DOE-2 cannot model inter-zone air flows, the building was modeled as eight thermal zones (main space, 1st floor bedroom, 2nd floor master bedroom, 2nd floor master bathroom, and 2nd floor bedroom, 1st floor attic, main attic, and garage) to model, partially at least, temperature variations between the first and second floors.

The modeling of the floor slab is particularly problematic because of DOE-2's limited ability to model ground heat flows, and the large thermal lag of the soil. While the design simulations are done for two 5-day design sequences, the heat flows through the slab core should still reflect long-term average seasonal conditions, with only the slab edge affected by the transient increase in air temperatures. For this analysis, a specialized method was developed that uses results from two-dimensional analysis of foundation heat flows for

California climates, and models the floor slab so that both the temporary heat gain through the perimeter as well as the heat sink effect of the slab core are taken into account. This modeling detail can have a significant impact on the thermal behavior of the house, and is discussed in more detail in Appendix C of this report.

2.3 DOE-2 Model of Cooling Systems

This study considered five different modes of operation of the "Summer Comfort House" : (1) none, i.e., the house is closed and has no ventilation of any kind (although there remains stack and wind-driven infiltration), (2) natural ventilation through windows, (3) mechanical ventilation with a ducted 1500 CFM fan system operating in an economizer mode, (4) indirect evaporatively-cooled ventilation, i.e., same as 3 but with the intake air passing first through an indirect evaporative cooler, and (5) small 1½ ton air-conditioner with a 1500 CFM fan operating in an economizer mode. The first mode represents a worst case scenario that would virtually guarantee overheating in almost all climates. The second mode is also not considered seriously because of its dependence on occupant action. Moreover, the simulation results are not credible since there are no available data on wind conditions during the 5-day design sequences. This leaves the last three modes as the cooling system options under contention. Lastly, additional parametric studies were done: with increased fan capacity for the third option, and an improved evaporative cooling control system for the fourth option.

The mechanical ventilation and indirect evaporatively-cooled ventilation systems were both modeled in DOE-2 using user-defined Input Functions. Both systems required two functions, one to add ventilation air to the space depending on indoor and outdoor air conditions, and another to record the zone temperature. For the mechanical ventilation system, a fixed amount of ventilation air (1500 CFM) is added to the house if the previous hour's indoor temperature is above 68°F and higher than the outdoor air temperature. When the previous hour's indoor temperature is below 68°F, but still higher than outdoor air temperature, the fan
CFM is reduced proportionally to zero at 62°F, at which point ventilation is stopped. The intent of this control logic is to model ventilative cooling down to 65°F and eliminate the oscillation seen with a simpler 65°F cut-off.* The DOE-2 results show that the Function produces minimum zone temperatures slightly below 65°F.

The Input Function for indirect evaporatively-cooled ventilation is similar, except that the temperature of the ventilation air is reduced by 60% of the wet-bulb depression (the difference between the dry- and wet-bulb temperatures), assuming an effectiveness of 0.60 for the indirect evaporative cooler. Although the ideal control for such a cooling system would be to ventilate whenever the temperature of the evaporatively-cooled air is below the indoor air temperature, but practically this would be difficult because this temperature can only be detected after the system has been turned on. For the "standard" 1500-CFM system, a simpler control system was used where the dry-bulb temperature minus 10°F is used as an approximate indicator of the evaporatively-cooled air temperature. This temperature offset was derived by trial and error and resulted in slight overcooling in Northern California climates (down to 62-63°F), but in Southern California climates such as Pasadena, it shut down the system when the evaporatively-cooled air temperature was still lower than that of the indoor air.

* The oscillations result because the User Function uses the previous hour's zone temperature to determine whether ventilative cooling is done. With a simple 65°F cutoff, the zone would alternate between venting and no venting with a 2-3°F oscillation.

To study the practical maximum cooling capacity of the ventilation systems, the simulations were repeated with a 3000 CFM fan, and for the indirect evaporatively-cooled system, with an improved control based on the actual evaporatively-cooled air temperature.

The 1½ ton air-conditioner system was modeled using the standard DOE-2 RESYS (Residential) system with the cooling setpoint held at 78°F. The fan capacity was kept at 1500 CFM, and mechanical ventilation down to 65°F mimicked by modeling natural ventilation using a fixed air-change rate. The air-conditioner was given a cooling capacity of 18,000 Btu/hour, and modeled with part-load performance curves for a high-efficiency air conditioner and a COP of 2.70.

For the annual simulations, the building was modeled with a 1½ ton air-conditioner with a COP of 2.70 and a 50,000 Btu pulse-combustion furnace with a steady-state efficiency of 0.74. Attempts to simulate the building with the ventilative cooling systems described earlier was unsuccessful due to the lack of a control algorithm to prevent overcooling on mild days or during the heating season. As a result, these runs showed unreasonably high heating energy consumption and have been omitted from this study.

3.0 RESULTS

3.1 Maximum indoor temperatures

The DOE-2 calculated maximum and minimum indoor temperatures from the two design periods in the five conditioned zones for the "Summer Comfort House" in 171 California climates are shown in Table 1. For each city, the first line gives its geographical coordinates, followed by the max/min temperatures for the warm-up period and the five days of the design sequence. The following four lines give the maximum and minimum temperatures by zone for the following control options: Closed (Option 1), Vent (Option 3), IEC (Option 4), and A/C (Option 5). For the A/C line, the last column gives the peak A/C electricity demand over the two design sequences. A blank in that column indicates for that location the air-conditioner never came on. The results for some representative cities are also plotted in Figures 3 through 16, and discussed in greater detail in the following section.

Those cities identified by an "S" or "EI" are those for which there were detailed hourly dry- and wet-bulb temperature data. For the other cities, the design sequences are based on max-min dry-bulb temperatures only, with extrapolated wet-bulb temperatures.

Since Table 1 does not indicate how often the maximum and minimum temperatures were reached, it tends to accentuate the range of temperatures. For example, Table 1 shows the maximum indoor temperatures with mechanical ventilation in Los Angeles (LAX) to be from 78.1 to 78.9°F depending on the location in the house. However, Figure 7 shows that this temperature was reached 78°F only two of the ten days, and that the average peak indoor temperature was actually 76°F or less.

Figure 17 plots the maximum indoor temperature against the average outdoor temperature over the 5-day design sequence for the four control options. Except for the last air conditioner option, the maximum indoor temperatures for the other three options correlate quite well to the average outdoor temperature over the 5-day design sequence, with a secondary effect when the average temperature on the hottest day is significantly higher than that for the entire 5-day period. When the windows are closed, the maximum indoor temperature is roughly 8° higher than the average outdoor air temperature, with another 2°

increase if one of the five days is particularly hotter than the other four. Of the 171 climates, only a handful of coastal locations have maximum indoor temperatures falling within the Comfort Line at 78°F. With mechanical ventilation, the maximum indoor temperatures are now 6°F higher than the average outdoor temperature in the cooler locations, and 2° higher in the hotter locations, with roughly a third of the locations falling within the Comfort Line. With indirect evaporatively-cooled ventilation, the maximum indoor temperatures are now roughly the same as the average outdoor temperature in the hotter locations, so that nearly half of the 171 locations have maximum indoor temperatures below the Comfort Line. With a 1½ ton air-conditioner, the maximum indoor temperatures are held within a degree of 78°F until the average outdoor temperature over the 5-day period exceeds 86°, at which point the air-conditioner cannot meet the cooling load.

3.2 Hourly temperature profiles

Figures 3 through 14 show 12 representative hourly temperature plots for selected California locations: four extending inland from the Bay Area, four for the Los Angeles area, and four for the San Diego area. The format is identical on the twelve plots, with the outdoor dry-bulb shown as a thin solid line, the outdoor wet-bulb as a thin dashed line, and the indoor temperatures for 1500 CFM mechanical ventilation (Vent), indirect evaporatively-cooled ventilation (IEC), and a 1½ ton air-conditioner (AC) shown as thick solid, dashed, and dotted lines, respectively. A thick horizontal line at 78°F indicates the upper limit of the comfort zone.

Figures 3 and 4 show that mechanical ventilation is adequate in Northern California locations in the vicinity of the Bay Area. Although the daytime peak temperatures in Martinez and Walnut Creek are quite high, they are offset by large diurnal swings and low nighttime temperatures that facilitate night cooling. Because ventilative cooling is stopped when the indoor temperature drops to 65°F, there is little difference between the Vent and IEC options.

Figures 5 and 6 show that as one proceeds further inland, the extremely high daytime outdoor peaks cause maximum indoor temperatures to rise to nearly 80°F in Fairfield and Davis, although an indirect evaporatively-cooled ventilation system will still keep them below the Comfort line (78°F).

Figures 7 and 8 for Los Angeles (LAX) and Pasadena show striking differences in design temperature conditions and cooling performance as compared to in Northern California. At LAX, the peak temperatures are low but the temperature swings are also small, due to the marine influence at the coast. The house performs satisfactorily under all three modes, but the nighttime cooling potentials are minimal. In Pasadena, the daytime peak outdoor temperatures are now in the 90's, while the nighttime outdoor lows are near 70°F, greatly reducing night cooling potentials as compared to in Northern California. Consequently, both the mechanical venting and indirect evaporatively-cooled systems result in maximum indoor temperatures from the mid to low 80's. The improvement in indoor temperatures with the indirect evaporatively-cooled system, however, is significantly more than in Northern California due to its ability to capture some night cooling potential. Figure 15 shows that this performance is constrained by the 1500 CFM fan size and control strategy. Figures 9 and 10 show the cooling performance further inland in Pomona and Riverside to be similar to that in Pasadena.

Figures 11 and 12 are for San Diego airport and Bonita. In San Diego, the nighttime outdoor minima are so high and the diurnal outdoor temperature swings so minimal that the mechanical venting system could not provide any night cooling, resulting in indoor temperatures that exceed 80°F on the fourth day. In Bonita, however, the system performed quite satisfactorily.

Figure 13 and 14 show that further inland, the indirect evaporatively-cooled system seems to be sufficient in La Mesa. However, the 1½ ton air-conditioner is needed in El Cajon. In both locations, mechanical ventilation alone will result in peak temperatures in the low 80's in La Mesa and in the mid 80's in El Cajon.

Figures 15 and 16 show the results in Pasadena and La Mesa when the fan size is doubled from 1500 to 3000 CFM, and the indirect evaporative cooling control is improved to check the actual evaporatively-cooled supply air temperature. In both cities, the performance of the mechanical venting is not improved because the air temperatures are too high to permit much use. However, the increased air flow rate clearly increased the cooling capacity of the indirect evaporatively-cooled system, so that the house in Pasadena overheated by 1°F or so on three of the five days, a level of performance similar to that achieved using the 1½ ton air-conditioner.

3.3 Mapping of indoor temperatures

The simulated performance of the "Summer Comfort House" in 171 California locations is entered into the commercial *DISSPLA* mapping software to produce contour maps of the state that show the geographical distribution of applicability for the various cooling options. The contour maps for four cooling options (1500 CFM mechanical ventilation, 1500 CFM indirect evaporatively-cooled ventilation, 1½ ton air conditioner, and 3000 CFM indirect evaporatively-cooled ventilation) are shown in Appendix A.1 through A.8. The average outdoor temperatures over the 5-day design sequence are mapped in Appendix A.9 and A.10, while the names of the 171 locations are mapped in Appendix A.11 and A.12. Some words of caution are needed about these contour maps. Only a few of the 171 locations are located in the mountainous areas, which show up on the contour maps as odd bull-eyes. The contour mapping routine also is not aware of coastal conditions, resulting in concentric contours around each station rather than parallel to the coast as common sense would indicate. Despite these shortcomings, the maps are useful in turning a large amount of numbers into coherent pictures that quickly reveals the geographical applicability for each cooling option.

On Figures 18 and 19, the 79°F contours for each cooling option are combined to show the regions for which each is appropriate for the prototypical house. These are labeled as

Vent for 1500 CFM mechanical ventilation
IEC for 1500 CFM indirect evaporatively-cooled ventilation
IEC+ for 3000 CFM indirect evaporatively-cooled ventilation with improved controls
AC for 1½ air-conditioner with a 1500 CFM fan
AC+ for conventional sized air-conditioner

The reason for using 79° instead of the 78°F comfort line (and cooling setpoint for the air conditioner) is to make allowances for a small 1°F "deadband" that occurs even with mechanical air conditioning.

3.4 Annual heating and cooling performance

Although the primary criteria for the acceptability of the Summer Comfort House are the maximum indoor temperatures reached during peak cooling conditions, there was a secondary concern about the building's energy use over the entire year. The building's annual energy performance was calculated by repeating the DOE-2 simulations using the California Energy Commission's weather tapes for the 16 climate zones defined for Title-24 calculations (California Energy Commission 1980, 1992). Because the building model and operating assumptions used in this study differed from those used for Title-24 compliance calculations, the annual simulations were done in three ways – (1) with the original building conditions and operating assumptions, i.e., low internal loads level due to the use of energy-efficient appliances and shading from neighboring buildings to the north and south, (2) with Title-24 building conditions and operating assumptions, i.e., Title-24 level of internal loads and no shading from neighboring buildings. and (3) with Title-24 building conditions, operating assumptions, and conservation levels, i.e., the house had it been built to Title-24 requirements for wall and roof insulation, window type, and medium gray color on the roof and walls.

The results from the three sets of runs are shown on Table 2, and plotted in Figures 20 and 21. The use of Title-24 operating conditions resulted in a 10-20% reduction in the calculated heating energy use, and up to a 15% increase in the calculated cooling energy use. This is the offset due to the DOE-2 modeling of shading and internal gain conditions beyond those considered in Title-24 conditions. Using the Title-24 operating conditions as a neutral benchmark for comparison, Table 2 shows that the prototypical design uses 40% less heating fuel in Northern California, 50% less in Southern California, and 25% less in the Central Valley, than the same house built to Title-24 requirements. In cooling and fan electricity, the prototypical design saves from 50% up to 70% compared to the same house built to Title-24 requirements. In Figure 22, the annual fuel and electricity usages have been converted to costs at $0.60/Therm and $0.10/kWh, and summed to derive total annual energy costs. These show the annual energy costs of the prototypical design to be roughly 30-40% lower than the same house built to Title-24 requirements.

Table 3 gives further information about the impact from each of these parameters on the calculated building performance – Title-24 internal loads, insulation levels, and glass type, wall and roof color, carpeted floor, and shading from neighboring houses. The most important parameter that increased the prototypical building's heating loads is its low internal loads, with shading from neighboring buildings, partially exposed floor space, and light-colored walls and roofs all of similar impact. These heating penalties are, however, more than offset by the savings due to the higher wall and roof insulation levels, and improved glazing.

4.0 CONCLUSIONS

With the 1500 CFM mechanical ventilation system, the building is comfortable during the 5-day design sequences in the San Francisco Bay Area out to Walnut Creek, but not beyond, i.e., Livermore, Fairfield. It's also adequately comfortable for San Luis Obispo and the inland areas of Santa Barbara, but starting from Los Angeles, indoor comfort would be maintained only at the coast, with the exception of San Diego.

With the 1½ ton air conditioner, the house will not maintain adequate indoor comfort in the upper areas of the Central Valley (Red Bluff), the deserts east of Los Angeles and San Diego counties, and is marginally adequate in the Fresno area.

With the 1500 CFM indirect evaporatively-cooled ventilation system and a crude dry-bulb temperature minus 10°F control logic, the building is comfortable in Northern California to Fairfield and Livermore, but in Southern California only 10 miles inland. With the 3000 CFM system and a better indicator for the cooled air temperature, the building would work in half of greater Los Angeles, the southern half of the Inland Empire, and most of San Diego county. In Northern California, the building would be comfortable from the San Francisco Bay Area out to Davis and Sacramento.

In terms of energy use, the prototypical house requires substantially less than the same building built to Title-24 requirements, with annual cost savings ranging from 0.20 to 0.43 in northern California, 0.20 to 0.53 in southern California, and 0.16 to 0.35 in the Central Valley. The energy performance of the prototypical house compared to other houses in general, however, is difficult to evaluate due to differences in house size, surface-to-volume ratio, solar gain, and other architectural details.

5.0 ACKNOWLEDGEMENTS

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Table 1. Maximum and minimum indoor temperatures for CIEE's "Alternatives to Compressor Cooling" house with 1500 CFM fan during 2% 5-day design periods in 171 California climates

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Alpine	Lon 116.77 Lat 32.83				
Closed	89.5	80.3	90.8	81.4	
Vent	85.4	71.0	87.9	69.1	
IEC	81.9	67.1	83.1	65.4	
A/C	78.5	68.1	78.5	65.0	1.61
Alturas	Lon 120.55 Lat 41.50				
Closed	79.7	67.7	81.8	69.0	
Vent	75.4	62.3	77.5	62.2	
IEC	73.6	62.3	74.5	62.1	
A/C	74.2	63.8	75.4	63.9	
Angwin	Lon 122.43 Lat 38.57				
Closed	84.5	75.7	86.2	76.6	
Vent	79.9	66.3	81.8	65.1	
IEC	77.1	64.7	77.5	63.9	
A/C	77.8	65.0	78.5	65.0	0.09
Antioch	Lon 121.77 Lat 38.02				
Closed	88.3	77.5	89.8	78.4	
Vent	84.2	66.5	85.9	65.1	
IEC	80.5	64.6	80.6	63.5	
A/C	78.2	65.0	78.6	65.0	1.38
Arcata S*	Lon 124.10 Lat 40.98				
Closed	69.3	63.2	70.6	63.7	
Vent	67.2	61.0	68.0	61.3	
IEC	65.9	61.1	66.0	61.4	
A/C	67.2	62.0	68.2	62.4	
Auberry	Lon 119.50 Lat 37.08				
Closed	92.2	84.1	93.3	85.4	
Vent	87.9	76.4	90.0	74.9	
IEC	83.7	71.7	84.1	69.8	
A/C	78.5	73.0	77.7	70.2	1.68
Auburn	Lon 121.07 Lat 38.90				
Closed	92.3	80.9	93.8	81.7	
Vent	87.9	70.9	89.6	68.5	
IEC	83.7	66.5	84.4	65.0	
A/C	78.7	67.8	78.2	65.0	1.83
Avalon	Lon 118.32 Lat 33.35				
Closed	79.3	73.3	80.7	74.6	
Vent	76.6	66.5	77.5	65.8	
IEC	72.5	65.2	72.1	64.6	
A/C	74.7	65.0	75.3	65.0	
Bakersfield S*	Lon 119.05 Lat 35.42				
Closed	98.0	87.0	99.7	88.0	
Vent	94.8	79.0	97.3	77.3	
IEC	88.7	71.8	89.2	69.1	
A/C	80.5	74.5	78.1	72.1	1.94
Barstow	Lon 117.03 Lat 34.90				
Closed	94.9	86.4	96.0	87.8	
Vent	89.4	76.9	91.4	74.8	
IEC	83.9	70.0	84.1	66.8	
A/C	78.7	72.2	77.3	68.7	2.01
Beaumont	Lon 116.97 Lat 33.93				
Closed	90.4	78.6	92.0	79.5	
Vent	86.9	66.4	89.4	64.9	
IEC	83.4	64.6	84.4	63.1	
A/C	78.2	65.0	78.4	65.0	1.77
Ben Lomond	Lon 122.10 Lat 37.08				
Closed	81.4	72.4	82.9	73.4	
Vent	75.3	63.6	77.1	62.6	
IEC	74.1	63.2	75.0	61.9	
A/C	74.6	65.0	75.9	64.5	
Berkeley	Lon 122.25 Lat 37.87				
Closed	78.5	70.3	79.8	71.2	
Vent	75.1	64.6	77.0	63.9	
IEC	72.4	63.7	73.0	63.4	
A/C	73.4	65.0	73.8	65.0	
Big Bear Lake	Lon 116.88 Lat 34.25				
Closed	74.1	65.3	75.5	66.7	
Vent	70.4	61.9	72.1	62.0	
IEC	69.2	61.6	69.6	62.0	
A/C	70.4	63.0	71.4	63.4	
Blythe	Lon 114.60 Lat 33.62				
Closed	98.9	93.7	100.2	94.7	
Vent	98.4	83.2	100.0	80.7	
IEC	92.5	76.0	92.8	72.3	
A/C	82.5	75.7	79.7	73.0	2.21
Bonita	Lon 117.03 Lat 32.67				
Closed	81.3	73.2	82.6	74.4	
Vent	77.2	66.6	78.7	65.9	
IEC	74.4	64.9	74.4	64.3	
A/C	75.3	65.0	76.0	65.0	
Brawley	Lon 115.55 Lat 32.95				
Closed	98.8	93.7	100.2	94.1	
Vent	97.9	81.6	99.6	78.5	
IEC	92.4	74.8	92.7	70.6	
A/C	81.9	74.4	79.3	70.5	2.15
Burbank	Lon 118.37 Lat 34.20				
Closed	89.6	79.7	91.0	80.7	
Vent	85.4	68.7	87.1	66.7	
IEC	82.2	66.1	82.4	64.7	
A/C	78.2	65.7	78.5	65.0	1.55
Burlingame	Lon 122.35 Lat 37.58				
Closed	77.8	69.8	79.7	70.6	
Vent	74.0	62.9	75.5	62.4	
IEC	73.3	63.1	74.7	62.8	
A/C	73.8	64.2	75.4	64.1	
Burney	Lon 121.67 Lat 40.88				
Closed	78.3	67.9	79.8	68.8	
Vent	72.8	62.2	73.7	62.0	
IEC	72.0	62.3	72.9	61.9	
A/C	72.9	63.7	74.1	63.5	
Buttonwillow	Lon 119.47 Lat 35.40				
Closed	92.5	83.6	93.7	84.9	
Vent	86.9	74.0	88.3	72.0	
IEC	82.8	69.6	82.9	67.1	
A/C	78.6	70.0	77.8	65.1	1.69
Calistoga	Lon 122.58 Lat 38.57				
Closed	86.2	75.8	87.7	76.6	
Vent	80.7	65.1	83.2	63.8	
IEC	78.5	63.9	79.8	62.8	
A/C	78.0	65.0	78.7	65.0	0.81

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Table 1. Maximum and minimum indoor temperatures for CIEE's "Alternatives to Compressor Cooling" house with 1500 CFM fan during 2% 5-day design periods in 171 California climates

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW	Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Canyon Dam	Lon 121.08 Lat 40.17					**Corcoran**	Lon 119.57 Lat 36.10				
Closed	78.5	68.1	80.4	69.1		Closed	93.5	83.1	94.9	84.2	
Vent	73.8	62.7	75.3	62.4		Vent	88.8	72.2	90.8	69.8	
IEC	72.2	62.5	73.2	62.5		IEC	84.9	68.0	85.2	65.8	
A/C	72.9	63.9	74.1	64.0		A/C	79.1	68.7	78.1	65.0	1.72
Carmel Valley	Lon 121.73 Lat 36.48					**Corona**	Lon 117.55 Lat 33.88				
Closed	81.3	71.2	83.3	72.2		Closed	88.5	79.6	89.6	80.6	
Vent	77.2	64.0	78.9	63.1		Vent	82.5	68.3	84.5	66.4	
IEC	76.1	63.6	77.0	63.2		IEC	78.9	65.5	79.0	64.4	
A/C	76.2	64.8	77.3	64.6		A/C	78.1	65.3	78.8	65.0	1.02
Cherry Valley	Lon 119.92 Lat 37.97					**Covelo**	Lon 123.25 Lat 39.78				
Closed	83.4	74.6	84.8	75.9		Closed	85.7	74.6	87.5	75.7	
Vent	77.9	66.4	79.2	65.4		Vent	79.5	64.3	81.1	63.4	
IEC	74.8	64.5	75.2	63.9		IEC	76.8	63.6	77.5	62.2	
A/C	75.4	65.0	75.9	65.0		A/C	77.1	65.0	77.9	65.0	
Chester	Lon 121.23 Lat 40.30					**Crescent**	Lon 124.20 Lat 41.77				
Closed	78.3	67.7	80.3	68.8		Closed	71.4	65.7	72.6	66.6	
Vent	73.8	62.5	75.4	62.4		Vent	68.6	62.3	69.4	62.2	
IEC	72.4	62.5	73.5	62.1		IEC	66.5	62.3	66.3	62.5	
A/C	73.1	63.9	74.3	64.0		A/C	68.3	63.2	69.3	63.6	
Chico	Lon 121.82 Lat 39.70					**Crockett**	Lon 122.22 Lat 38.03				
Closed	93.0	81.6	95.0	82.6		Closed	84.5	73.7	86.1	74.3	
Vent	88.1	71.1	89.5	67.8		Vent	79.6	65.3	81.2	64.3	
IEC	84.9	66.9	85.9	64.8		IEC	77.4	64.0	78.2	63.5	
A/C	79.1	67.0	78.1	65.0	1.95	A/C	77.8	65.0	78.6	65.0	0.08
Chula Vista	Lon 117.08 Lat 32.62					**Culver**	Lon 118.40 Lat 34.02				
Closed	82.5	74.6	84.0	75.4		Closed	83.1	76.3	84.3	77.2	
Vent	79.0	67.0	81.3	65.7		Vent	79.4	68.1	81.4	66.8	
IEC	76.6	65.0	77.7	64.1		IEC	76.6	66.0	77.2	65.0	
A/C	77.2	65.0	78.4	65.0		A/C	77.4	65.6	78.5	65.0	
Claremont	Lon 117.72 Lat 34.10					**Davis**	Lon 121.77 Lat 38.53				
Closed	88.6	79.2	90.2	80.2		Closed	87.2	78.1	88.2	78.9	
Vent	84.9	70.6	87.3	68.8		Vent	80.0	66.5	81.0	64.9	
IEC	81.8	67.5	82.3	65.7		IEC	77.1	64.7	77.9	63.0	
A/C	78.3	68.0	78.0	65.0	1.52	A/C	77.8	65.0	78.5	65.0	0.03
Cloverdale	Lon 123.02 Lat 38.82					**Dunsmuir**	Lon 122.27 Lat 41.20				
Closed	87.7	75.8	89.4	76.7		Closed	84.6	74.2	86.1	75.2	
Vent	81.3	65.5	82.5	64.1		Vent	78.3	64.6	80.0	63.6	
IEC	79.1	64.3	79.9	63.4		IEC	75.7	63.7	76.3	63.1	
A/C	78.0	65.0	78.6	65.0	0.94	A/C	76.1	65.0	76.9	65.0	
Coalinga	Lon 120.35 Lat 36.15					**East Park Res**	Lon 122.52 Lat 39.37				
Closed	94.8	84.6	96.4	86.0		Closed	90.9	79.0	92.9	80.1	
Vent	90.3	74.2	92.5	72.0		Vent	87.6	67.9	90.1	66.2	
IEC	86.2	69.8	87.0	67.1		IEC	83.9	65.2	84.9	64.0	
A/C	79.2	70.2	77.7	66.1	2.06	A/C	78.5	65.0	78.6	65.0	1.95
Colfax	Lon 120.95 Lat 39.10					**El Cajon**	Lon 116.97 Lat 32.82				
Closed	89.2	80.0	90.4	81.0		Closed	88.1	79.6	89.3	80.8	
Vent	83.8	70.9	85.3	69.0		Vent	84.2	70.9	85.5	69.3	
IEC	79.8	66.5	79.7	65.2		IEC	80.1	67.0	80.3	65.5	
A/C	78.1	68.0	77.9	65.0	1.16	A/C	78.2	68.2	78.5	65.0	1.17
Colusa	Lon 122.02 Lat 39.20					**El Centro**	Lon 115.57 Lat 32.77				
Closed	90.2	80.8	91.8	81.9		Closed	98.8	93.3	100.1	94.4	
Vent	84.2	69.5	86.7	66.9		Vent	95.8	83.8	97.2	81.4	
IEC	81.1	66.1	82.3	64.5		IEC	90.0	76.6	90.0	73.1	
A/C	78.5	66.0	77.8	65.0	1.51	A/C	81.3	76.5	78.6	73.7	2.15

