CONSULTANT REPORT

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Energy Efficiency

ALTERNATIVES TO COMPRESSOR COOLING

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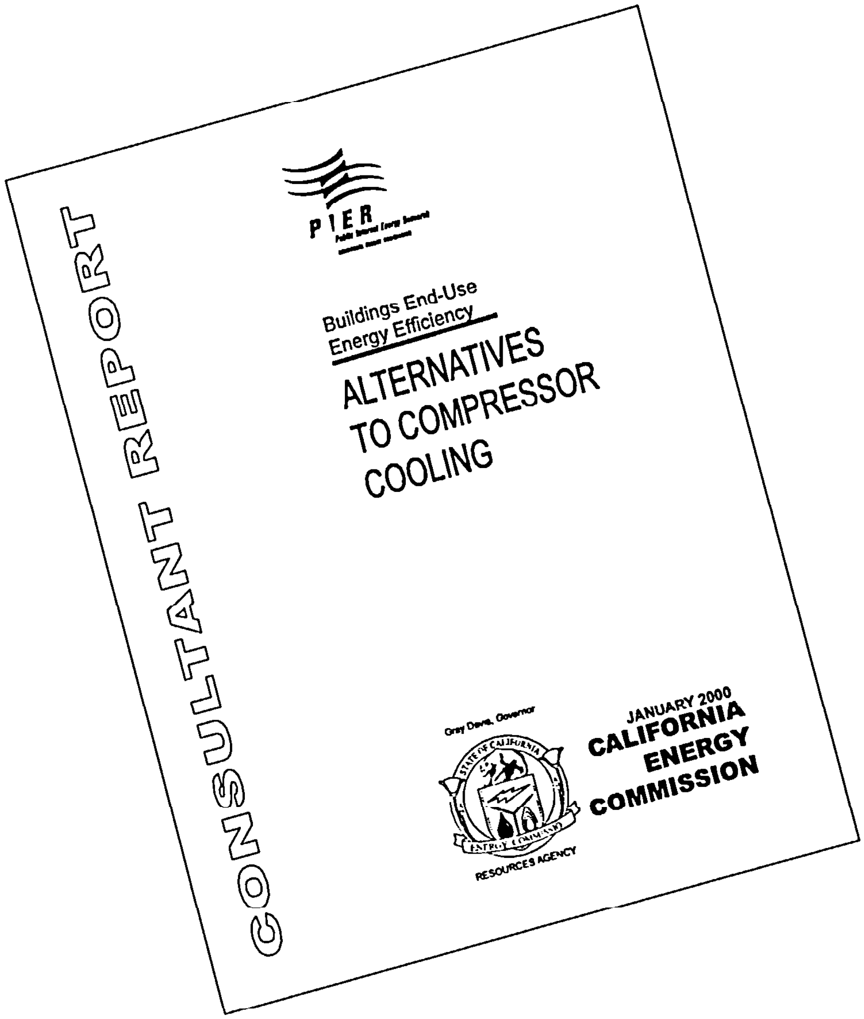

CALIFORNIA ENERGY COMMISSION

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial / Agricultural / Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Alternatives to Compressor Cooling, one of nine projects conducted by the California Institute for Energy Efficiency. This project contributes to the Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

This report presents the results of the Public Interest Energy Research (PIER) Transitional phase (Phase IV) of a multiphase project titled Alternatives to Compressor Cooling (ACC). The ACC project addresses rapid growth in the use of residential compressor-based cooling in the "transitional climate" areas situated between coastal urban centers and the Central Valley and desert regions.

Previous Phases I - III of the ACC project developed background research on alternative cooling for California transition climates and developed a prototype compressorless house design for the Southern California market. The house design uses night ventilation, improved envelope characteristics and thermal mass as cooling mechanisms. The controls necessary for this new approach consist of specially configured versions of existing off-the-shelf equipment.

Phase IV of the ACC project is the PIER Transitional phase presented in this report. This phase extended previous work to the design of a Northern California prototype house, development of an optimized ventilation control and solicitation of a pilot project by a builder or developer. Research on barriers to and opportunities for industry adoption and technology transfer activities were continued and extended from previous phases. Following this PIER Transitional phase, a successive phase of work titled "Integrated Ventilative Cooling" has been funded under the PIER II program.

Objectives

- To develop and test an optimized control for ventilation cooling while maintaining comfort conditions.
- To develop a user interface that allows users to successfully maintain comfort and reduce compressor use.
- To develop a prototype house design that incorporates features necessary for compressorless cooling in Northern California transitional climates. A key element in the design is that the house is also marketable.
- To solicit builders and developers to build a pilot house or subdivision project.
- To plan for the evaluation and monitoring of pilot projects.
- To examine a broadened characterization of "performance" appropriate for compressorless houses and occupants.
- To develop applications and sizing information in California climates for compressorless cooling systems and hybrid cooling systems with a downsized compressor.
- To characterize barriers and to identify opportunities for adoption of compressorless cooling concepts by residential builders, developers, and customers.
- To present compressorless house concepts and prototype designs to building industry representatives, utility program managers, energy researchers and the general public.

Outcomes

- A prototype low energy cooling control system to enable operation of the house for night ventilation was developed and tested in two houses. The result was a demonstrated reduction in compressor cooling use while comfort was maintained in a relatively hot climate.

- Based on occupant interviews, the user interface was successfully used by the occupants to maintain comfort and reduce compressor use during an overheated period.
- Occupants were able to operate the controller effectively although they did not necessarily understand the technical details of the mechanical system.
- Feedback from the controller web page simulation identified modifications to the interface, which will inform the next phase.
- Feedback from the controller web page simulation confirmed the usefulness of the comfort range strategy in the interface design
- A Northern California prototype house design was developed. The Southern California prototype house was modified and a variation with street access to the garage was designed.
- Builders and developers in California were solicited to initiate a pilot house or subdivision program. Everyone contacted was interested in the prototype concepts and designs, but were unwilling or unable to commit to building a pilot project.
- A draft monitoring plan for physical factors such as climate and comfort, developed in Phase II of the ACC project (Huang memo July 31, 1996) forms the framework for physical performance evaluation of a pilot project.
- An expanded definition of “comfort” and the impact of time of use charges were both found to support the technology concept of the compressorless cooling design.
- During the performance analysis, problems were discovered in the DOE2 simulation that are still under investigation. The performance simulations for this phase of the ACC project have been re-checked and are correct.
- The Northern California prototype house performance simulations were not completed so applications and sizing information is based on the results from the Southern California house. The Northern California house is expected to perform even better.
- Performance simulations demonstrated that compressorless technologies will not maintain comfort in the Southern California prototype house in all California transitional climates. However, a substantially downsized compressor (1.5 tons) operated in concert with the night ventilation and house design will maintain comfort in all transitional climate areas and in all but the most severe hotter inland climates.
- Appraisers indicated that the disadvantages of a smaller compressor or no compressor would be offset by the superior construction. However, they would prefer to make their determination of tradeoffs based on an existing model for comparison with standard designs and construction.
- Current trends in the residential industry, which are complementary with compressorless strategies, provide opportunities for market adoption. These include interest in “green buildings” “new urbanism” and the embracing of “quality’ as a marketing strategy.
- The concepts and details of the compressorless house have been supported and given visibility through a regional design awards program, a series of public presentations, publications and web sites.

Conclusions

- Controls to provide optimized night ventilation cooling can be readily commercialized
- The optimized night ventilation cooling control is acceptable to and reasonably well understood by homeowners
- A marketable compressorless house design is possible to achieve technically and aesthetically within a reasonable cost-increase over standard construction.
- The adoption of the compressorless house approach by the residential builders and developers of California will require the completion of at least one pilot project to be used for demonstration of the technology.
- Financial incentives provided by energy cost savings are insufficient as a market driver for this technology. Time of Use incentives planned for Title 24 will improve this situation, however the first cost is still a significant barrier for builders and developers.
- Adoption of this technology offers significant energy savings, electrical demand reduction and increased infrastructure efficiency for the State of California.
- Air conditioning energy demand and peak electrical demand would be eliminated in many climate zones and significantly reduced in others. Under a conservative and a more aggressive market penetration scenario, air conditioning electrical consumption can be reduced by one-quarter to nearly one-half through the adoption of ACC technologies (Huang and Lutzenhiser, 1997). Peak electrical demands estimated under the same scenarios could be reduced by one-quarter.

Recommendations

The following major steps are necessary to advance the compressor cooling alternatives technology to commercialization:

- Decrease hardware and installation cost and increase system reliability by integrating components.
- Value-engineering and increased volume are necessary to decrease costs.
- Documentation of the controls and mechanical system should be developed.
- Transfer the technology to residential equipment manufacturers.
- Demonstrate compressorless technology and concepts in high visibility / high impact projects to influence builder / buyer awareness.

Abstract

This report presents the research and results of the PIER Transitional Phase (1998-1999) of the Alternatives to Compressor Cooling Project (ACC). In previous phases, the ACC project developed background research and applications information for residential new-construction performance improvements that eliminate compressor-based cooling and produced a prototype house design for the Southern California market. In this phase, the project focused on the development of an advanced ventilation control and user interface, the design of a prototype compressorless house appropriate for the Northern California market, technology transfer and a study of barriers and opportunities in industry adoption of the compressorless technology and design approach. The prototype house features an improved building shell with increased mass over standard California practice. The cooling strategies and mechanical options vary by climate zone and range from simple window ventilation to mechanical night ventilation. This phase has introduced the application of significantly downsized compressors for heat storm periods in hotter climate regions farther inland from the coast. The controls design includes an interim design of specially configured off-the-shelf equipment and the design and prototype of an ideal custom controls system. Field tests indicate that the controller can control night ventilation to provide comfort for occupants when coupled with indoor thermal mass, good shading, perimeter insulation and interior ceiling fans. Performance simulations indicate that the house will exceed Title 24 annual performance requirements and provide interior comfort with no compressor or reduced compressor use.

1.0 Introduction

This report presents the results of the Public Interest Energy Research (PIER) Transitional Phase (Phase IV) of a multiphase project titled Alternatives to Compressor Cooling (ACC). The ACC project, initiated by the California Institute for Energy Efficiency (CIEE), addresses rapid growth in the use of residential compressor-based cooling in the “transitional climate” areas situated between coastal urban centers and the Central Valley and desert regions.

There is no rigorous definition of the “transition climates” in California, but they can be roughly delineated as the area inland from the coast before reaching the Central Valley or Southern desert. These areas of transitional climates are alternately affected by marine and inland influences. As urbanization expands into the transition climate areas, new housing is constructed with central air-conditioning systems, although the overheated period in a transitional climate lasts for a limited number of days. In these “transitional climate” areas, low hours of air conditioning use create an extremely poor load factor with a substantial adverse effect on costs of service and electric system operations.

Phases I - III of the ACC project developed background research on alternative cooling for California transition climates and used the results as inputs for a design process which included leading architects from the California residential housing industry and award winning residential design architects. Parametric analysis and industry cost were used to optimize the designs and performance of a prototype three bedroom house. This design was refined into a prototype compressorless house design for the Southern California market, including a full set of mechanical options, acoustical and pressurization evaluation, completed structural design and cost estimates. The house design uses night ventilation, improved envelope characteristics and thermal mass as cooling mechanisms. The controls necessary for this new approach consist of specially configured versions of existing off-the-shelf equipment.

Phase IV of the ACC project is this PIER Transitional phase. This phase extends the previous work to address the Northern California markets, an optimized ventilation control and the possible initiation of a pilot project. Market transformation research and technology transfer activities will be continued and extended from previous phases.

Phase V of the ACC project, recently funded under the PIER II program, is titled "Integrated Ventilative Cooling." The goals of the PIER II phase include the development, refinement and integration of mechanical components, improvements to the advanced control design, extension of the integrated house design applicability to hot inland climates in California, and the commissioning, evaluation and documentation of demonstration houses in transitional and inland climates.

The ACC project in Phases I-III developed a single two-story house for Southern California which utilized an alley access to the garage in line with the “New Urbanism” trends evidenced in many Southern California municipalities. In The PIER Transitional phase reported here, the original Southern California house was modified to better fit a standard lot, a second alternative with garage access off the street was developed and a single-story Northern California prototype design was completed. Thus at the end of the PIER Transitional phase the prototype houses are: the Southern California house with alley access, the Southern California house with street access and the Northern California house.

The objectives of the PIER Transitional Phase of the Alternatives to Compressor cooling project were:

- To develop and test an optimized control for ventilation cooling while maintaining comfort conditions.
- To develop a user interface that allows users to successfully maintain comfort and reduce compressor use.
- To develop a prototype house design that incorporates features necessary for compressorless cooling in Northern California transitional climates. A key element in the design is that the house is also marketable.
- To solicit builders and developers to build a pilot house or subdivision project.
- Alternatives to Compressor Cooling o plan for the evaluation and monitoring of pilot projects.
- To examine a broadened characterization of “performance” appropriate for compressorless houses and occupants.
- To develop applications and sizing information in California climates for compressorless cooling systems and hybrid cooling systems with a downsized compressor.
- To characterize barriers and to identify opportunities for market adoption of compressorless cooling concepts.
- To present compressorless house concepts and prototype designs to building industry representatives, utility program managers, energy researchers and the general public.

This final report presents the work of the PIER Transitional Phase. Following this Introduction, section “2.0 Project Approach” addresses the need for compressorless cooling technologies in California, the technology concepts and the specific contribution of this phase to previous and future work. The next section, “3.0 Discussion” presents the research in four areas: 3.1 Ventilation Control Development, Testing and Evaluation; 3.2 House Designs, Evaluation, Performance and Application; 3.3 Market Transformation Research and 3.4 Technology Transfer. Following this in “4.0 Results”, the report presents the outcomes of the PIER Transitional Phase work. Section “5.0 Conclusions and Recommendations” discusses what was learned from this phase of the ACC project and identifies specific directions and tasks for the future, including steps for commercialization and economic and environmental benefits to the State of California.

1.1 Project Approach

Although current practice in the residential industry meets Title 24, new houses are still reliant on prosthetic compressor cooling systems and by themselves do not provide comfortable indoor conditions in any regions except the coast. Improved house designs with integrated advanced controls can substantially reduce or alleviate the need for compressor cooling, thereby addressing the extremely poor load factors of five percent or less which make residential air conditioning one of the least cost effective loads to serve. The relatively high distribution and transmission capacity development costs to serve these peak loads can also be reduced if houses are designed and built to reduce or avoid the need for compressor cooling. As one moves inland to hotter climate zones, compressor cooling is still required for comfort but improved house design and operation can significantly reduce both compressor size and use, resulting in significant energy savings and infrastructure reductions.

New residential development is a competitive, cost conscious and market driven industry, risk averse and skeptical of technological change. Reducing the compressor cooling loads in California houses depends on a whole systems design which includes the house design, building envelope, cooling technologies and control systems and operation, an integrated system approach to house design and performance that is not part of current design practice. Analysis tools, design guidelines and demonstrated effectiveness with currently available technologies and building trades are required for the adoption of alternative cooling strategies.

For the prototype house, technology concepts are defined as construction and mechanical system alternatives that are close to current construction practices and that have been shown to deliver performance and comfort as required for compressorless or significantly downsized compressor based cooling. Compressorless house designs have architectural features that reduce overheating during normal summer conditions as well as during the more extreme heat storms of the transitional climate areas. The design also features automatically controllable ventilation cooling concepts based on prototype controls. The technology that makes this work relies on ventilation cooling components selected from available components but assembled in ways that are not conventional in production housing.

This project has drawn from multi-disciplinary approach using architects, energy researchers, engineers, and sociologists to create an infusion of different ideas and concepts to inform the project. Unlike other efforts in residential energy efficiency that seek to improve an individual component, this project has approached this problem as an integrated design problem. Mechanical systems, controls, building envelope and construction, architectural organization, occupant behavior and market forces have been designed to operate together as an approach to reducing compressor cooling.

2.0 Discussion

2.1 Ventilation Control Development, Testing and Evaluation

The previous Phase III of the ACC project identified desirable control functions and user interface features for an optimal control that eliminates or minimizes air conditioner use by providing night ventilation cooling (Loisos 1998). In the current PIER Transitional phase the research team worked to develop and test a prototype optimal control (thermostat) that integrates ventilation cooling, air conditioning, and heating functions. A user interface design, conceived in the ACC project Phase III, was developed by the project team. From this design a "virtual" user interface design was developed and evaluated using an interactive web page[1]. A survey of hardware capable of accommodating the user interface and control functions yielded a control system manufactured by a local (Gold River, CA) firm, ZTECH. Software programs were developed for this hardware, and programmed controls were tested at two test houses previously equipped with outdoor air ventilation damper systems. To evaluate the controls, owners of the test houses were interviewed to determine how well they understood the concept of ventilation cooling and operation of the controls. This work is presented and discussed below.

