The Summer Comfort House: A Prototype Compressorless House For California Transitional Climates

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ABSTRACT

Demonstration houses that stress energy efficiency have traditionally concentrated on achieving good building performance, but often look experimental and alienate potential developers. This has resulted in a history of demonstration designs with limited market penetration. This ongoing research project investigates the elimination of residential compressive cooling in transitional California climates through design and technical alternatives to the typical single-family, detached production house. The goal is to avoid peak electrical demand while continuing to provide occupant comfort during overheated periods.

A design workshop produced an initial set of house designs and cost estimates which were then reviewed by developers and builders. Comfort and energy use parameters were used to optimize the building technologies and to define the climatic range of application. The design most representative of market directions was taken through design development, including complete mechanical and structural design. Further discussions with industry representatives are generating interest in constructing a set of demonstration houses while industry design award sponsorship is broadening the introduction in the merchant housing industry.

The prototype house does not look substantially different than the average contractor-built house, but has a number of innovations which increase thermal performance and marketability. Achieving a compressorless house with good building performance delivers other desirable characteristics: a heavier house with more sound and fire resistance, enhanced connections between interior and exterior living spaces, and a level of year-round thermal comfort not found in standard production housing. These characteristics can be packaged in a form that the industry can understand and sell.

The Alternatives to Compressor Cooling (ACC) Program

The multi-year ACC program developed and sponsored by the California Institute for Energy Efficiency[1] is designed to address the development and construction of a compressorless house design for the California residential building industry. Designed with a team approach, the program has included the expertise of a wide range of building scientists, designers and researchers to define the technologies, industry context, house design and performance. As an ongoing program, the teams are working with hardware manufacturers, builders and developers with the goal of changing the industry in California climates where non-compressive cooling is possible and marketable.

The Energy Conservation Opportunity

The geography of California contains an extensive climatic zone, between the mild coast and the much hotter Central and Coachella Valleys, in which non-compressor cooling is technically easy. This is also an area of California experiencing huge growth in residential development. California's transitional climates are characterized by relatively temperate summer days with cool nights. These design conditions are interrupted a few times each year by heat storms, such as the Santa Ana winds in southern California, which bring high temperatures and cause home owners to desire air conditioning. These periods typically last 2-5 days and cause real discomfort in standard production houses.

Current practice in these transition zones responds by installing compressor-based central air conditioning in virtually all new houses. Because the house occupants can rely on compressor cooling sys-

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[1] Karl Brown of CIEE has served as Technical Liaison for the ACC program since it was initiated. He deserves a large part of the credit for the direction, continuation and accomplishments of the program.

tems during these hot periods, standard construction practice produces houses which are not able to provide comfortable indoor conditions even during less extreme periods. This guarantees a dependence on the compressor cooling system during peak temperatures and extends use into the more typical, less hot summer days. The compressor substitutes for a higher quality house in providing comfort.

The infrequency and short term nature of the "heat storm" periods in the transitional climates creates an infrequent but high compressive cooling demand. This occurs at peak demand times for the electric utilities. As a result, residential air conditioning in these areas becomes one of the least cost-effective loads to serve and have been characterized as the "load from hell" (Brown et al. 1996, 8.15). Residential utility rates are adversely impacted by the relatively high distribution and transmission capacity development costs to serve these peak loads. Post-deregulation forecasts in the electricity industry indicate that these will also be the most expensive loads for residential consumers. Removing the compressor from transitional zone houses can vastly improve the load and demand situation, resulting in significant overall and peak energy savings.

Program Goals

The goal of the ACC program is to develop and demonstrate cost effective residential building designs for California transitional climate zones. The focus of the design approach is to develop houses which will provide comfortable interior environments without the assistance of compressor based or gas-fired cooling technologies (air conditioning). This recognizes that Title 24, the State of California energy code, is insufficient in residential requirements to capture the potential energy savings from residential growth in these transitional climate areas.

Houses designed and built to meet Title 24 do not alleviate the need for compressor air conditioning. They are designed to keep the overall energy use of the house below what the industry might otherwise build, but not necessarily to provide comfortable interiors during hot summer days. In order to eliminate the compressor from new residential construction, the house must provide interior comfort levels such that the occupants neither desire nor purchase a compressive air conditioner. This means that the performance goal of the house, unlike all other low-energy designs and demonstration houses, is not explicitly to reduce annual energy consumption or annual energy cost, but rather to provide occupant comfort during the summer (Feustel et al. 1992).

In the past, marketing energy efficiency has had mixed results at best, in part because the public associates discomfort, inconvenience and low resale value with energy efficient demonstration houses. This approach aims at targeting specifically those strategies and technologies that will deliver comfort and provide a number of other tangible desirable aspects to the house, such as increased connection to the outside, increased sound isolation between rooms, and increased resistance to fire, among others. The program is explicitly working within the aesthetics, construction methods, planning processes and marketing strategies embraced by the residential industry, offering an improved product that can give the builder an edge in the marketplace while also reducing the number of compressively cooled houses in California.

Program Approach

The ACC program was designed to begin with necessary research on residential thermal performance, comfort and advanced cooling technologies, to develop simulation tools to evaluate non-compressive cooling performance, to investigate occupant attitudes toward cooling technologies, and to identify industry barriers. This research informed the initial design of four prototype houses. Of these, the house design which best addresses the residential market in California has been taken forward into design development, including detailed architectural and structural designs, mechanical system designs and new control protocols, coupled with parametric performance simulations and further research on barriers and change in the residential housing industry. Parallel technology transfer activities reaching out to developers and builders and sponsoring industry design awards are laying the groundwork for building some demonstration houses and monitoring their performance.