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Table 1. Maximum and minimum indoor temperatures for CIEE's "Alternatives to Compressor Cooling" house with 1500 CFM fan during 2% 5-day design periods in 171 California climates

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW	Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Escondido	Lon 117.08 Lat 33.12					**Half Moon Bay**	Lon 122.45 Lat 37.47				
Closed	86.7	77.2	88.2	78.3		Closed	71.6	65.6	72.4	66.4	
Vent	82.3	67.1	84.0	65.7		Vent	69.1	62.3	69.8	62.3	
IEC	78.7	65.0	79.1	64.0		IEC	67.0	62.4	66.6	62.6	
A/C	78.0	65.0	78.5	65.0	0.85	A/C	68.9	63.5	69.5	63.8	
Eureka	Lon 124.17 Lat 40.80					**Hanford**	Lon 119.65 Lat 36.30				
Closed	70.7	64.7	72.1	65.6		Closed	91.3	80.9	92.7	81.8	
Vent	68.3	62.1	68.9	62.3		Vent	86.2	69.4	88.2	66.9	
IEC	66.3	62.2	66.1	62.7		IEC	82.6	66.0	83.0	64.5	
A/C	67.9	63.0	68.7	63.8		A/C	78.6	66.2	77.9	65.0	1.65
Fairfield	Lon 122.03 Lat 38.27					**Healdsburg**	Lon 122.87 Lat 38.62				
Closed	85.9	76.3	87.0	77.1		Closed	86.7	75.5	88.4	76.2	
Vent	79.7	65.9	81.5	64.4		Vent	80.6	65.0	82.5	63.6	
IEC	76.5	64.2	77.0	63.3		IEC	78.2	64.0	79.0	62.8	
A/C	77.4	65.0	77.9	65.0		A/C	77.9	65.0	78.7	65.0	0.58
Ferndale	Lon 124.28 Lat 40.60					**Hollister**	Lon 121.42 Lat 36.83				
Closed	70.6	63.1	72.4	64.5		Closed	79.2	71.7	80.2	72.6	
Vent	68.9	61.4	70.3	61.9		Vent	74.4	64.0	76.1	63.3	
IEC	67.6	61.2	68.1	61.9		IEC	72.7	63.7	72.9	63.3	
A/C	68.8	62.2	70.2	63.0		A/C	72.8	65.0	73.6	65.0	
Folsom	Lon 121.17 Lat 38.70					**Huntington Lake**	Lon 119.22 Lat 37.23				
Closed	91.9	81.4	93.5	82.3		Closed	72.0	65.4	73.6	66.9	
Vent	86.9	70.9	88.5	68.6		Vent	69.8	62.3	72.0	62.4	
IEC	83.1	66.9	83.4	65.3		IEC	68.4	61.9	69.3	62.3	
A/C	78.6	67.8	77.9	65.0	1.86	A/C	69.8	63.5	71.3	63.8	
Fontana	Lon 117.43 Lat 34.10					**Idyllwild**	Lon 116.72 Lat 33.75				
Closed	93.0	83.8	93.8	84.8		Closed	80.2	72.5	81.3	73.6	
Vent	88.1	72.8	88.8	70.3		Vent	74.5	64.9	75.8	64.0	
IEC	83.9	68.7	83.5	66.0		IEC	72.6	63.9	73.2	63.4	
A/C	78.6	69.1	77.9	65.0	1.74	A/C	73.1	65.0	74.0	65.0	
Fort Bragg	Lon 123.80 Lat 39.45					**Imperial EI****	Lon 115.57 Lat 32.83				
Closed	70.4	64.0	71.9	65.4		Closed	78.2	72.7	79.3	73.8	
Vent	68.5	61.8	69.9	62.1		Vent	75.7	66.8	76.3	66.2	
IEC	67.4	61.7	67.8	62.3		IEC	74.1	66.0	74.3	65.4	
A/C	68.8	62.6	70.2	63.4		A/C	74.4	65.0	75.0	65.0	
Fresno S*	Lon 119.72 Lat 36.77					**Indio**	Lon 116.27 Lat 33.73				
Closed	94.6	84.7	95.9	86.0		Closed	98.8	93.8	100.1	95.1	
Vent	89.9	76.1	91.3	74.4		Vent	98.8	85.2	101.2	83.2	
IEC	84.4	71.8	84.6	69.5		IEC	93.7	77.9	94.0	74.8	
A/C	79.5	72.4	77.6	69.5	1.69	A/C	82.5	77.6	79.9	75.7	2.19
Gilroy	Lon 121.57 Lat 37.00					**Kern River**	Lon 118.78 Lat 35.47				
Closed	83.5	74.9	84.9	76.0		Closed	93.3	83.3	94.7	84.4	
Vent	79.3	64.9	81.7	63.8		Vent	88.5	73.1	91.0	70.9	
IEC	77.5	64.3	78.6	63.5		IEC	84.6	68.9	85.5	66.4	
A/C	77.7	65.0	79.1	65.0		A/C	78.6	69.6	78.0	65.0	1.99
Grass Valley	Lon 121.07 Lat 39.22					**Kettleman City**	Lon 120.08 Lat 36.07				
Closed	85.4	75.6	87.1	76.6		Closed	96.5	87.4	98.2	88.9	
Vent	80.1	66.8	81.6	65.6		Vent	93.6	78.6	96.2	77.0	
IEC	76.7	64.5	77.1	63.8		IEC	89.3	74.4	89.8	72.1	
A/C	77.6	65.0	78.0	65.0		A/C	80.0	73.9	77.9	71.3	1.86
Graton	Lon 122.87 Lat 38.43					**Klamath**	Lon 124.03 Lat 41.52				
Closed	79.2	69.8	80.3	70.6		Closed	72.1	64.9	73.8	66.2	
Vent	73.5	62.6	74.6	61.9		Vent	69.6	62.1	71.6	62.2	
IEC	72.8	62.7	73.7	62.0		IEC	68.5	62.0	68.9	62.5	
A/C	73.6	64.3	74.8	63.9		A/C	69.7	63.1	71.0	63.7	

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Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
La Mesa	Lon 117.02 Lat 32.77				
Closed	86.1	77.5	87.4	78.2	
Vent	82.0	68.8	84.0	67.2	
IEC	79.2	66.2	79.3	65.0	
A/C	78.1	66.3	78.4	65.0	0.84
Lake Arrowhead	Lon 117.18 Lat 34.25				
Closed	81.1	73.1	82.8	74.5	
Vent	77.3	65.7	79.4	64.9	
IEC	74.4	64.2	75.6	63.8	
A/C	75.3	65.0	76.5	65.0	
Lakeport	Lon 122.92 Lat 39.03				
Closed	87.5	77.6	89.4	78.7	
Vent	81.4	67.3	82.9	65.6	
IEC	78.4	65.2	79.0	64.1	
A/C	77.9	65.0	79.0	65.0	0.59
Livermore	Lon 121.77 Lat 37.67				
Closed	85.8	75.9	87.5	76.9	
Vent	80.6	65.5	82.7	64.3	
IEC	77.6	64.1	78.4	62.9	
A/C	77.9	65.0	78.6	65.0	0.54
Lodi	Lon 121.28 Lat 38.12				
Closed	88.5	76.2	90.0	76.9	
Vent	82.1	65.0	84.1	63.6	
IEC	78.7	63.5	79.8	62.0	
A/C	78.0	65.0	78.6	65.0	0.96
Lompoc	Lon 120.45 Lat 34.65				
Closed	78.7	70.2	80.7	71.1	
Vent	74.4	63.5	76.3	63.0	
IEC	73.1	63.2	74.4	63.1	
A/C	73.5	64.4	75.1	64.5	
Long Beach S*	Lon 118.15 Lat 33.82				
Closed	87.1	78.2	88.6	79.3	
Vent	84.0	71.2	86.0	70.1	
IEC	80.6	68.5	81.1	67.0	
A/C	78.1	68.9	78.4	66.3	1.37
Los Angeles S*	Lon 118.40 Lat 33.93				
Closed	81.2	74.9	82.2	75.9	
Vent	78.1	69.6	78.7	69.0	
IEC	74.8	66.9	74.8	66.3	
A/C	76.3	68.0	76.5	66.6	
Los Banos	Lon 120.87 Lat 37.05				
Closed	89.2	80.9	90.7	82.2	
Vent	84.1	70.3	86.1	68.3	
IEC	80.2	66.4	80.3	65.0	
A/C	78.2	67.1	78.4	65.0	1.28
Los Gatos	Lon 121.97 Lat 37.23				
Closed	83.2	73.6	84.7	74.6	
Vent	78.3	64.7	80.4	63.7	
IEC	76.3	64.0	77.0	63.5	
A/C	76.2	65.0	77.0	65.0	
Lucerne	Lon 116.95 Lat 34.45				
Closed	92.8	83.4	94.0	84.7	
Vent	87.3	72.6	88.7	70.2	
IEC	81.7	66.3	82.0	64.6	
A/C	78.2	68.6	78.1	65.0	1.90

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Madera	Lon 120.03 Lat 36.95				
Closed	92.6	82.3	93.9	83.3	
Vent	86.7	71.5	88.2	69.1	
IEC	82.7	67.2	82.7	65.4	
A/C	78.5	68.0	78.1	65.0	1.64
Manteca	Lon 121.20 Lat 37.80				
Closed	89.0	78.9	90.4	79.9	
Vent	83.4	67.5	85.2	65.9	
IEC	79.8	64.9	80.3	63.9	
A/C	78.1	65.0	78.5	65.0	1.31
Maricopa	Lon 119.38 Lat 35.08				
Closed	97.2	87.3	98.6	88.7	
Vent	93.2	79.7	94.7	78.2	
IEC	88.7	75.0	89.1	73.0	
A/C	80.4	75.1	78.4	72.8	1.94
Martinez	Lon 122.13 Lat 38.02				
Closed	85.3	76.2	86.5	77.1	
Vent	79.2	66.6	80.6	65.3	
IEC	76.5	64.9	76.8	63.9	
A/C	76.9	65.0	77.2	65.0	
Marysville	Lon 121.60 Lat 39.15				
Closed	92.5	81.5	93.7	82.3	
Vent	87.2	70.2	88.5	67.7	
IEC	83.1	66.1	83.2	64.6	
A/C	78.6	66.8	78.0	65.0	1.71
Mecca	Lon 116.07 Lat 33.57				
Closed	98.8	92.7	100.5	93.1	
Vent	96.9	80.1	98.6	76.2	
IEC	91.4	72.8	91.6	67.6	
A/C	81.9	72.0	79.4	66.9	2.17
Merced	Lon 120.52 Lat 37.28				
Closed	91.4	82.0	92.6	83.2	
Vent	85.3	72.1	86.7	70.1	
IEC	81.4	68.0	81.6	66.0	
A/C	78.2	69.0	78.2	65.0	1.57
Modesto	Lon 121.00 Lat 37.65				
Closed	90.6	80.9	92.3	81.9	
Vent	85.4	70.0	86.8	67.7	
IEC	82.5	66.5	83.4	65.0	
A/C	79.5	67.0	78.2	65.0	1.32
Mojave	Lon 118.17 Lat 35.05				
Closed	94.5	85.4	95.7	86.9	
Vent	90.0	76.4	92.2	74.5	
IEC	85.8	72.1	86.4	69.7	
A/C	78.7	72.2	77.7	68.8	2.00
Montebello	Lon 118.10 Lat 34.03				
Closed	89.4	80.0	90.9	81.0	
Vent	84.7	70.8	86.2	68.7	
IEC	80.8	66.6	81.0	65.3	
A/C	78.2	67.9	78.0	65.0	1.39
Monterey	Lon 121.85 Lat 36.58				
Closed	75.0	67.5	76.6	68.6	
Vent	71.7	62.8	73.0	62.5	
IEC	70.6	63.0	71.5	62.8	
A/C	71.2	64.1	72.6	64.1	

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Table 1. Maximum and minimum indoor temperatures for CIEE's "Alternatives to Compressor Cooling" house with 1500 CFM fan during 2% 5-day design periods in 171 California climates

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW	Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Morro Bay	Lon 120.85 Lat 35.37					**Ojai**	Lon 119.23 Lat 34.45				
Closed	73.7	65.4	75.1	66.3		Closed	87.3	76.2	88.8	77.1	
Vent	70.6	62.2	72.2	62.1		Vent	80.4	65.4	81.2	64.1	
IEC	69.7	62.2	70.0	62.4		IEC	78.2	64.4	79.0	63.3	
A/C	70.7	63.2	71.7	63.5		A/C	77.9	65.0	78.6	65.0	0.42
Mt Shasta EI**	Lon 122.32 Lat 41.32					**Orange Cove**	Lon 119.30 Lat 36.62				
Closed	82.6	74.7	84.4	75.8		Closed	92.8	82.4	94.0	83.2	
Vent	77.5	64.8	79.4	63.6		Vent	87.7	71.1	88.9	68.3	
IEC	74.6	63.5	75.3	62.4		IEC	83.7	66.8	83.5	65.1	
A/C	75.4	65.0	76.2	65.0		A/C	78.8	67.6	78.2	65.0	1.74
Napa	Lon 122.27 Lat 38.28					**Orinda**	Lon 122.17 Lat 37.87				
Closed	82.3	73.3	83.5	74.1		Closed	81.3	71.6	83.0	72.4	
Vent	76.3	64.6	77.5	63.6		Vent	76.9	63.9	79.2	63.1	
IEC	74.7	63.8	75.4	63.0		IEC	74.8	63.4	75.3	62.7	
A/C	75.1	65.0	76.1	65.0		A/C	75.5	65.0	76.2	64.8	
Needles	Lon 114.62 Lat 34.77					**Orland**	Lon 122.22 Lat 39.75				
Closed	98.9	96.4	99.7	96.2		Closed	92.8	81.9	94.8	82.9	
Vent	98.9	91.0	100.6	89.5		Vent	88.1	70.8	90.4	68.3	
IEC	97.5	83.7	98.5	80.9		IEC	84.5	66.6	85.6	65.1	
A/C	84.2	78.1	81.5	75.9	2.21	A/C	79.2	67.4	78.1	65.0	1.82
Nevada City	Lon 121.03 Lat 39.25					**Oroville**	Lon 121.55 Lat 39.52				
Closed	83.4	74.8	85.0	75.9		Closed	93.0	83.3	94.8	84.3	
Vent	77.9	66.8	79.4	65.7		Vent	87.5	72.8	89.1	70.5	
IEC	74.3	64.0	74.9	63.4		IEC	83.8	68.6	84.1	66.0	
A/C	75.6	65.0	76.3	65.0		A/C	78.9	68.5	77.9	65.0	1.96
Newark	Lon 122.03 Lat 37.52					**Oxnard**	Lon 119.08 Lat 34.22				
Closed	81.0	72.7	82.1	73.5		Closed	79.6	72.5	80.9	73.5	
Vent	75.5	65.4	76.7	64.6		Vent	75.3	65.7	76.8	64.9	
IEC	73.9	64.5	74.1	63.9		IEC	73.8	64.9	73.9	64.2	
A/C	73.9	65.0	74.6	65.0		A/C	73.5	65.0	74.3	65.0	
Newman	Lon 121.03 Lat 37.30					**Pacific Grove**	Lon 121.89 Lat 36.62				
Closed	90.9	80.3	92.7	81.4		Closed	76.2	67.9	77.9	68.9	
Vent	86.8	68.2	89.6	65.6		Vent	72.4	62.9	74.2	62.6	
IEC	83.5	65.4	84.5	63.9		IEC	71.7	63.0	73.2	63.0	
A/C	78.9	65.0	78.3	65.0	1.82	A/C	72.5	64.2	74.1	64.3	
Newport Beach	Lon 117.88 Lat 33.60					**Palm Springs**	Lon 116.50 Lat 33.83				
Closed	79.2	72.9	80.3	74.0		Closed	98.9	94.2	100.4	94.1	
Vent	76.6	67.7	78.3	67.2		Vent	98.4	84.0	100.2	80.9	
IEC	73.6	66.2	73.8	65.9		IEC	92.6	77.0	93.3	72.5	
A/C	74.9	66.0	75.9	65.0		A/C	82.7	75.7	79.9	72.2	2.20
Oakdale	Lon 120.87 Lat 37.87					**Palmdale**	Lon 118.08 Lat 34.63				
Closed	78.8	70.6	79.7	71.1		Closed	94.2	81.8	95.7	82.8	
Vent	74.9	64.3	76.3	63.5		Vent	88.8	70.6	90.5	67.5	
IEC	72.7	63.6	72.8	63.2		IEC	83.3	65.2	83.6	64.0	
A/C	73.2	65.0	73.5	64.8		A/C	78.8	66.8	78.1	65.0	2.05
Oakland EI**	Lon 122.20 Lat 37.75					**Palo Alto**	Lon 122.13 Lat 37.45				
Closed	77.9	69.9	79.1	70.7		Closed	79.5	69.6	81.1	70.4	
Vent	75.0	64.2	76.5	63.7		Vent	75.4	63.0	77.4	62.5	
IEC	73.1	63.8	73.5	63.5		IEC	74.1	63.0	75.4	62.8	
A/C	72.8	64.9	73.8	65.0		A/C	74.4	64.3	75.7	64.2	
Oceanside	Lon 117.40 Lat 33.22					**Paradise**	Lon 121.62 Lat 39.75				
Closed	80.6	73.5	82.0	74.5		Closed	92.3	81.8	94.0	82.9	
Vent	77.7	67.7	79.4	66.9		Vent	88.2	73.2	90.4	69.7	
IEC	74.9	65.5	75.0	64.9		IEC	84.0	68.8	84.4	65.5	
A/C	75.9	65.9	76.4	65.0		A/C	78.6	67.8	78.0	65.0	1.75

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Table 1. Maximum and minimum indoor temperatures for CIEE's "Alternatives to Compressor Cooling" house with 1500 CFM fan during 2% 5-day design periods in 171 California climates

Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW	Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
Pasadena	Lon 118.15 Lat 34.15					**Redwood City**	Lon 122.23 Lat 37.48				
Closed	88.5	80.5	89.9	81.6		Closed	82.1	73.3	83.7	74.2	
Vent	84.0	71.0	85.5	69.0		Vent	76.4	64.9	78.2	64.0	
IEC	80.9	68.0	81.0	66.1		IEC	74.7	64.1	75.5	63.6	
A/C	78.2	68.1	78.5	65.0	1.25	A/C	75.0	65.0	76.0	65.0	
Perris	Lon 117.23 Lat 33.78					**Richmond**	Lon 122.35 Lat 37.93				
Closed	90.5	80.0	91.7	80.8		Closed	77.0	70.9	77.9	71.9	
Vent	84.9	69.2	86.2	66.8		Vent	73.2	65.1	74.5	64.5	
IEC	80.8	65.8	81.1	64.4		IEC	70.7	64.1	70.6	63.8	
A/C	78.2	65.9	77.9	65.0	1.51	A/C	71.5	65.0	72.1	65.0	
Petaluma	Lon 122.63 Lat 38.23					**Riverside**	Lon 117.35 Lat 33.97				
Closed	82.0	70.7	83.2	70.9		Closed	91.3	82.7	92.3	83.7	
Vent	76.8	63.0	77.9	62.3		Vent	86.3	72.6	87.8	70.4	
IEC	74.8	63.0	75.6	62.6		IEC	82.0	68.5	82.4	66.1	
A/C	75.3	64.3	76.4	63.9		A/C	78.6	69.3	78.0	65.0	1.65
Pismo Beach	Lon 120.63 Lat 35.13					**Rocklin**	Lon 121.23 Lat 38.80				
Closed	75.5	68.5	76.3	69.1		Closed	90.7	80.0	91.9	80.7	
Vent	71.5	63.2	72.6	62.7		Vent	83.1	68.0	84.3	66.1	
IEC	70.3	63.0	70.4	62.8		IEC	79.5	65.2	80.0	63.9	
A/C	71.1	64.4	71.8	64.4		A/C	78.1	65.0	78.8	65.0	1.17
Placerville	Lon 120.80 Lat 38.73					**Sacramento S***	Lon 121.50 Lat 38.52				
Closed	87.1	78.1	88.3	79.1		Closed	89.4	78.0	90.8	78.4	
Vent	80.7	68.0	82.0	66.4		Vent	84.1	66.5	85.5	64.8	
IEC	77.2	65.3	77.5	64.3		IEC	80.6	64.7	81.6	63.7	
A/C	77.8	65.3	78.5	65.0	0.24	A/C	78.8	65.0	78.3	65.0	1.23
Pomona Cal Poly	Lon 117.82 Lat 34.07					**Sagehen**	Lon 120.23 Lat 39.43				
Closed	87.3	77.4	88.4	78.3		Closed	71.0	62.2	72.5	63.1	
Vent	82.9	68.3	84.9	66.8		Vent	68.7	60.2	70.0	60.4	
IEC	80.0	66.0	80.4	64.9		IEC	68.3	60.0	69.0	60.2	
A/C	78.2	65.8	79.1	65.0	1.19	A/C	69.4	61.2	70.5	61.6	
Porterville	Lon 119.02 Lat 36.07					**Salinas**	Lon 121.60 Lat 36.67				
Closed	94.0	85.0	95.2	86.2		Closed	77.5	69.2	79.0	69.9	
Vent	89.4	75.3	91.2	73.2		Vent	74.2	63.4	75.8	62.9	
IEC	85.5	71.1	85.4	68.5		IEC	72.8	63.1	74.2	63.0	
A/C	79.0	71.4	77.7	67.7	1.75	A/C	73.1	64.4	74.7	64.4	
Ramona	Lon 116.85 Lat 33.07					**San Bernadino**	Lon 117.27 Lat 34.13				
Closed	87.1	78.0	88.3	79.1		Closed	91.7	82.7	92.5	83.7	
Vent	82.1	69.6	84.1	67.7		Vent	85.8	71.3	87.3	68.6	
IEC	78.7	66.1	79.5	64.9		IEC	83.3	69.0	83.1	66.4	
A/C	78.1	67.1	78.5	65.0	1.03	A/C	78.2	67.8	78.2	65.0	1.55
Red Bluff EI**	Lon 122.25 Lat 40.15					**San Diego S***	Lon 117.17 Lat 32.73				
Closed	93.8	85.2	95.4	86.3		Closed	83.2	77.7	84.3	78.9	
Vent	88.9	75.9	91.2	73.9		Vent	80.6	72.0	81.2	71.3	
IEC	83.2	69.2	83.3	66.5		IEC	77.6	69.4	77.7	68.5	
A/C	78.4	71.9	77.3	68.6	1.96	A/C	78.0	70.0	78.2	68.0	0.45
Redding EI**	Lon 122.40 Lat 40.58					**San Francisco S***	Lon 122.38 Lat 37.62				
Closed	96.2	83.5	98.3	84.4		Closed	77.9	68.8	79.1	69.6	
Vent	91.4	73.0	93.5	70.5		Vent	74.7	63.7	76.3	63.3	
IEC	87.1	69.3	87.6	66.8		IEC	72.8	63.2	72.9	63.1	
A/C	80.4	69.4	78.3	65.0	2.11	A/C	73.3	64.5	73.9	64.6	
Redlands	Lon 117.18 Lat 34.05					**San Gabriel**	Lon 118.10 Lat 34.10				
Closed	93.2	81.0	94.5	81.6		Closed	88.3	80.3	89.8	81.3	
Vent	87.0	68.5	88.1	65.8		Vent	82.9	71.6	84.7	69.8	
IEC	83.7	65.4	84.3	63.8		IEC	80.0	68.6	80.3	66.6	
A/C	79.1	65.0	78.3	65.0	1.98	A/C	78.1	68.9	78.1	65.4	1.09