[1] The web page is located at www.davisenergy.com/acc

2.1.1 User Interface Design

Prior work developed concepts for design of a user interface (or thermostat display) that would convey the concepts of ventilation cooling and that could be operated with minimal need to refer to an instruction manual (Loisos 1998). For ventilation cooling to be effective, the occupant must accommodate a comfortable range of temperatures, rather than a discreet thermostat temperature setting that the air conditioner maintains. At the same time, the occupant must be provided with some control over the indoor environment. The current phase of the project inherited several ideas from the prior project phase. The fundamental concept is to provide a means of setting upper and lower temperature limits such that ventilation cooling will not operate below the lower limit and air conditioning will not run above the upper. The design shown in Figure 1 was the product of an U.C. Berkeley master's thesis completed by project team member Eric Freitag.

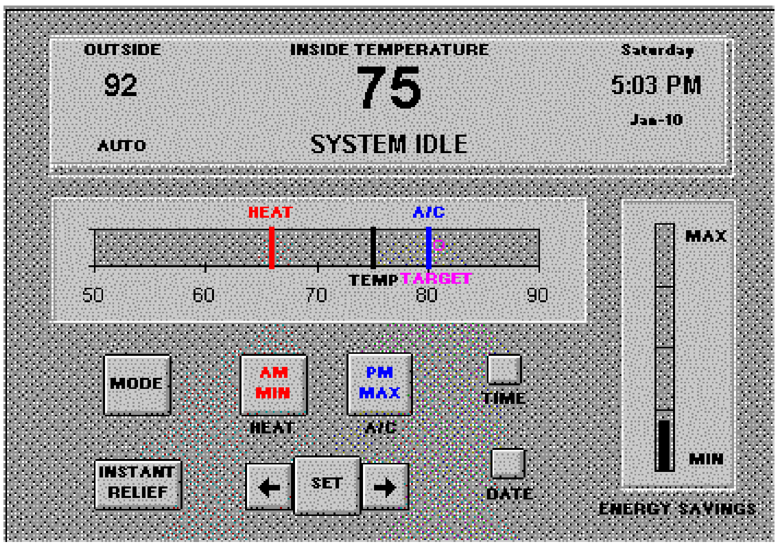

Figure 1. UCB User Interface Design

Design meetings were conducted during 1998 and 1999 to refine this control concept into a design that could be practically implemented. The team's architects, engineers, and social scientists contributed ideas to these meetings. Numerous iterations were developed and modified, both to meet the goals of simplicity and ease of use, and to satisfy functional requirements, which were evolving concurrently. The evolution of the control design involved compromises between simplicity of operation with little user control versus complexity of operation with complete user control, and between having a "busy" appearance with few menu options versus a simple appearance with numerous menu options. Other design issues dealt with by the team included:

- If the ventilation system cools to some established target temperature, what should this temperature be in mild weather and how should it be established?
- How should the system transition from air conditioning to ventilation cooling?
- What is the best way to implement manual override (instant comfort demand)?
- Should the display indicate only what the system is currently doing, or what it would do if the system were operating?

- Should auto changeover from cooling to heating be provided?
- Should the display of the expected temperature range be based on the current day or the peak day?
- What terminology and icons best convey control functions?

Early in the design process it was determined that the user interface should predict and display the expected indoor temperatures for the current day. This allows the user to readily see the impact of lowering the minimum nighttime temperature setting on the maximum afternoon temperature. This approach also introduces a valuable gaming aspect that may encourage the user to select settings that avoid air conditioner operation. For example, if the predicted maximum afternoon temperature exceeds the air conditioner (high limit) temperature setting, the air conditioner will run. The user can play with different low and high temperature limits to "beat" the air conditioner.

Several preliminary design versions of the Figure 1 user interface were developed and modified to arrive at the designs shown in Figure 2. The image shown in Figure 2 is displayed when the user opts to change "permanent" summer temperature settings.

Figure 2. User Interface Cooling Settings Screen

A menu structure with 20 individual displays was eventually developed, plus help screens to accompany each menu option. Figures 3 and 4 show the complete menu structure. The Mode key allows the user to cycle through the four operating modes (off, auto cool, auto heat, and vacation). In all modes the status of the fan and damper are indicated by an arrow icon that is an arc when air is recirculating and a wavy arrow when the fan is drawing in outside air. A window icon shows when it is appropriate to open windows for ventilation. The base display also indicates indoor and outdoor temperatures, and time.

The underlying strategy behind the user interface design is to ventilate the house to as low a temperature as acceptable whenever it is cooler outside than inside, and to inform the user of the impact of his/her temperature choices. The Set key provides access to permanent temperature settings, as well as immediate settings that override the permanent settings for short-term changes in temperature settings. Selecting permanent cooling settings displays the "comfort bar", which shows the predicted temperature range, based on the low and high temperature limits chosen, and is updated each day.

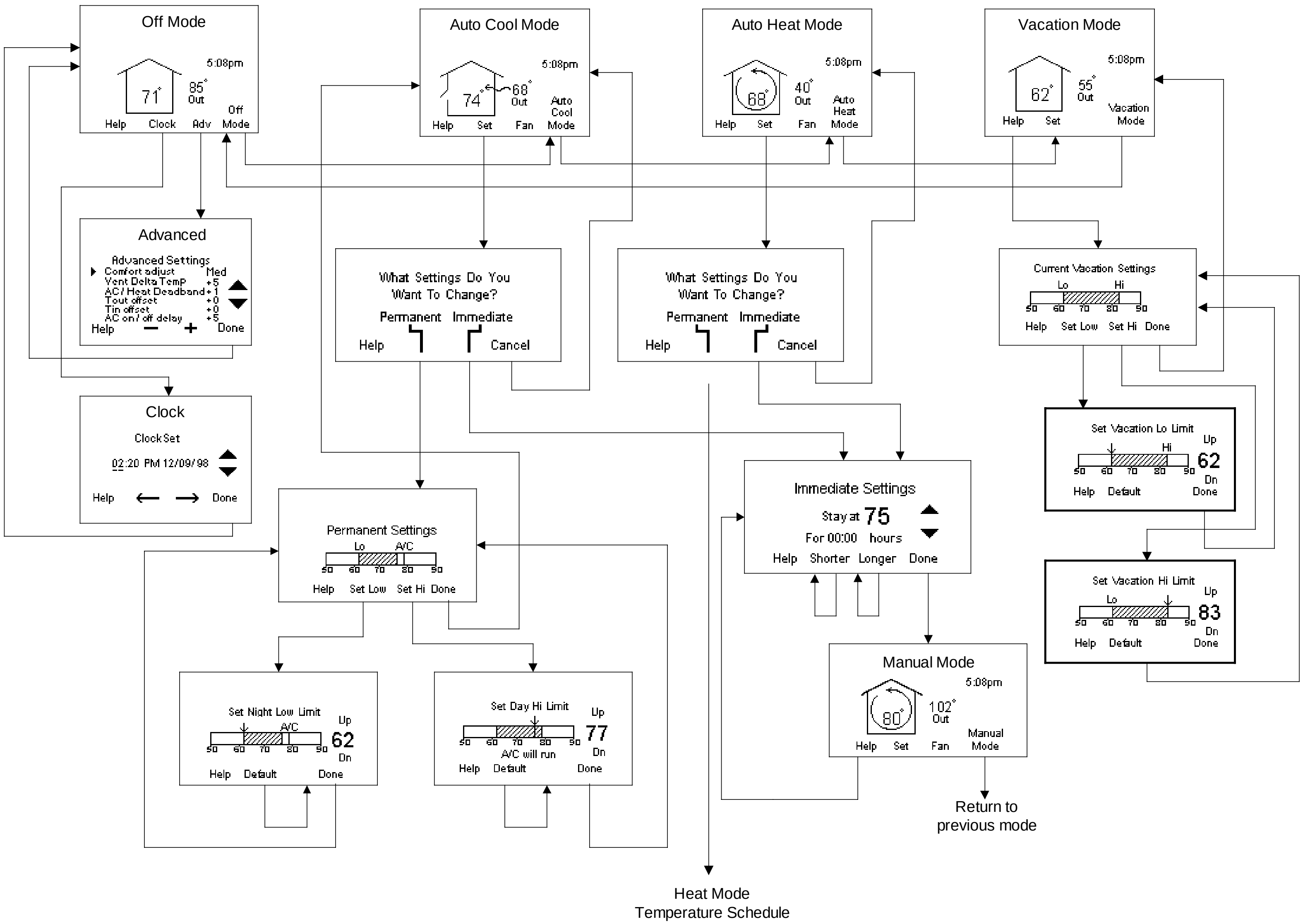

Figure 3. User Interface Menu Tree

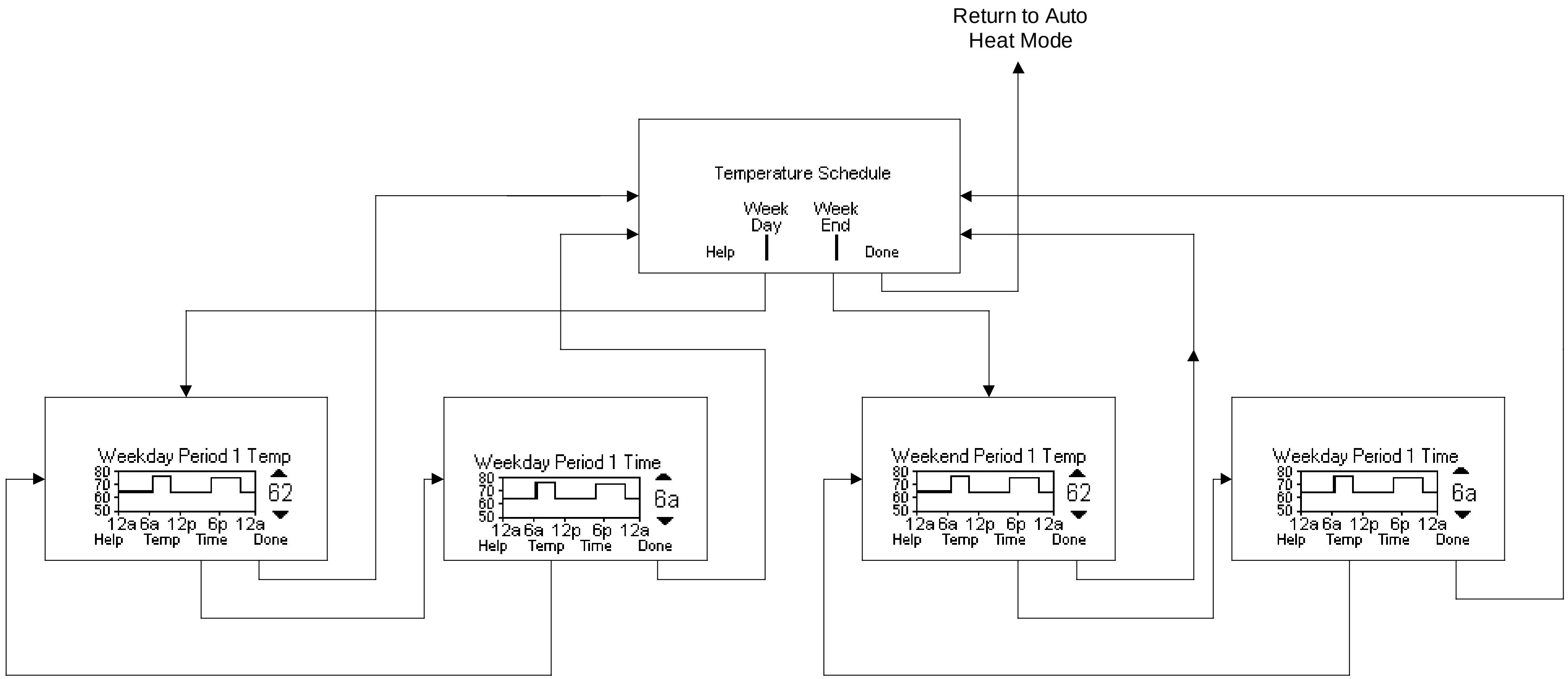

Figure 4. User Interface Menu Tree – Heating Mode Schedules

If the predicted maximum indoor temperature exceeds the air conditioner set point (Hi Limit), "A / C will run" is displayed. The temperature is displayed digitally as well as by the comfort bar while settings are being made.

To solve the problem of how much to cool the house by ventilation during mild weather, three comfort options were developed. For those who prefer cool temperatures, the control will always try to ventilate to the low limit. For those who prefer warm temperatures, the control will ventilate just enough so that the house reaches the high limit (without running the air conditioner). For those who are in between, the control attempts to maintain temperatures close to an average of the low and high limit settings. These options are selected through the advanced settings menu option ("Adv").

Vacation Mode provides a means of maintaining indoor temperatures within the specified range using the ventilation system, heating system, and air conditioner. This mode may also be useful for those who desire automatic switching between heating and air conditioning (auto changeover).

The "Immediate Settings", or manual mode option was included to meet the need for manual control of indoor temperatures for specific time periods, such as might be used if guests are expected, or if settings do not meet immediate comfort needs. Immediate settings can be accessed either by pressing an up / down temperature setting key, or by selecting Set, Immediate. After the time and temperature are set, the time display counts the remaining time backward to indicate how much longer the current temperature will be maintained.

Temperature scheduling, provided with conventional programmable thermostats, would conflict with the ventilation cooling strategy and so was not provided in cooling mode. However, a typical weekday / weekend schedule with four time periods was provided in heating mode. The graphical display of the indoor temperature schedule is unique, and provides an instant view of all settings, eliminating the need to execute a large number of keystrokes to view or modify an existing schedule.

The Fan key, which is seen while in Auto Cool, Auto Heat, or Manual modes, is used to manually operate the fan and damper (not shown in Figure 3). One press turns on the fan and recirculates air. Two presses turns on the fan and opens the outdoor air damper. Three presses returns to Auto mode. The fan arrow icon displays what the fan is doing.

2.1.2 User Interface Evaluation

In order to evaluate the distinctive features of the thermostatic control for the ventilation cooling system the project team developed a web-page prototype that allowed people to "run" the system in simulated form. Three dozen individuals were invited to "test drive" the simulation and then to fill out a brief questionnaire describing their responses to it. Twenty-five persons took up this invitation; the sample is of course small and also somewhat narrow, consisting primarily of persons involved in some way with energy or resource consumption issues, but in this initial interface study we wanted to solve problems that were clear even to those likely to be sympathetic to and not intimidated by the technology.

The results of this exercise were mainly what we had hoped for; in some cases respondents expressed enthusiasm for the venting approach, and responses were favorable beyond exceeded expectations. At least as a concept the approach was thought to be "excellent" or "marvelous," or "great" or "an elegant idea, one that directly addresses shortcomings in the existing residential thermostat approach." It is of some significance that several of the respondents emphasized the newness or novelty of the idea of a comfort zone or comfort range while several also noted that night venting was already a widespread practice. The novelty of the idea and the sophistication of the controller were matters of concern as well as celebration: is the notion of a comfort zone somehow inherently confusing? Will the fact that many people use their thermostats as a "valve" undermine the features of this system? Does the "look" of the controller make it seem too "technical and difficult?" or as in one case, "scary?" There were several suggestions for ways to improve the look of the icons or other features of the display, and a number of the respondents were concerned that in general the control process should be simplified. Some of the suggestions or concerns were not strictly appropriate or applicable, concern that the system dealt inadequately with humidity, for example. Some comments are especially difficult to address in advance, for example whether people will in fact tolerate the low indoor temperatures at 7 a.m. that they find quite acceptable at 2 a.m.

Several respondents addressed the problem of "educating" users to the use of the system; some because they needed help and the "Help" file in the controller was deemed unhelpful (though one person argued that even having a Help button would "lose half the audience"). Others urged that instruction be contained in a separate document that could be read while operating the controller. A significant, revealing feature of a number of the respondents' own learning, however, was their willingness to "play" with the technology. In some cases the simulation seems to have been approached as if one were setting a conventional set-point thermostat, this assumption undergoing correction only in the act of pushing buttons, interacting with, trying to "figure out" the control. This suggests to us that a user-friendly interaction between user and controller will require a learning-by-doing emphasis, one that features a written "walk-through" that gives attention to actual fingers on actual buttons, perhaps augmented by a CD or video and perhaps also by numbers to call for technical support.

2.1.3 Selection of a Development Platform

Work completed under the previous project phase sought to identify control hardware that presented a familiar appearance (similar to a thermostat) and provided the required functional capability. The best match was found in a prototype control that was developed by ZTECH for real-time pricing applications. The control has two components, a user interface (or wall display unit), and a controller. Both components include microcontroller chips that can be programmed to provide a specific display appearance and specific control functions. These components are linked by a communications bus, and can be coupled to an outdoor temperature sensor. The controller includes the necessary outputs to control an outside air damper, also manufactured by ZTECH, and the system fan, furnace, and air conditioner.

The wall display unit is similar in appearance to the user interface shown in Figure 2. It includes six buttons, which can be programmed to provide any function. Labels for the buttons can be programmed into the LCD display, and modified to suit any need. The combination of programming flexibility, similarity in appearance to conventional thermostats, and support by a manufacturer of residential HVAC controls make the ZTECH control a nearly ideal selection for accomplishing the project's control development goals. The major drawback to the control system is its high cost, which is attributable to its communications capabilities, and primarily to its prototype status and low production volume.