Preliminary Research. The initial phase of the Alternatives to Compressor Cooling program involved seven research teams from a variety of disciplines and institutions, including UC Berkeley, UCLA, UC

Davis, Cal Poly Pomona and Lawrence Berkeley National Lab[2]. Research focused on envelope technologies, thermal storage, ventilative cooling, evaporative cooling, comfort standards, indoor air quality, barriers to implementation and improvement of tools for non-compressive cooling building design simulation (Ubbelohde 1996).

Design Workshop. To bring the research to bear on the design of prototype houses, a design workshop was held in July 1995 in San Francisco at the PG&E Energy Center. The intense three-day workshop involved architects and design professionals with demonstrated expertise in the fields of custom residential design, buildings and energy, occupant comfort and California residential development. Four prototype compressorless house designs, each addressing a different size and lot configuration for the market, were developed by the design teams during the workshop. Designers were able to quickly evaluate their design proposals using a DOE2-based simulator and custom input format (Huang 1995). Reviews and critique sessions were held with input from the seven research teams and invited engineers and residential energy experts.

Refinement and Tuning of the Prototype House Design. The "Standard Lot House" design produced during the workshop was identified as most functionally and aesthetically responsive to the California housing market and taken into schematic design. Extensive computer simulations of comfort performance conducted by Huang were combined with architectural development to produce a prototype design. The house was designed with a set of architectural and technological alternatives, such as glazing, overhangs, additional mass, a number of mechanical systems options, etc., ranging from a base case (equivalent to a Title 24 house which meets the state energy code) to advanced and high performance options.

The impact of each alternative was modeled parametrically for comfort performance and an industry-prepared cost estimate was developed in 1996 for the base house and set of alternative options. At this stage, the base case house was estimated at $47.45 per square foot. When the thermal performance and cost of the house were optimized together, the overall added cost of the energy/comfort features was $7,300 or an additional $2.40 per square foot. The prototype house optimized for performance and cost would therefore cost approximately $49.85/square foot.

The house design, along with performance and cost information, was presented in workshops and individual discussions with builders, developers and residential energy experts to develop feedback. In response, the prototype house has gone through a more detailed design and analysis. We now have drawings and specifications ready to hand over to a builder for site adaptation. This phase has involved a significant effort in control protocols and hardware adaptations, three mechanical system design options coordinated with architectural changes and a full structural design for California seismic conditions[3]. The designs and changes were again guided by a continuing series of performance simulations for the transitional climate zones of California. Additional work on consumer acceptance, industry barriers and a detailed cost estimate is in preparation by a national residential developer.

Industry Award Programs. The prestigious Gold Nugget Awards are sought by California's leading developers, architects and builders of production housing. The awards are presented through a large event at the annual Western Building Show (formerly the Pacific Coast Builders Conference) and then are publicized and exhibited. The annual show supports an attendance of over 12,000 from the regional building industry. The ACC program has worked with the Gold Nugget Awards program to establish and sponsor a "Summer Comfort House" award which recognizes residential developments moving toward the compressorless house ideal. In the first two years, the Summer Comfort Award has been awarded to entries which also won important non-energy related design awards, confirming that summer comfort as a design strategy does not have to be at odds with industry recognition or success.

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[2] Research teams for this first phase of the program were led by Ed Arens, UC Berkeley; Helmut Feustel, LBNL; Baruch Givoni, UCLA; Bruce Hackett, UC Davis (with Loren Lutzenhiser, Consultant); Joe Huang, LBNL; Fred Winkelmann, LBNL; and Hofu Wu, Cal Poly Pomona.

[3] Research teams working on the current phase include the authors; the Davis Energy Group; Joe Huang, LBNL; Ed Arens, Fred Bauman and Eric Freitag, UC Berkeley; Bruce Hackett, UC Davis (with Loren Lutzenhiser); Taylor Engineering; and Bruce Wilcox, Berkeley Solar Group.

The Prototype Compressorless House

The prototype house is a two story, single family detached house on a standard size lot with a three car garage on a rear alley access. The lot is 5,000 square feet: a 50 foot street front with 100 foot depth. The total house is 2,369 square feet with a 1,326 square foot ground floor area and a 1,043 square foot upper floor area. This type and size of house forms the "bread and butter" (80%) of the California housing industry output, positioning it in the mainstream of development houses in the state. The house is designed to be built in the context of a subdivision or development. Variations on this or similarly sized and arranged houses with varying aesthetic treatments would be typical.

Figure 1. Prototype Compressorless House

Design Response To California Housing Market.

This house is intended to occupy the "mainstream" of design, construction and cost so that it will appeal to customers and be something that a builder or developer will build and sell with little risk. The house is a two-story wood frame and stucco structure with a slab-on-grade ground floor, bedrooms upstairs and a garage accessed from a rear alley. Unlike most energy demonstration houses, the orientation and location of glazing are not part of the optimization, since residential developers are seldom willing or able to match specific design elements with particular lot conditions.