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Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW	Location/ mode	Main Space Max T	Main Space Min T	Master Bdrm Max T	Master Bdrm Min T	peak AC kW
San Jacinto	Lon 116.97 Lat 33.78					**Sonoma**	Lon 122.47 Lat 38.30				
Closed	91.8	82.1	92.7	83.0		Closed	84.3	74.3	85.9	75.1	
Vent	84.5	69.5	86.1	66.8		Vent	78.3	64.3	79.9	63.1	
IEC	80.5	65.9	80.7	64.3		IEC	76.3	63.2	77.1	62.7	
A/C	78.1	65.7	78.4	65.0	1.59	A/C	76.7	65.0	77.5	65.0	
San Jose	Lon 121.90 Lat 37.35					**Squaw Valley**	Lon 120.23 Lat 39.20				
Closed	81.8	74.4	83.3	75.6		Closed	73.7	64.2	75.5	65.6	
Vent	77.1	66.4	79.1	65.4		Vent	70.2	61.5	71.4	61.7	
IEC	75.3	65.1	76.3	64.4		IEC	69.6	61.1	70.5	61.5	
A/C	75.2	65.0	76.4	65.0		A/C	70.7	62.4	71.8	63.0	
San Luis Obispo	Lon 120.67 Lat 35.30					**St. Marys**	Lon 122.11 Lat 37.85				
Closed	81.0	70.2	83.0	70.9		Closed	82.5	72.8	84.3	73.6	
Vent	77.4	63.4	79.7	62.7		Vent	77.9	64.8	79.8	63.9	
IEC	75.9	63.2	77.5	62.9		IEC	75.7	63.9	76.5	63.4	
A/C	76.2	64.6	77.9	64.4		A/C	76.1	65.0	76.9	65.0	
San Mateo	Lon 122.30 Lat 37.53					**Stockton EI****	Lon 121.25 Lat 37.90				
Closed	80.3	71.7	81.8	72.0		Closed	90.9	80.7	92.3	81.8	
Vent	75.3	63.0	77.0	62.4		Vent	85.6	70.1	87.4	67.9	
IEC	73.9	63.1	74.4	62.3		IEC	81.0	66.2	81.3	64.8	
A/C	74.1	64.4	75.2	64.2		A/C	78.4	66.9	77.8	65.0	1.62
Santa Ana	Lon 117.87 Lat 33.75					**Strawberry Valley**	Lon 121.10 Lat 39.57				
Closed	86.9	80.2	88.2	81.1		Closed	80.8	71.5	82.4	72.4	
Vent	81.9	71.0	83.4	69.2		Vent	76.3	64.0	77.7	63.2	
IEC	78.9	67.9	79.1	66.2		IEC	73.4	63.4	73.7	62.9	
A/C	78.0	68.4	78.2	65.0	0.74	A/C	74.1	65.0	74.8	64.8	
Santa Barbara EI*	Lon 119.83 Lat 34.43					**Sun City**	Lon 117.20 Lat 33.72				
Closed	78.0	72.0	79.5	73.0		Closed	92.2	82.8	93.2	83.7	
Vent	74.3	65.7	76.3	65.0		Vent	86.8	71.1	88.1	68.1	
IEC	72.5	64.5	72.8	64.0		IEC	83.3	68.0	83.5	65.8	
A/C	72.7	65.0	73.6	65.0		A/C	78.4	67.4	78.2	65.0	1.71
Santa Clara	Lon 121.93 Lat 37.35					**Susanville**	Lon 120.57 Lat 40.37				
Closed	80.4	73.9	81.6	74.8		Closed	82.5	71.8	84.2	73.1	
Vent	75.2	66.5	76.9	65.4		Vent	77.0	63.8	78.6	63.2	
IEC	73.4	64.9	74.3	64.3		IEC	74.3	63.4	74.7	62.8	
A/C	73.6	65.0	74.7	65.0		A/C	74.8	65.0	75.5	64.9	
Santa Cruz	Lon 122.02 Lat 36.98					**Tahoe City**	Lon 120.13 Lat 39.17				
Closed	77.9	68.7	79.4	69.3		Closed	73.2	67.2	74.8	68.6	
Vent	73.2	62.8	74.3	62.3		Vent	69.7	62.5	71.0	62.4	
IEC	72.6	63.1	73.8	62.3		IEC	68.7	62.3	69.7	62.4	
A/C	73.3	64.2	74.6	64.0		A/C	70.0	63.8	71.0	64.0	
Santa Monica	Lon 118.50 Lat 34.00					**Tehachapi**	Lon 118.45 Lat 35.13				
Closed	78.1	72.7	79.0	73.7		Closed	83.9	75.5	85.3	76.7	
Vent	74.8	67.8	75.7	67.5		Vent	80.5	66.9	82.8	65.8	
IEC	72.2	66.4	71.9	66.2		IEC	77.5	65.0	78.0	64.2	
A/C	73.1	66.5	73.3	65.5		A/C	77.9	65.0	79.1	65.0	0.40
Santa Paula	Lon 119.15 Lat 34.32					**Torrance**	Lon 118.33 Lat 33.80				
Closed	83.1	74.4	84.4	75.2		Closed	83.3	75.7	84.5	76.8	
Vent	80.5	65.0	82.2	63.8		Vent	78.6	67.9	80.5	66.7	
IEC	76.6	64.1	76.3	63.1		IEC	76.6	66.3	76.7	65.4	
A/C	78.0	65.0	78.6	65.0	0.49	A/C	76.8	65.5	77.4	65.0	
Santa Rosa	Lon 122.70 Lat 38.45					**Truckee**	Lon 120.18 Lat 39.33				
Closed	83.6	72.9	85.2	73.7		Closed	75.5	64.7	77.3	66.1	
Vent	78.1	64.1	79.8	63.1		Vent	71.5	61.4	73.5	61.6	
IEC	75.9	63.5	77.0	62.3		IEC	70.7	61.1	72.4	61.1	
A/C	76.4	65.0	77.6	64.9		A/C	71.7	62.5	73.6	62.5	

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Location/	Main Space		Master Bdrm		peak
mode	Max T	Min T	Max T	Min T	AC kW
Tule Lake	Lon 121.47 Lat 41.97				
Closed	78.3	67.5	80.4	68.8	
Vent	73.7	62.2	75.4	62.1	
IEC	72.2	62.1	73.1	62.0	
A/C	73.0	63.6	74.2	63.7	
Twin Lakes	Lon 120.03 Lat 38.70				
Closed	68.6	60.4	70.4	62.5	
Vent	67.1	59.7	68.8	61.2	
IEC	65.9	59.4	66.6	61.0	
A/C	67.6	60.0	69.2	62.1	
Ukiah	Lon 123.20 Lat 39.15				
Closed	87.5	77.9	89.0	78.9	
Vent	81.9	66.9	83.2	65.4	
IEC	78.7	65.2	78.8	64.1	
A/C	77.9	65.0	78.5	65.0	0.63
Upland	Lon 117.68 Lat 34.13				
Closed	90.5	78.8	92.0	79.5	
Vent	85.6	67.1	86.6	65.4	
IEC	82.2	65.0	82.7	63.8	
A/C	78.2	65.0	78.1	65.0	1.90
Vacaville	Lon 121.95 Lat 38.37				
Closed	89.5	78.9	91.0	79.8	
Vent	84.6	67.0	87.3	65.6	
IEC	81.5	64.9	82.8	63.6	
A/C	78.4	65.0	78.9	65.0	1.55
Victorville	Lon 117.30 Lat 34.53				
Closed	91.8	81.9	93.0	83.0	
Vent	87.0	70.9	88.9	68.3	
IEC	81.5	65.7	81.9	64.2	
A/C	78.2	67.3	78.1	65.0	1.78
Visalia	Lon 119.30 Lat 36.33				
Closed	92.1	83.5	93.4	84.6	
Vent	86.5	73.6	88.2	71.5	
IEC	82.7	69.5	82.9	66.9	
A/C	78.6	70.2	77.9	65.9	1.64
Vista	Lon 117.25 Lat 33.25				
Closed	85.2	77.6	86.1	78.7	
Vent	81.7	69.4	82.4	67.9	
IEC	77.3	66.6	77.2	65.5	
A/C	78.0	66.9	78.5	65.0	0.62
Walnut Creek	Lon 122.03 Lat 37.88				
Closed	84.3	74.3	85.9	75.2	
Vent	77.9	64.6	79.3	63.6	
IEC	75.9	63.8	76.6	62.6	
A/C	76.4	65.0	77.4	65.0	
Watsonville	Lon 121.77 Lat 36.93				
Closed	76.2	69.6	77.0	70.5	
Vent	71.7	63.0	72.5	62.5	
IEC	70.7	63.2	70.9	62.7	
A/C	71.3	64.6	72.0	64.4	
Weed	Lon 122.38 Lat 41.43				
Closed	80.4	70.1	82.4	71.0	
Vent	75.9	63.0	77.9	62.5	
IEC	74.0	63.0	74.9	62.2	
A/C	74.5	64.6	75.6	64.4	
Williams	Lon 122.15 Lat 39.15				
Closed	92.7	81.3	94.4	82.3	
Vent	86.9	67.7	88.4	65.2	
IEC	83.7	65.0	84.5	63.5	
A/C	79.0	65.0	77.8	65.0	1.91
Willows	Lon 122.30 Lat 39.52				
Closed	91.4	80.9	93.0	81.8	
Vent	86.7	70.0	88.1	67.7	
IEC	83.6	66.9	84.6	65.3	
A/C	79.0	67.0	78.0	65.0	1.74
Winters	Lon 121.97 Lat 38.53				
Closed	92.4	81.0	94.1	81.8	
Vent	88.3	69.3	90.3	66.9	
IEC	84.5	65.9	85.3	64.5	
A/C	78.9	66.1	78.1	65.0	1.88
Woodland	Lon 121.80 Lat 38.68				
Closed	89.6	80.0	91.0	80.9	
Vent	83.3	67.8	84.6	65.9	
IEC	79.6	65.3	79.9	64.0	
A/C	78.1	65.0	78.6	65.0	1.08
Woodside	Lon 122.25 Lat 37.43				
Closed	82.7	73.3	84.8	74.0	
Vent	78.3	63.3	81.3	62.5	
IEC	76.9	63.0	78.7	62.4	
A/C	77.1	64.7	78.7	64.3	
Yreka	Lon 122.63 Lat 41.72				
Closed	85.6	74.6	87.3	75.7	
Vent	79.4	65.3	81.1	64.2	
IEC	76.6	64.2	77.3	63.6	
A/C	76.9	65.0	77.8	65.0	

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Table 2. Annual heating and cooling energy use for protypical house modeled as designed, with Title-24 modeling assumptions, and with Title-24 conservation levels

	As Designed (low internal loads, light-colored walls and roofs, and shading from neighboring houses)				Title-24 Operating Conditions (Title-24 internal loads, gray-colored walls and roofs, and no shading from neighboring houses)				Title-24 Conservation Levels (Title-24 internal loads and conservation levels, carpeted floor, gray-colored walls and roofs, and no shading from neighboring houses)			
Climate Zone	Heating Fuel (MBtu)	Cooling Elec (kWh)	Fan Elec (kWh)	Total Elec (kWh)	Heating Fuel (MBtu)	Cooling Elec (kWh)	Fan Elec (kWh)	Total Elec (kWh)	Heating Fuel (MBtu)	Cooling Elec (kWh)	Fan Elec (kWh)	Total Elec (kWh)
1 (Arcata)	60.15	0	153	153	52.33	0	132	132	78.85	0	200	200
2 (Santa Rosa)	44.73	3	115	118	37.38	8	96	104	60.32	324	192	516
3 (Oakland)	46.07	0	116	116	38.38	0	96	96	61.88	29	160	188
4 (Sunnyvale)	38.59	0	97	97	31.59	0	79	79	48.68	106	143	249
5 (Santa Maria)	41.30	0	104	104	32.92	0	82	82	54.35	22	139	161
6 (San Diego)	26.88	0	67	67	20.29	0	50	50	30.60	35	82	117
7 (Los Angeles)	22.55	2	56	57	16.11	10	41	50	26.38	98	82	180
8 (El Toro)	21.76	8	56	64	15.99	24	44	69	31.10	117	96	213
9 (Pasadena)	20.24	38	58	97	14.70	72	50	122	29.17	255	120	374
10 (Riverside)	21.43	128	71	200	15.83	200	66	265	31.20	574	152	725
11 (Red Bluff)	44.16	258	140	399	37.93	349	134	483	49.71	887	224	1111
12 (Sacramento)	44.17	64	119	183	37.68	96	107	202	47.03	375	164	539
13 (Fresno)	30.17	697	161	858	24.88	858	167	1025	33.08	1608	279	1888
14 (China Lake)	38.59	678	169	847	32.06	824	166	990	42.44	1203	233	1437
15 (El Centro)	8.70	3210	380	3590	5.68	3539	406	3945	9.52	4314	497	4812
16 (Mt. Shasta)	82.78	1	234	234	75.49	2	213	215	82.17	263	266	529

Table 3. The impact of various modeling conditions on the annual heating and cooling energy use of the protypical house in three typical climates.

	Heating Fuel (MBtu)	Cooling Elec (kWh)	Fan Elec (kWh)	Total Elec (kWh)
Climate Zone 4 (Sunnyvale)				
as designed and modeled	38.59	0	97	97
Title-24 internal loads	33.68	0	84	84
No shading from neighboring buildings	36.44	0	91	91
Title-24 insulation levels	47.37	0	119	119
Title-24 glass type	39.34	15	102	117
Medium gray-colored roof and walls	36.70	0	92	92
Carpeted floor slab	36.37	0	91	91
Climate Zone 9 (Pasadena)				
as designed and modeled	20.24	38	58	97
Title-24 internal loads	16.63	63	53	116
No shading from neighboring buildings	18.00	46	54	99
Title-24 insulation levels	26.04	69	79	148
Title-24 glass type	25.29	118	86	204
Medium gray-colored roof and walls	18.61	52	57	109
Carpeted floor slab	19.46	63	61	123
Climate Zone 12 (Sacramento)				
as designed and modeled	44.17	64	119	183
Title-24 internal loads	39.66	89	111	200
No shading from neighboring buildings	42.13	69	115	183
Title-24 insulation levels	54.24	109	150	260
Title-24 glass type	45.30	137	131	267
Medium gray-colored roof and walls	42.67	78	117	195
Carpeted floor slab	42.16	98	118	216