2.1.4 Control Logic Development and Programming

A functional specification first drafted in the prior project phase was updated to include the control features previously described. Development of the control logic and programming was influenced by the design of the user interface, and by the capabilities and limitations of the hardware. Many control issues that were discovered in the process of defining how the user interface should respond were dealt with in the process of developing the control programs. Individual programs were written (in C language and assembly code) for the wall display unit and the controller. Upon completion of the necessary communications routines, the two devices were linked and tested as a unit. Improvements to the algorithm that predicts indoor temperatures are ongoing, and is the subject of a master's thesis in Statistics being prepared by Barbara Okihiro of Davis Energy Group.

2.1.5 Preliminary Testing

Prior to testing the controller in the field, it was first "bench" tested to identify software bugs. Upon elimination of obvious bugs the system was tested with the Davis Energy Group office heating and cooling system, and in an employee residence, where it was used to control a whole house fan. These tests resulted in minor improvements to the display and control algorithms.

2.1.6 Field Test Methods and Technical Results

The primary objective of field tests conducted in this project phase was to evaluate whether the user interface effectively guides its users towards effective operation of the ventilation cooling system, and conveys an understanding of the principals of ventilation cooling. A secondary objective was to test the operational capabilities of the advanced control in typical residential settings. Since the two test houses do not incorporate the design features of the "compressorless" house and are located in a hot climate, the test was not intended to demonstrate elimination of air conditioner use.

Two locations were selected for installation and testing of the advanced control. They were selected from the four sites that were used for the previous Night Vent monitoring field study because 1) the occupants were already familiar with the night ventilation concept, 2) the houses had working night vent dampers installed, and 3) data were available from previous monitoring for comparison. Both sites selected are located approximately 15 miles east of Sacramento, in the Granite Bay and Folsom Lake areas. Both houses are approximately 2900 ft2 two story slab-on-grade houses built in 1996. Both houses have 5-ton air conditioners that are controlled by a two-zone thermal equalizer system consisting of two thermostats and two zone dampers.

The Folsom Lake house is semi-custom built with high ceilings, a large percentage of exposed mass, north-south orientation, interior shutters on most windows, and ceiling fans in most of the rooms. The occupants are very active in operation of the house, opening and closing the windows every morning and evening in order to help cool off the house.

The Granite Bay house is a typical spec development house with an east-west orientation. The occupants, while enthusiastic about the night vent controller, do not manage their windows and are for the most part disinterested in the day-to-day operation of the house.

A test plan was developed to guide field test procedures. Before monitoring was initiated, the conventional ZTECH SmartVent controller was replaced with the prototype advanced Night Vent controller, and one of the standard thermostats was replaced with the new control user interface. A separate low limit thermostat was eliminated, as low limit functions are included in the advanced control. Since advanced control uses a different type of outdoor air temperature sensor, this sensor was also replaced.

Data monitoring equipment consisting of three ACR "stick-on" loggers was then installed at each site to record seven channels of data on a 10 minute basis. The measurement points recorded are summarized in Table 1.

Table 1. Measurement Points for Advanced Night Vent Controller

Logger	*Location*	*Measurement*
ACR SR2	at thermostat	Dry bulb temperature Relative humidity
ACR SR2	at outdoor sensor	Dry bulb temperature Relative humidity
ACR SR7	at HVAC unit	Fan status Vent damper status A / C status

The homeowners were given a tutorial on the use of the new control, an owner’s manual, and a log sheet on which to record any comments or questions that they had during the monitoring.

The new controls and monitoring equipment were installed at the Granite Bay house on July 30, 1999 and at the Folsom Lake house on August 5, 1999. Data were recorded for 70 days until October 15th. During the course of the monitoring, a number of changes were made to the control firmware to incorporate new prediction algorithms and to correct bugs that were discovered. On September 10th the outdoor sensor at the Granite Bay house failed and night venting was not active until the sensor was replaced on the 21st. The Folsom Lake house was occupied the entire time but the occupants of the Granite Bay house left on vacation three times for a total of twenty days.

Initial thermostat settings are shown in Table 2.

Table 2. Thermostat Settings

	Granite Bay	*Folsom Lake*
Low Set Point	65	65
High Set Point	78	76
Comfort Setting	Medium	Cool

Average daily values for all of the monitored data are summarized in Table 3. The average daily outdoor temperatures of the sites are very similar, with the Folsom Lake area being slightly cooler due to its higher altitude. The daily indoor temperatures reflect the difference in the thermostat settings and operation at the two houses; The Granite Bay house average minimum temperatures were six degrees warmer than the Folsom Lake house because of the Medium comfort setting and worse ventilation performance due to the closed windows. Even though the Granite Bay residents were away for almost one-third of the time, the average A/C operating hours are still almost 50 percent higher than the Folsom Lake house due to the poorer house design and orientation, and less effective night ventilation. The Folsom Lake house exhibits significantly greater vent operating hours due to a smaller vent delta-T setting and the faulty outdoor sensor at the Granite Bay house.

Table 3. Summary of Average Daily Performance Data

	Granite Bay	*Folsom Lake*
Average Daily Monitored Temperatures (°F)		
Indoor		
Maximum	77.3	76.3
Minimum	72.4	66.4
Average	75.1	71.4
Outdoor		
Maximum	93.5	91.7
Minimum	60.7	59.7
Average	75.0	74.4
Average Daily Hours of Operation		
Air Conditioning	1.5	1.1
Night Vent	8.7	12.0

Figures 5 and 6 show the daily ventilation and air-conditioner operating hours graphed versus the daily high temperature. Both houses exhibit a steady decline in vent operation and an increase in A/C operation with increasing temperature, although the trend is not as clear for the Granite Bay house due to the changes in operation and control problems there. The ventilation hours decrease with increasing temperature because there are fewer hours during hot days when effective ventilation can take place. One would also expect a reduction of ventilation hours under mild outdoor temperature conditions, but this is not observed at either site, probably due to the less-than-ideal design of the houses.

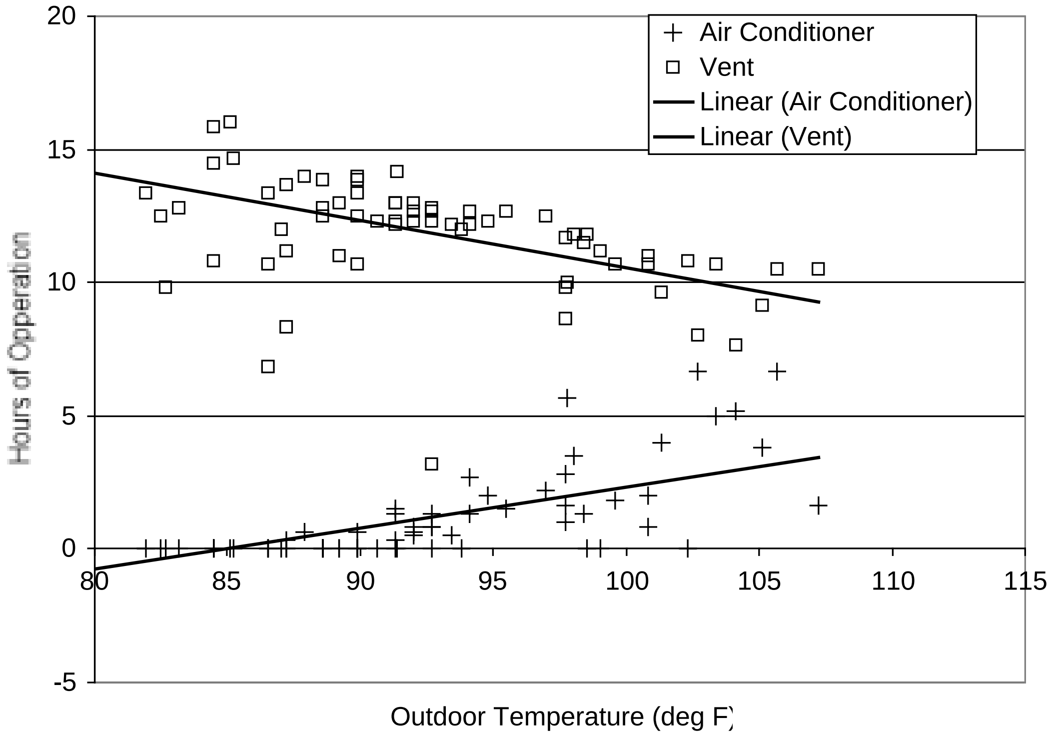

Figure 5. Folsom Lake Operating Hours

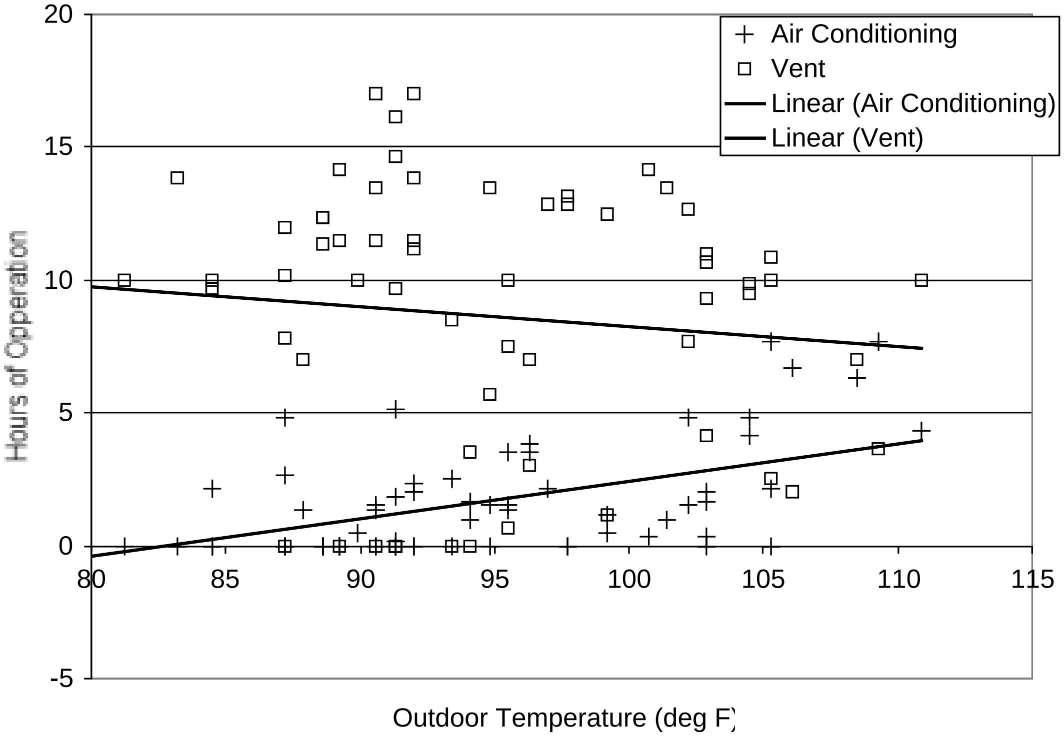

Figure 6. Granite Bay Operating Hours

Figures 7 and 8 show the temperature profiles for both sites for day of August 19th. Differences between the sites can be seen most clearly in the indoor temperature profile. The Folsom Lake indoor temperature falls with decreasing outdoor temperature during the night but the Granite Bay indoor temperature drops only five degrees due to its lower relative ventilation rate and higher solar gain. Because of this, the air-conditioner ran twice during the afternoon in order to maintain the air conditioner set point.

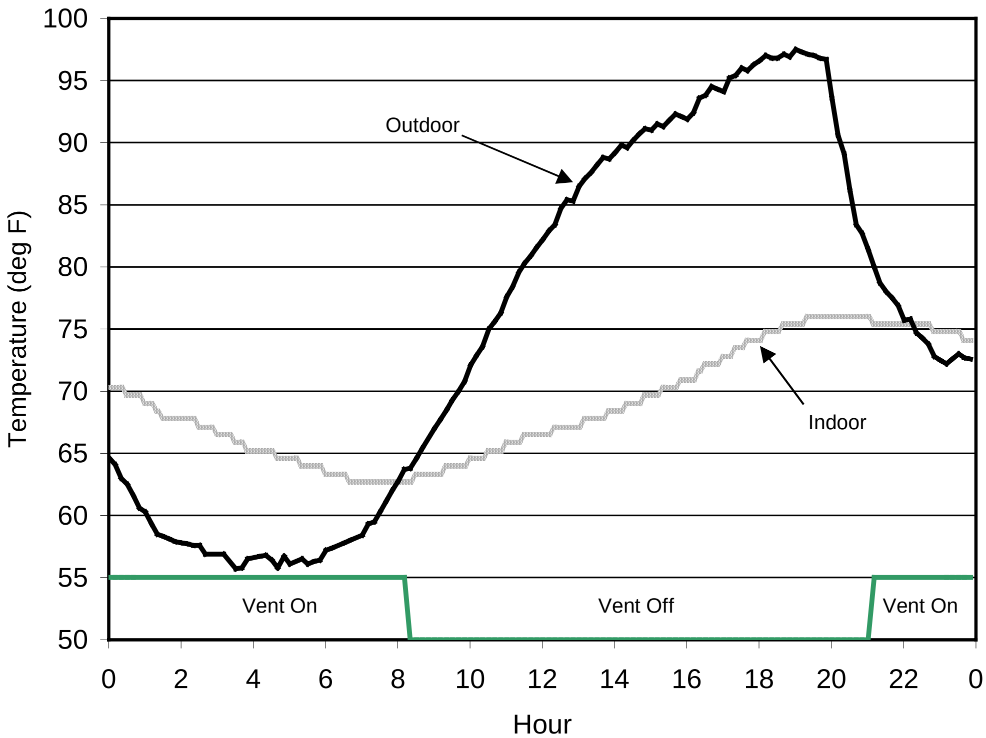

Figure 7. Folsom Lake Test Site Temperatures, August 19th, 1999

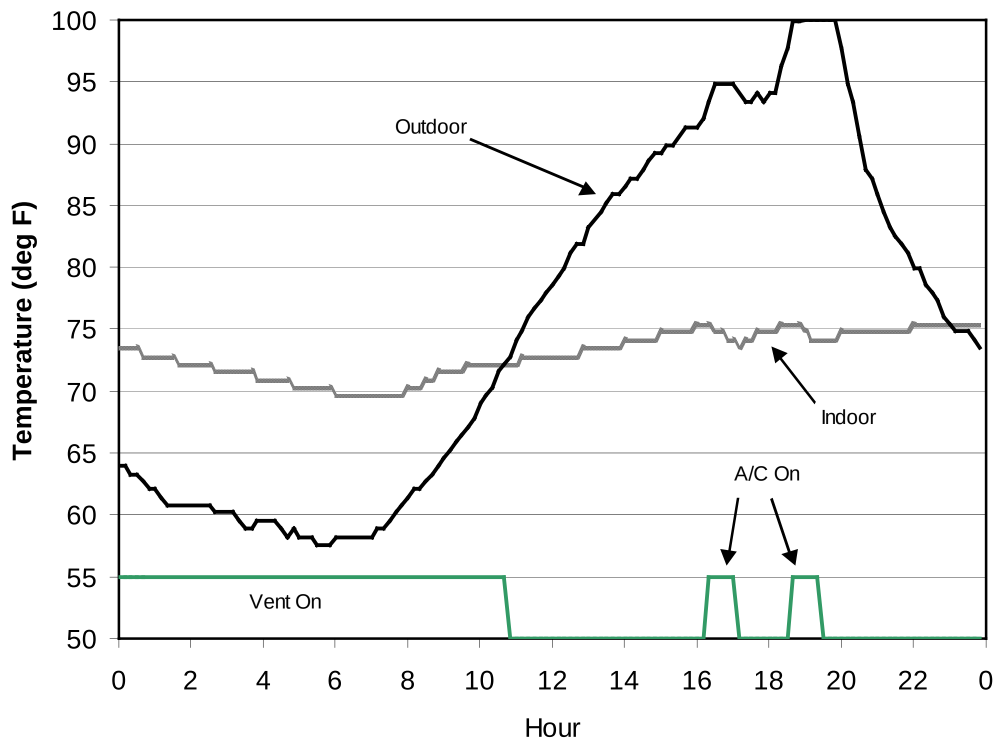

Figure 8. Granite Bay Test Site Temperatures, August 19th, 1999

Summarizing these results, the advanced control met technical design criteria, and operated the dampers, system fans, and air conditioner compressors as intended, with the exception of the problems noted above. The test houses lack the added thermal mass, efficient windows, and other measures included in the "compressorless" house, and have inadequate ventilation (about 1600 cfm) and insufficient air relief (especially the Granite Bay house). Despite these handicaps, the data suggest that the ventilation cooling systems effectively offset air conditioner use. Favorable owner responses (see below) indicate that the advanced control may find a market niche in standard houses and retrofit applications, not only in compressorless house designs.

2.1.7 Field Test Occupant Interviews

The occupants of the two homes where the new controls and monitoring systems were installed, both of them married couples without children at home, were interviewed at the time of the installation and at the end of a period of approximately two weeks during which time they had agreed to rely on the venting alone and to use the new controller. The objective of the interviews was to determine the occupants' perceptions of how well the system worked, and also whether they understood its workings and what improvements might be made.