The house aesthetics ("curb appeal") are addressed by the massing, treatments of the frame and stucco walls and the tile roof. Entering the house from the porch into the double-height entry, one is able to see through into the shaded courtyard, as well as to see the stairs which 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 (two story great room) and easy connections, and are drawn together around the courtyard which can serve as an additional room for much of the year in the transitional climates. The media wall and fireplace finish out the great room as the center of household activity. Following a growing practice in the industry, an additional room with bath is provided on the ground floor adjacent to the entry. This "bonus room" can serve as an extra bedroom, home office and/or in-law room and adds value to the house. Upstairs, the hall is visually connected to the ground floor rooms with a bridge to the stairs and a view into the great room and to the courtyard beyond. The bedrooms share a full bathroom and the laundry room provides acoustical privacy between bedrooms. The mechanical room is pulled away from the second floor living space to provide acoustical separation and yet easy access. 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. The master bedroom is also connected visually back to the courtyard at the center of the house.

The three car garage is now standard for this size and cost of house. New developments in California, as well as elsewhere, are increasingly locating the garage at the back of the lot on an alley which is also used for trash collection. This has not typically been the choice of the developer, but rather a requirement of the local planning agencies, which are trying to end the domination of the street by garage doors and promote the revitalization of the street with front porches and windows onto the street. This interest in traditional forms such as porches, trellises and courtyards is yet another trend in the housing industry and supports the porch entry, increased overhangs and the courtyard approach to the prototype house.

The mechanical systems for the prototype house address another trend in the residential market which equates advanced electronic control systems, such as security and climate control systems, with high-end houses and quality design. This development, most vividly illustrated by the home automation demonstrations at industry conferences, is consistent with the introduction of an advanced controls system for the various mechanical options of the prototype house. Rather than being seen as a difficult or experimental part of the demonstration house, the controls system can add value to the house in concert with the other electronic controls buyers are choosing.

In addition to recognizing the market requirements of the housing industry, this house offers additional lifestyle and quality features which are integral with the architectural planning and energy design. The shaded courtyard reconnects the interior with a controlled private outdoor room useable during much of the year in the transitional climates and is not as strictly separated from the inside by the need to keep the interior air conditioned. The porch also offers the ability to throw open the living room and move between inside and out as people used to. The increased thermal mass of the house gives the occupants a feel of permanence and solidity now missing in much new construction, as well as increased acoustical privacy and cooler interiors in the summer months.

Energy Features of the Prototype House

To eliminate compressor cooling and still maintain comfort for the occupants during overheated periods, the house 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, as well as the operation of the house in response to exterior conditions. For the prototype house we have defined a base option and a number of alternative options. Each successive option changes both the cost and the performance of the house. The alternatives can be viewed much like the option packages people purchase when buying a car.