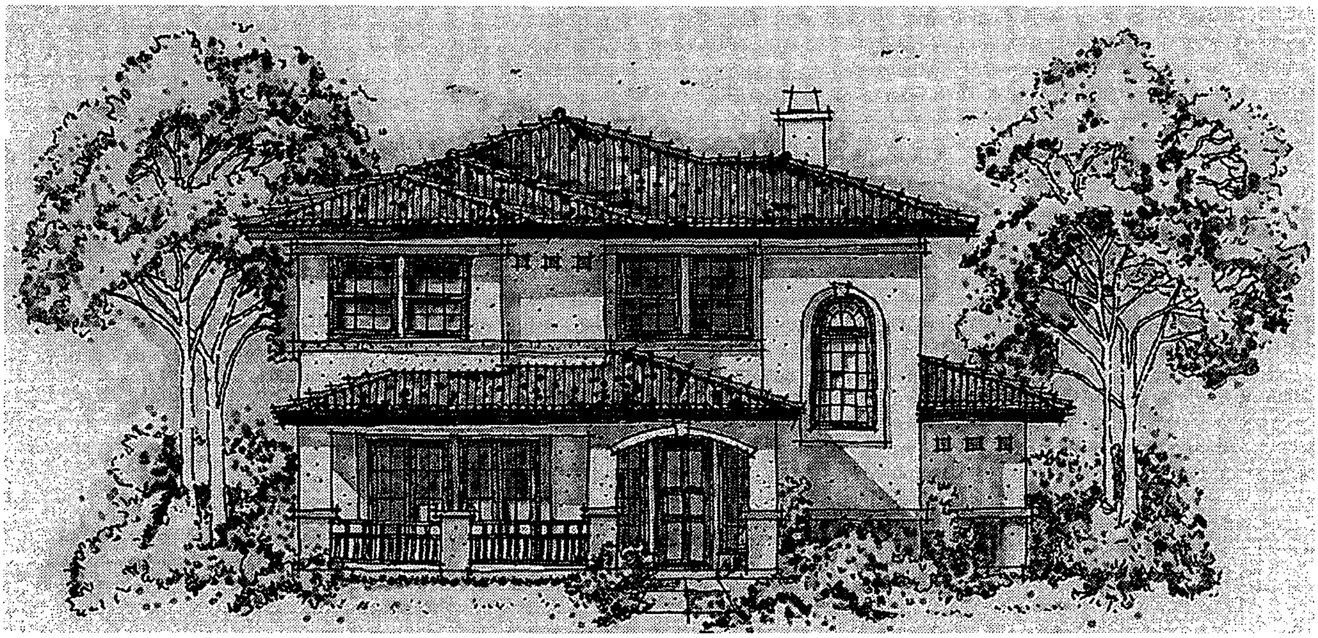


Figure 1. Front Elevation of Prototype House

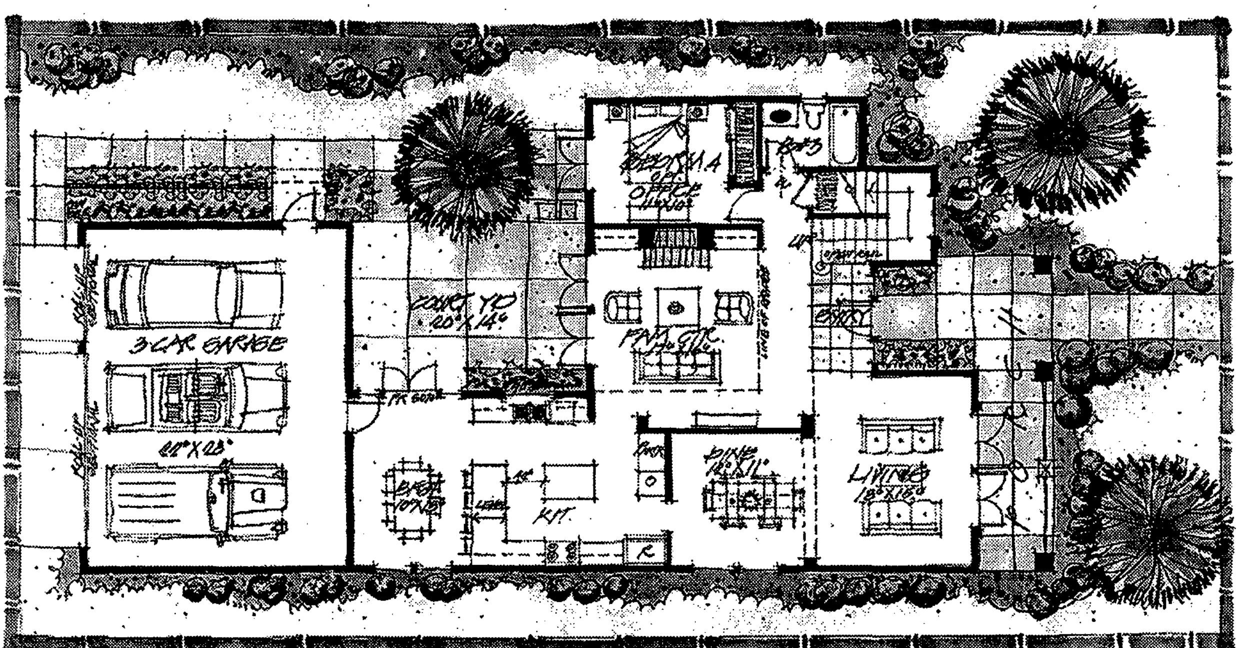


Figure 2. Floor plan of Prototype House

Figure 3. 1500 CFM system in Martinez

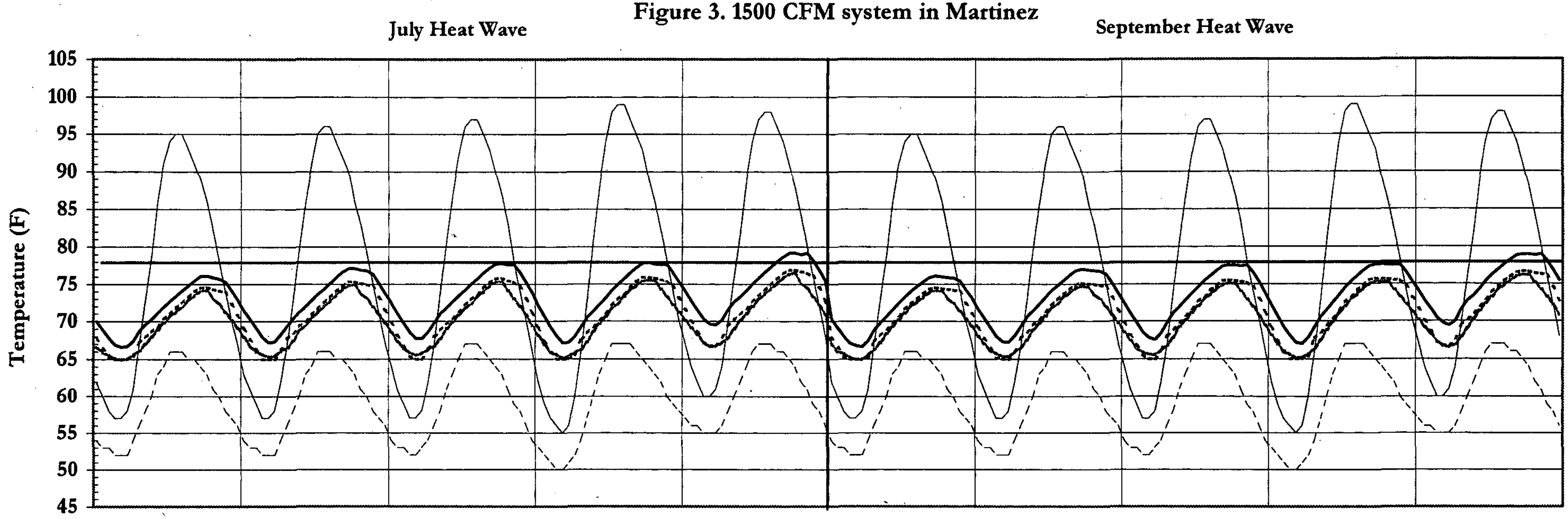


Figure 4. 1500 CFM system in Walnut Creek

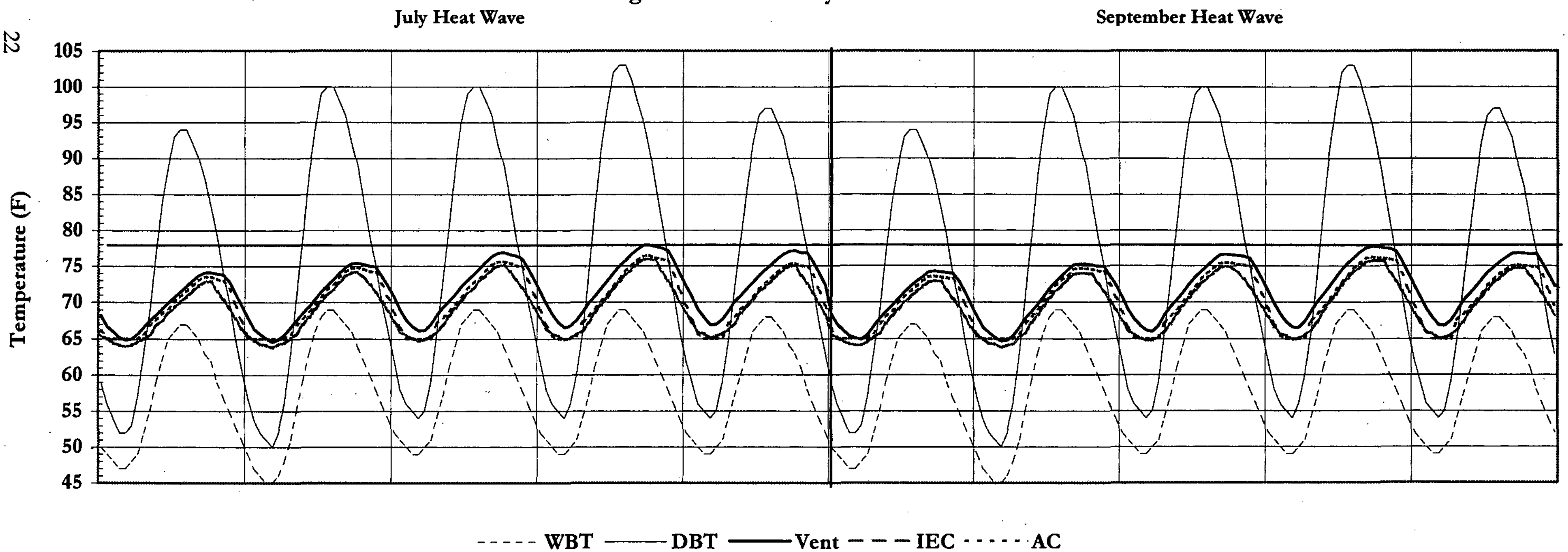


Figure 5. 1500 CFM system in Fairfield

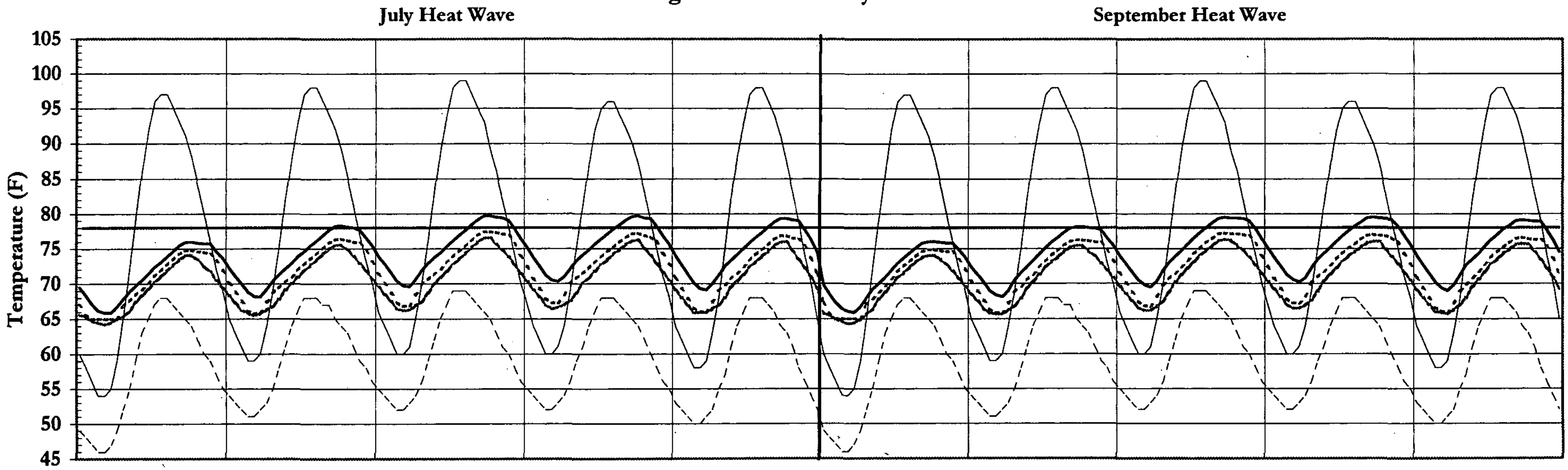


Figure 6. 1500 CFM system in Davis

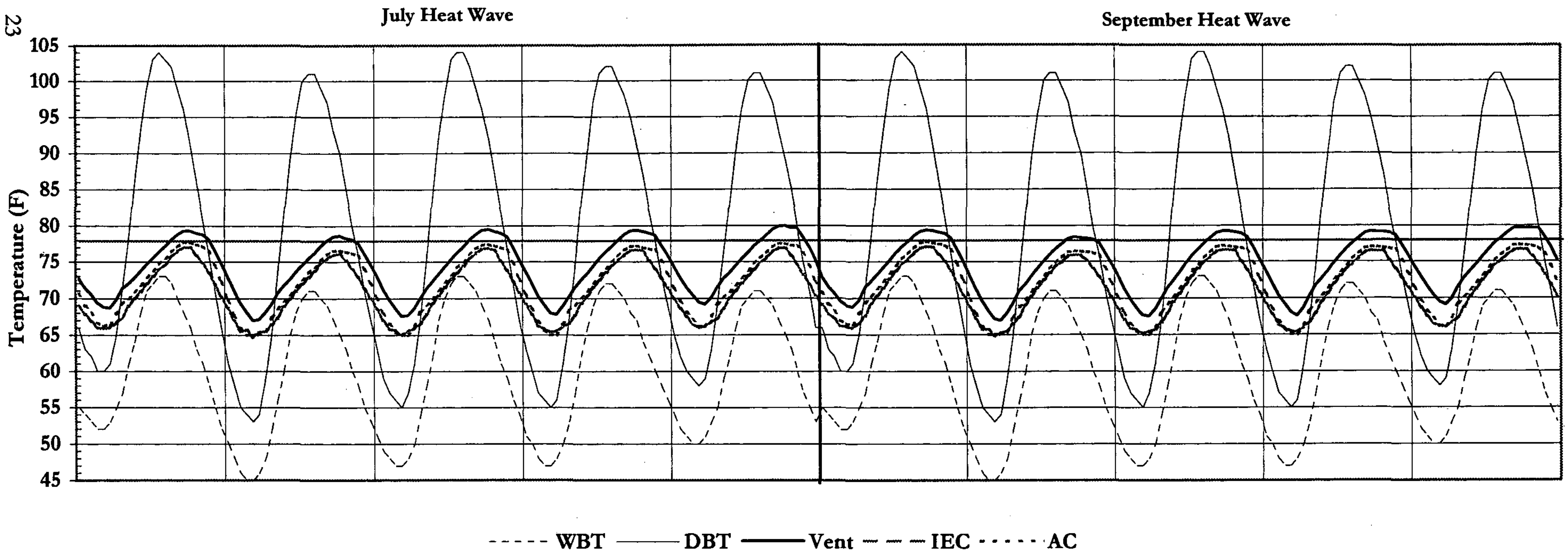


Figure 7. 1500 CFM system in Los Angeles (LAX)

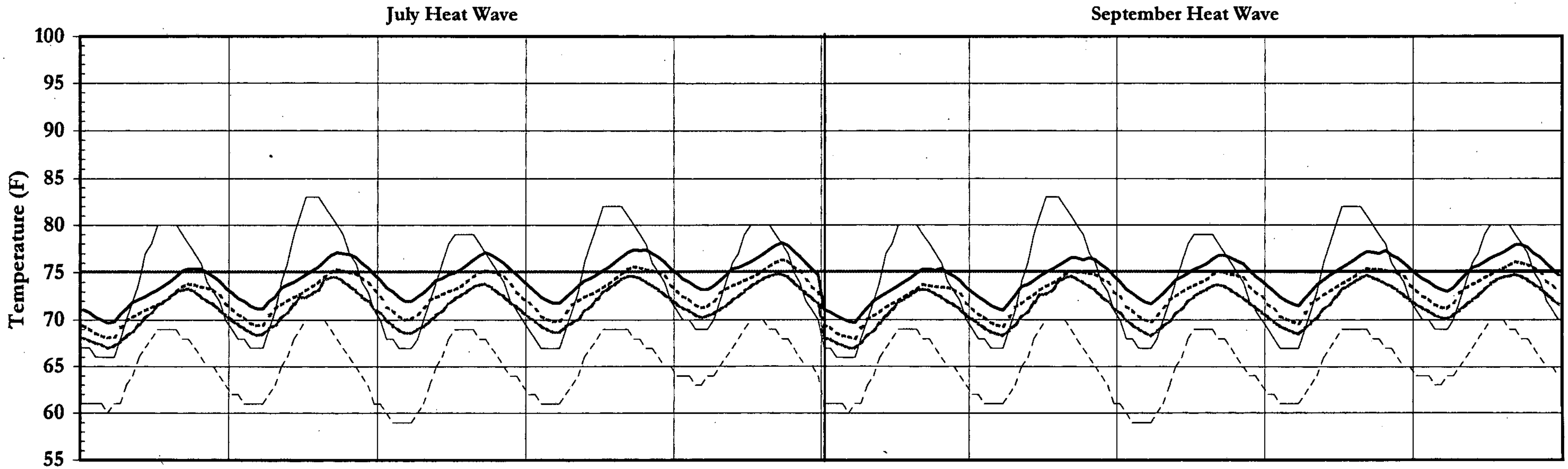
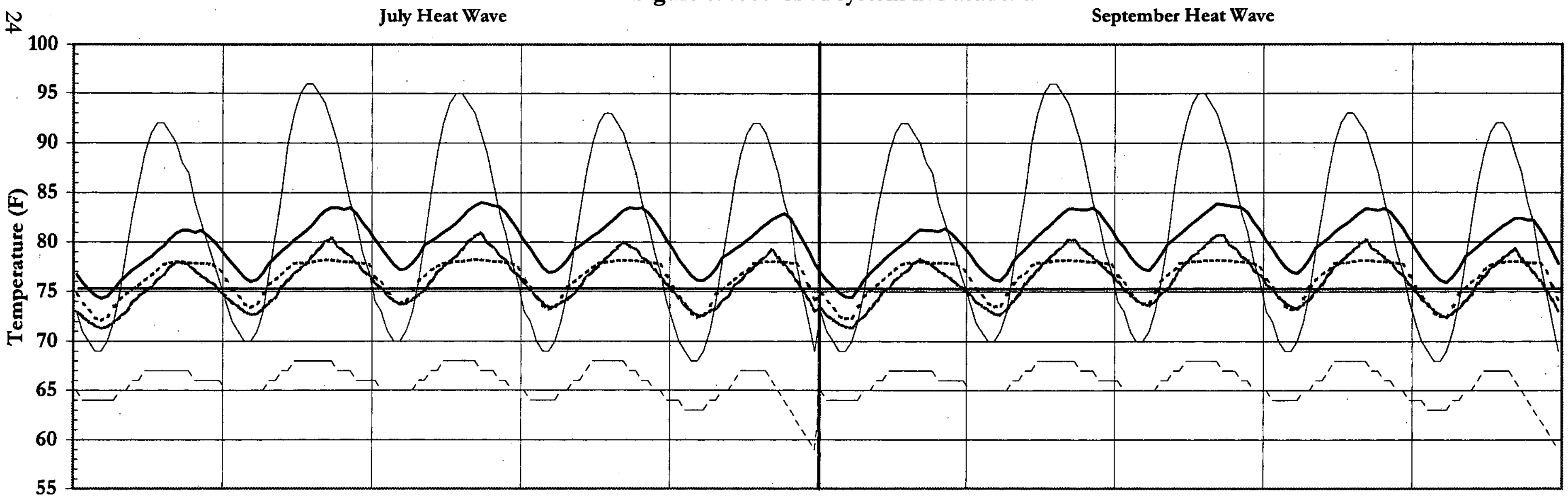