In both homes the couples were pleased with the operation of the night ventilation system -- "Every home should have one of these!" in the words of one husband-- and agreed that if they were to buy or build another home they would surely install one. Apparently one of the unanticipated pleasures of this cooling technique has been invidious in both cases: they enjoyed listening to the sound of their neighbors' air conditioners running while theirs was not. It surprised us somewhat to find, however, that in spite of this enthusiasm neither couple fully understood how the venting system operated. We suppose this to be explained in part by the short period of our monitoring and by the fact that extensive knowledge of the system was hardly required, since they were asked to establish a comfort range and to avoid varying the settings or operating the system "manually" during the monitoring period. Of course how much "knowledge" of the system can be realistically expected, or even needed, remains an open question and, where "learning by doing" is required is largely a product of, rather than a prerequisite for actual system use in any case.

Both couples (the women primarily) were also somewhat concerned about being too cold. In one home this was expressed as mainly a problem of cold air falling directly on a person in one part of the house, a problem that could probably be treated as a register-placement issue, but at both test homes low early-morning temperatures were less than happily received. In neither case did this seem to count seriously against the night ventilation system, but in the absence of our monitoring it could well result in some upward creep in the low-end temperature setting. This possibility is reinforced by the fact that in both homes there was some evidence of the usual "thermostat wars" (e.g. husband closes the house at 6:30 a.m., goes jogging; wife arises and opens the house); heating and cooling has an ineluctably "sportive" dimension here --the "comfort" provided by the sound of the neighbor’s air conditioner is another example-- that makes it difficult to predict the system’s actual use after the evaluators have departed.

The two homes differed in that one couple kept the windows and doors closed whereas the other opened the house in the evening, and here we discovered another unanticipated feature of this venting arrangement: when the SV fan turned on it told the "open house" couple that it was now all right to open the windows. The other couple didn’t enjoy this feature, of course, but they did give pride of place to what otherwise might be thought a secondary feature of this machinery, namely the availability of a "Vacation" mode; with the SV system in place, their previous tasks in preparation for being away from the house for an extended period (a frequent occurrence) seemed especially laborious.

When the new controllers were installed the two couples were given operating manuals designed to smooth their interactions with the system; except for very cursory initial examination the manuals were not utilized. The "If all else fails, read the manual" rule seems to have been in force here as it apparently often is, especially among men. Our sense from these and other interviews is that the manual is an ancillary device that at best exists to confirm or disconfirm what the learning-by-doing process produces. In fact the manual’s consequence may be at best double-edged or even negative, as in the case of the Help option in the simulation noted above. In a related inquiry undertaken during this research period, regarding the effort to sell a super-efficient PG&E research house in Davis, the owner said that he "should never have shown people the operating manual for the heating and cooling system because having a manual made the house seem like a terribly complicated appliance."

2.1.8 Recommendations for Control Improvements

Based on these very limited data sets, interview results suggest the following:

- Cooling by night venting seems to work well, at the very least to limit AC use, and to be well received by people not opposed to air conditioner use. This acceptance, however, may be primarily a consequence of experiencing the venting system, so that promotional efforts might emphasize testimonials or even, where the new controller can be installed, direct experience of the sort made possible by this research.
- The "education" of the user of the controller should not depend on the use of a conventional manual, though one can supplied, but should emphasize a practical, hands-on walk-through that should be separate from and not pre-empt the use of the controller --a written-down and illustrated document, perhaps also a CD or video.
- Careful attention should be given to making the ventilation cooling as unobtrusive as possible, perhaps especially in the early morning; we assume this to be primarily a register-placement issue.

These interview and evaluation data will be significantly augmented in the next phase of this project.

Several improvements to the control system are planned in the next phase of this project, and include:

- Improvements to the user interface design improvements based on current project results and additional evaluations to be completed
- Adding the capability to control a variable speed blower motor
- Improvements to ventilation cooling algorithms to take advantage of variable speed technology
- Potential provisions for continuous fresh air ventilation
- Potential provisions for off-peak air conditioner operation

Marketability of the advanced ventilation control would be substantially improved by the availability of a single integrated heating, cooling, and ventilation delivery unit to which the control can be easily connected. This technology is slated for development in the next project phase. Further work is needed to reduce the cost of the control by eliminating unnecessary communications capability and otherwise simplifying the hardware.

2.2 House Designs, Evaluation, Performance and Application

In this phase of the ACC project, the research team developed a complete design package for a single story Northern California house, solicited builder and developers to build a pilot project, continued planning the evaluation of a pilot project, developed a broadened definition of "performance" more appropriate to the compressorless house and used simulation tools to predict the performance of the prototype house for applications information. This work is presented and discussed below. For full details see "Prototype Summer Performance Houses for California Climates - Builders Information Package" available from Loisos / Ubbelohde dated January 2000 (e-mail: george@coolshadow.com)

2.2.1 House Designs

In this PIER Transitional phase, the design of the Southern California house was modified based on comments from the advisory committee and outside reviewers. In addition, a variant of that house which provides garage access directly off the street was developed that increases its marketability. A smaller, single story Northern California prototype was developed to respond to the market in Northern California.

The prototype houses all share the following features:

- Cooler Interiors during hot summer days. In the afternoon after work the interior of the house will be welcoming cool and comfortable without the necessity of running the air-conditioner. This will allow the residents to enjoy the indoor-outdoor nature of the house participating in activities such as barbecues, child playing with the doors and windows open. If the residents want to retreat inside and keep the doors closed the house will be comfortable with all doors and windows closed.
- Sound Walls. The construction of the house will provide a quieter interior. The parents will be able to rest while their children enjoy their music, video games etc.
- Increased Fire Safety. The walls provide increased fire separation within the house. The walls are built to commercial two- hour fire separation levels.
- A Solid House. The construction of the house feels solid. The prospective homeowner will appreciate the permanent feel of the house.
- A Healthy House. The house designs create a pressurized interior allowing the option of complete filtration of exterior and interior air from allergens. In addition the finishes of the house are designed to reduce the most common sources of allergies.
- Large Spaces, High Ceilings. The house designs offer large ceiling heights in the common areas with vistas through to the garden allowing a spacious feeling.
- Modern Large Master Bedroom Suites. All designs offer large spaces for the homeowners with walk in closets and large bathrooms.
- Porches. All designs offer porches that provide outdoor sitting areas
- Hidden Garages. Both homeowners and local planning officials will appreciate the lack of garage doors on the street side elevation.
- Modern Amenities. All designs have spaces for Media Centers to provide the most current home entertainment systems.
- Walk in Equipment Closet. All conditioning equipment is accessible for easy maintenance.

These houses form the "bread and butter" of the California housing industry output, positioning them in the mainstream of development houses in the state. The houses are assumed to be built in the context of a subdivision or development that contain similar houses, either variations on these ones or similarly sized and arranged houses with varying aesthetic treatments on similar plan arrangements.

2.2.2 Architectural Description of the Prototype Houses

1. Southern California Prototype House and variation

Figure 9. Southern California House Prototype Street Side Elevation

A two story, single-family detached house on a standard size lot with 3 bedrooms, 1 bonus room (office / bedroom) 3 bathrooms, a three car garage accessible by a driveway on the side of the house (zero lot line). (Illustrated in Figures 9, 10 and 12):

Lot Size:	6,066 sf
First Floor Area:	1,349 sf
Second Floor Area:	1,033 sf
Total:	2,382 sf

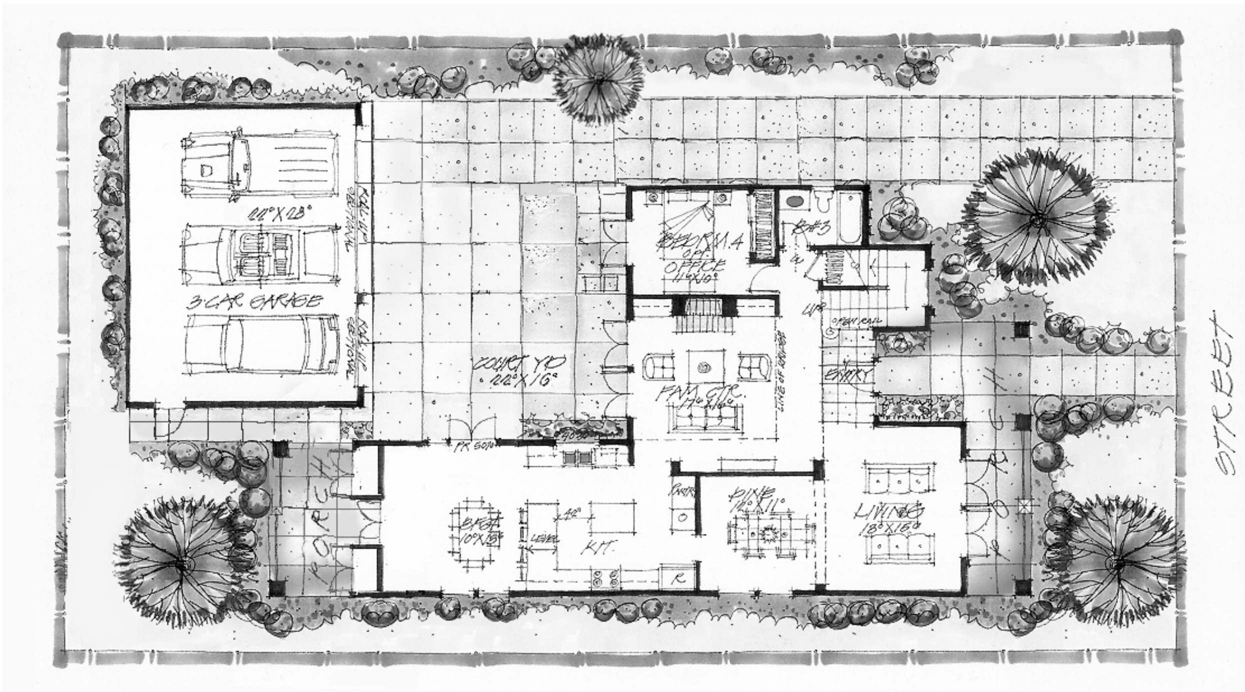

Figure 10. Southern California House Prototype with Street Access First Floor Plan

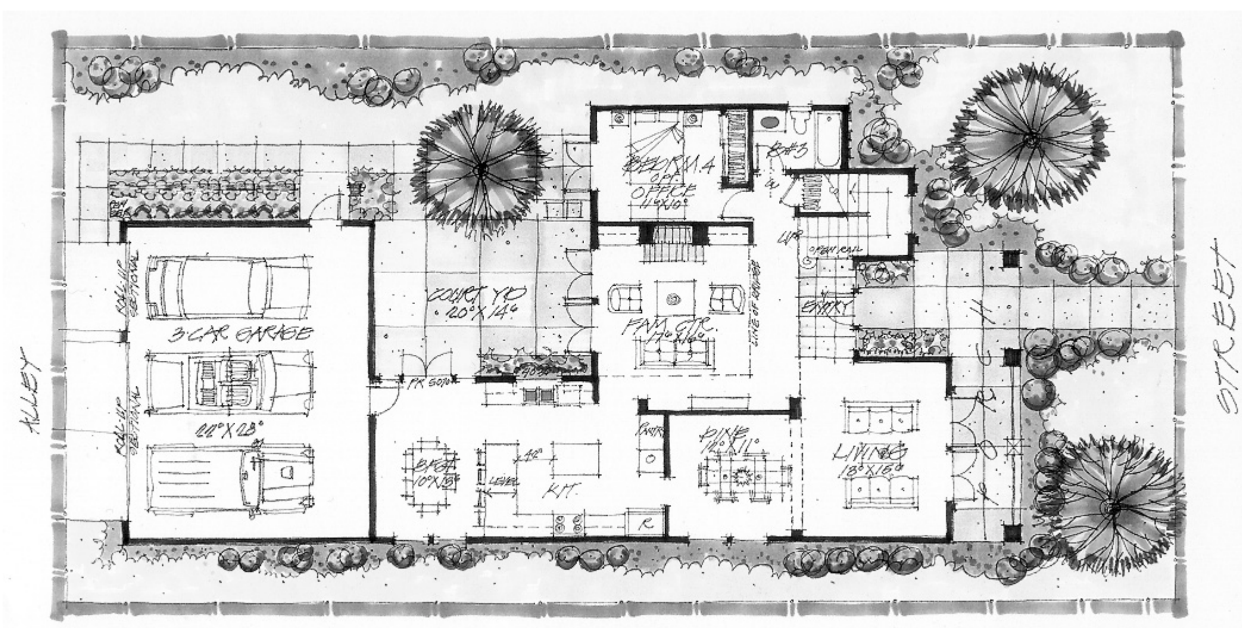

Figure 11. Southern California House Prototype with Alley Access First Floor Plan

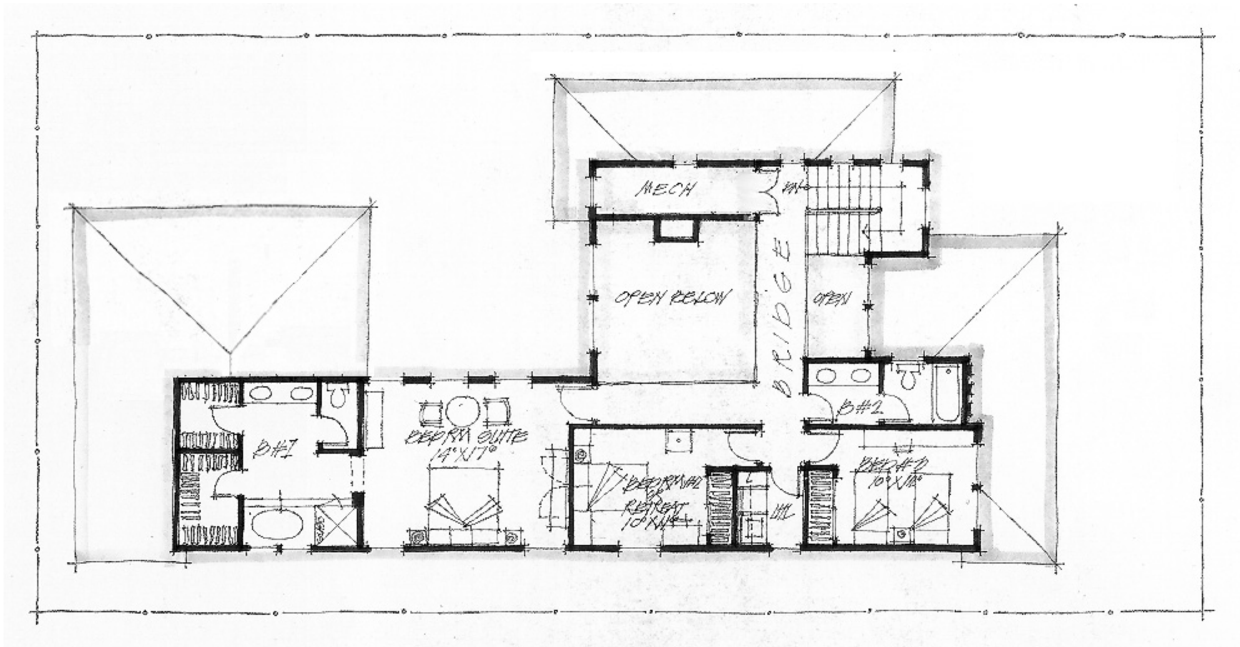

Figure 12. Southern California House Prototype with Alley Access Second Floor Plan

A two story, single-family detached house on a standard size lot with 3 bedrooms, 1 bonus room (office / bedroom) 3 bathrooms, a three car garage on a rear alley access. (Illustrated in Figures 9, 11, 12)

Lot Size:	5,000 sf
First Floor Area:	1,310 sf
Second Floor Area:	1,092 sf
Total:	2,402 sf

The ground floor of both houses features a front porch entry off the street into a double height entry space and a formal living room with double French doors onto a small porch facing the street. The living room gives onto a formal dining room, which connects to a kitchen with breakfast nook facing onto the courtyard. The entry also brings one directly to a double-height family "great" room with media wall and fireplace. The kitchen, nook and family room give onto a shaded courtyard through paired French doors, creating an exterior room for eating, play and entertaining. A fourth bedroom or home office with bath and the garage complete the ground floor.

The upper floor contains two bedrooms with shared bath and a large master bedroom suite overlooking the courtyard with private bath and his and her walk-in closets. The house construction is based on standard industry techniques and materials: concrete slab on grade with wood frame walls and wood truss roof, batt insulation and exterior stucco. Windows and French doors are vinyl frame with double pane insulated glass. Interior options include tile or slate floors on the ground floor to replace carpeting.

Concerns about the visual impact from the curb are addressed in the massing and the aesthetic treatments of the frame and stucco walls. Upon entering the house, one is able to see through into the back garden, in this case the shaded courtyard, as well as to see the stairs that lead to the rooms above. The suite of rooms which form the "family" area of the ground floor (kitchen, nook and great room) are celebrated with extra volume, easy connections and drawn together with the courtyard, which will serve as an additional room for much of the year in the transitional climates. The provision of the media wall and fireplace finish out the great room. The master bedroom is large enough to serve as a separate "parents' realm" with features such as a luxury bathroom and individual walk-in closets. Following the growing practice of the housing industry, an additional room with bath is provided on the ground floor to serve as an extra bedroom, home office and / or in-law room.