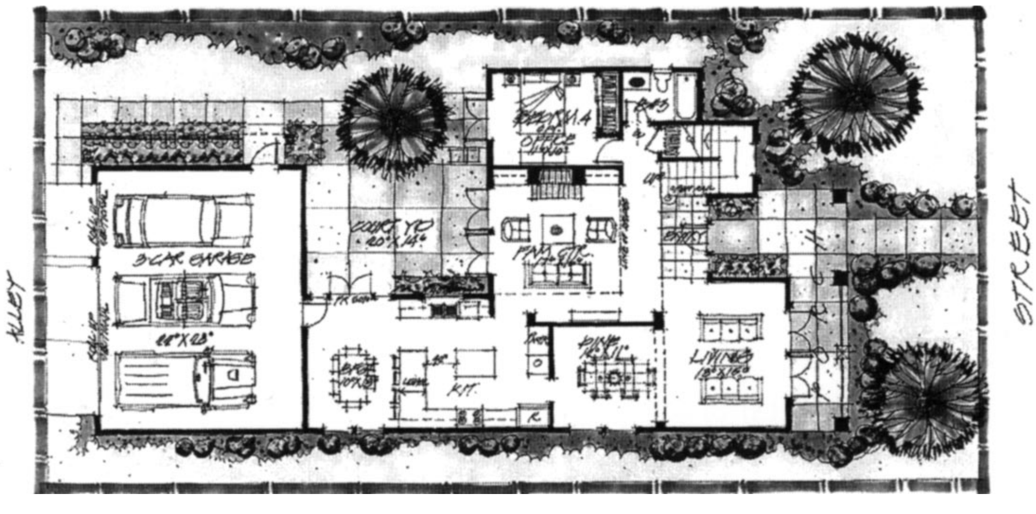

Figure 2. Prototype Compressorless House ground floor and site plan

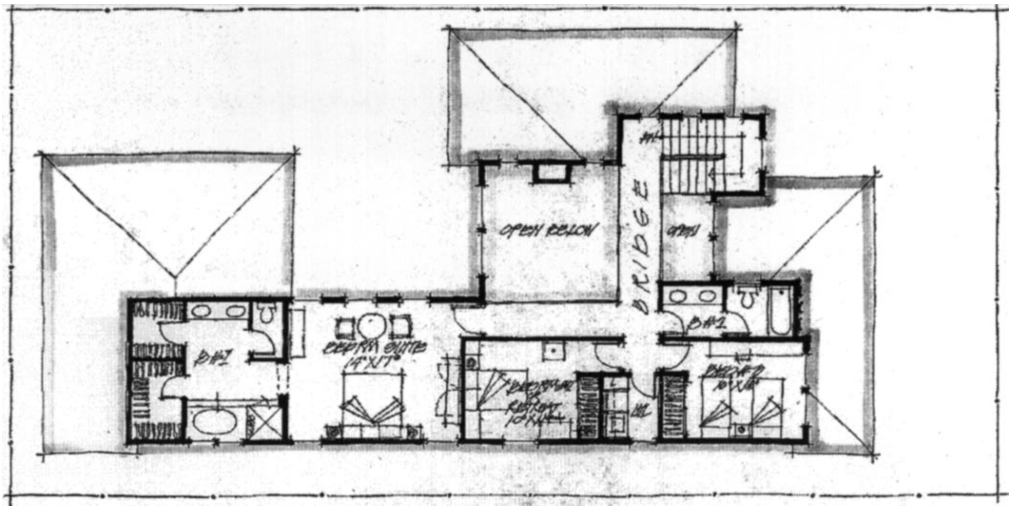

Figure 3. Prototype Compressorless House upper floor plan

The option package becomes an investment which increases comfort, performance and value. The great difference between the car and the house is that the options for the prototype house are capable of paying for themselves in reduced energy costs and preferential energy loans. The car options often only increase the operating cost of the vehicle.

These construction and system alternatives are close to current construction practice and have been shown to deliver performance and comfort as required for compressorless cooling. The list below does not in any way preclude other construction techniques and materials such as engineered wall systems or wet-blown cellulose insulation. Some options not included below can improve the house performance over those we have investigated, but they have not been simulated for performance or cost in the work to date.

Building Shell

Most strategies for improvements in the residential building shell have been the object of previous research and 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 a compressorless house.

Insulation. In the roof, increasing use of truss systems in production housing permits the easy addition of increased insulation levels. Roof insulation options range from R19 to R38. Wall insulation has far less impact on the house cooling performance than roof insulation. In the walls, batt insulation is less expensive than rigid; however, additional insulation over that which fits into the stud construction is most easily achieved with rigid board. Rigid insulation as a separate option is too expensive, but could be included as part of a stucco finish system to achieve some cost savings. Due to the well-insulated attics, variations in roof color produce only a minor impact on cooling performance (Huang & Zhang 1995).

Windows. Window technology has developed to satisfactorily control heat loss and infiltration, although the impacts of direct solar radiation cannot be controlled by glazing choice alone. Low-e and multi-glazed windows are now standard in many markets. "Good windows," although commonly understood to be expensive, are often also considered a good investment by home buyers. The appropriate types of low-e glazing and coatings used in the prototype house are determined by the particular location within the transitional climate region. Options we have identified range from U-value = 0.48 with Solar Heat Gain Coefficient (SHGC) = 0.71 to a high performance U-value = 0.31 and SHGC = 0.43. A glass with a SHGC of 0.43 and a high visible transmission (above 0.60) is in the "spectrally selective" or "cool glazing" category. Such glass allows most of the visible spectrum to enter while excluding the wavelengths that increase heat gain. A less expensive option is to use glass with the same U-value and shading coefficient (or SHGC) but lower visible transmittance. This delivers similar thermal performance, however the glass will be tinted.

Shading. Part of the current marketing strategy for many residential developments is to use traditional forms and architectural components to recall a more generous, leisured lifestyle. Vernacular elements such as overhangs, porches and trellises offer both marketing and shading opportunities for a compressorless house. Eave overhang options for the prototype house are 12", 24" and 36" in depth.

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 (infiltration crack area as a fraction of the total house floor area). Because the summer infiltration rate tends to be low due to low wind speeds and temperature differences, we did not include more than one building envelope infiltration rate in the architectural options.

Interior Construction

Transitional climates are good candidates for increased thermal mass, especially coupled with summer night ventilation. However, most new residential construction in California uses wood stud walls with stucco, slab-on-grade and a wood joist upper floor, which offers only the concrete slab as thermal mass. The difficult design question about 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 marketed as a higher quality covering than carpeting. We have specified the option of tile floors on one-half of the first floor as an option in the performance analysis, and looked at both slate and tile in the early cost estimates.

Walls. Another strategy for increasing thermal mass is to add layers of gypsum wallboard to both interior and exterior walls. Increasing the mass in interior walls works as a thermal flywheel and the prototype options include regular 1/2" gypboard on either side of interior walls, 3/4" gypboard on either side, and interior walls constructed entirely of a sandwich of 3 1/4" gypboard. This last option had the best performance but costs too much relative to other possible measures. External walls with additional mass can significantly delay the thermal impact of high exterior temperatures and solar radiation. The prototype options include standard 1/2" gypboard and a 3/4" gypboard as the interior finish of the exterior walls.

Volume. The ceiling height of 9'-0" is typical of California production houses which offer a "volume amenity" of a double-height entry and living, dining, or great room. Move-up and luxury houses are sometimes offered with a higher ceiling, such as 10'-0", in lieu of double-height spaces.

Mechanical Systems And Controls

The prototype house is designed to require less cooling than current production houses, but using the building shell alone can become prohibitively expensive in the hotter transitional climate locations. In order for the house to work in these areas, mechanical cooling must be an option. In addition, the house should be designed to be unoccupied and therefore unattended during the day. This requires automatically controlled mechanical ventilation which can deliver comfort to an occupant returning from work on a hot afternoon. Mechanical cooling can take a number of different forms based on the amount of cooling that is required, the relative fit of the proposed technology to the design of the house and the economics of the system proposed. In addition, the house will need heating in the winter. To address these issues, the mechanical conditioning systems described below are designed as options. 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 (Huang & Zhang 1995).