Figure 8. 1500 CFM system in Pasadena



WBT — DBT — Vent — IEC — AC

Figure 9. 1500 CFM system in Pomona

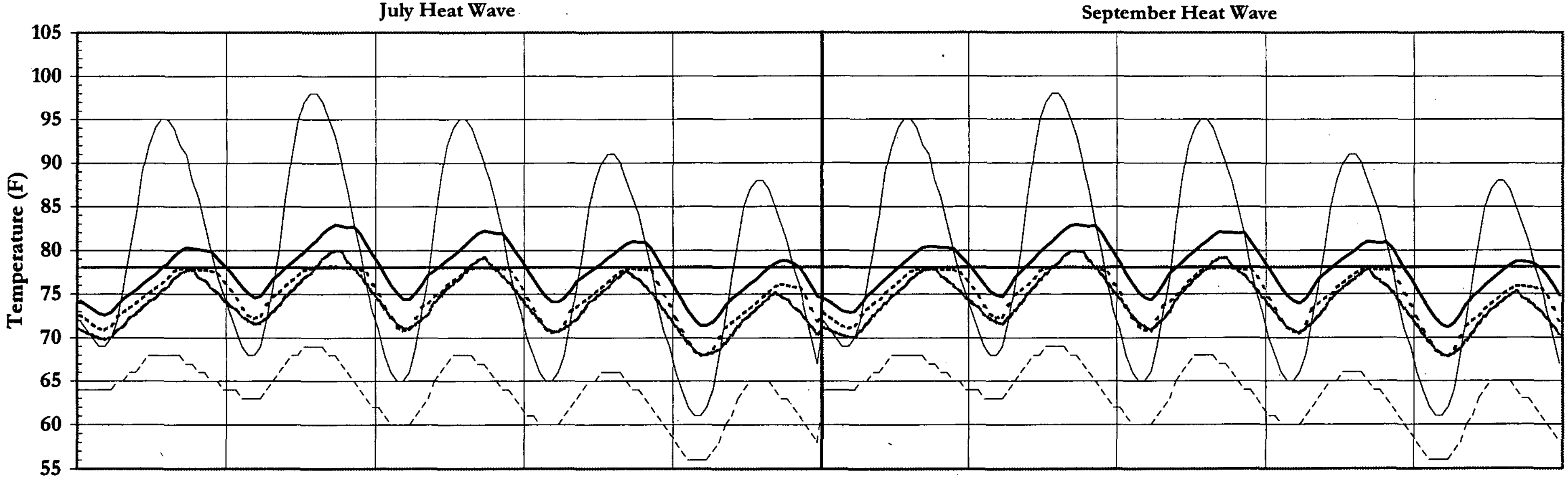


Figure 10. 1500 CFM system in Riverside

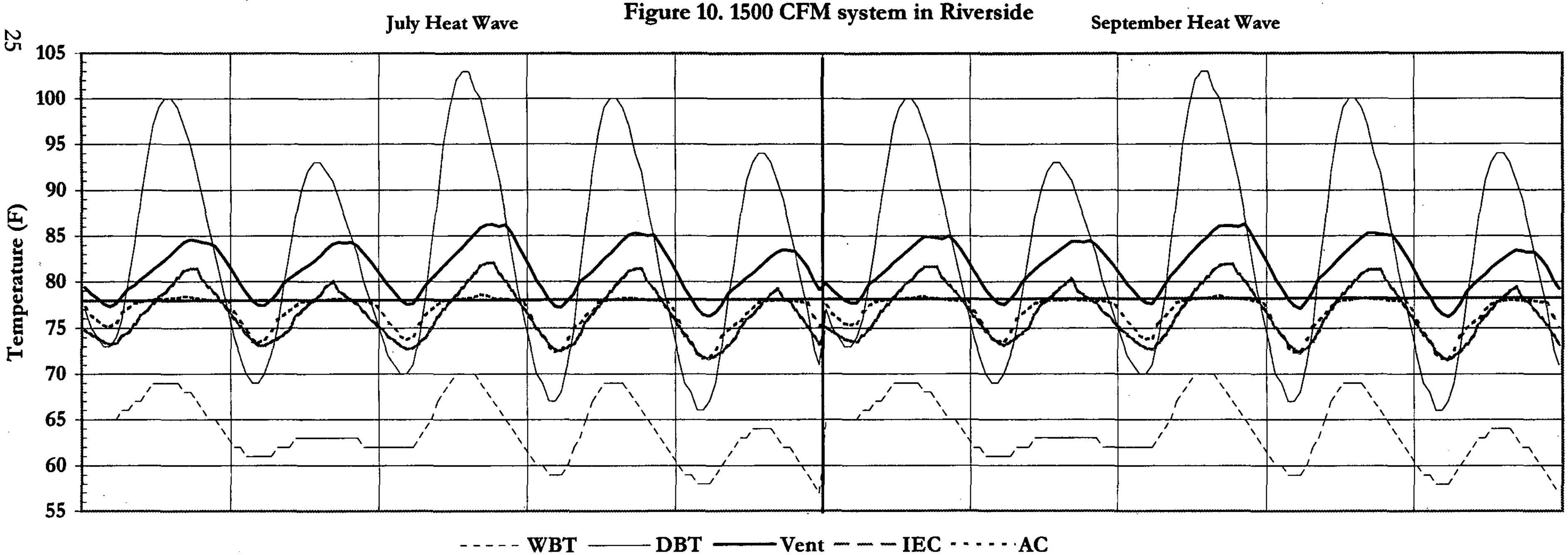


Figure 11. 1500 CFM system in San Diego

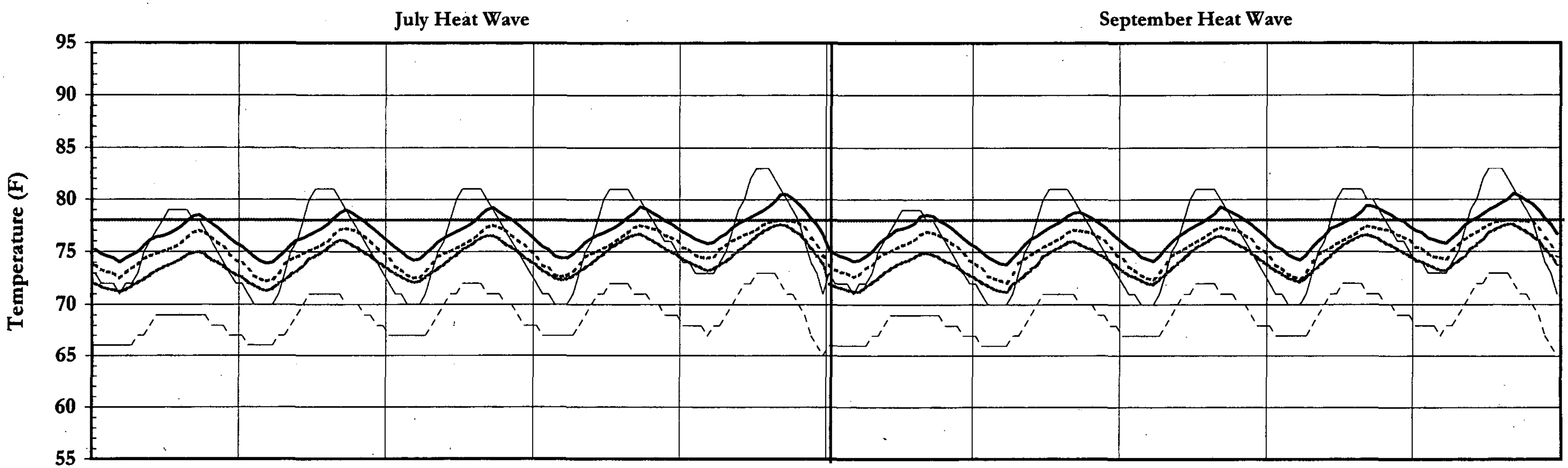


Figure 12. 1500 CFM system in Bonita

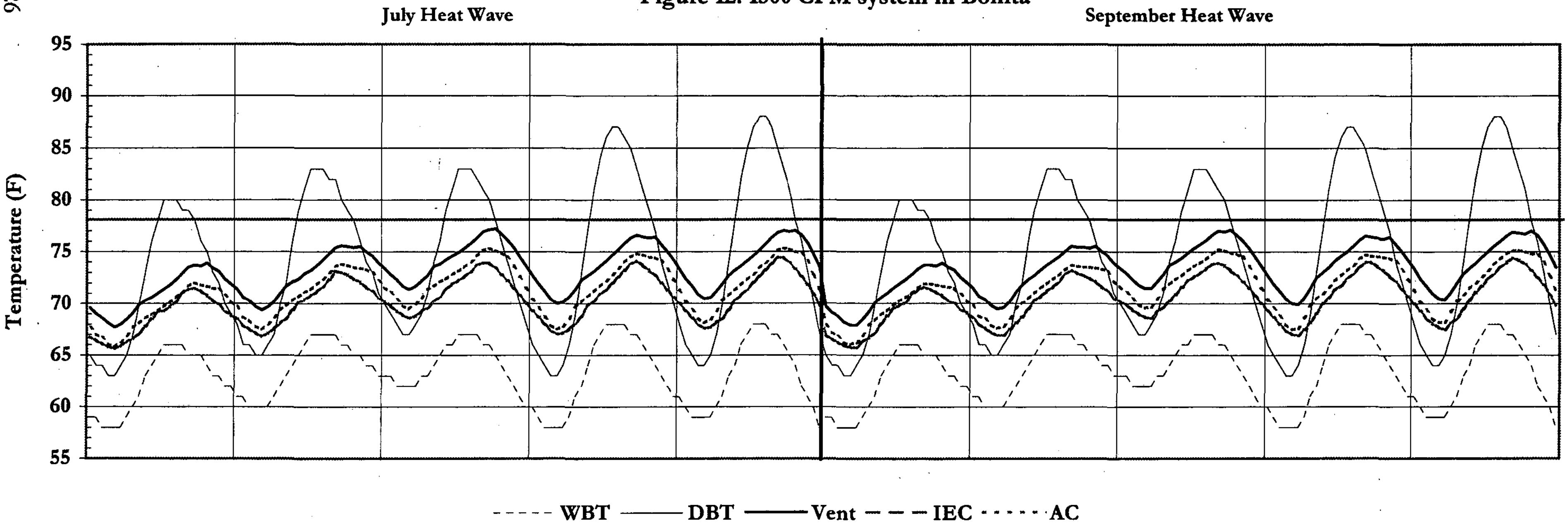


Figure 13. 1500 CFM system in La Mesa

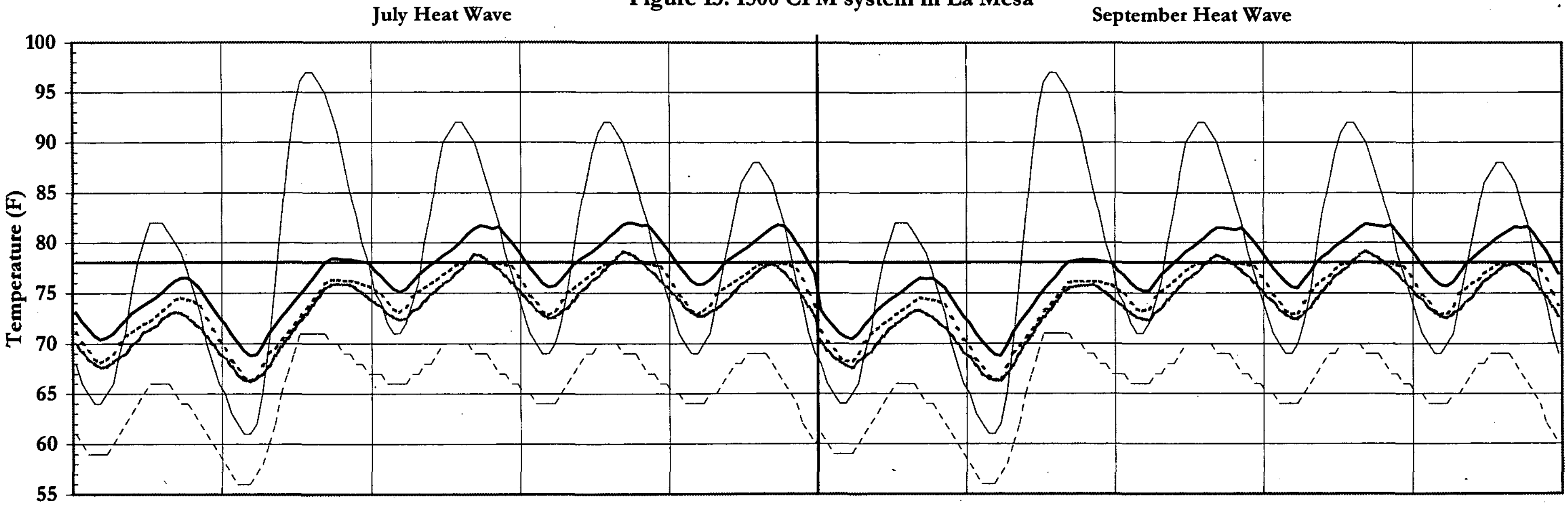


Figure 14. 1500 CFM system in El Cajon

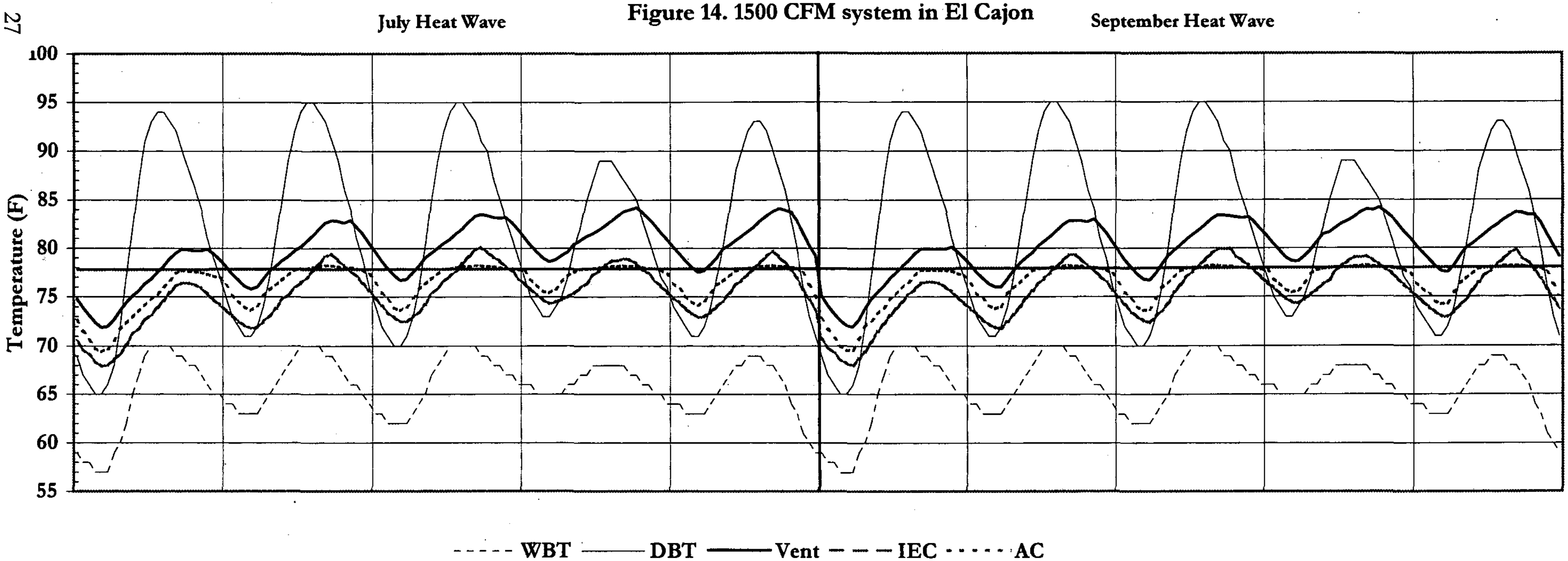


Figure 15. 3000 CFM system in Pasadena

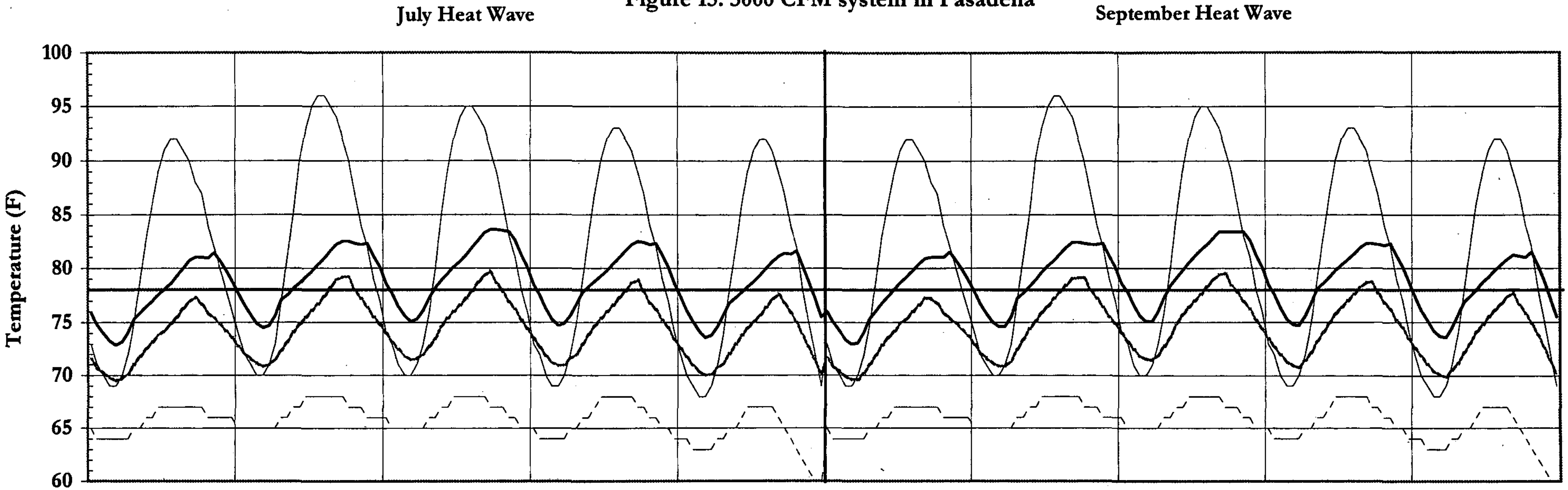


Figure 16. 3000 CFM system in La Mesa

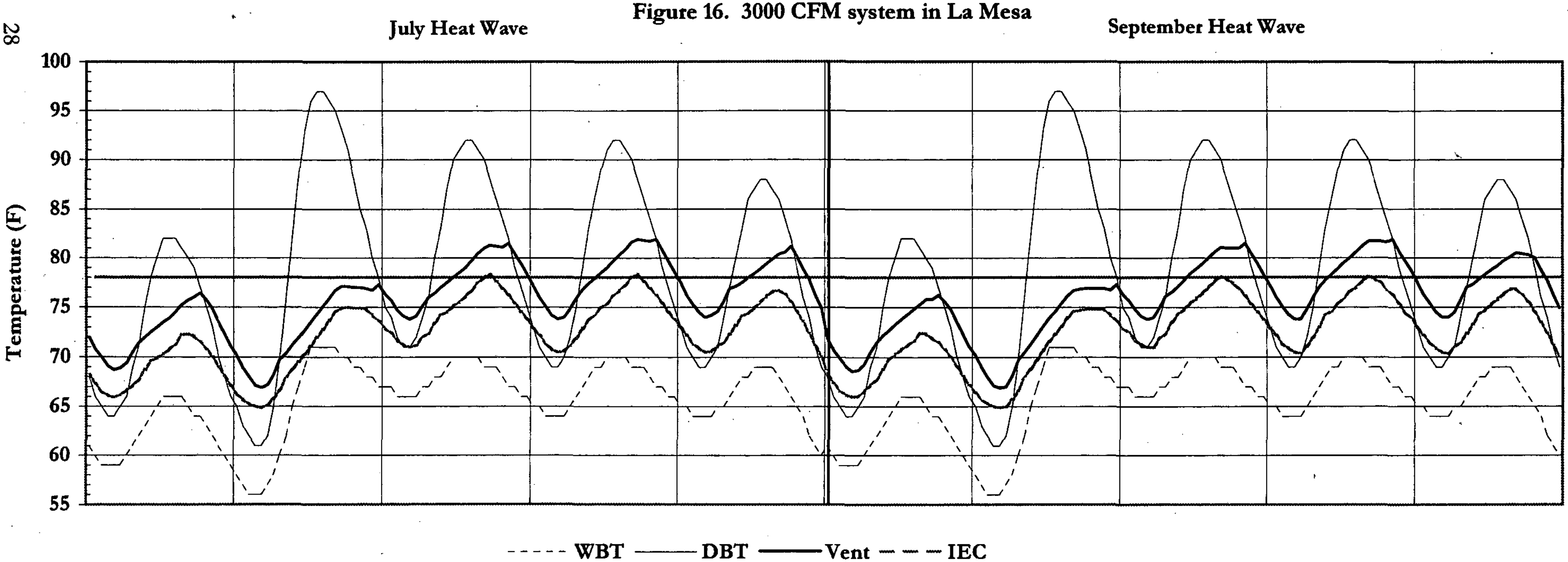
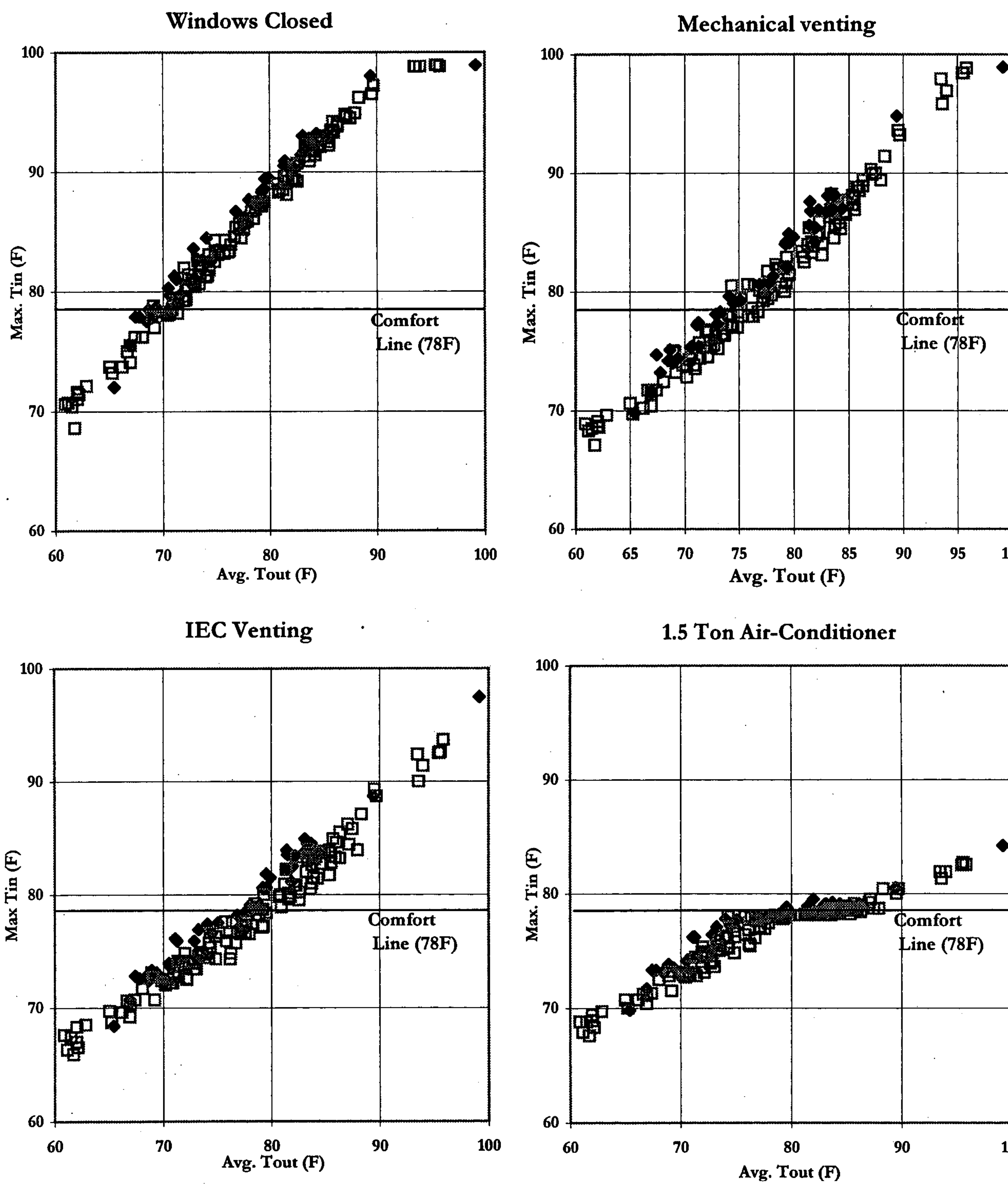


Figure 17. Comparison of Indoor/Outdoor Temperature Differences for Different 1500 CFM Systems in Prototypical House



Open squares indicate cities where peak daily max. is less than 5 degrees higher than average daily max. for the 5-day period.
Solid diamonds indicates cities where peak daily max is 5 degrees or more than the average daily max for the 5-day period.

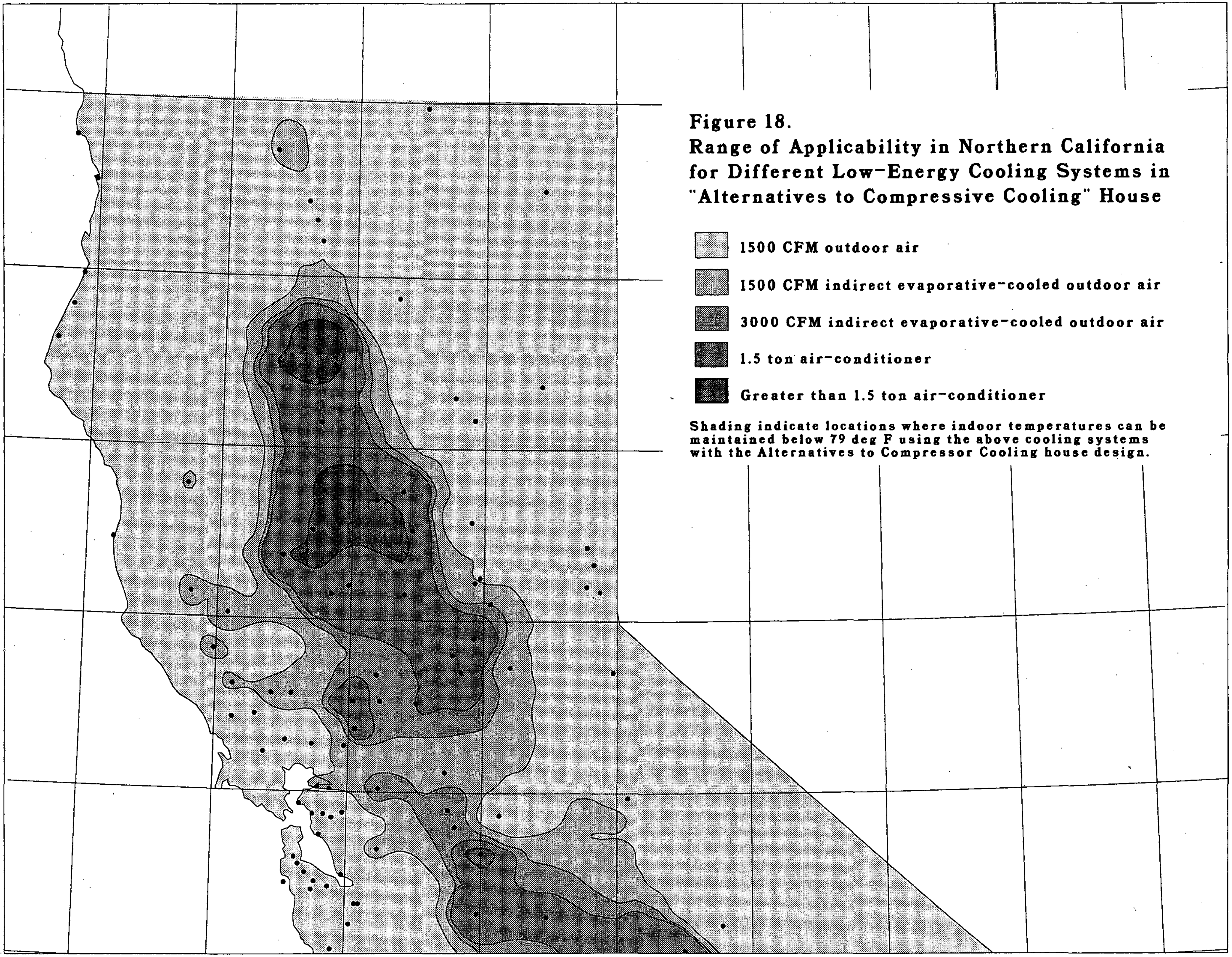


Figure 18.
Range of Applicability in Northern California for Different Low-Energy Cooling Systems in "Alternatives to Compressive Cooling" House

Shading indicate locations where indoor temperatures can be maintained below 79 deg F using the above cooling systems with the Alternatives to Compressor Cooling house design.

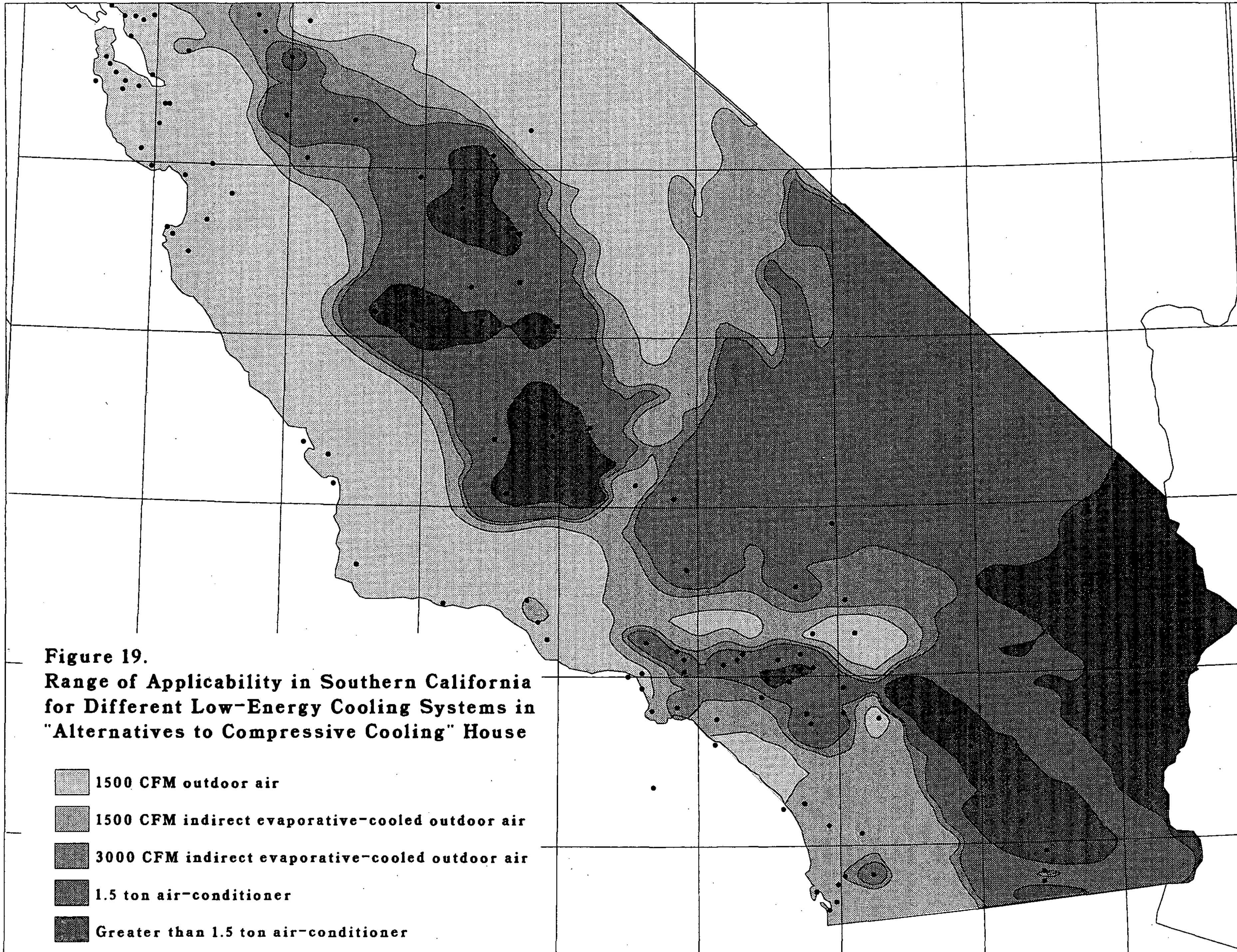


Figure 19.
Range of Applicability in Southern California for Different Low-Energy Cooling Systems in "Alternatives to Compressive Cooling" House

Figure 20. Annual Heating Energy Use for Prototypical House in Title-24 Climate Zones

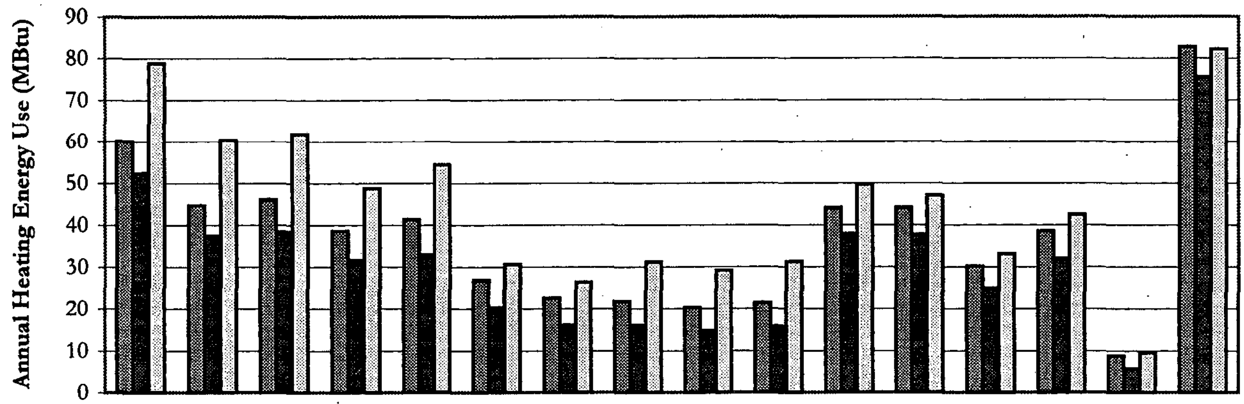


Figure 21. Annual Electricity Use for Cooling and Fans for Prototypical House in Title-24 Climate Zones

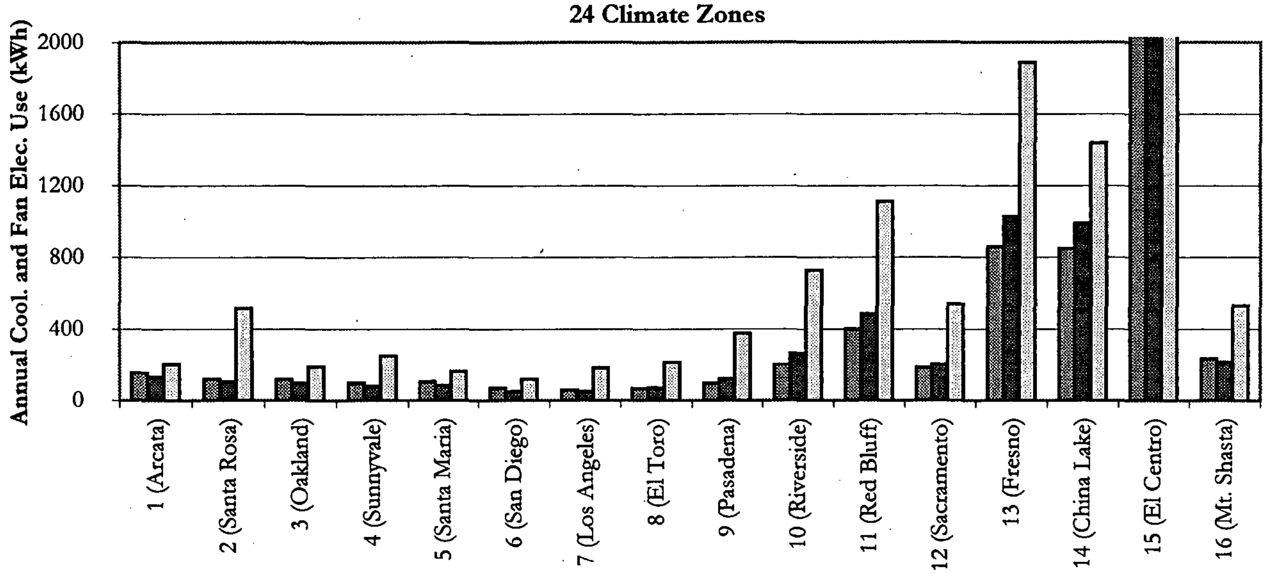
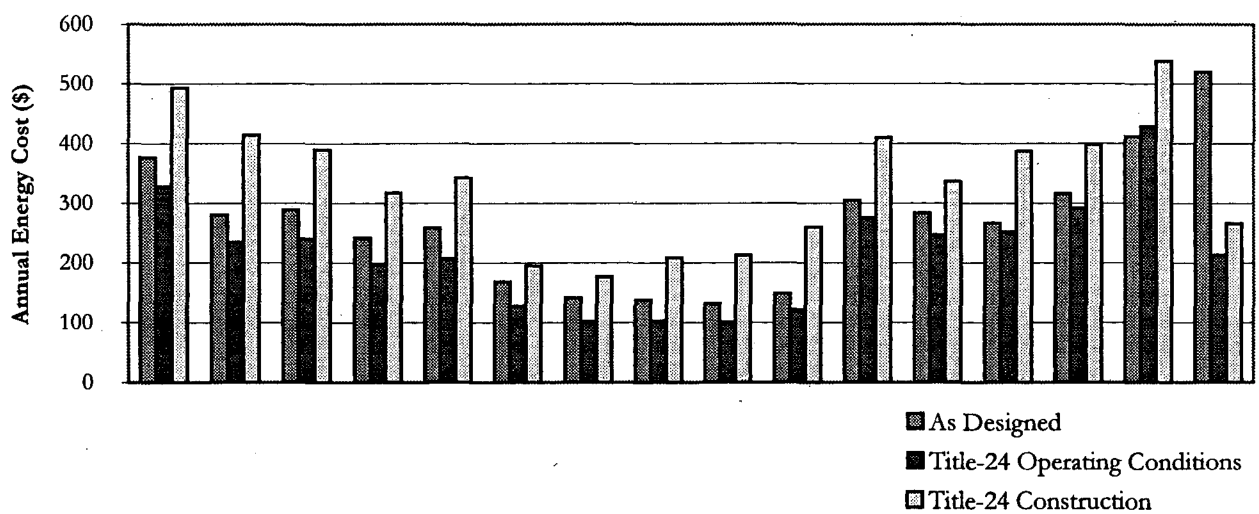
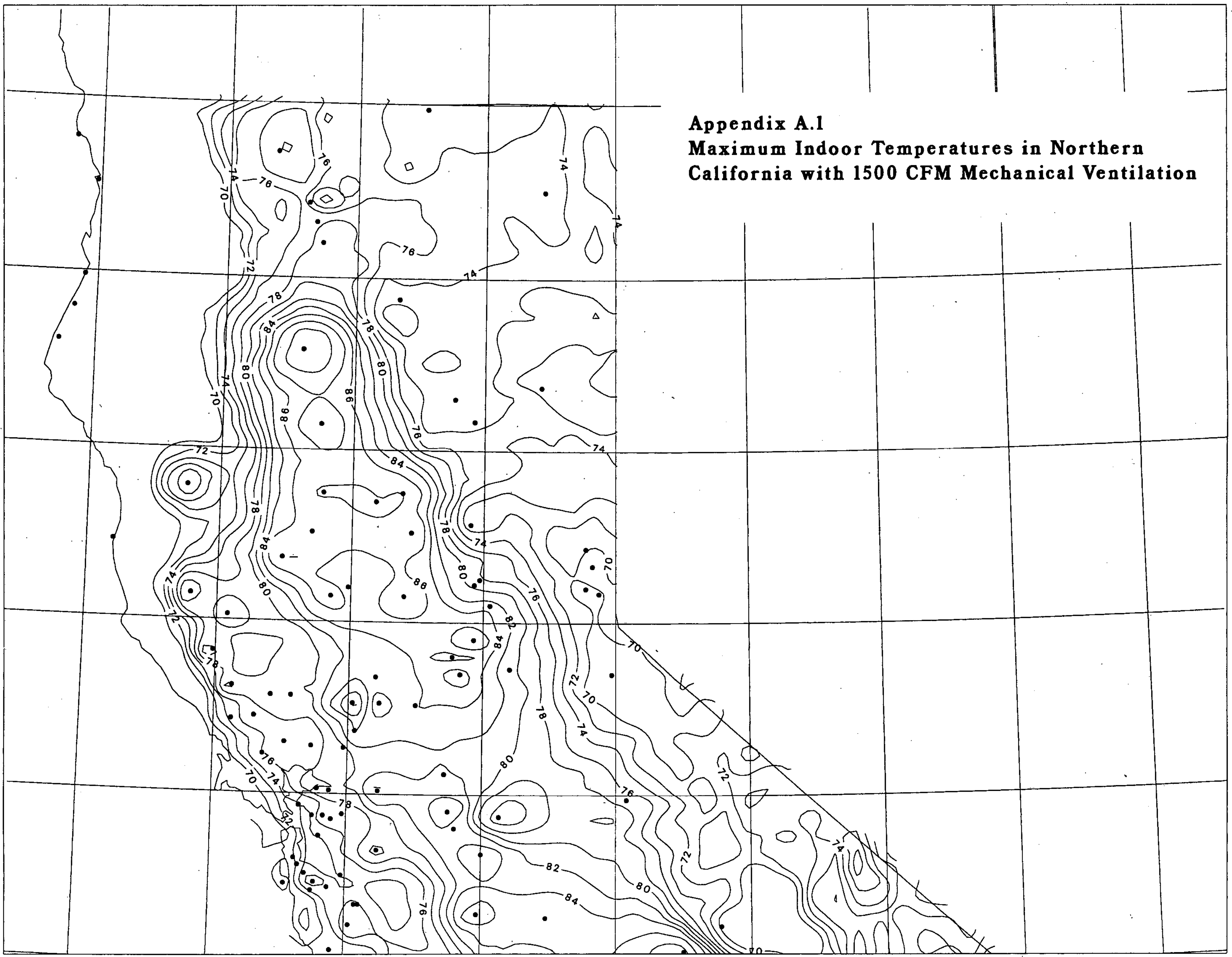