The three car garage is now standard for this size of house. Some new developments in the state of California are locating the car and garage at the back of the lot with the provision of an alley. This has not typically been the choice of the developer, but usually a requirement of the local planning agencies, which are trying to promote the revitalization of the street as a public place in these new developments. Both the alley access and the street access houses feature a front porch and windows onto the street, bringing back traditional street conditions before the advent of the large garage dominating the front of the house. This interest in traditional forms, such as porches, trellises, and courtyards is a growing trend in the housing industry and is supportive of the porch entry, the overhangs and the courtyard approach to exterior space designed into this house.

2. Northern California Prototype House

A single story, single-family detached house on a standard size lot with 3 bedrooms, 2 bathrooms, and a two car garage accessible by a court on the front of the house. (Illustrated in Figures 13 and 14):

Lot Size:	5,460 sf
Floor Area:	1,998 sf

Figure 13. Northern California House Prototype Street Side Elevation

This house features a front entrance off a court that serves both as a formal entry and a driveway to the garage. This feature removes the garage door from the front elevation making the facade less dominated by the car, and also provides for a semi private usable space in the front of the house. This is further reinforced by the porch that faces the court. Inside, the raised sloping ceiling of the living / dining area provides an expansive space leading into the family, kitchen, and breakfast nook areas to the rear of the house. To the right are the bedrooms, given privacy with the tech center and linen closet that separates the more private areas from the living room. Through double doors off this hall, one enters the master bedroom suite, which features a walk in closet, large bathroom and access to the back patio and garden through French doors.

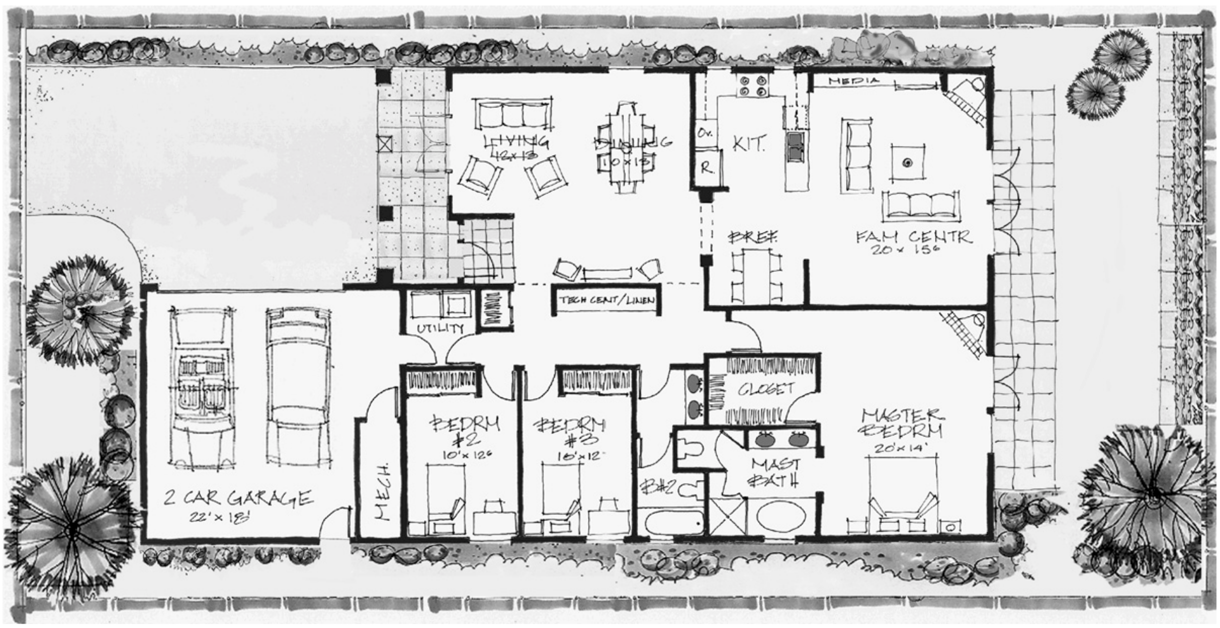

Figure 14. Northern California House Prototype Floor Plan

2.2.3 Energy Features of the Prototype Houses

To reduce dependence on compressor cooling and still maintain comfort for the occupants during overheated periods, the houses cannot be built exactly like a standard industry house, but must improve the performance of both the building shell (walls, roof, windows) and the mechanical systems. In addition, a critical component is the advanced thermostat that controls the operation of the house in response to exterior conditions.

Building Shell

Most strategies for improvements in the residential building shell have been the object of previous research, market outreach and exhibit few technical barriers. They are also easily described and understood in the residential construction industry, even if not widely used or optimized in current residential construction. As such, these may be the best developed and least contentious strategies for helping to achieve the desired thermal performance.

- Insulation. In the roof, increasing use of truss systems permits the easy addition of increased insulation levels. Roof insulation options we have investigated range from R19 to R40 and R40 was selected. In the walls, batt insulation is far less expensive than rigid, however, additional insulation over that which fits into the stud construction is most easily achieved with rigid board. The cost of the rigid insulation relative to improved performance of the walls ruled out the use of this option in the final optimized prototype design except where used as part of the stucco application system. The wall insulation was specified at R-33. Slab edge insulation for the ground floor slab at R-5.

- Windows. Window technology has certainly been developed to satisfy all but the shading requirements for residential applications with costs of high performance glass falling. Low-E and multi-glazed windows are now standard in many markets and "good windows" although commonly understood to cost more are often also considered a good investment by homebuyers. The particular location within the transitional climate region of the state, however, will determine the appropriate type of low-e glazing and coatings used. Options looked at ranged from U values of 0.48 with heat gain coefficient of 0.71 to a high performance U value of 0.31 and Solar Heat Gain Factor of 0.37 (Shading Coefficient of 0.43). The latter was specified. If combined with high visible transmission (above 0.50) this glass is spectrally selective, or cool glazing category, glass that allows most of the visible spectrum to enter while excluding other spectra that increase heat gain. This will allow the residents to enjoy the transparency and light without the thermal penalty of this glass. A less expensive option is to use glass with the same U value and Shading Coefficient (or Solar Heat Gain Coefficient) and a lower Visible Transmittance. This will allow similar thermal performance. However, the glass would appear tinted and therefore would not allow as much light as a spectrally selective glass.
- Shading. Part of the current marketing strategy for many residential housing developments is to use traditional forms and architectural components which recall a more generous, leisured lifestyle.
- Vernacular elements such as overhangs, porches, trellises and the like are back into vogue in a large way, and offer both marketing and shading opportunities for the Summer Performance house. Eve overhangs are 12" where there are no windows to shade and 36" over all wall areas that include windows. Additional shading is provided by neighboring houses at 10’ away on the long sides of the houses.
- Infiltration. The tightness of the building envelope was assumed to be similar to a moderately tight house and modeled with a leakage fraction of 0.0006. Because the summer infiltration rate tends to be low due to low wind speeds and temperature differences, we did not investigate a variety of building envelope infiltration rates. Varying this characteristic does not affect the results in any significant way.

Interior Construction

Transitional climates are good candidates for increased thermal mass, especially coupled with night ventilation. However, most new residential construction in California uses standard wood stud walls, stuccoed, slab on grade first floor with wood joist upper floor. This offers the first floor concrete slab as thermal mass. The primary question relative to thermal mass is how and where to incorporate the mass into a typical residential design, both technically and economically.

Floors. One approach to increasing thermal mass is to cover the slab with a non-insulative covering such as stone or tile. In the right locations in the house, these can also be perceived as a higher quality covering than carpeting. We have specified tile floors on one-half the first floor as an option in the performance analysis and looked at both slate and tile in the cost estimates.

Walls. Another strategy for increasing thermal mass is adding layers of gypsum wallboard to both interior and exterior walls. Increasing the mass in interior walls works as a thermal flywheel. Thermal mass options investigated included added thicknesses of gypboard (e.g. ¾" as compared to regular ½") as well as interior walls constructed entirely of a sandwich of 3- ¼" gypboard. The 3- ¼" sandwich approach yielded the best performance as expected, but cost criteria for this project eliminated it from the final designs. External walls with additional mass can significantly delay the thermal impact of high exterior temperatures and solar radiation and the options studied include standard 1/2" gypboard and a 3/4" gypboard on the interior finish of the exterior walls.

Mechanical Systems

The houses are designed to require less cooling than current production houses, however, in order for them to work in climates where it is not economical to rely on envelope design alone, the houses will need additional cooling. This can take a number of different forms based on the amount of cooling that is required by the local climate and the economics of the system proposed. In addition, winter conditions will necessitate some heating. Interior loads have been assumed as 45,322 Btu/day plus three people coupled with a load schedule based on a series of previous research projects on residential energy use in California. Cooling is provided through nighttime ventilation with filtered air and thermal storage of "coolth" in the building mass. Besides saving energy and reducing peak load, this approach is advantageous to those occupants who need to control allergens introduced with outside air and who now rely on compressive cooling to filter the air. Optimal control of ventilation cooling depends on the type of system described in Section 3.1 of this report. The following mechanical options for providing ventilation cooling systems that respond to all California climate types were explored:

- Option 1. Mechanical Ventilation Using Outside Air. Cool night air is delivered using the furnace fan and heating duct distribution system. The airflow required for heating is much less than what is desirable for ventilation cooling; to avoid substantial duct over-sizing this option limits the ventilation rate to 1500 cfm. A damper added to the system switches from indoor air recirculation to outside air ventilation when it is cooler outdoors than indoors. The SmartVent damper manufactured by ZTECH appears to provide a reliable, affordable alternative to commercial economizer dampers and other damper systems not designed for this application.
- Option 2. Indirect Evaporative Cooling Precooling. This option augments mechanical ventilation by adding an indirect evaporative cooler to pre-cool the ventilation air. The mechanical drawings and specifications identify the indirect cooling module as an IDAC two stage evaporative cooler with the direct evaporative cooling disabled. The capacity of the IDAC also constrains this option to 1500 cfm.
- Option 3. High Volume Indirect Evaporative Cooling. This option is identical to the one above except that the air volume is increased to 3,000 cfm. There is currently no "off-the-shelf" equipment meeting this airflow specification.

- Option 4. Small Compressor Cooling. This option employs the use of a small (1.5 ton) central air-conditioner that allows application of the house designs to almost all California climate zones except the hottest regions of the State. A control option could use the air conditioner to pre-cool the house during the night to eliminate operation during peak load periods.

2.2.4 Cost of the Energy/Comfort Features

House construction costs can vary widely depending on volume of house construction, location (this refers to labor and material cost as opposed to site costs and permitting) and time of construction (some materials, such as lumber, have volatile pricing depending on demand). In general during this project, we have observed construction cost fluctuations that go from a low of $45.00 per square foot (for production building in Southern California during 1997) to a high of $130.00 per square foot for the same house (for one-off custom construction in Northern California at the end of 1999). Given this reality, any discussion about cost has to be accompanied with caveats to ensure that the cost comparison is rational. We have performed cost estimates at various stages during the entire ACC project and during this phase by both production builders and small builders who usually build limited numbers of houses. For this discussion we have assumed a snapshot of time and cost that assumes a house built in Northern California at the end of 1999. This estimate includes all costs except land.

The three houses as designed would cost a homeowner as follows:

Two Story Attached Garage:	$332,950
Two Story Detached Garage:	$349,560
One Story:	$264,069

Given the existing market these costs are well within reason and competitive with other houses built in the same location under similar circumstances. However, for this project what we needed to know is how much more expensive they would be in comparison to a similar house without the energy performance features. Since the houses were developed from the ground up to have the performance requirements of this project we assumed that the base case houses have identical architecture, including finishes, but standard envelope, construction and mechanical components such as windows, HVAC etc. Our base case includes the exposed tile and other options that the homeowner may purchase individually in other houses. The increase in costs are as follows (the base case is the two story house with attached garage):

Strategy	Incremental Cost	Total House Cost
Increased mass:	+3.65% (+$12,150)	-
High performance windows:	+0.12% (+$3,995)	-
HVAC Option 1:	-1.32% (-$4,395)	+3.53% (+$11,753)
HVAC Option 2:	-1.18% (-$3,929)	+3.67% (+$12,219)
HVAC Option 3:	-0.98% (-$3263)	+3.87% (+$12,885)
HVAC Option 4:	+0.08% (+$266)	+4.93% (+$16,414)

The total cost increase may seem significant but taken in context is well within market standards. Recent housing enhancements indicate that given the appropriate builder these options are competitive to other enhancements. Features such as a three car garage or whirlpool bath or home entertainment center have similar costs to the homeowner. Given an appropriate marketing campaign, features such as complete soundproofing, smart controllers, and even increased comfort can be brought to the market competitively.

2.2.5 Builder Solicitation for Pilot Projects.

Over the duration of the PIER Transitional phase, the research team discussed the possibility of a pilot project with a number of builders and developers in both Northern and Southern California. Although each contact demonstrated interest in the possibility, individual circumstances prevented any builder from taking on the pilot project. The single most important factor was an increase in the work pace, due to the heated up economy, and work load which prevented builders and developers from trying anything new and unproven (this was the response of almost everyone the research team talked with, including Pardee and McMillan). Other circumstances included changing political contexts for the development project (Playa Vista project in Los Angeles), the loss the development job to a competitor (Bruce Hammond, Sonoma County), lack of follow through on the part of planning officials and builders (Chula Vista project in San Diego County) and the location of the developments in hotter than transitional climate areas for which the prototype performance was not yet simulated or appropriate (proposed developments in Fresno and Bakersfield).

2.2.6 Evaluation and Monitoring Plans

Development work has been undertaken on process evaluation design for the project (see Rossi, Freeman and Lipsey 1999, Patton 1997, and Chelimsky and Shadish 1997 for detailed discussions of the use of process evaluation in program development). In the process evaluation, broad issues to be investigated include builder and buyer satisfaction, user adaptation and control strategies developed in use of non-compressor systems, installation and maintenance, and optimum usage potentials. The evaluation design will consider these issues, along with some key processes discussed below, across several phases of the project. At this stage, the research design differentiates 6-7 phases along what is actually a developmental continuum. These phases begin with initial negotiation (between the design team and builder(s) and developer(s)), and extend through plan review, siting, construction and system installation, code compliance, commissioning and occupant training, and post-occupancy activities. We expect the research design and our understanding of the development / construction / occupancy process to be refined as we gain experience evaluating the pilot projects.

At each phase, a variety of data gathering and analysis techniques will be used and a variety of key social processes explored. The latter include: adaptation and modification of the house design / systems, participants' knowledge and understandings of cooling system design and operation, participants' representations of the house design / systems to others (industry actors, other potential customers, associates of the buyers), conflicts and their resolution, and ongoing processes of refinement and diffusion of the technology through builder and buyer networks. It is anticipated that other important processes will be discovered in the course of the project that will also be considered in the evaluation.

A variety of data sources will be used in the evaluation. These include (1) repeated interviews with key actors (construction firm managers, site supervisors, subcontractors, carpenters, HVAC installers and other workers, sales staff, realtors, code officials and, of course, buyers and prospective buyers), (2) observation and documentation of the design, construction, commissioning, and occupancy processes, (3) documentary sources (correspondence between the parties, internal memoranda, brochures, videos, webpages and other marketing materials, coverage in the trade and popular presses), and (4) post-occupancy surveys and self-recorded occupant usage logs. The evaluation will employ an unusually wide range of data sources to provide a rich description of the processes involved and an analysis that is designed to benefit future efforts to encourage the wider adoption and diffusion of residential non-compressor cooling technology.

A draft monitoring plan for physical factors such as climate and comfort, developed in Phase II of the ACC project (Huang memo July 31, 1996), forms the framework for physical performance evaluation of a pilot project. The monitoring plan begins with the construction period, including field measurements of the thermal characteristics of the building, the solar characteristics of the site and the performance of the cooling equipment *in situ*. Simultaneously, the instrumentation package and dataloging equipment will be installed as construction proceeds. Performance of the unoccupied house will be monitored for as long a period as possible to develop baseline data. Data will be monitored during occupancy for a full year. The data analysis will be corroborated with results from the occupant evaluation. As with the occupant evaluation, further development of monitoring and evaluation techniques will be as appropriate for the specific pilot project.

2.2.7 Advanced Characterization of House Performance

Performance in relation to energy efficiency and occupant comfort tends to be understood and quantified best if presented as a single metric or number. Dollars per year savings, kW load reduction, or a maximum indoor temperature have all been used to describe the performance of energy efficient housing. The ACC project has reoriented the focus of house performance to emphasize the reduction of compressive cooling through the elimination of the compressor or the significant downsizing of the compressor. In concert with this strategy, occupant comfort has become a major performance criterion and demand charges related to peak electrical demand might become a significant aspect of performance criteria. These two aspects of house "performance" were examined in the PIER Transitional phase of the project.