Option 1A. Window Ventilation with Heating Only. This "mechanical" option is appropriate for mild climates which can deliver summer comfort with operable windows. The only mechanical system provides heating in the winter. Opening windows to remove heat cannot depend on wind direction, since house orientation is not specified, however, the use of a stack effect (height difference between inlet and outlet windows) can exhaust the heat. Open windows raise issues of security, especially at night which is the optimal time for ventilation in transitional climates, but wired window screens connected to home security systems can provide full security. Hydronic baseboard heating is used in this option, but presents a cost premium.

Option 1B. Mechanical or Forced Ventilation. Cooling is provided through nighttime ventilation and associated thermal storage of "coolth" in the building mass. This option would be advantageous to those occupants who need to control allergens introduced with outside air and who now rely on compressive cooling to filter the air. During times of forced ventilation the house is pressurized (and may be fitted with optional filters for allergens and other outdoor contaminants). The forced air is supplied by a dedicated house fan. In the energy simulations, this option is constrained for acoustical reasons to a 1500 cfm fan and 5 ACH per hour, which limit the cooling capacity. Forced air heating utilizes the duct work for winter conditions.

Option 1C. Mechanical or Forced Ventilation with Z-Tech Smart Vent Damper. The Smart Vent damper option is a motorized economizer which enables the house to be cooled with outside air when the interior/exterior temperature differential is advantageous. In the past, motorized controls have demonstrated problems with reliability, but this product delivers reliable, high quality performance when commissioned properly (Bourne et al. 1998).

Option 2. Indirect/Direct Evaporative Cooling. In addition to the mechanical ventilative strategy above, an indirect/direct evaporative cooler is added. This strategy

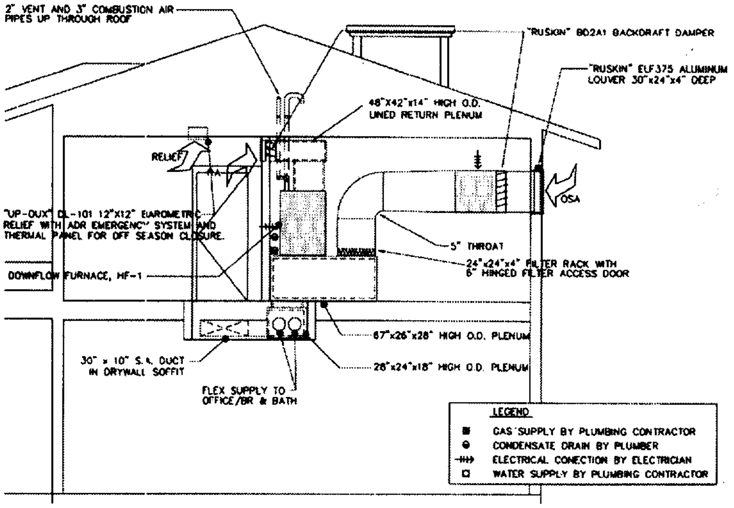

Figure 4. Option 1B. Mechanical Ventilation

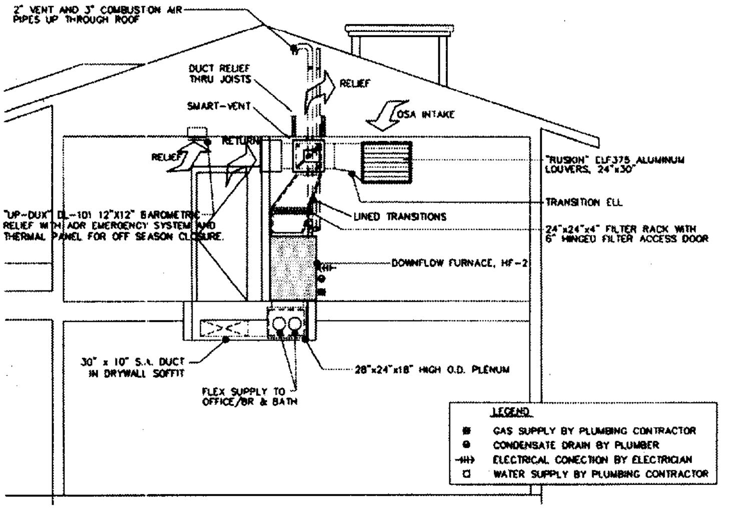

Figure 5. Option 1C. Z-Tech Smart Vent Damper

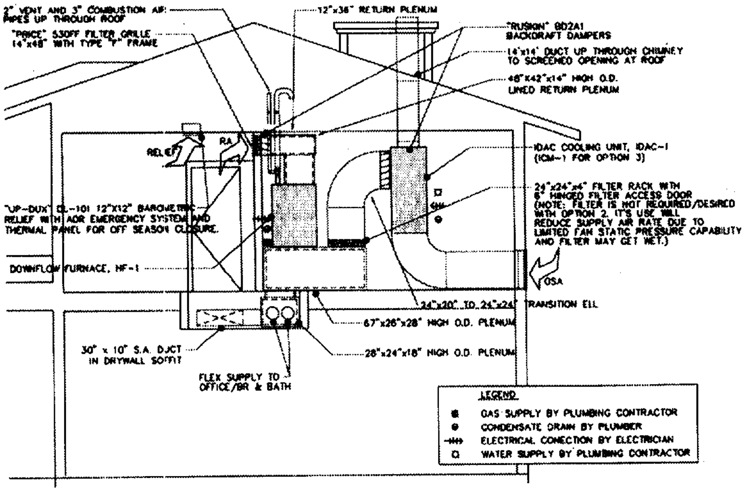

Figure 6. Option 3. Indirect Evaporative Cooling

is not recommended at this time for the prototype house. Part of the current program work is to investigate humidity levels and associated dust mite potential in direct evaporative cooling applications and carpeted slabs.