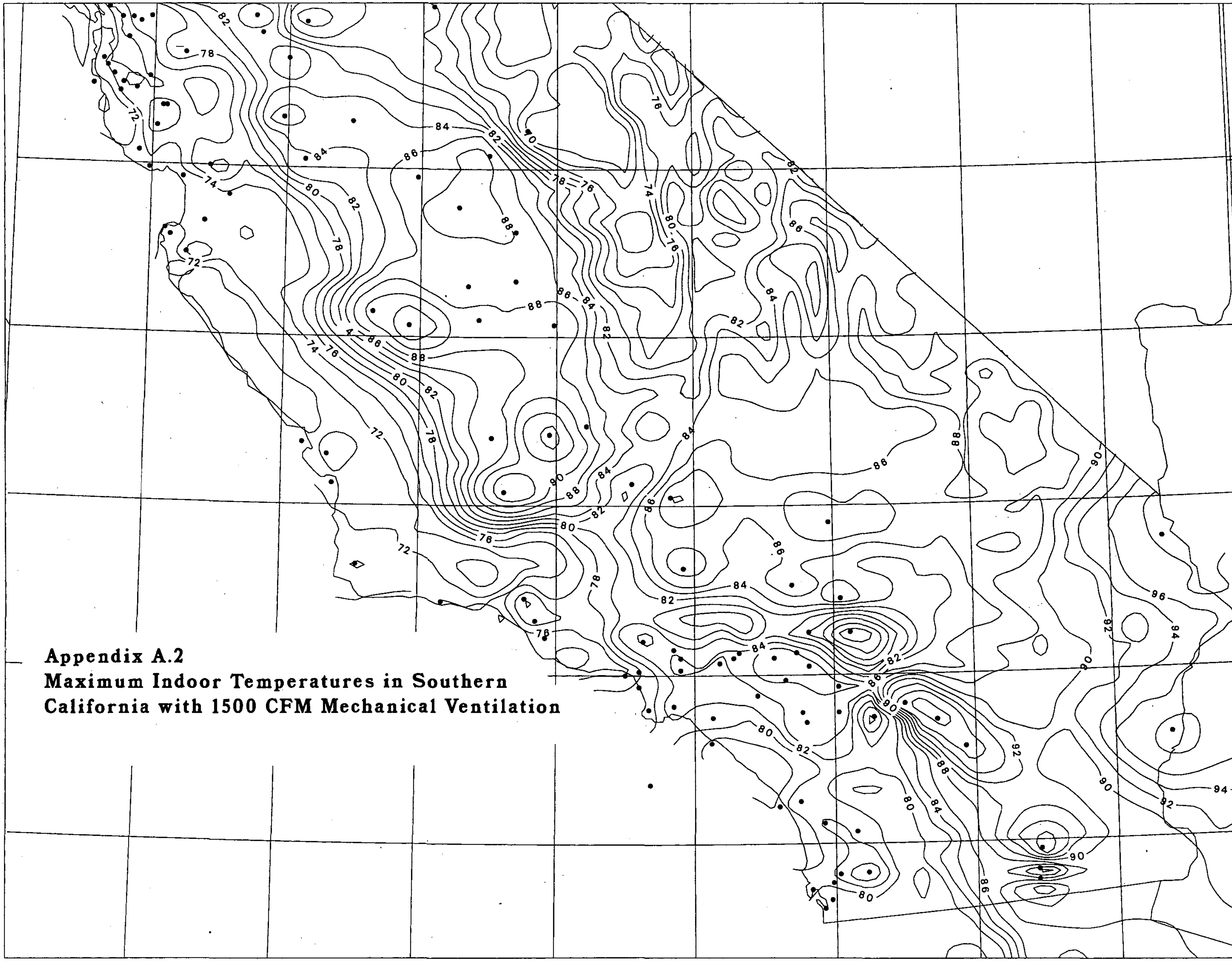
Figure 22. Annual Energy Costs for Prototypical House in Title-24 Climate Zones



APPENDIX A. CONTOUR MAPS

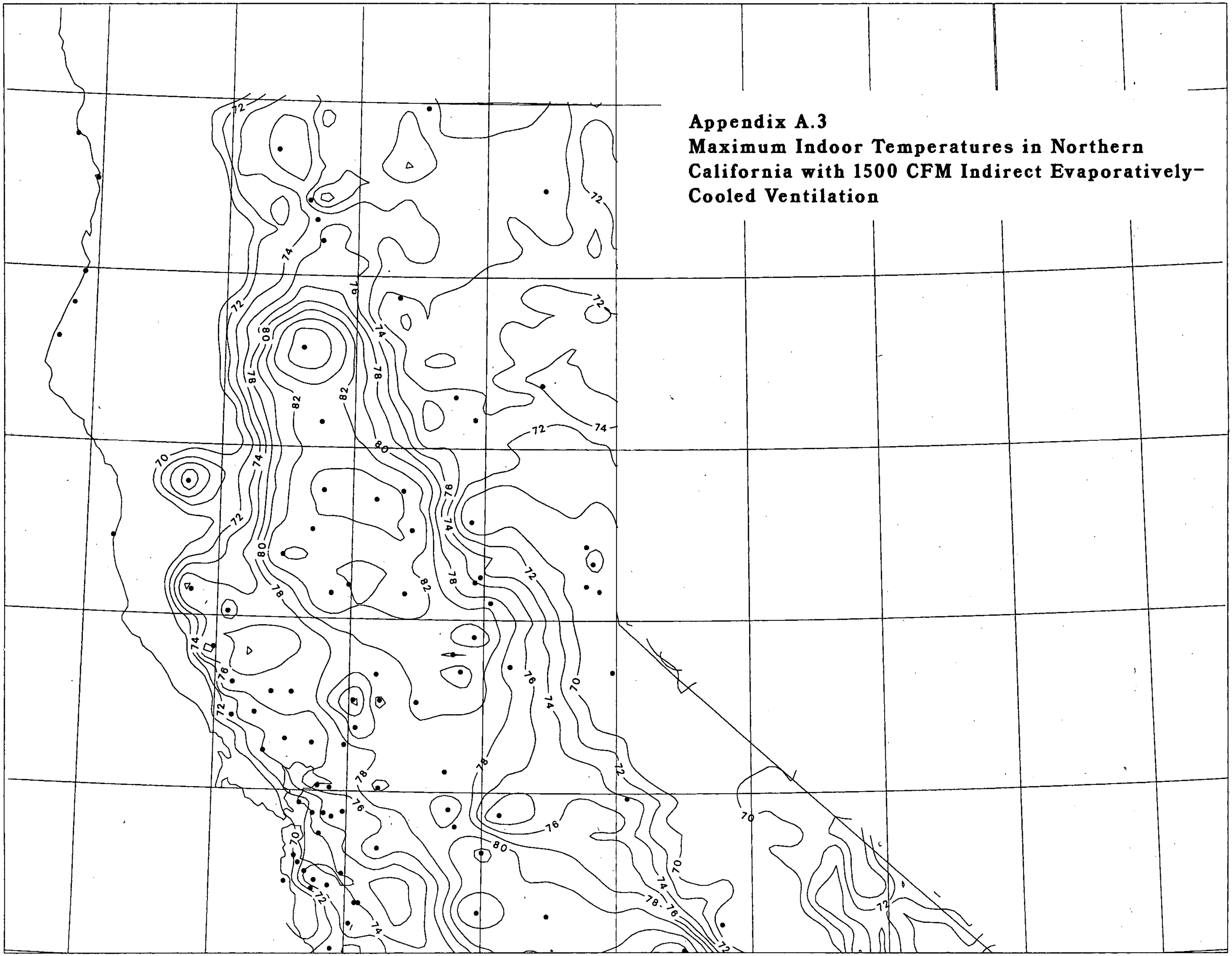
Appendix A.1
Maximum Indoor Temperatures in Northern California with 1500 CFM Mechanical Ventilation

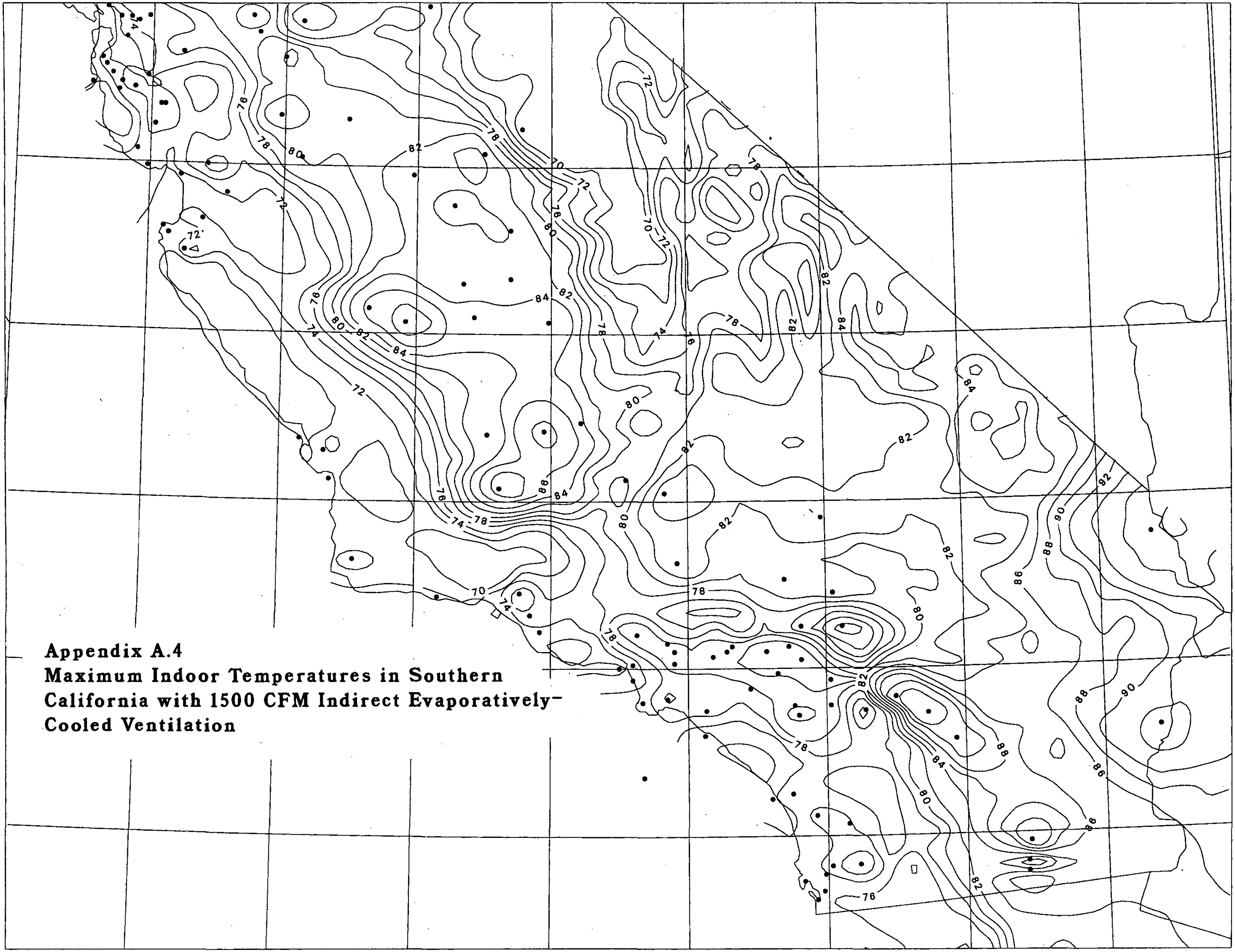




Appendix A.2
Maximum Indoor Temperatures in Southern California with 1500 CFM Mechanical Ventilation

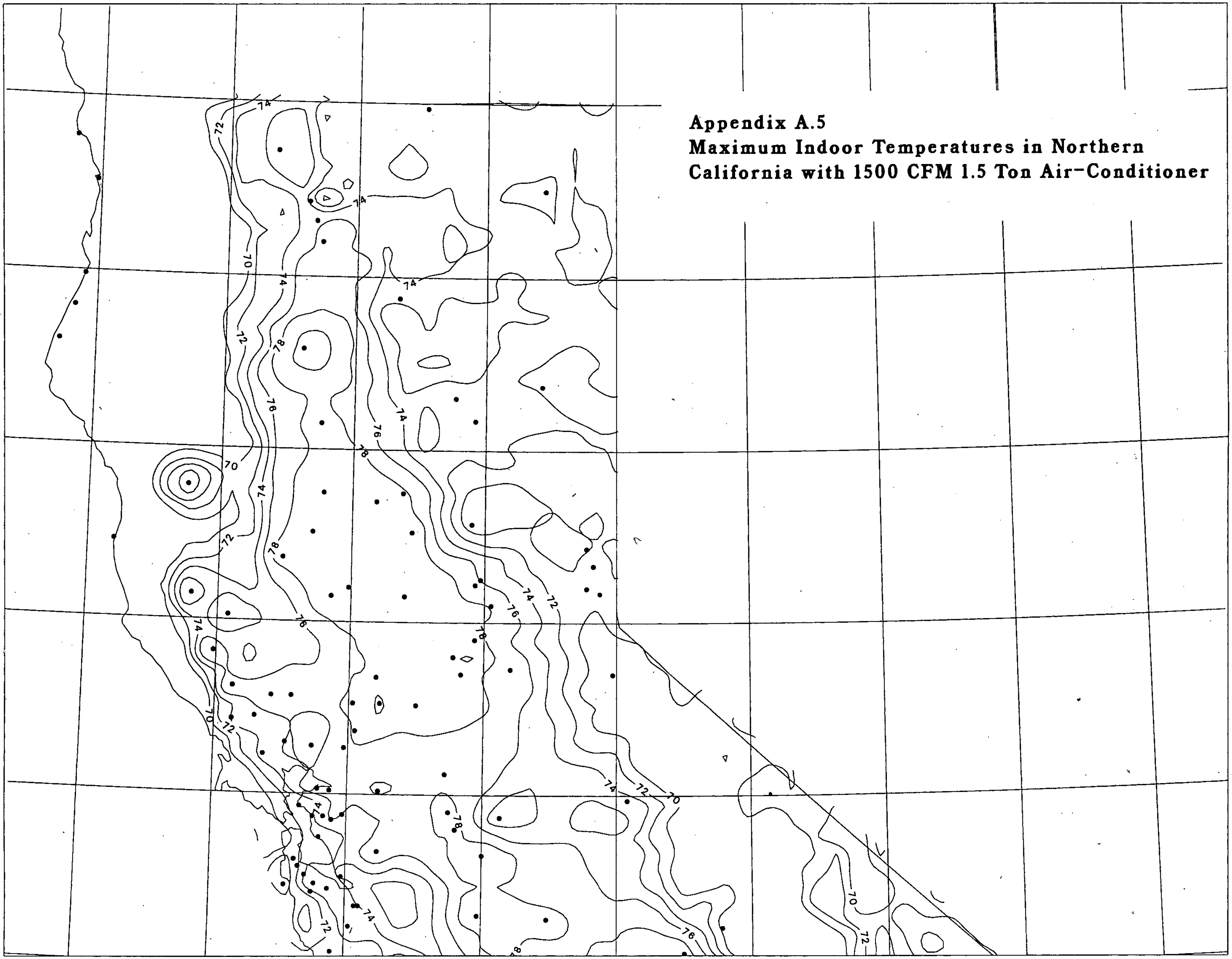
Appendix A.3
Maximum Indoor Temperatures in Northern California with 1500 CFM Indirect Evaporatively-Cooled Ventilation

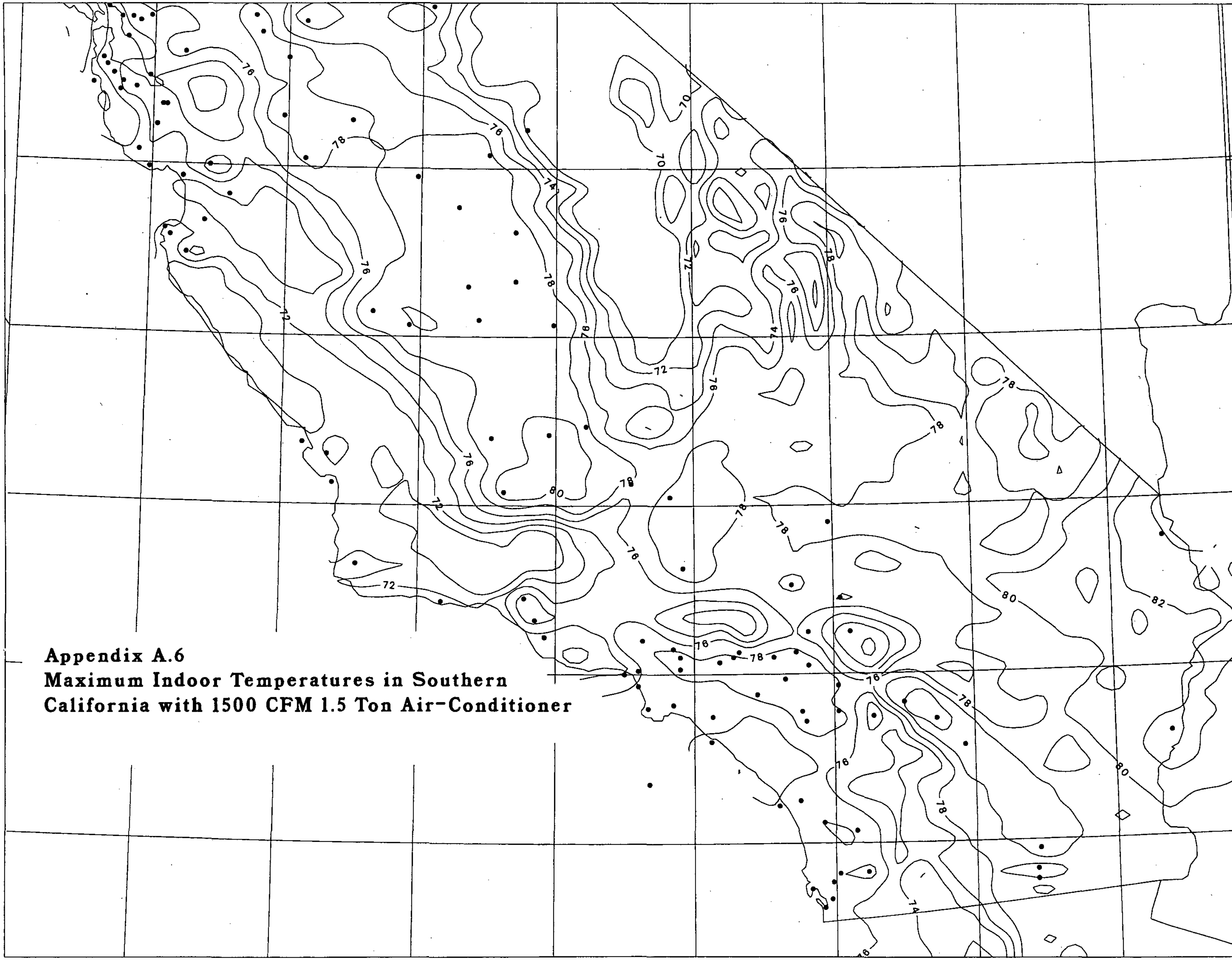




Appendix A.4
Maximum Indoor Temperatures in Southern California with 1500 CFM Indirect Evaporatively-Cooled Ventilation

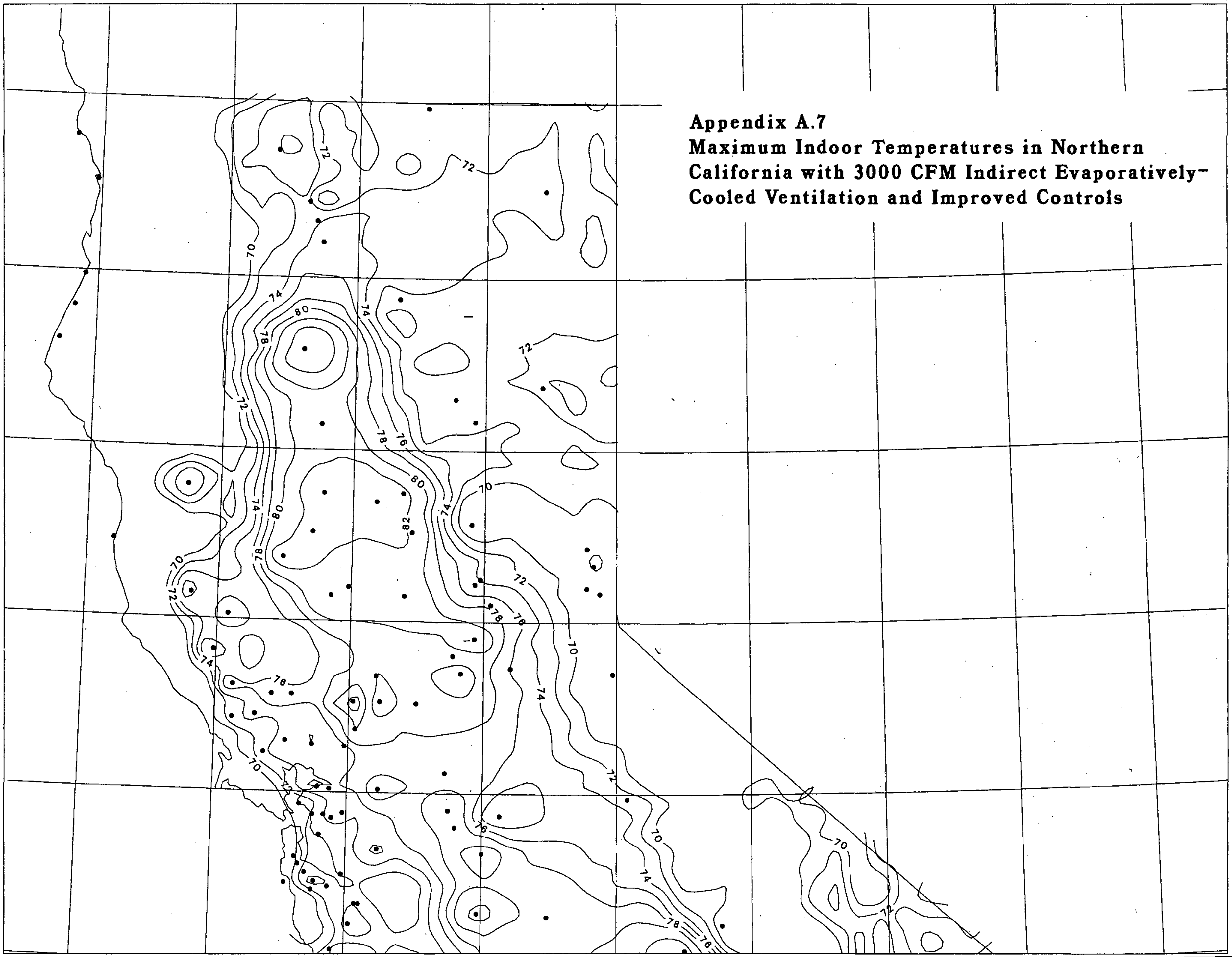
Appendix A.5
Maximum Indoor Temperatures in Northern California with 1500 CFM 1.5 Ton Air-Conditioner