<u>Adaptive Comfort Model</u>

This project questions the widely held assumption within the housing industry that thermal comfort depends on the static thermostat setting and the narrow temperature range that this implies. Thermal comfort results from a combination of factors including mean radiant temperature, air velocity, relative humidity and radiant asymmetry in addition to the indoor dry bulb temperature. The ACC project recognizes that occupant comfort can be provided given the proper combination of these variables. Such an advanced characterization of thermal comfort will:

Allow the house to drift into higher dry bulb temperatures during the day without causing thermal stress on its occupants

- Allow the house to achieve lower nighttime temperatures while the structure discharges heat while keeping the occupants comfortable
- Reduce the interior mean radiant temperature during the afternoon of a heat storm period, enabling the occupants to open and ventilate the house in the late afternoon. A

standard compressor-cooled house at the same time would be sealed to the outside, allowing the compressor to operate at maximum capacity in its effort to lower the temperature to the thermostat setting.

Research in an earlier phase of the ACC project verified that interior temperatures can be allowed to drift into the mid-80 degrees F while keeping occupants comfortable, as long as air movement is maintained (Arens 1995). For the compressorless houses, the team decided that allowing the houses to drift much higher than 78 degrees could create a market barrier. The maximum interior dry bulb temperature was defined as 78 degrees and the prototype house designs were fine tuned not to exceed that temperature. During peak summer weather events, the dry bulb temperature will drift higher than this setting as it would in a conventional compressor based system that is sized for “design” conditions that are exceeded some percentage of the time. This criteria for thermal comfort which relies on air movement and mean radiant temperatures as well as dry bulb temperature is gradually being included and augmented in ASHRAE Standard 55.

As described in adaptive comfort research, lower internal radiant temperatures and air movement produced by ceiling fans, are expected to maintain comfort at temperatures higher than 78 degrees. This concept has been introduced to industry players and researchers through the analogy of an "Italian Villa" experience during a hot summer day. The delight experienced on entering a heavy masonry structure during a hot dry summer in Italy can well be compared to the experience of the prototype houses. While these descriptions are evocative and advertiser friendly, they fall short in describing the full degree of comfort that the occupant may experience.

Published work in thermal comfort (de Dear and Brager 1998) has consistently shown that in places where the occupants have control over their environment people exhibit wider tolerance in variations of thermal conditions. This control can be the ability to operate windows and French doors, the control over a ceiling fan, the lowering of shades, etc. Conversely, in situations where the occupants rely on an active machine in a sealed environment, expectations rise and smaller variations in thermal conditions can be regarded as annoying and bothersome. We expect not only that the actual conditions of the house will be more conducive to an acceptable thermal environment, but the thermal tolerances of the occupants will also be wider and further enhance the perceived thermal comfort. Whether this actually happens remains to be seen and will be examined after some of these houses have been built and monitored.

<u>Temperature Correlated Electricity Value (Time of Use - TOU)</u>

California’s Title 24 Energy Efficiency Standards for Residential Buildings regulate the energy performance of building envelopes, lighting, water heating and HVAC systems. Current Title 24 energy standards compliance is based on source energy accounting which does not account for seasonal or time-of-use patterns. However, some interests are arguing that energy standards that place a higher value on conservation during the high cost times of the year and are more closely tied to the actual variations in energy costs could better optimize the use of energy resources in California. A recent feasibility study (Heschong Mahone Group 1999) explored the impact of this approach and recommended a compliance energy accounting scheme in which electricity value is correlated with outdoor daytime temperature and gas and propane pricing is seasonal. The electricity value structure recommended results in electricity use during the hottest hour of the year in Fresno being valued at approximately 20 times higher than the same consumption during the preceding night. The value ratio of a Btu of electricity to the value of a Btu natural gas also changes with the increase in electricity value.

The ACC prototype house designs are intended to minimize on-peak electricity use for cooling. The on-peak performance of the designs are produced by a combination of factors which reduce the solar gain to the house, increased ventilation and cooling during cool night hours and increased thermal mass of the buildings. Under current Title 24 compliance standards the designs are penalized because the reduced solar gain increases the heating energy required during the winter, and because compliance methods do not attribute value to mechanical ventilation cooling. Compliance standards also underestimate air conditioner energy use that is displaced by ventilation cooling because the SEER rating used in compliance calculations is developed at an outdoor temperature of only 82ºF. The temperature correlated electricity value approach, and other improvements to Title 24, would significantly favor the ventilation cooling design strategy because it would count the energy savings at the highest temperature value. Also, a kWh of electricity consumed for cooling and ventilation during night hours is now worth 10 to 20 times less than the kWh of cooling electricity saved on peak. Under current Title 24 they have the same value.

2.2.8 Applications Information

Energy Savings, Demand Reduction, and Comfort

A study was undertaken as part of this phase (see Huang, 1999) to determine indoor thermal conditions during peak cooling periods for over 170 California locations. The peak cooling periods are five day sequences corresponding to a two percent design condition. This means that these conditions are exceeded two percent of the time on an annual basis as determined through statistical analysis of long term historical weather data. The DOE-2 program was used to simulate the indoor temperatures of the house. The study found that a 1500 CFM mechanical ventilation system 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 comfort only along the coast. With indirect evaporative precooling, the applicability of the house design can be extended to Fairfield and Livermore in Northern California. In Southern California a 3000 cfm evaporative system is 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 use of a 1.5 ton air conditioner, the proposed design is satisfactorily through most of the state, except in the upper areas of the northern Central Valley (Red Bluff) and the hot desert areas east of Los Angeles and San Diego. The simulations also showed that energy savings for the prototype house are 20 to 43 percent in Northern California, 20 to 53 percent in Southern California, and 16 to 35 percent in the Central Valley relative to a house of the same physical design built to Title 24 requirements.

The DOE-2 calculated maximum and minimum indoor temperatures for two 5-day peak cooling periods ("design sequence") are shown in Table 4 below (see Huang 1999 for details of these peak cooling periods and a full report of the performance of the prototype house with three alternative cooling systems). For each city, the first line gives geographical coordinates. The next line corresponds to the min / max temperatures for two zones (first floor and second floor) of a house that is Closed (and has no ventilation of any kind except for stack and wind-driven infiltration). The following three lines give the maximum and minimum indoor temperatures by zone for the following control options: night ventilation (Vent), indirect evaporative cooling (IEC), and compressor cooling (A/C). For the A/C line, the last column gives the peak A/C electricity demand over the weather sequence. A blank in the column indicates for that location air-conditioning is not needed.

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	74.5		A/C	78.6	67.8	78.0	65.0	1.75

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

Table 4. Maximum and Minimum Indoor Temperatures for the Southern California House Prototype with 1500 CFM Fan During 2% Design Periods

The results are also plotted for Davis in Figure 15.

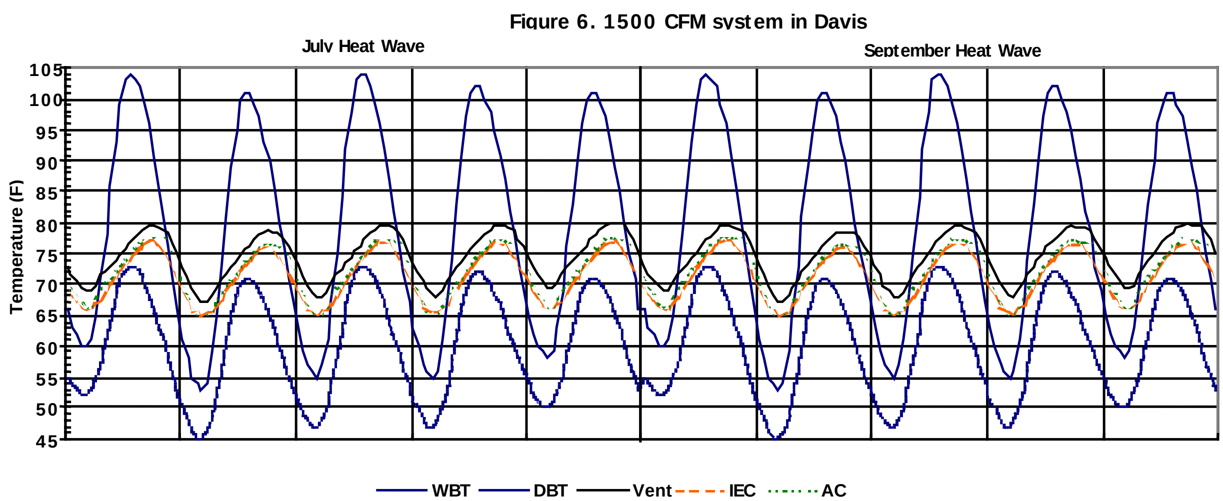

Figure 15. Hourly Indoor Temperature Profiles during July and September Heatstorms

These results apply to the Southern California prototype. The Northern California prototype is expected to perform better due to its reduced skin to volume ratio, less windows and exposed skin.

<u>Energy Star Ratings</u>

The Southern California prototype house meets EPA Energy Star Rating requirements in all California climate zones except, ironically, those where compressor cooling is most likely to be unnecessary. To obtain an Energy Star rating, houses must demonstrate that they are 30 percent better than the 1993 Model Energy Code. The most appropriate tool for this purpose is the C-HERS rating method. This method evaluates both building envelope and heating/cooling system performance, but does not account for energy benefits resulting from night ventilation cooling. Energy Star ratings are therefore only partially reflective of how well the Alternatives house will perform in summer, but will aid builder marketing efforts in most areas.

Figure 16 compares C-HERS ratings in five California Climate zones in all four cardinal orientations. Despite a HERS cooling rating of 100 in Climate Zone 3, water heaters and furnaces that exceed minimum standard efficiency must be used to obtain an Energy Star rating. Efficient water heaters (0.58 Energy Factor) were applied to Climate Zones 3 and 4 to obtain the ratings shown in Figure 16. All ratings assume standard efficiency heating systems.

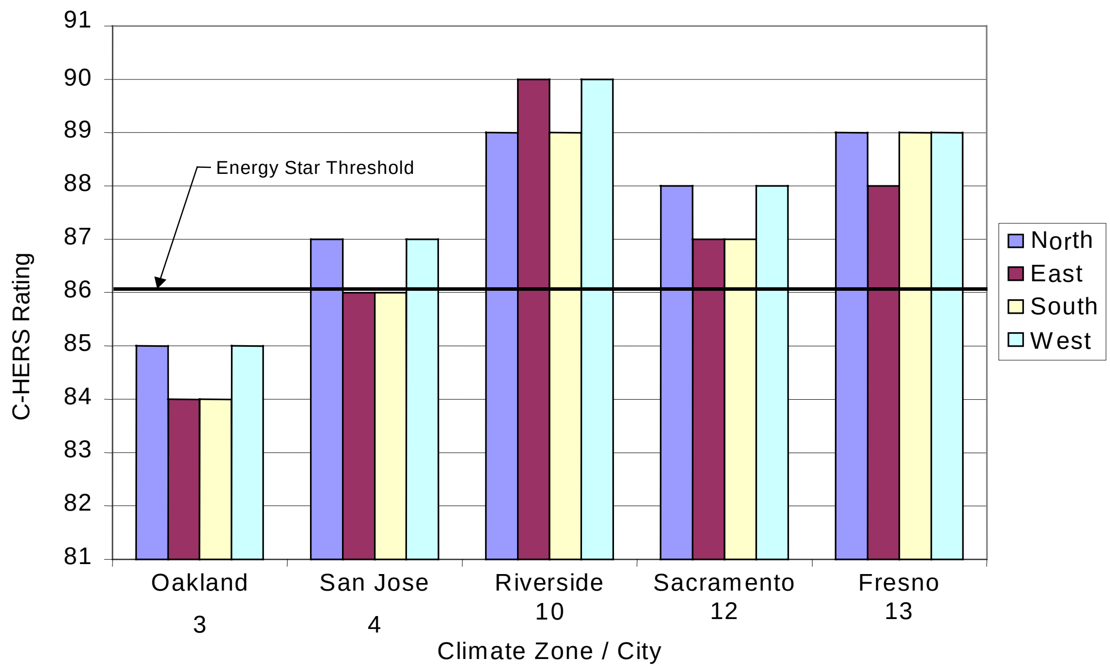

Figure 16. Energy Star ratings for Five Representative California Climate Zones in All Four Cardinal Orientations.

2.3 Research on Barriers and Opportunities for Market Adoption

For the PIER Transitional Phase of the ACC project, the research team interviewed a range of players in the new residential construction industry and examined industry innovations and trends. From this, we were able to identify barriers to and opportunities for adoption of the compressorless house concepts, technology and designs in California. Discussed below, these segments of the industry included builders and developers, appraisers and financial institutions, home buyers and sales staff.

2.3.1 Identification Of and Interviews With Industry Builder/Developers

Interviews with builders and product suppliers were supplemented by observation of formal sessions and informal interactions at industry meetings (e.g., the Pacific Coast Building Conference and the National Association of Home Builders' Green Building Conference) in order to (1) identify builders who might be interested in adopting non-compressor designs and (2) to better understand the nature of constraints on adoption of innovation in the industry in general. A number of builders and developers have been identified and briefed on the ACC house design, and several have expressed interest in the non-compressor approach. Builder feedback, interviews and industry observation all reveal a number of builder disincentives to innovation in a general sense, and specifically in terms of adoption of non-compressor cooling designs. These include satisfaction with existing technology, lack of awareness of alternatives and perceived riskiness of not including AC their house designs.

Builders believe that the products that they are offering satisfy consumer demand, are of high quality (often compared to "old fashioned building") and are energy efficient. High volumes of customers moving through their model houses, steady sales and good results on buyer satisfaction surveys all reinforce their understanding that consumer demand for housing and for quality housing is being satisfied by conventional practices and products. The durability of contemporary materials, and the fact that all of their designs meet California Title 24 energy codes, also reinforces their belief that existing housing products are of high quality and are highly energy efficient—and that efficiency is now a common feature of housing in California. They report no explicit consumer demand for energy efficiency when prospective buyers visit their model homes. In the current home building "up cycle," there is little incentive to innovate in order to capture customers. In fact, in many of the most desirable parts of the state, the prices of new homes are successively *raised* with each new "release" of a series of homes in a subdivision, simply because high demand will allow very high profits to be made by producing a conventional product.

Builders are not generally aware of or motivated by energy efficiency or environmental issues related to conventional air conditioning (AC). They point to the use of "high efficiency" AC in some of their subdivisions—although none of the sales agents interviewed could tell us what the tonnage or seasonal energy efficiency rating were of the AC units used in their model houses. Some see the sense of non-compressor alternatives for cooler climates (e.g., Santa Rosa and Petaluma), but in many of the subdivisions being built in these locales, AC is not automatically installed, but is offered as an option. In these locales, AC is selected by 30-100 percent of buyers (sales agent estimates), depending on the price level of the housing. The more expensive housing is almost always equipped with AC, even in cooler climates, either by the builder ("because our buyers expect it") or the buyers ("for only an additional $3000 on a $500,000 house, they always take it").

As one moves inland, all new housing comes already equipped with AC ("it's needed here" "it's not an option here" "people expect it" "people wouldn't consider a house that didn't have it"). Non-AC designs are seen as involving a variety of risks to builders. There are concerns about the availability of subcontractors to install and service novel equipment, the willingness of known subcontractors to innovate (particularly when this involves *not* purchasing AC equipment from them), failure of the system to keep occupants cool, failure of occupants to correctly operate the system, and issues of product liability, maintenance and warranty service. Concerns are also expressed about building codes, finance and appraisal, prospective buyer reactions, and resale value. More detailed discussions of factors constraining innovation in the residential construction industry in general can be found in Lutzenhiser (1994) and Lutzenhiser and Janda (1999).

2.3.2 Barriers in Financial Institutions & Real Estate Industry

Most production housing is partially financed by banks, savings and loans and credit unions. Buyers are usually required to provide a down payment as a sign of good faith to the lending institution. In the event that the buyer defaults on the loan, the down payment or equity in the house acts as a buffer to cover lost loan payments and selling costs incurred between the period of default and the transfer of the property from the lender to another party. Loan officers and loan underwriters from the financial institution attempt to only make loans where this buffer zone of equity will cover any future expenses and the possible decline in the property's sales price during the foreclosure and re-sale process.

Financial institutions are dependent upon real estate appraisers to identify the behavior of a specific set of consumers: the buyers of production homes. The appraiser notifies the lender, via an appraisal report, what most consumers in a certain area are willing to pay for housing and what factors home buyers consider most important in making the purchase decision. The appraisal report concludes an appraised value of a specific property as of a certain date that if done correctly, provides a snapshot of a portion of the marketplace at a set point in time. The appraiser's role is to recognize the actions and behavior of consumers in the marketplace; the home buyers are validating the value of real estate by their willingness to risk a cash down payment and take on indebtedness to purchase the property. If the appraiser correctly values the property as of the sales date, the financial institution is able to make an informed decision about whether to make the loan or reject the loan application.