Option 3. Indirect Evaporative Cooling. In contrast to Option 2, this option specifies an indirect evaporative cooler only to precool the ventilation air being brought into the house, in addition to the mechanical ventilation specified in Option 1A or 1B. The mechanical drawings and specifications identify this as the IDAC system with the direct evaporative cooling disabled.

Performance of the Prototype House

In order for the prototype house to be an effective replacement for a compressively cooled Title 24 house, the performance of the prototype house under both typical summer conditions and under heat storm conditions are important. The house must deliver comfort or builders and developers will not take the risk of adopting this design approach. However, this assumes that we can describe and predict comfort, as well as agree on what comfort is.

Comfort Definition

One of the challenges in the ACC program is to develop a definition of comfort which makes sense for the compressorless prototype house. In their 1996 paper (Brown 1996, 8.13-8.14), the authors describe the interplay between ASHRAE load calculations, ACCA residential sizing recommendations and what actually seems to happen in the field, which is oversizing. A steady state of 75 degree F with a possible 3 degree swing is set as the goal by the ACCA recommendations. However, both the American Society of Heating, Refrigerating and Air Conditioning (ASHRAE) and the Air Conditioning Contractors of America (ACCA) describe design temperatures for system sizing that contain hours of exceedence, i.e. hours during which the compressor cannot keep the interior temperature as low as recommended. These range from a single exceedence of 73 hours per summer from ACCA to a set of ASHRAE design temperatures with exceedences of 36 hours, 88 hours and 175 hours to choose from. This indicates that, if properly sized, the compressive system for a California house would allow the house to overheat for some hours at a time during a heat storm period. Of course, the answer is that residential systems are typically oversized to take care of complaints when people are most upset about the heat. This causes the systems to run less efficiently than a properly sized system during all other times of use, but this mode of "failure" is much less obvious to the occupant.

At this point in the ACC program, we have adopted a 78 degree reference temperature for interior conditions to be comfortable and describe the performance of the house in relationship to this interior temperature on all the performance charts. We have not focused on percent relative humidity as part of the house performance since the overheated periods we are designing and simulating for occur during high temperature/low humidity heat storms driven from the Central Valley and desert areas by large-scale wind shifts. The house performance is simulated for specific design temperatures for each location. The charts included below were developed for a 0.5% annual basis peak design temperature, which means that the house will exceed these interior temperatures 44 hours during the summer season. This level of exceedence is based on a review of guidelines published by the ASHRAE and ACCA (Brown et al. 1996).

Performance Simulations

The performance of the house was modeled by Huang of LBNL for a number of cities both in and progressively out of the transitional climate region. In northern California, the house performance was simulated for Berkeley, Sunnyvale, Vallejo, Benicia, Walnut Creek, Pittsburgh, Fairfield, Davis and Sacramento. As we move east from the San Francisco Bay, the five-day sequences become hotter at the peak temperature (90 degrees in Berkeley versus 104 degrees in Sacramento) and also less humid. An equally important difference between the transitional areas and the Central Valley summer conditions is not illustrated in these five-day snapshots. In southern California, the performance of the house during peak hot periods was modeled for Pasadena, Pomona and Riverside. All three locations have relatively high peak summer design temperatures compared to the northern California locations (99 degrees for Pasadena and 103 degrees for Riverside) accompanied by lower humidity levels. Interior loads are assumed to be the same as in the mechanical systems design: 45,322 Btu/day plus three people.

To simulate the summer conditions produced by these infrequent heat storms, weather files were constructed from actual weather data for all locations possible in the transitional climate zones. These weather files portray a five-day heat storm sequence in which the second, third and fourth day peak at the 0.5% design temperature. Summer overheated periods occur from early July through October, during which time the solar radiation loads change substantially. To capture this, one sequence was developed for July and a second for September. These five-day sequences were generated for each of the locations studied.

In the true transitional climates such as Walnut Creek, mechanical ventilation of the prototype house (described in Options 1a and 1b above) can keep interior temperatures close to the recommended 78 degrees F during all but 44 hours per year (Huang 1997a). The five-day heat storm sequences from July and September are graphed in Figure 7. Supplementing the mechanical ventilation with an indirect evaporative cooler (Option 3 above) further improves house performance and allows the house to meet the 78 degree target in a wider range of locations. The graphs in Figure 8 are for Sacramento, a Central Valley location far hotter than true transitional climates.

The Sacramento performance data indicates that an extension of the ACC program to look at hotter climate zones would result in the need for significantly smaller compressors in concert with the building shell and controls strategies developed to date. The prototype house is more challenged to perform under the higher humidity conditions of northern California transitional zones which are near water (such as Benicia) than the hotter but dryer southern California locations (such as Pasadena). The thermal mechanisms of the house which produce interior comfort rely on cool night temperatures and low daytime relative humidity, both of which are more predominant inland.