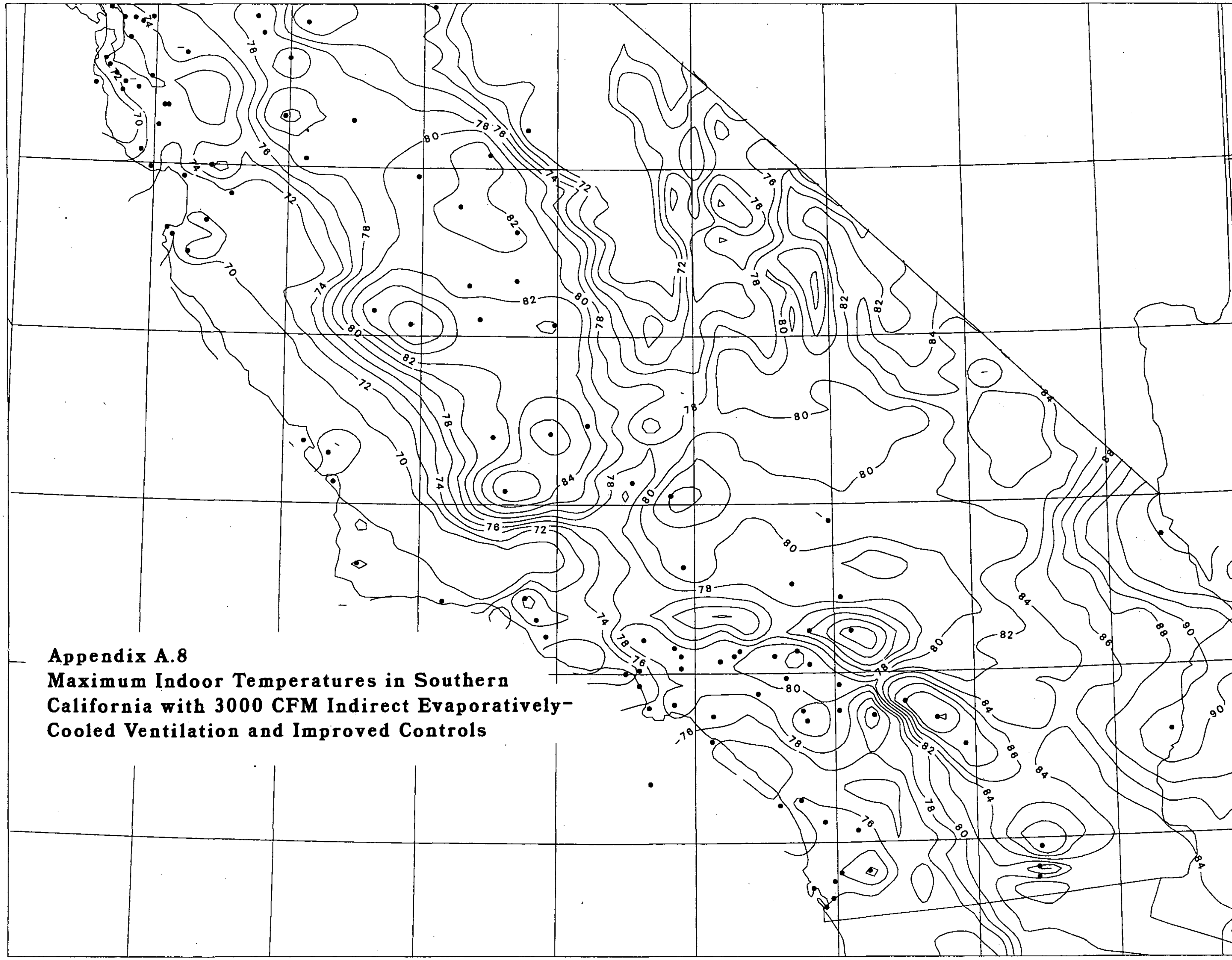




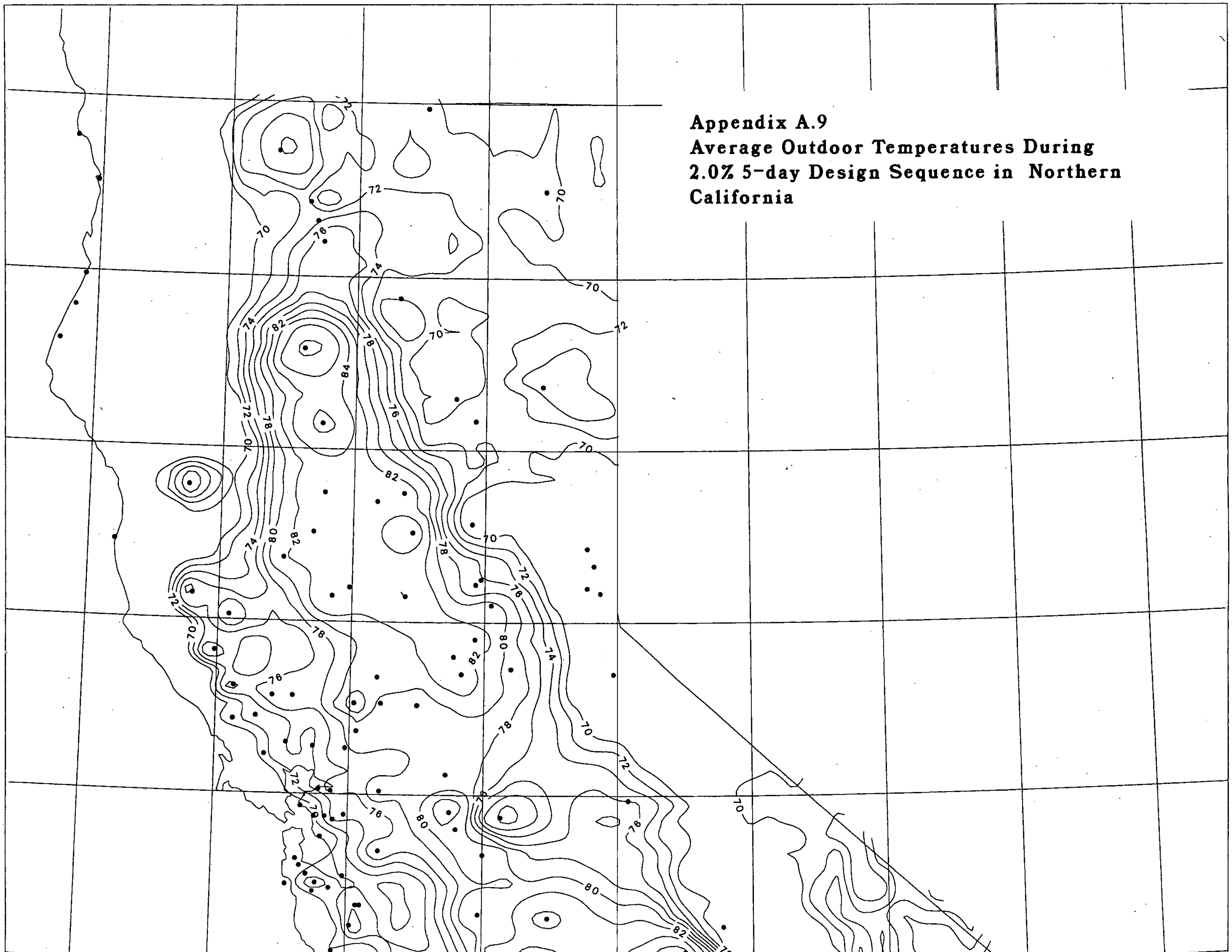
Appendix A.6
Maximum Indoor Temperatures in Southern California with 1500 CFM 1.5 Ton Air-Conditioner

Appendix A.7
Maximum Indoor Temperatures in Northern California with 3000 CFM Indirect Evaporatively-Cooled Ventilation and Improved Controls

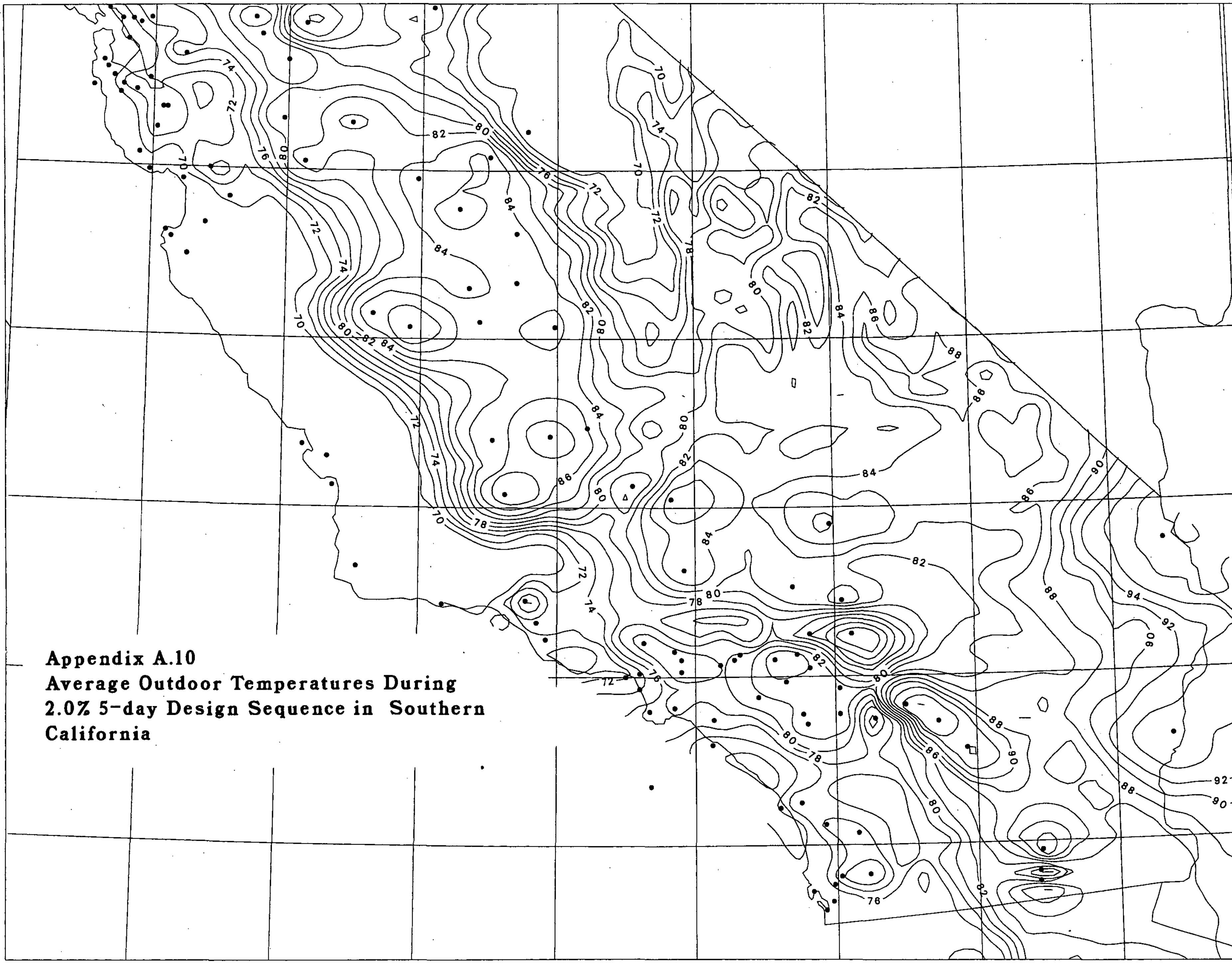




Appendix A.8
Maximum Indoor Temperatures in Southern California with 3000 CFM Indirect Evaporatively-Cooled Ventilation and Improved Controls

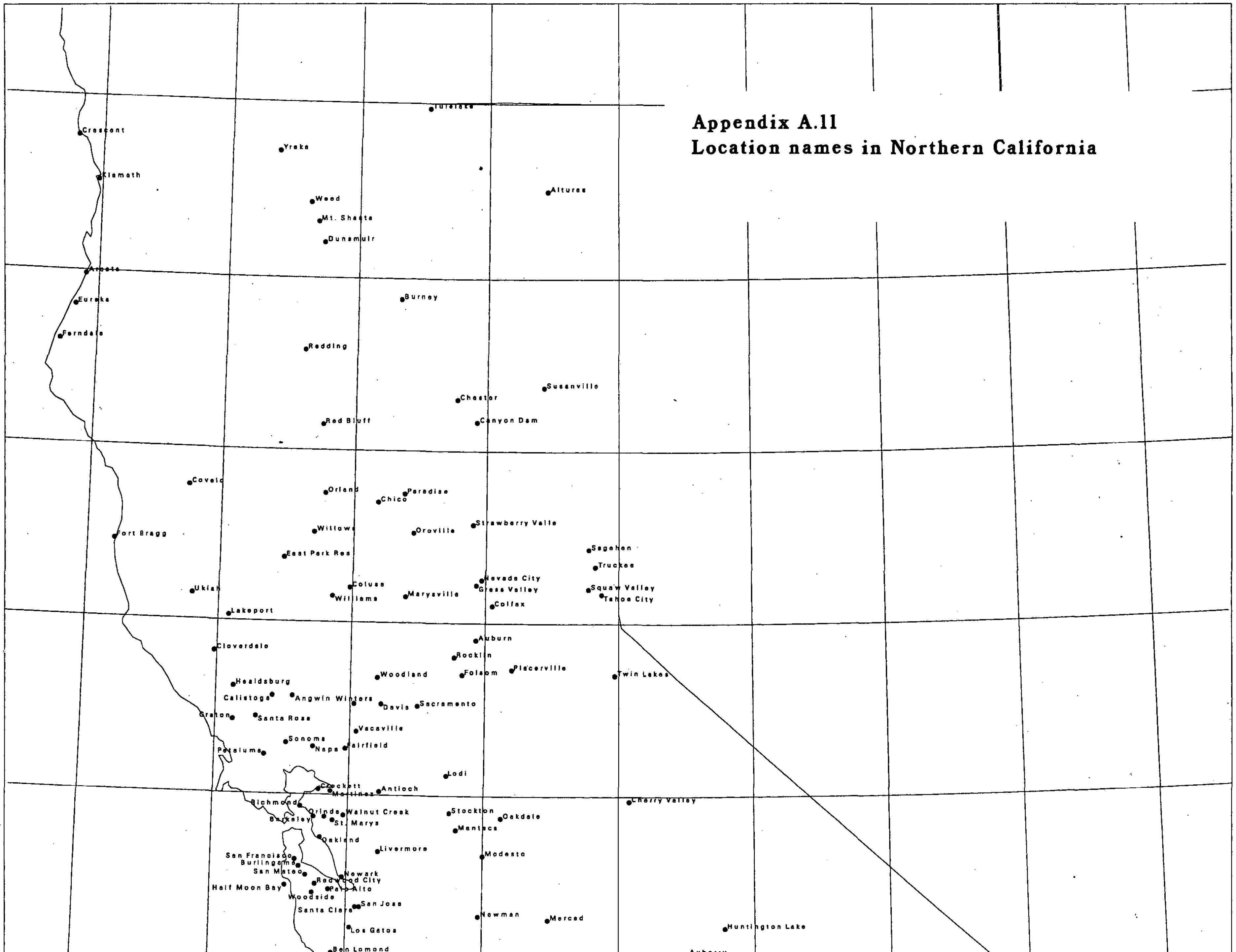


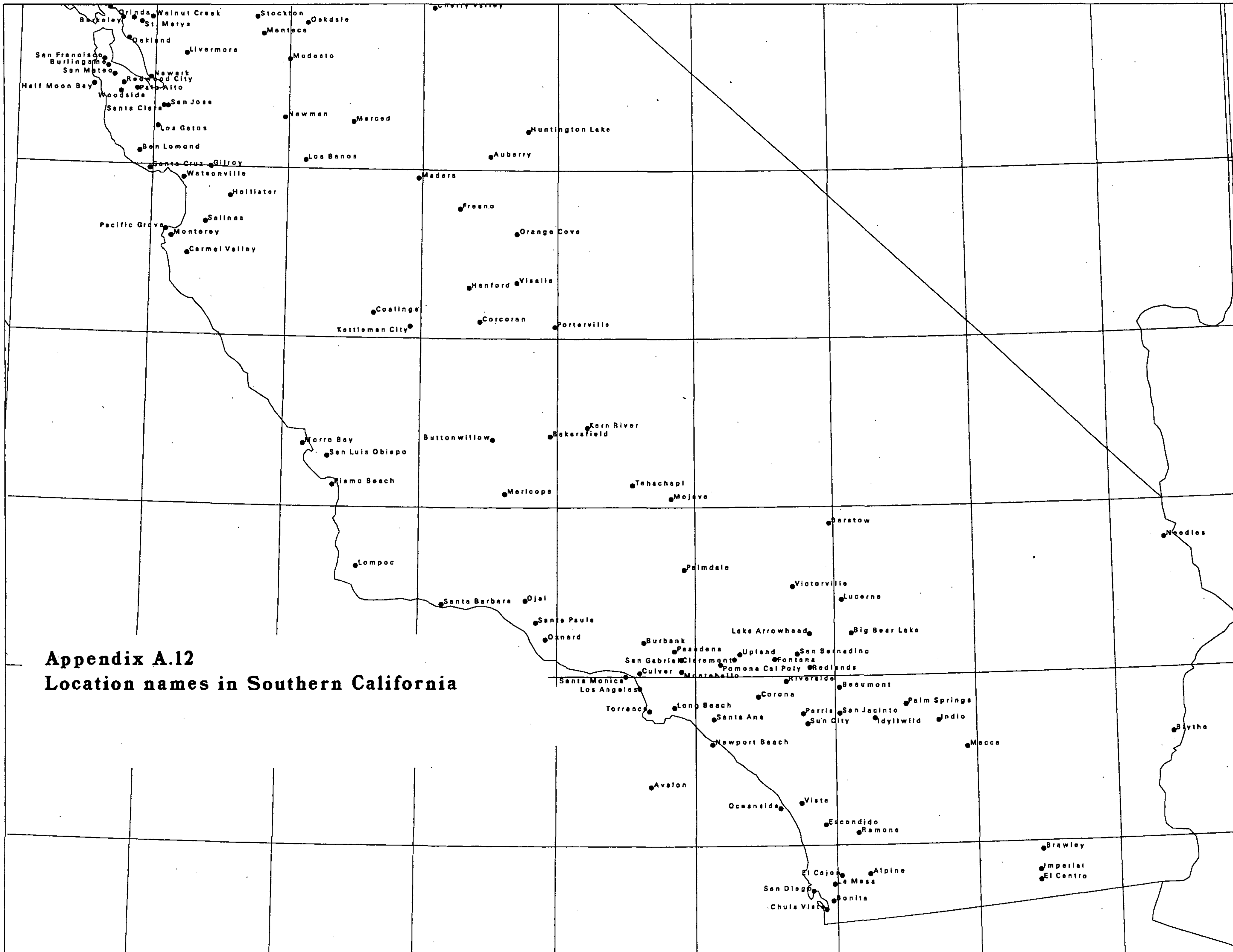
Appendix A.9
Average Outdoor Temperatures During 2.0% 5-day Design Sequence in Northern California



Appendix A.10
Average Outdoor Temperatures During 2.0% 5-day Design Sequence in Southern California

Appendix A.11
Location names in Northern California





Appendix A.12
Location names in Southern California

Appendix B. 2.0% 5-Day design Period Temperatures for 171 California Climates

Location	Lon	Lat	Warm-up Max T/	Warm-up Min T	Day1 Max T/	Day1 Min T	Day2 Max T/	Day2 Min T	Day3 Max T/	Day3 Min T	Day4 Max T/	Day4 Min T	Day5 Max T/	Day5 Min T	5-day Avg (F)
Alpine	116.77	32.83	91	61	97	67	101	73	96	69	90	69	92	68	82.2
Alturas	120.55	41.50	87	43	93	45	91	42	92	43	96	50	97	57	70.6
Angwin	122.43	38.57	87	56	100	60	94	65	93	60	94	54	93	61	77.4
Antioch	121.77	38.02	94	55	95	56	92	55	97	64	97	68	100	69	79.3
Arcata S*	124.10	40.98	61	54	62	51	64	55	68	57	60	44	69	50	58.0
Auberry	119.50	37.08	93	68	100	73	99	75	96	72	98	71	100	72	85.6
Auburn	121.07	38.90	91	64	93	61	97	63	101	69	103	73	104	70	83.4
Avalon	118.32	33.35	79	59	78	67	80	67	80	67	78	64	78	64	72.3
Bakersfield S*	119.05	35.42	95	73	93	71	96	71	105	80	107	78	109	80	89.0
Barstow	117.03	34.90	101	66	105	74	104	73	105	70	107	69	106	68	88.1
Beaumont	116.97	33.93	97	52	104	69	100	76	95	66	99	60	97	60	82.6
Ben Lomond	122.10	37.08	85	52	92	61	96	44	102	48	100	50	88	45	72.6
Berkeley	122.25	37.87	72	57	73	62	78	56	88	60	85	62	68	55	68.7
Big Bear Lake	116.88	34.25	77	48	84	45	82	48	83	55	85	50	85	51	66.8
Blythe	114.60	33.62	111	72	114	72	113	72	114	76	114	83	118	78	95.4
Bonita	117.03	32.67	77	60	80	63	83	65	83	67	87	63	88	64	74.3
Brawley	115.55	32.95	112	69	112	85	110	83	109	82	105	78	102	73	93.9
Burbank	118.37	34.20	94	58	96	64	94	64	94	64	98	70	100	71	81.5
Burlingame	122.35	37.58	79	51	,98	56	79	55	78	49	86	49	87	53	69.0
Burney	121.67	40.88	91	39	96	46	96	45	93	44	93	47	96	47	70.3
Buttonwillow	119.47	35.40	97	64	109	66	103	63	102	68	103	69	103	69	85.5
Calistoga	122.58	38.57	93	53	93	51	101	68	104	55	102	51	100	51	77.6
Canyon Dam	121.08	40.17	79	51	92	47	92	50	90	52	93	54	86	51	70.7
Carmel Valley	121.73	36.48	82	52	93	55	99	62	86	52	75	57	80	52	71.1
Cherry Valley	119.92	37.97	86	55	96	60	92	58	92	58	95	59	95	59	76.4
Chester	121.23	40.30	83	45	95	46	96	47	94	53	88	50	85	44	69.8
Chico	121.82	39.70	96	61	102	64	108	66	107	73	94	63	95	59	83.1
Chula Vista	117.08	32.62	74	66	78	67	77	65	85	59	97	66	85	66	74.5
Claremont	117.72	34.10	87	62	90	66	97	68	100	71	85	66	91	62	79.6
Cloverdale	123.02	38.82	91	55	88	53	99	62	107	62	108	55	93	53	78.0
Coalinga	120.35	36.15	101	64	102	68	103	68	103	69	106	69	108	75	87.1
Colfax	120.95	39.10	90	63	96	62	99	66	99	66	99	65	98	67	81.7
Colusa	122.02	39.20	96	58	105	70	105	62	104	61	99	62	96	57	82.1
Corcoran	119.57	36.10	99	61	106	66	105	70	103	74	101	67	101	65	85.8
Corona	117.55	33.88	95	57	97	65	96	68	97	64	100	60	103	61	81.1
Covelo	123.25	39.78	96	48	100	55	98	57	100	57	104	57	97	49	77.4
Crescent	124.20	41.77	66	53	69	60	66	54	69	52	69	58	68	58	62.3
Crockett	122.22	38.03	85	55	79	56	86	56	87	58	95	59	104	61	74.1
Culver	118.40	34.02	82	60	90	69	86	67	85	66	84	64	79	64	75.4
Davis	121.77	38.53	95	54	104	60	101	53	104	55	102	55	101	58	79.3
Dunsmuir	122.27	41.20	92	50	96	54	100	55	97	55	98	58	98	57	76.8
East Park Res	122.52	39.37	95	56	91	63	89	63	96	65	102	67	105	75	81.6
El Cajon	116.97	32.82	89	63	94	65	95	71	95	70	89	73	93	71	81.6
El Centro	115.57	32.77	106	76	105	74	111	79	114	77	113	73	112	77	93.5
Escondido	117.08	33.12	91	57	86	60	87	60	104	60	97	67	95	68	78.4