Financial institutions are dependent on the field real estate appraiser to identify and support the actions of buyers and sellers in the marketplace. Therefore, loan underwriters will let the appraisers "make the call" as far as the indicated value of the proposed compressorless house. So, it is up to the appraiser to provide market support for any and all factors that influence the final sales price of the house being appraised (typically referred to as the "subject property").

In the case of the production home without compressor cooling, but with certain features to increase interior comfort on hot summer days, the financial institution is dependent on the real estate appraiser to identify how this product will be received in the marketplace. Several lenders and real estate appraisers were interviewed to identify barriers, if any, to the prototype compressor less house designed by Loisos and Ubbelohde if built and marketed in transitional climatic areas in California. The interviews were concerned with not only the initial sale of the compressorless production house, but also the re-sale or refinancing of the same product.

The consensus of the appraisers who were interviewed is that the initial appraisal reports of the proposed subject property could be written up to conclude a value similar to a conventional home (with a compressor) in the same neighborhood with all other similar features. If, for example, the cost of an added compressor was $3,000 for the subject property, the appraisers would adjust the value downward for the lack of the air conditioning unit but make an upward adjustment for the superior insulation, thicker walls, shading and stone or tile floor coverings. These upward adjustments in the "Sales Comparison Approach" of the report, would be included in both the "energy efficient" section and the design and appeal section of the report.

Appraising is not an exact science and, realistically, all real estate has a range of values, not one specific value. Though a specific value conclusion is necessary for most real estate transactions, it serves only as an agreement between the buyer and the seller. The appraisers "bless" the agreement, or sales price, by determining whether the agreement falls within the range of value of other transactions in the same or similar market.

Another section of the appraisal report is the "Cost Approach." In this portion of the report, the appraiser concludes a site value for the subject property and adds to this the construction costs of the proposed subject property. In the case of the compressorless house, the cost approach conclusion may be higher than for similar homes with compressors but without the comfort factors included in the prototype house. The appraiser has the discretion to put the most "weight" on whatever approach to value is best supported by market data. Therefore, the cost approach conclusion could be used as the basis for the loan on the subject property. One way of supporting a value for a new product, such as the proposed subject property, is to interview potential buyers of the compressorless house. The results of this type of survey could be included in both the sales comparison approach section of the appraisal report and also in the final section which reconciles the indicated value conclusions of two or more of the traditional approaches to market value.

Once the initial compressorless home has been sold, the appraisal community will have an opportunity to gather more objective data on how the product is received in the marketplace. The existing, compressorless home will eventually be listed in the marketplace against other comparable homes with compressors, but without the comfort items included in the prototype. In this case, the appraiser has an easy job: determining whether buyers in the marketplace are willing to pay the same or more or less for the prototype house than for a conventional house. Actual transactions can be analyzed, and buyers, sellers and real estate brokers and agents can be interviewed to confirm the reasons for the purchase price (or the reasons potential buyers were not interested in purchasing the prototype house). These appraisals, which include the resale of prototype homes, will then be used for loan refinancing and property sales. In these cases, the appraiser is more comfortable concluding a value based on actual transactions in the marketplace instead of the somewhat subjective analysis and conclusions in the initial appraisal reports of the proposed property.

2.3.3 Home buyers’ Impediments and Constraints

Interviews with prospective home buyers, analysis of marketing materials used to inform prospective home buyers about the features of model homes, and interviews with new home sales staffs reveal a variety of consumer disincentives to demand and adoption of non-compressor alternatives house designs. Similar to the case of builders, these include satisfaction with existing technology, lack of knowledge of alternatives and perceived riskiness of not having AC.

Compressor AC is seen as a basic, expected, feature of California housing by most buyers. As noted, in some cooler climates, a proportion of new home buyers opt not to buy AC when it is offered as an option—but this is probably a minority in most cases. The cost of AC is relatively small compared to the overall cost of the house, and in most climate areas it is simply "part of the package" offered by all competing builders. Even though the operating cost of conventional AC can easily exceed $100 / mo, many buyers have mortgages in the $1800 / mo range—something that is fairly easily managed on two professional-level salaries. For most new home buyers, it would be unthinkable to not use their AC for this cost at their status levels. For others, who are operating closer to their budgetary limits, strategic use of AC may be the norm—and there is some evidence of persons who "like it hot," as well as persons who dislike AC for a variety of reasons related to health, comfort and environmental concern. Without systematic survey research (which was not in the scope of this project), it is impossible to determine the relative sizes of these groups. As a result, we can only observe that, while there is certainly variation among buyers and occupants of new housing in their cooling preferences and views of AC, most likely accept it as a taken-for-granted feature of California housing.

Even those who express dislike for AC are not well-informed about alternatives. They report their primary sources of information on new homes and housing innovation to be mass media coverage (e.g., newspaper "lifestyle" sections, home improvement magazines, television programs) and product literature offered at subdivision model home sales offices. The former rarely consider cooling in their discussions of housing. The latter tend not to mention energy, efficiency, or environment at all (although we have found cases of *high* energy use implicitly celebrated in sales materials for high-end houses, e.g., "has two AC units" and "high volume hot water"). As noted, interviews with sales staffs also indicate low levels of awareness, knowledge and interest in these features—suggesting that even informed and inquisitive buyers could gather little information about cooling or energy from sales agents.

In addition, non-AC alternatives are seen—at least when initially proposed—by buyers as risky for a variety of reasons. The system may fail to provide comfort in extremely hot weather or "heat storm" conditions of many hot days in a row. Not only might the usual occupants be adversely affected by the possible uncomfortable temperatures, guests might as well. This risks both subjecting guests to unusual and unpleasant conditions, as well as stigmatizing the hosts. Concerns are also expressed about financing non-AC systems, the inability to easily retrofit if the non-compressor alternatives don’t work satisfactorily, the costs of retrofit, and the financing of those costs (conventional AC, as part of the package, is also part of the mortgage; a $3,000-4,000 retrofit expense could require refinancing or additional financing, with additional up front and monthly costs). The riskiness of resale is also mentioned. Buyers are encouraged by sales agents, realtors, friends and neighbors to view their house as an investment, and themselves as investors.

As such, they are discouraged from personalizing their house and grounds in ways that might be seen as "extreme" or "unusual," since this could negatively affect the home's resale value and its prospects of quick sale (Susanka 1998).

2.3.4 Assessment of Complementary Industry Innovations

Despite the variety of constraints on both buyers and builders that serve to limit their abilities to demand and supply non-compressor cooling alternatives, a number industry trends and complementary innovations offer openings and opportunities for the diffusion of this technology. Using key informant interviews, field observation and a variety of documentary sources (e.g., industry trade press, professional and academic journals, mass media publications, and web-based data sources), the following trends and innovations have been identified and explored. It is anticipated that these are likely to contribute to the expansion of buyer and builder awareness and receptivity to non-compressor cooling technologies. The degree to which this will happen in each case is likely to be highly variable. On the other hand, some synergies between trends and movements is also quite likely, providing a potentially even more aware and receptive audience for non-compressor cooling innovation in some industry sectors and locales.

"Green" building — a growing movement among architects and builders to produce structures that use fewer raw materials, produce less landfill wastes, better relate to surrounding environment and climate, use less water and energy and produce less pollution while in service, and are more easily retrofitted, dismantled, recycled and disposed of when their useful lives are over. The trend in commercial-scale green design may be toward more innovative ventilation and cooling systems (Cole 1999). Increased experience in the commercial/institutional sector with design elements that are central to the ACC design may reduce industry actors' perceived risks and offer documentation of energy and environmental benefits.

Integrated design — another growing movement among designers intended to simultaneously optimize (or at least effectively harmonize through conscious trade-offs) a variety of design goals related to energy and resource efficiency. Integrated design would, for example, incorporate daylighting while minimizing attendant cooling loads, increase shell performance to the point that HVAC systems can be downsized or eliminated, etc. The ACC house is a highly integrated design that can and should be recognized as such by the design community and building industry.

Federal, regional, State & local initiatives — a variety of these initiatives (from Building America, to CARB and PATH at the federal level; the Northwest Energy Efficiency Alliance's ambitious program to increase the efficiency of building practices in that region; CBEE and utility efforts in California; city-level efforts to promote sustainable building practices) are engaged in promoting technologies and design approaches that are closely related to the aims of the PIER program and the ACC house.

Urban planning — several relatively new planning movements that stress a rediscovery of community and environmental sensitivity have goals that are potentially complementary to those of non-compressor cooling advocates. These include "liveability" and community sustainability movements, as well as the "new urbanist" or "traditional neighborhood design" movement. Most share an interest in higher housing densities, a more durable and adaptable urban fabric, energy saving from reduced travel and local shopping, etc. We have observed the lowering of "privacy walls" in some subdivision as these movements start to have effects on conventional planning practice. A more "public" community design is also one that devalues noise (e.g., noise from AC compressors as well as from traffic) and raises the value of environmental innovation.

Movement to promote and embrace "quality" — within the building industry itself, we have observed an increased interest in building quality, variously defined. In many instances, quality is believed to = design features (alcoves, complex angles, multiple roofs on front elevations), as well as more costly and elegant finishes (trim, flooring, kitchen / bath surfaces), cabinetry, and appliances. New entrants to local markets (firms from the East Coast and the U.K.) claim in their marketing materials to have brought with them to California "higher quality" standards in design, details and finishes. Large building firms are also aware of the International Standards Organization's criteria for quality in production and their applicability to the building industry. Increased concern for product liability claims, legal and warrantee costs also encourage an interest by progressive firms in quality issues. These trends support a definition of a quality dwelling being one that does not require mechanical cooling and the clever ways in which the ACC house replaces hardware with design. The conventional definition of tile surfaces as being high quality items also places the ACC design squarely in the quality building category by that conventional definition.

Concern for indoor air quality, health and environment — a growing number of consumers seem to be interested in improvement in these areas, as evidenced by a rapidly growing proliferation of retail offerings and magazines that prominently feature air and water cleaning equipment, low VOC paints, naturalistic interiors, and environmentally friendly designs. The improved air quality, acoustical performance, thermal stability, ventilation, and environmental benefits of the ACC house are certainly in accord with evolving consumer values.

Energy Efficient Mortgages — although many California builders are able to sell whatever they produce before it is built, some do target buyers of more "affordable" housing. These buyers, who must sometimes go to lengths to qualify for home loans, are candidates for energy efficient mortgages that provide more favorable than usual terms to buyers of energy efficient housing. Particularly in cases where builders are bringing their own financing operations into the sales office to walk new buyers through the process, there would seem to be possibilities for the energy saving advantages of the ACC house to be used to qualify a larger pool of home buyers—something that benefits both buyers who are increasingly being priced out of local housing markets and builders who serve this target market. Additional costs for ACC features may, of course, offset the mortgage advantages.

Marketing — some important innovations in marketing by builders include moving at least parts of the sales process out of the office and into virtual space. Increasing use is being made of virtual reality walk-throughs. Marketing specialists note that home buying is a very visual process that lends itself to virtual comparisons of decorating schemes, room arrangements, exterior views, etc. Buyers are also increasingly viewing industry websites, comparing prices and features, mapping the location of subdivisions, and communicating questions to builder marketing staff. At some point soon, buyers may expect that all builders will have websites and internet email capabilities. In the virtual world, the relative advantages of the ACC house (e.g., it's diurnal cooling performance, interior acoustics, shading logic, mechanical system, controller) may be more readily communicated than in paper brochures or even model homes.

2.4 Technology Transfer

During the PIER Transition phase of the ACC project the concepts, ideas and designs of the Alternatives to Compressor Cooling project have been disseminated through a number of channels and venues. These technology transfer activities, described below, include sponsoring an industry award program, presentations, one-on-one meetings, publications and web sites. The audience has varied from building industry representatives and leaders to utility program managers and the general public.

2.4.1 Industry Award Program

Started in 1963, the Gold Nugget Award recognizes builder / developer excellence for California, the western United States and the Pacific Rim. The awards ceremony draws an average of 1200 attendees and is scheduled as a major event at the annual Western Building Show (formerly the Pacific Coast Builders Conference or PCBC). The Alternatives project team has served on the Gold Nugget Advisory Committee with the leading architects, planners and builders in the production housing industry since 1995, including in 1998 and 1999 as part of the PIER Transitional phase. The award category of Summer Comfort Home, renamed the Summer Performance Home in 1999, was initiated in 1996 as a result of these activities. In 1996, 1997 and 1999 the award was financially sponsored as part of the Alternatives project to promote the concepts of the compressorless house to the industry and public.

In 1999, as part of the PIER Transitional phase, a professional slide show and script on the concepts and prototype designs were developed and presented during the awards ceremony. Two custom homes with low energy cooling, shading, thermal mass and night ventilation received the 1999 Summer Performance awards, presented by the research team during the June 1999 ceremony. A Malibu, California house by the Landry Design Group, Inc. earned the Grand Award for non-compressor cooling, natural ventilation, increased mass, effective shading and quality construction and Paradise Valley Builders' Sonoran Highlands received the Award of Merit for shading and reduced compressor use. (Figures 17 and 18)

Figure 17. The 1999 Gold Nugget Summer Performance Grand Award winner

Figure 18. 1999 Gold Nugget Summer Performance Award of Merit winner

Evaluation of the Award for Technology Transfer. Initially, this award was created to put the project ideas before the residential building industry in a highly visible way and to encourage builders and developers to adopt this technology with the promise of a public award. The power of a single award to push or pull such a large industry, however, is questionable. There is little evidence from the submissions that the existence of the award is changing the way the industry designs and builds houses, except that in 1999 the entries responded more specifically and in a more sophisticated manner to the design concepts promoted by the award than in previous years. There has been a strong consensus from individuals in the industry that change is slow and the award should stay in existence for a number of years before drawing any firm conclusions. In Phase II of the ACC project, the industry leaders interviewed noted that new ideas tend to be adopted first in custom home designs and "trickle down" to the production houses. This could indicate some affect on the industry is possible through the Summer Comfort and Summer Performance award winning custom houses.

2.4.2 Presentations of the Compressorless House and Technology Concepts.

During the PIER Transition phase of the ACC project, the research team has presented the house designs, control design and program concepts to many individual builders, developers, architects and owners. The research team also presented the project in more formal venues during this phase. These include:

- Project Advisory Committee January 1999. Presentation and discussion of this phase of the ACC project with members of the PAC.
- Presentations to utility and industry representatives to discuss possible collaborative support for new developments include: Los Angeles Department of Water and Power in regard to Playa Vista Development, November 1998, and the San Diego Regional Energy Office in July 1999.
- A series of one-on-one presentations and discussions with residential energy program directors took place with team members in March 1999 in Washington DC. these were used to present the CCC program and results in detail and to initiate discussions about collaboration as a means of building a pilot house or subdivision. The team spoke with: Rich Karney (DOE), Mark Ginsber (FEMP Director), George James (Building America), Larry Zarker (PATH), Sam Rashkin (Energy STAR Homes, EPA), Mark Nowak (NAHB Research Center).
- LBNL Noon Lecture Series. A presentation of the house performance simulation methodology and results to research scientists and interested participants at Lawrence Berkeley National Labs, March 1999.
- CIEE Triennial Review, April 1999. A presentation to and discussion with a panel of energy experts in the process of reviewing CIEE.
- NAHB Green Building Conference April 1999. Brochure targeted to builders and developers on Summer Comfort House program distributed to conference attendees followed by one on one conversations with builders.
- Green Building Challenge Conference, Seattle. April 1999. Brochure targeted to builders and developers on Summer Comfort House program distributed to conference attendees followed by one on one conversations with energy researchers.

- Poster presentation of the ACC project and project results at the Energy Innovations '99 Conference in San Diego, CA. October 25-27, 1999.

2.4.3 Publications.

During this project phase, the team has produced two publications aimed at the general public:

"Smart Thinking About Smart Houses" by Barbara Roether. San Jose Magazine August 1998 p. 50-53. Aimed at Santa Clara county residents, this story includes information on the Summer Comfort House as another way of thinking about the trends in home automation. Presented along with various home automation systems (security, sprinkler control, home theaters and programmed lighting) the summer comfort house is described as a "smart house" which addresses environmental issues and provides increased luxury through good thermal performance and operation.

"Ventilation Cooling Without Losing Control" by Katy Janda. Home Energy Magazine, April 1999. This article introduces the compressorless house design and control concept with special emphasis on the control design for night ventilation and requests for reader participation through the interactive web site.

For the peer audience of energy professionals an abstract has been submitted to the ACEEE Summer Study 2000 bi-annual conference for a paper which describes the methodology and results of the latest phase of the ACC project.