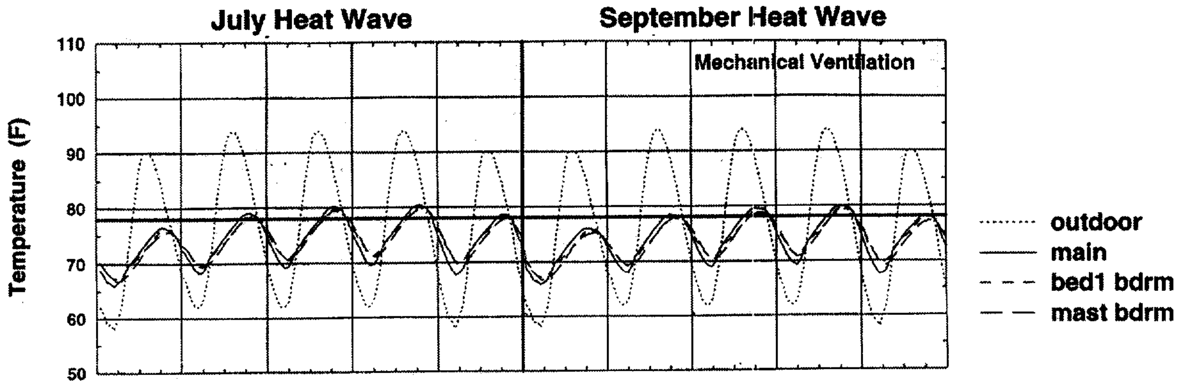

Figure 7. Walnut Creek performance of prototype house with mechanical ventilation

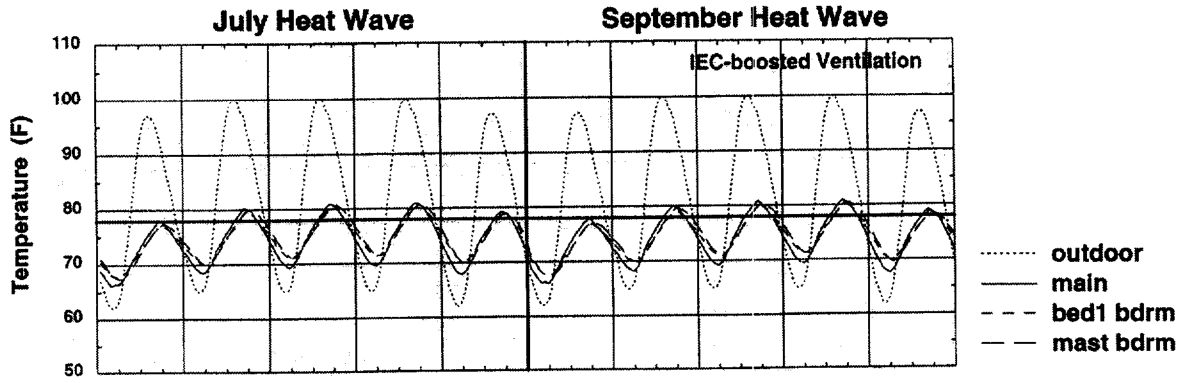

Figure 8. Sacramento performance of prototype house with indirect evaporative cooling

Title 24 Comparison. Operating the house by keeping the windows closed 24 hours a day during the heat storm period results in severely overheated interior rooms. The Davis comparison below (Loisos 1996), with the windows closed and a 0.5% design temperature (44 hours of exceedence) provides an indication of the building shell contribution to thermal comfort. In the absence of ventilation or mechanical cooling, the prototype house is more protective and will deliver more comfortable interiors during non-heat storm summer conditions than the Title 24 house, which relies on the compressor to deliver comfort.