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Appendix B. 2.0% 5-Day design Period Temperatures for 171 California Climates

Location	Lon	Lat	Warm-up Max T/	Warm-up Min T	Day1 Max T/	Day1 Min T	Day2 Max T/	Day2 Min T	Day3 Max T/	Day3 Min T	Day4 Max T/	Day4 Min T	Day5 Max T/	Day5 Min T	5-day Avg (F)
Eureka	124.17	40.80	63	53	68	58	68	59	63	57	64	54	66	55	61.2
Fairfield	122.03	38.27	92	54	97	54	98	59	99	60	96	60	98	58	77.9
Ferndale	124.28	40.60	67	50	73	50	80	47	73	55	66	51	64	49	60.8
Folsom	121.17	38.70	95	61	92	63	99	64	105	68	107	68	104	64	83.4
Fontana	117.43	34.10	98	62	97	70	102	72	101	69	99	72	98	75	85.5
Fort Bragg	123.80	39.45	68	50	76	56	75	49	65	54	72	53	65	51	61.6
Fresno S*	119.72	36.77	96	67	100	68	102	68	105	71	105	73	104	73	86.9
Gilroy	121.57	37.00	92	51	95	64	93	61	71	59	87	59	97	68	75.4
Grass Valley	121.07	39.22	86	57	97	58	100	61	99	60	90	55	92	57	76.9
Graton	122.87	38.43	93	40	93	49	98	47	95	44	95	48	97	45	71.1
Half Moon Bay	122.45	37.47	68	50	71	58	66	56	65	58	64	59	67	58	62.2
Hanford	119.65	36.30	96	62	97	58	101	71	101	72	101	61	103	71	83.6
Healdsburg	122.87	38.62	89	57	92	55	92	51	102	52	108	51	107	58	76.8
Hollister	121.42	36.83	83	51	81	59	86	61	84	58	88	56	87	56	71.6
Huntington Lake	119.22	37.23	73	48	81	59	71	56	77	49	78	54	76	56	65.7
Idyllwild	116.72	33.75	84	52	88	57	89	53	92	55	90	56	85	57	72.2
Imperial EI**	115.57	32.83	74	61	75	67	75	67	76	69	76	67	75	68	71.5
Indio	116.27	33.73	105	79	104	76	116	78	106	83	111	88	112	83	95.7
Kern River	118.78	35.47	96	63	105	71	104	74	103	70	100	70	98	66	86.1
Kettleman City	120.08	36.07	99	70	105	80	101	76	103	84	102	74	101	72	89.8
Klamath	124.03	41.52	69	50	78	52	76	56	68	58	68	54	66	52	62.8
La Mesa	117.02	32.77	85	62	82	64	97	61	92	71	92	69	88	69	78.5
Lake Arrowhead	117.18	34.25	83	55	93	65	89	63	83	62	78	61	78	60	73.2
Lakeport	122.92	39.03	93	56	100	57	107	58	106	58	99	55	100	55	79.5
Livermore	121.77	37.67	93	52	101	61	99	64	96	60	94	58	90	56	77.9
Lodi	121.28	38.12	95	54	90	50	98	55	108	63	108	56	104	60	79.2
Lompoc	120.45	34.65	75	57	97	58	95	53	86	52	70	53	75	54	69.3
Long Beach S*	118.15	33.82	83	65	91	64	89	64	89	64	91	68	96	73	78.9
Los Angeles S*	118.40	33.93	73	65	80	66	82	66	78	66	82	66	80	69	73.5
Los Banos	120.87	37.05	96	60	101	65	100	65	99	68	99	64	100	66	82.7
Los Gatos	121.97	37.23	89	52	90	53	83	58	95	60	98	60	93	59	74.9
Lucerne	116.95	34.45	102	60	104	62	103	67	104	70	104	69	104	66	85.3
Madera	120.03	36.95	98	61	100	62	102	65	106	66	106	66	105	67	84.5
Manteca	121.20	37.80	96	56	94	58	99	60	101	62	104	65	102	62	80.7
Maricopa	119.38	35.08	96	72	104	74	103	73	108	78	106	78	101	72	89.7
Martinez	122.13	38.02	87	57	95	57	96	57	97	57	99	55	98	60	77.1
Marysville	121.60	39.15	96	59	100	64	100	64	100	67	102	71	105	68	84.1
Mecca	116.07	33.57	112	68	108	82	115	65	117	79	115	79	110	73	94.3
Merced	120.52	37.28	95	62	103	69	103	64	102	67	101	64	105	66	84.4
Modesto	121.00	37.65	95	59	102	66	104	70	93	71	91	68	96	60	82.1
Mojave	118.17	35.05	98	66	101	76	96	75	100	73	104	76	105	71	87.7
Montebello	118.10	34.03	90	64	96	62	92	70	98	66	100	68	100	68	82.0
Monterey	121.85	36.58	73	52	88	55	84	54	77	53	80	49	78	49	66.7
Morro Bay	120.85	35.37	69	53	67	50	81	54	81	57	85	51	73	50	64.9
Mt Shasta EI**	122.32	41.32	89	53	93	62	93	60	91	58	89	52	86	50	73.4

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Appendix B. 2.0% 5-Day design Period Temperatures for 171 California Climates

			Warm-up		Day1		Day2		Day3		Day4		Day5		5-day
Location	Lon	Lat	Max T/	Min T	Max T/	Min T	Max T/	Min T	Max T/	Min T	Max T/	Min T	Max T/	Min T	Avg (F)
Napa	122.27	38.28	87	52	89	56	96	53	92	56	88	52	99	57	73.8
Needles	114.62	34.77	108	82	114	95	110	91	101	85	111	86	115	87	99.5
Nevada City	121.03	39.25	84	58	95	58	94	59	94	57	96	59	91	59	76.2
Newark	122.03	37.52	78	58	80	57	88	58	88	58	91	58	90	58	72.6
Newman	121.03	37.30	94	59	103	66	105	74	104	62	95	60	92	55	81.6
Newport Beach	117.88	33.60	73	63	72	64	77	64	81	69	78	68	78	68	71.9
Oakdale	120.87	37.87	73	56	73	58	81	55	86	59	82	62	74	61	69.1
Oakland EI**	122.20	37.75	73	56	77	57	76	60	85	63	81	62	68	60	68.9
Oceanside	117.40	33.22	73	65	76	63	77	67	83	68	80	67	85	67	73.3
Ojai	119.23	34.45	95	52	101	52	103	57	99	55	102	53	108	58	78.8
Orange Cove	119.30	36.62	97	62	100	60	100	67	103	68	106	68	101	72	84.5
Orinda	122.17	37.87	83	54	95	51	95	50	93	62	85	55	96	52	73.4
Orland	122.22	39.75	97	59	111	66	105	73	96	68	95	65	96	63	83.8
Oroville	121.55	39.52	97	62	106	70	110	67	104	60	104	62	105	62	85.0
Oxnard	119.08	34.22	77	58	81	60	81	60	83	62	89	60	81	62	71.9
Pacific Grove	121.89	36.62	76	52	96	51	87	53	76	53	74	53	83	54	68.0
Palm Springs	116.50	33.83	111	72	116	84	119	77	118	75	115	76	107	71	95.8
Palmdale	118.08	34.63	97	64	102	58	105	61	109	65	111	67	110	69	85.7
Palo Alto	122.13	37.45	81	53	85	48	84	54	97	59	89	57	84	54	71.1
Paradise	121.62	39.75	91	65	99	66	100	71	100	75	100	74	90	59	83.4
Pasadena	118.15	34.15	91	61	92	69	96	70	95	70	93	69	92	68	81.4
Perris	117.23	33.78	89	65	100	59	101	57	102	64	103	67	103	65	82.1
Petaluma	122.63	38.23	84	52	77	54	86	47	100	53	98	54	89	62	72.0
Pismo Beach	120.63	35.13	74	53	78	52	78	53	81	54	81	57	85	50	66.9
Placerville	120.80	38.73	90	58	101	62	99	60	96	58	98	58	102	60	79.4
Pomona Cal Poly	117.82	34.07	85	60	95	69	98	68	95	65	91	65	88	61	79.5
Porterville	119.02	36.07	98	65	101	74	99	77	102	75	102	67	99	69	86.5
Ramona	116.85	33.07	86	61	101	62	100	66	96	63	92	62	90	60	79.2
Red Bluff EI**	122.25	40.15	98	67	99	68	102	71	103	74	103	72	100	71	86.3
Redding EI**	122.40	40.58	96	65	97	63	108	71	113	74	110	72	101	73	88.2
Redlands	117.18	34.05	96	63	98	55	104	60	108	65	112	67	106	66	84.1
Redwood City	122.23	37.48	85	53	97	54	97	53	97	55	87	56	84	54	73.4
Richmond	122.35	37.93	73	58	81	60	79	60	72	60	76	62	81	61	69.2
Riverside	117.35	33.97	95	62	100	73	93	69	103	70	100	67	94	66	83.5
Rocklin	121.23	38.80	96	59	108	56	106	57	109	58	105	59	109	57	82.4
Sacramento S*	121.50	38.52	92	60	89	57	93	55	100	60	107	66	100	66	79.3
Sagehen	120.23	39.43	81	34	85	47	86	42	86	38	83	37	82	37	62.3
Salinas	121.60	36.67	75	53	71	58	73	53	93	60	82	61	74	60	68.5
San Bernadino	117.27	34.13	99	60	104	67	98	69	98	70	99	68	100	70	84.3
San Diego S*	117.17	32.73	78	67	78	71	80	69	80	69	80	69	82	72	75.0
San Francisco S*	122.38	37.62	68	58	73	57	68	57	73	55	80	60	87	60	67.0
San Gabriel	118.10	34.10	89	63	104	65	101	64	92	65	92	64	95	67	80.9
San Jacinto	116.97	33.78	103	56	109	62	105	62	108	61	104	61	104	61	83.7
San Jose	121.90	37.35	82	58	85	60	97	60	86	63	87	62	82	62	74.4
San Luis Obispo	120.67	35.30	79	54	75	50	85	60	106	58	85	58	78	56	71.1

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Appendix B. 2.0% 5-Day design Period Temperatures for 171 California Climates

Location	Lon	Lat	Warm-up Max T/	Warm-up Min T	Day1 Max T/	Day1 Min T	Day2 Max T/	Day2 Min T	Day3 Max T/	Day3 Min T	Day4 Max T/	Day4 Min T	Day5 Max T/	Day5 Min T	5-day Avg (F)
San Mateo	122.30	37.53	78	57	90	56	95	57	95	52	85	46	82	46	70.4
Santa Ana	117.87	33.75	91	63	88	65	88	65	93	63	95	68	97	65	78.7
Santa Barbara EI**	119.83	34.43	74	61	83	59	86	61	79	59	81	59	75	61	70.3
Santa Clara	121.93	37.35	78	60	92	59	88	59	82	59	88	58	86	59	73.0
Santa Cruz	122.02	36.98	75	54	99	50	95	48	85	47	86	45	75	46	67.6
Santa Monica	118.50	34.00	70	64	76	65	75	65	75	65	76	66	78	65	70.6
Santa Paula	119.15	34.32	87	51	87	67	85	73	80	68	82	67	83	55	74.7
Santa Rosa	122.70	38.45	89	49	104	57	97	58	79	59	81	60	80	55	73.0
Sonoma	122.47	38.30	86	55	102	54	103	46	102	57	95	51	88	50	74.8
Squaw Valley	120.23	39.20	82	41	85	42	85	47	90	44	87	46	90	46	66.2
St. Marys	122.11	37.85	83	55	83	54	97	60	98	59	88	58	87	58	74.2
Stockton EI**	121.25	37.90	95	59	107	67	102	63	101	68	100	69	97	65	83.9
Strawberry Valley	121.10	39.57	84	51	89	50	90	55	91	58	90	59	85	61	72.8
Sun City	117.20	33.72	99	59	100	71	101	70	102	69	97	68	92	66	83.6
Susanville	120.57	40.37	90	48	93	51	92	57	93	59	95	55	96	58	74.9
Tahoe City	120.13	39.17	81	47	86	46	81	47	83	48	84	49	82	45	65.1
Tehachapi	118.45	35.13	87	56	93	62	91	70	90	60	88	64	80	67	76.5
Torrance	118.33	33.80	82	60	90	67	88	65	86	65	90	65	82	65	76.3
Truckee	120.18	39.33	85	38	96	49	93	46	88	48	83	54	77	37	67.1
Tulelake	121.47	41.97	89	41	87	47	92	47	93	45	94	50	95	53	70.3
Twin Lakes	120.03	38.70	68	45	75	53	75	48	75	45	76	48	77	47	61.9
Ukiah	123.20	39.15	93	55	92	63	95	66	100	62	100	62	94	58	79.2
Upland	117.68	34.13	95	56	94	55	100	59	97	67	99	66	107	69	81.3
Vacaville	121.95	38.37	97	55	103	58	102	72	101	64	97	56	86	60	79.9
Victorville	117.30	34.53	100	59	102	65	104	68	101	72	100	65	101	62	84.0
Visalia	119.30	36.33	96	64	99	68	104	68	104	68	101	68	100	68	84.8
Vista	117.25	33.25	85	61	86	64	90	64	95	63	88	69	86	71	77.6
Walnut Creek	122.03	37.88	92	51	94	52	100	50	100	54	103	54	97	54	75.8
Watsonville	121.77	36.93	84	46	77	56	76	57	75	57	83	58	86	51	67.6
Weed	122.38	41.43	88	45	93	49	95	49	94	58	84	59	90	53	72.4
Williams	122.15	39.15	96	60	109	66	109	69	109	63	100	58	101	52	83.6
Willows	122.30	39.52	95	60	91	60	96	71	98	65	106	71	101	70	82.9
Winters	121.97	38.53	97	60	96	61	100	58	100	66	104	69	106	73	83.3
Woodland	121.80	38.68	98	56	105	61	105	61	101	63	95	64	103	59	81.7
Woodside	122.25	37.43	88	51	101	65	98	56	89	48	88	45	93	53	73.6
Yreka	122.63	41.72	90	53	95	54	97	59	99	55	102	57	100	58	77.6

S* = hourly SAMSON 30-year data, EI* = hourly EarthInfo data.

Appendix C. Modeling of Foundation Heat Flows in Design Simulations with DOE-2.1E

This section describes the general approach used to model foundation heat flows for the design simulations of the prototype "Alternatives to Compressive Cooling" house. This modeling issue has been studied with some detail because 1) the thermal storage effects of the floor slab can have a significant impact in moderating indoor temperatures during peak cooling periods, and 2) the standard modeling method in DOE-2 for underground heat transfer is extremely simplified and provides very little guidance for even a first-order approximation of heat flows.

The approach used in this analysis is to separate the floor slab into two surfaces – a "perimeter" section assumed to respond in a delayed fashion to outdoor air temperature, and a "core" section assumed to respond only to long-term ground temperatures. These sections should be considered less as physical sections, but as modeling abstractions, since the heat flows of the "perimeter" also include the long-term heat flows of the "core" region. In the design sequence simulations, the "perimeter" heat flows would respond with a 2-3 day delay to the increased outdoor air temperatures, but the "core" heat flows are assumed to be unaffected by such transient effects. This is done by modeling the "core" in DOE-2 as an UNDERGROUND-FLOOR with an annual sinusoidal monthly GROUND-TEMPERATURE profile.

The foundation heat flows were calculated for a one-ft cross-section for the following foundation conditions in three transitional climates using a two-dimensional finite-difference program, *hdbk.c*, originally developed by the University of Minnesota's now-defunct Underground Space Center (Labs et al. 1988) :

Cover	Insulation condition	Climate zones
rug	uninsulated and insulated	CTZ04, 09, 13
wood	uninsulated and insulated	CTZ04, 09, 13
dirt	uninsulated and insulated	CTZ04, 09, 13

Another utility program, *fdnreg.f*, was then used to calculate average heat fluxes per ft^2 for the perimeter and core regions of the foundation. The annulus method was used to extrapolate to a typical 28x55 building foundation. The discrepancy between this footprint and the "Alternatives" prototype should be insignificant. *fdnreg.f* outputs give the indoor/outdoor temperature difference, perimeter heat flow, and core heat flow per ft^2 of area.

For the "perimeter" region, linear regressions were done between the heat flows and the indoor/outdoor temperature difference, and the resulting slope used as the U-value for a DOE-2 EXTERIOR-WALL. The residuals from this regression are added to the heat flows for the "core" section. These heat fluxes were then reduced to a sine curve, and used to calculate DOE-2 GROUND-TEMPERATUREs which would produce the same heat flows given the appropriate indoor zone temperature and floor slab U-value.

Table C.1 gives the results for the linear regressions for the "perimeter", and sine curve regressions for the "core" region heat flows.

C.1 "Perimeter" Section

The averaged regression slopes from CTZ04 and CTZ09 are used since these two are most representative of Transition Climates. Furthermore, interpolated Slopes are developed for the half carpet/half wood and half carpet/half tile cases. These U-values are listed in Table C.2. To dampen air temperature fluctuations, 2 ft. of dirt are included in the foundation layer. In addition, a resistance layer is added to produce the desired conductivity from Table C.2. The layer-by-layer R-values are listed in Table C.3 .

Table C.1 Regression Coefficients for Various Foundation Types in Three California Climates

			"Perimeter" Region			" Core" Region		
Clim	Fdn Surf	Fdn Cond	Slope	Inter1	R^2	Ampl.	Phase	Inter2
CTZ04	carpet	ins	0.03566	-0.99833	0.525	0.16357	-2.515	-0.88110
CTZ09	carpet	ins	0.02495	-0.72953	0.515	0.18811	-2.319	-0.64140
CTZ13	carpet	ins	0.04318	-0.68084	0.649	0.34704	-2.654	-0.67630
CTZ04	carpet	unins	0.08772	-0.92016	0.740	0.21942	-3.256	-0.97760
CTZ09	carpet	unins	0.08726	-0.65223	0.739	0.25216	-3.062	-0.70530
CTZ13	carpet	unins	0.10116	-0.51309	0.855	0.45543	-3.397	-0.72120
CTZ04	wood	ins	0.04602	-1.14136	0.552	0.18423	-2.817	-0.95480
CTZ09	wood	ins	0.04511	-0.83368	0.542	0.21168	-2.616	-0.69410
CTZ13	wood	ins	0.05565	-0.76361	0.680	0.38935	-2.955	-0.73030
CTZ04	wood	unins	0.11725	-1.10499	0.753	0.25277	-3.330	-1.07770
CTZ09	wood	unins	0.11688	-0.77181	0.753	0.29055	-3.136	-0.77580
CTZ13	wood	unins	0.13499	-0.58980	0.866	0.52066	-3.458	-0.78680
CTZ04	tile	ins	0.06129	-1.32337	0.585	0.20541	-2.896	-1.02580
CTZ09	tile	ins	0.06013	-0.96581	0.575	0.23630	-2.698	-0.74480
CTZ13	tile	ins	0.07389	-0.86652	0.716	0.43200	-3.019	-0.77900
CTZ04	tile	unins	0.16636	-1.35860	0.774	0.28643	-3.398	-1.17550
CTZ09	tile	unins	0.16650	-0.94432	0.777	0.32874	-3.205	-0.84310
CTZ13	tile	unins	0.18961	-0.70313	0.881	0.58070	-3.507	-0.84800
CTZ04	dirt	unins	0.24655	-0.03401	0.895	0.22585	-3.050	-0.01170
CTZ09	dirt	unins	0.24530	0.03689	0.896	0.26061	-2.847	0.29110
CTZ13	dirt	unins	0.26885	0.31957	0.937	0.46110	-3.073	0.20640

Table C.2 U-value an R-value for Various Foundation Conditions

	Insulation condition	Carpet	Wood Floor	Tile Floor	½ Carpet, ½ Wood	½ Carpet, ½ Tile	Garage Floor	Crawl Dirt Floor
U-values								
	insulated	0.030305	0.04557	0.06071	0.03794	0.04551	-	-
	uninsulated	0.087491	0.11707	0.166427	0.10228	0.12696	0.17007	0.19738
R-values								
	insulated	32.99786	21.9443	16.47175	26.35741	21.9744	-	-
	uninsulated	11.42968	8.54212	6.00862	9.77703	7.8766	5.87993	5.06637

Table C.3 Calculation of R-value for resistance layer in foundation sections

	Carpeted	WoodFlr	TileFlr	GarFlr	DirtFlr
Inside-Air-Film	0.765	0.765	0.765	0.765	0.765
Floor surfacing*	2.08	0.3904	0.01953	-	-
4" Concrete	0.4167	0.4167	0.4167	0.4167	-
2' Soil	2.00	2.00	2.00	2.0000	2.00
Outside-Air-Film	0.17	0.17	0.17	0.17	0.17
Total R-value	5.4317	3.7421	3.37123	3.3517	2.935
Resistive layer R-value					
insulated	27.5662	18.2022	13.1004	-	-
uninsulated	5.99798	4.8	2.63742	2.52823	2.13137

* note : Rugn'Pad R = 2.08; 5/16" Wood R = 1/(.02604' x .0667) = 0.3904; 3/16" Tile R = 1/(.015625' x .800) = 0.01953

"Core" Section

Long-term climatic data from the UCEI project was used to define the annual monthly maximum and minimum ground temperatures. These are :

Location	2% Summer	0.6% Winter	Range	Average	74°F - Average
Fresno_SAN	97	30	67	63.5	10.5
Pasadena	88	40	48	64.0	10.0
Sunnyvale	80	36	44	58.0	16.0

1. Since UNDERGROUND-FLOOR heat flows in DOE-2 are calculated as UA x (T_{gnd} - T_{in}), T_{gnd} and U can be adjusted to produce the desired Q. Since the regressions were done per ft^2 of floor area, A drops out :

$$Qc = U * (T_{gnd} - T_{in}) = amp * \cos((im - phase)*0.5236) + inter2$$

$$T_{gnd} = T_{in} + (amp * \cos((im - phase)*0.5236) + inter2)/U$$

For the core areas, I modeled the same floor layers as defined for the perimeter section. The U-values are given in Table 1.

- AMP is estimated using the annual Range from the UCI climate data defined as the difference between the winter 0.6% and summer 2.0% design temperatures. Linear regressions for the 3 locations give good results, granted that the number of data points is very small. Values for the half carpet cases are averaged from the uniform covering cases :

	Insulated		Uninsulated	
	Amplitude	Range	Amplitude	Range
Carpet	0.00810	0.19634	0.01040	0.24213
Wood floor	0.00905	0.21813	0.01179	0.27038
Tile	0.00999	0.23838	0.01294	0.28726
½ carpet, ½ wood	0.00858	0.20723	0.01110	0.25625
½ carpet, ½ tile	0.00905	0.21736	0.01167	0.26470
Dirt			0.01033	0.23164

- INTER2 is estimated from the average annual temperature difference from the UCI Project defined as T_{in} - (sum20pct + win6pct)/2. For the slab cases, this is 74°F - (sum20pct + win6pct)/2. Values for the half carpet cases are averaged from the uniform covering cases :

Foundation Type	Intercept for Insulated cases	Intercept for Uninsulated cases
Carpet	-.03883 * (Tin - AvgT) - 0.26053	-.04589 * (Tin - AvgT) - 0.24299
Wood Floor	-.04236 * (Tin - AvgT) - 0.27767	-.05138 * (Tin - AvgT) - 0.25496
Tile	-.04602 * (Tin - AvgT) - 0.28993	-.05711 * (Tin - AvgT) - 0.26064
½ Carpet, ½ Wood	-.04060 * (Tin - AvgT) - 0.26910	-.04863 * (Tin - AvgT) - 0.24898
½ Carpet, ½ Tile	-.04243 * (Tin - AvgT) - 0.27523	-.05150 * (Tin - AvgT) - 0.25182
Dirt		-.03403 * (Tin - AvgT) - 0.12223

- PHASE values seem not to correlate to easily identifiable temperatures. They also do not vary that much between locations. Therefore, average phase lags are calculated from the three locations. Values for the half carpet cases are averaged from the uniform covering cases :

	Phase values	
Foundation type	Insulated	Uninsulated
Carpet	-2.496	-3.238
Wood Floor	-2.796	-3.308
Tile	-2.871	-3.370
½ Carpet, ½ Wood	-2.646	-3.273
½ Carpet, ½ Tile	-2.683	-3.304
Dirt		-2.990

T_{in} is set to 74°F for slab and 60°F for crawl space foundations.

Reference:

Labs, K., J. Carmody, R. Sterling, L. Shen, Y.J. Huang, and D. Parker 1988. *Building Foundation Design Handbook*, University of Minnesota, Minneapolis MN, also ORNL/Sub/86-72143/1, Oak Ridge National Laboratory, Oak Ridge TN.

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