2.4.4 Web site content and links.

During the PIER Transitional phase of the project much of the information generated by this project has been made available on the internet. The following web sites are maintained by organizations connected with the ACC project and make this information available to the public:

http://ciee.ucop.edu/BuildingSystems.html

CIEE overview of ACC project.

www.davisenergy.com/acc

Davis Energy Group site with an interactive prototype of the control user interface design. The site includes a questionnaire for receiving responses to the design.

www.coolshadow.com/ACCMainset.htm

Loisos / Ubbelohde site includes a downloadable version of the 1998 ACEEE Summer Study paper "The Summer Comfort House: A Prototype Compressorless House for California Transitional Climates"

http://aceee.org/pubs/pan298.htm

ACEEE Publications ordering page

3.0 Outcomes

- A prototype low energy cooling control system to enable operation of the house for night ventilation was developed and tested in two houses. The result was a demonstrated reduction in compressor cooling use while comfort was maintained in a relatively hot climate.
- Based on occupant interviews, the user interface was successfully used by the occupants to maintain comfort and reduce compressor use during an overheated period.
- Occupants were able to operate the controller effectively although they did not necessarily understand the technical details of the mechanical system.
- Feedback from the controller web page simulation identified modifications to the interface, which will inform the next phase.
- Feedback from the controller web page simulation confirmed the usefulness of the comfort range strategy in the interface design.
- A Northern California prototype house design was developed. The Southern California prototype house was modified and a variation with street access to the garage was designed.
- Builders and developers in California were solicited to initiate a pilot house or subdivision program. Everyone contacted was interested in the prototype concepts and designs, but was unwilling or unable to commit to building a pilot project.
- An expanded definition of "comfort" and the impact of Time of use charges were both found to support the technology concept of the compressorless cooling design.
- During the performance analysis, problems were discovered in the DOE2 simulation that are still under investigation. The performance simulations for this phase of the ACC project have been re-checked and are correct.
- Performance simulations using the Southern California prototype house demonstrated that compressorless technologies will maintain comfort in most but not all California transitional climates. However, a substantially downsized compressor (1.5 tons) operated in concert with the night ventilation and house design will maintain comfort in all transitional climate areas and in all but the most severe hotter inland climates.
- The Northern California prototype house performance simulation were not completed so applications and sizing information is based on the results from the Southern California house. The Northern California house is expected to perform even better.
- Appraisers indicated that the disadvantages of a smaller compressor or no compressor would be offset by the superior construction. However, they would prefer to make their determination of tradeoffs based on an existing model for comparison with standard designs and construction.
- Current trends in the residential industry, which are complementary with compressorless strategies, provide opportunities for market adoption. These include interest in "green buildings" "new urbanism" and the embracing of "quality' as a marketing strategy.
- The concepts and details of the compressorless house have been supported and given visibility through a regional design awards program, a series of public presentations, publications and web sites.

4.0 Conclusions

Work in the PIER Transition phase of the ACC project has produced the following conclusions:

- Controls to provide optimized night ventilation cooling can be readily commercialized
- The optimized night ventilation cooling control is acceptable to and reasonably well understood by homeowners
- A marketable compressorless house design is possible to achieve technically and aesthetically within a reasonable cost-increase over standard construction.
- The adoption of the compressorless house approach by the residential builders and developers of California will require the completion of at least one pilot project to be used for demonstration of the technology.
- Financial incentives provided by energy cost savings are insufficient as a market driver for this technology. Time of Use incentives planned for Title 24 will improve this situation, however the first cost is still a significant barrier for builders and developers.
- Adoption of this technology offers significant energy savings, electrical demand reduction and increased infrastructure efficiency for the State of California.

5.0 Benefits to California if Technology is Commercialized

Energy Savings

Figure 19 projects heating and cooling energy savings for the sixteen California Title 24 climate zones for the two-story prototype house design developed in this phase. Energy savings are relative to a similar house designed to Title 24 standards. This figure was developed using a detailed DOE-2 computer simulation model that includes eight interior thermal zones and a detailed method to account for short-term and long-term thermal storage effects of the concrete slab; a level of detail not provided by Title 24 compliance simulations The DOE2 simulations did assume Title 24 operating conditions, which do not include mechanical ventilation, so savings are attributable only to the building envelope improvements, not ventilation cooling. Significantly greater energy savings would be expected if ventilation cooling were accounted for. A more detailed description of the simulations and additional results are provided in Huang ,1999.

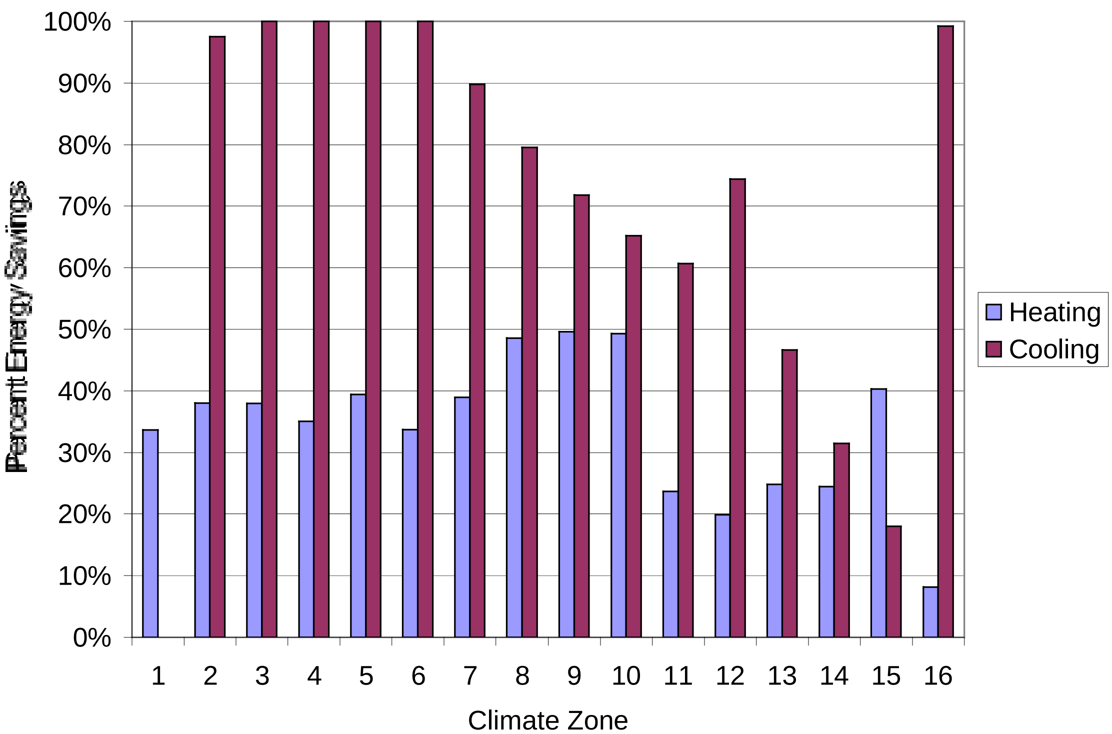

Figure 19. Percent Energy Savings, Prototype 2-Story House vs. Title 24 Standard Construction

Other analysis completed using the Micropas hourly simulation estimated total annual energy savings of 63 GWh if ventilation cooling were used in all new single family homes, based on 72,339 housing starts per year. This analysis also predicted that air conditioning energy demand would be eliminated in many climate zones and significantly reduced in others (Davis Energy Group, 1998). . Under a conservative and a more aggressive market penetration scenario, air conditioning electrical consumption can be reduced by one-quarter to nearly one-half through the adoption of ACC technologies (Huang and Lutzenhiser, 1997). Peak electrical demands estimated under the same scenarios could be reduced by one-quarter.

Energy Cost Savings

The DOE2 simulations showed that the prototypical two-story house design would save the homeowner from 20 percent to 43 percent in Northern California, 20 percent to 53 percent in Southern California, and 16 percent to 35 percent in the Central Valley, compared to a house of similar physical design built to Title 24 requirements. Figure 20 displays annual energy savings by climate zone.

Though current rate structures do not reward demand reduction in residential buildings, the average cost of power production is a function of the load factor (ratio of average demand to peak demand). Eliminating on-peak compressor energy use and increasing nighttime fan energy use will significantly improve upon the current five percent residential load factor. This reduced load factor will ultimately decrease the cost of producing power in California, resulting in potential rate decreases and additional savings to utility customers.

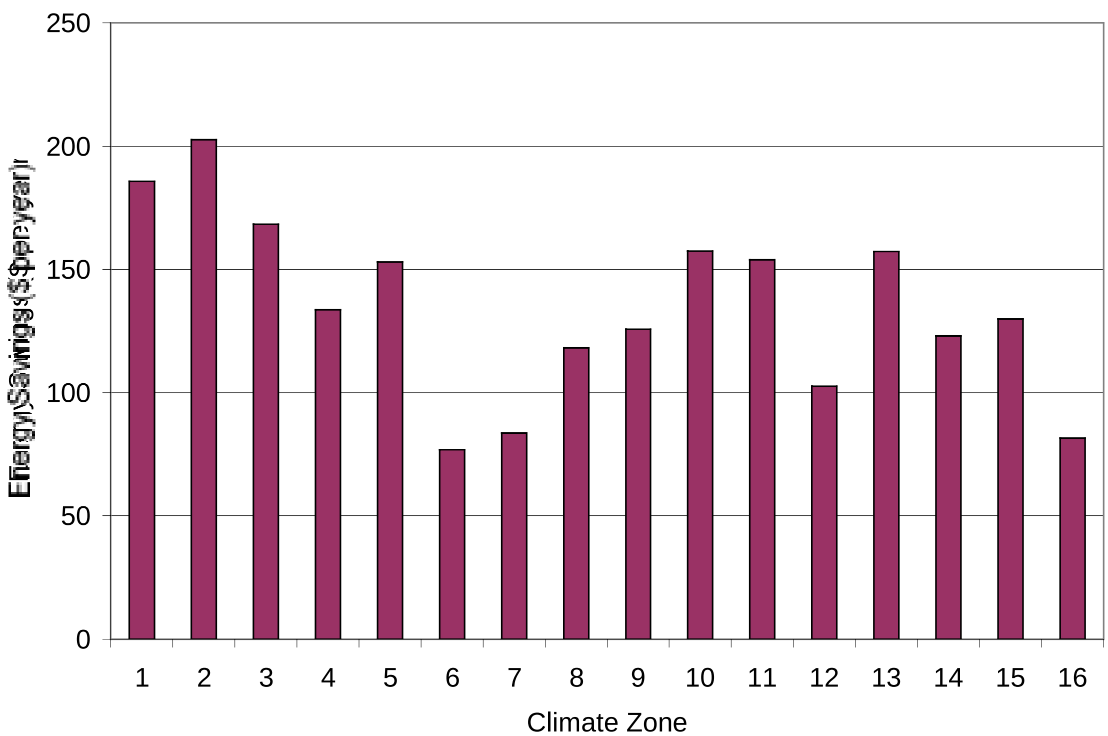

Figure 20. Energy Cost Savings, Prototype 2-Story House vs. Title 24 Standard Construction

Impact on State and Local Economies

Labor costs for construction of houses designed to non-compressor cooling standards are greater than for houses meeting Title 24 standards, resulting in no loss of revenue for the construction industry. Until volume is generated, ventilation cooling systems will be more costly than conventional systems, despite savings from compressor elimination or down-sizing. Higher mortgage costs for the better-built houses are offset by lower operating costs, resulting in little or no change in discretionary income, and no diminution of consumer spending. California utility revenues will probably show a net decrease, but profits would likely be higher as a result of improved load factor and decreased cost of generation.

California manufacturers of hardware will also contribute to the state economy. The manufacturer of the prototype ventilation cooling control and damper system is located in California, and several California companies manufacture related components.

Specific Environmental Benefits

Energy savings also decrease carbon emissions resulting from the combustion of fuel by power generation facilities. For the projected annual energy savings of 63 GWh, the corresponding reduction of carbon emissions would be about 7,533 tons for one year of construction (DEG 1998). An associated environmental impact will be the avoidance of siting new power plans and transmission facilities.

ASHRAE Standard 95P recognizes that mechanical ventilation is needed in residential buildings to maintain indoor air quality. Mechanical ventilation, rarely used in California construction, is a by-product of ventilation cooling that increases ventilation rates several-fold in summer. The ventilation cooling system can readily be adapted to provide ventilation in winter as well. Optimal ventilation control strategies will be explored in the next project phase.

The temperatures of interior surfaces of houses constructed with better insulation, efficient windows, massive elements, and well-controlled ventilation are higher in winter and lower in summer. At moderate mean radiant temperatures, indoor comfort is significantly improved. The air movement associated with ventilation cooling also improves summer comfort.

6.0 Recommendations

The following major steps are necessary to advance the compressor cooling alternatives technology to commercialization:

- Decrease hardware and installation cost and increase system reliability by integrating components. Currently all ventilation system hardware components (except the indirect evaporative pre-cooler) are available "off-the-shelf". However, field assembly of heating, ventilation cooling, and compressor cooling components increases the risk of improper installation and increases cost. Improper installation of ventilation system components was seen in most of the installations inspected under this project. Integration of these components is included in the next project phase.
- Value-engineering and increased volume are necessary to decrease costs. As with any technology, costs are a mostly a function of manufacturing costs and volume. The ZTECH control system was originally designed to provide communications capability for real-time pricing. While this feature may prove useful in the future, it also adds substantially to the cost of manufacturing. The wall display unit ($200), controller ($400), and outdoor temperature sensor ($130) are so far beyond competitive pricing that they are very unlikely to be accepted by merchant builders. Value-engineering is needed to eliminate unused features and lower manufacturing costs, which will stimulate market volume to further decrease costs. Re-engineering control hardware is not supported by funding under the coming phase.
- Documentation of the controls and mechanical system should be developed. Documentation, including operating manuals and installation guides, is needed for controls and other hardware to assure proper installation and operation. Supplements to manufacturers' installation documentation have been developed; complete documentation will be developed in the next project phase.
- Transfer the technology to residential equipment manufacturers. Making hardware readily accessible to builders by the participation of California or national manufacturers is key to commercialization success. ZTECH, manufacturer of the control hardware used in this project, is a subcontractor in the next project phase. Two manufacturers of fan coil units have expressed interest, and will be contacted in the next project phase. Results from demonstrations will be useful for soliciting manufacturer participation and will provide data to aid market transformation efforts.
- Demonstrate compressorless technology and concepts in high visibility / high impact projects to influence builder / buyer awareness. Efforts to entice merchant builders to construct non-compressor cooling homes have not been successful to date. Builder and buyer awareness of non-compressor residential cooling alternatives is quite low. A variety of approaches to increasing the familiarity of builders and buyers with these technologies and reducing their perceived riskiness are possible and have been considered by the project team. Some (e.g., linking the project to other efforts to encourage innovation in the industry, such as publicizing the project at the National Association of Home Builders' Green Building Conference) have already been undertaken. Others remain under consideration, with several requiring the construction of at least one demonstration building before they can be pursued. Most of these efforts will require additional (and significant) funding specifically directed to market transformation activities.

Strategies to influence builder and buyer knowledge include the following sort of activities:

- Provide information on non-compressor design to other initiatives whose goals include encouraging and supporting innovation in residential construction (e.g., DOE's Building America and CARB initiatives, EPA's EnergyStar™ homes efforts, and the DOE / EPA / HUD Partnership for Advanced Technology in Housing [PATH] program); encourage them to incorporate ACC home features in their building and subdivision plans
- Explore the treatment that EnergyStar™ and other evaluation schemes give to non-compressor designs and explore securing EnergyStar™ status for the ACC home
- coordinate with the NAHB Research Center's R&D program in an effort to get ACC home features incorporated into the industry's own demonstration and training efforts; also encourage, support and participate in (in cooperation with EPA) NAHB's green building efforts
- Coordinate with builders' target marketing efforts—e.g., use ongoing building market research efforts (e.g., focus groups, buyers surveys, etc.) to explore weaknesses in demand for AC, concerns about indoor air quality, environmental interests, and differing definitions of quality and comfort among consumer subgroups of interest to the industry (e.g., first-time buyers, move-up households, relocates, empty-nest baby boomers, green buyers, retirees, migrant groups and ethnic minorities, etc.); identify target market segments particularly interested in the environmental, health and economic benefits of the ACC home
- Use industry venues such as the Pacific Coast Builders' Conference and the NAHB annual meeting to disseminate information about AC alternatives
- Demonstrate ACC technology and document the performance of ACC buildings in informational / educational and marketing materials geared toward the needs and interests of builders, designers, real estate and new home sales professionals, consumers in general and new home buyers in particular
- Prepare and provide materials to trade press and mass media (trade magazines, newspaper lifestyle sections, consumer-oriented home building and decorating magazines)
- Use professional venues to disseminate information on ACC building characteristics and performance to building inspectors, code officials and the HVAC industry
- Work to get ACC design included in building rating systems (e.g., HERS, residential green building matrices analogous to LEED)
- Identify, provide technical support to, and publicize the successes of firms that can serve as "opinion leaders"

7.0 Timing of Market Introduction and Realization of Benefits

Since the conclusion of the previous project phase, the building designs, hardware, and necessary documentation have been available to enable application of compressor-less cooling technology at a rudimentary level. Upon the conclusion of the fifth phase of the Alternatives to Compressor Cooling Project (funded under PIER Contract #500-98-024) the advanced version of the technology will be fully ready for commercialization. The rate of market penetration will be strongly dependent on the success of market transformation programs, commercial marketing efforts, production volume, and of course, incremental costs. There are no technological or building code barriers to immediate introduction of the technology. Every house built henceforward can and should be applying this technology.

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