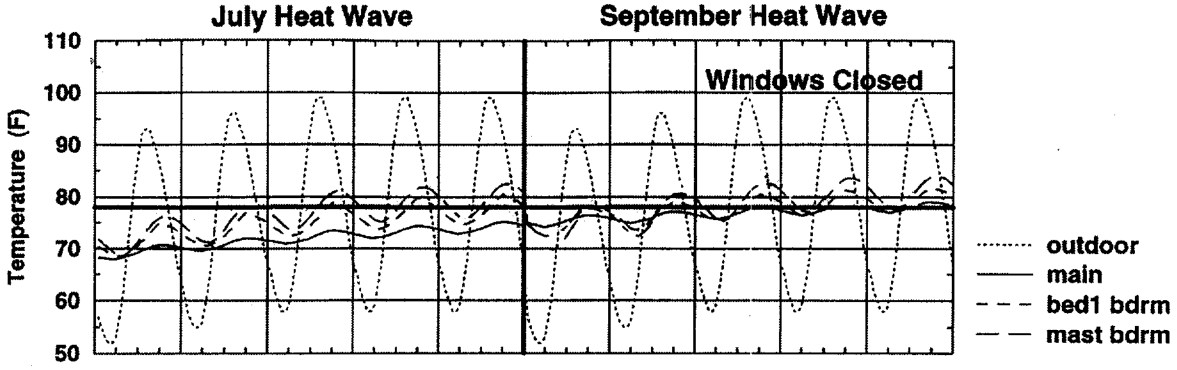

Figure 9. Davis performance of prototype house with no ventilation

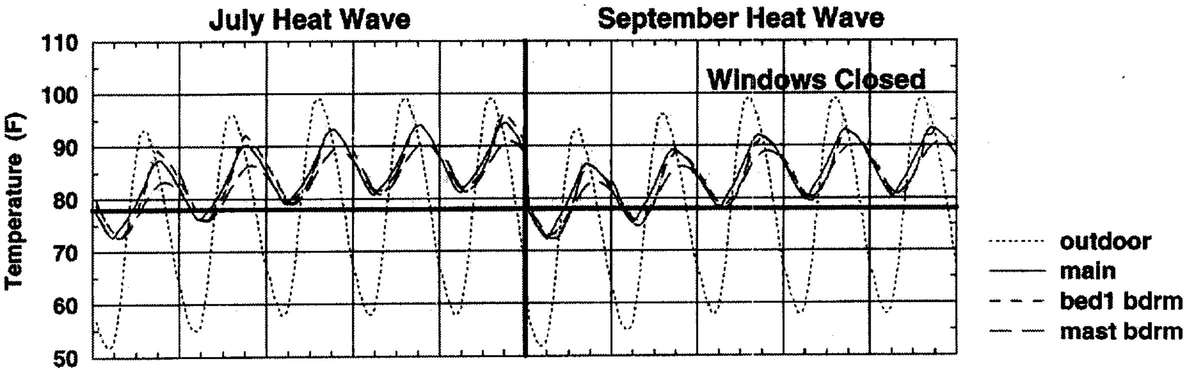

Figure 10. Davis performance of Title 24 house with no ventilation

Performance Under Periods of Exceedence

As indicated above, even in meeting the 78 degree F criteria, there will be hours during the heat storm periods for all locations in which the simulated exterior weather conditions are exceeded. During these hours, the interior temperatures will also move higher than the conditions shown in the graphs.

However, this comfort analysis of the prototype optimized house, based on the 78 degree criteria and the performance simulations, has not captured two extremely important aspects of occupant comfort which are offered by the prototype house. First is the capacity for increased comfort due to air movement. Research in the earlier phases of this project (Arens et al. 1995) supports ASHRAE Standard 55-1992 which states that occupant controlled air movement, for example from a ceiling fan, can extend the range of comfort above that of still air. A 78 degree interior coupled with air movement will be perceived as more comfortable than a room at 78 degrees with still air, and interior temperatures above 78 degrees can be acceptable to occupants when coupled with air movement. The study of houses near Sacramento which utilize the Smart Vent confirm this research with occupant interviews and monitoring (Bourne et al. 1998). In response to these findings, we are both reconsidering the 78 degree target and have specified variable speed ceiling fans throughout the prototype house.

A second aspect of the prototype compressorless house design which can increase interior comfort beyond that shown in the simulated analysis results from improved solar control and increased thermal mass. Compared to a lighter weight and more exposed Title 24 house, the compressorless house will have cooler interior surface temperatures which increase the perceived coolness of the house beyond that provided by the air temperature measure alone. Just as a warmed brick wall can keep a patio comfortable after sunset, the cooler surfaces can act like the cool stone floors and walls in an Italian villa, allowing the interior of the house to feel cooler to the occupant than the air temperature will indicate.

Continuing Research

The immediate continuation of the ACC program involves further development of controls protocol and hardware as well as a finalization of the house and mechanical design. A northern California version of the house, smaller with a somewhat different aesthetic and site plan, will also be developed. These steps will enable the program to find builders and developers to construct demonstration houses tuned for the location, budget and market of the builder. The demonstration houses will be monitored and the designs again refined. Future phases of the project will focus on expanding the climate range of applicability by designing a house with a down-sized compressor.

Conclusion: Redefining the "California House"

The performance analysis demonstrates that in all the transitional climate areas, as well as hotter locations in the Central Valley or nearer the desert, the prototype compressorless house significantly outperforms a Title 24 house without a compressive air conditioner. This means that the building shell and the operation of the house have been designed to moderate the effect of climate, reducing demand for a mechanical cooling system. In many of the transitional climate locations, the prototype compressorless house can deliver interior comfort equal or superior to a typical production house with a compressive air conditioner.

The prototype compressorless house still cannot match the performance of an oversized compressive air conditioner in the extreme conditions of a summer heat storm, at least as measured by the single criterion of interior dry bulb air temperature. In order for the superior overall performance of the compressorless house to be fully appreciated, it is necessary to characterize the more complex nature of the comfort delivered. Reduced short-term temperature swings, cooler interior surfaces, reduced noise levels, reconnection to the exterior and extended use of outdoor rooms all contribute to a competitive comfort performance by the prototype house not characterized by the single temperature reading.

In the past, low-energy houses were generally viewed as "experimental" and outside the realm of the production housing industry. In order to bring the compressorless house into the mainstream, the house must be sold in terms of design and livability, not energy bill reductions or innovative technologies. Previous housing innovations in California have taken maximum advantage of the California climate and landscape to define the essential nature of the house, producing the patio house, the Eichler courtyard houses and the spectacular view houses of Los Angeles and Palm Springs. While these have introduced new building technologies, the image and the selling point for the house has always been the quality of life.

The combination of strategies and technologies required for thermal performance in the non-compressor house provide real opportunity for such a definition. The DOE2 simulations show that no single machine or technology will solve the comfort requirements and that compressorless comfort is achieved with a combination of building envelope strategies, new technologies and operation strategies. These include low-solar heat gain coefficient glazing, increased wall and roof insulation, increased thermal mass in walls and floors, increased shading, operable windows, evaporative cooling, and advanced ventilation controls. When viewed as a set of technologies, the compressorless house is a hard sell in the competitive residential market because it carries no image, no lifestyle, no relationship to living in a particular place in a particular way. The "features" are not those consumers are looking for.

However, the same non-compressive technologies and building shell strategies can be interpreted in terms of the experience, image and quality of life in the house. For example, the house offers greater inside/outside connections without compressive cooling. This means an increased use of outdoor rooms such as courtyards and patios when the doors and windows do not have to be closed to be comfortable. A heavier house due to high mass provides greater sense of solidity and permanence, those aspects most missing in new housing construction and part of what people purchase in older homes where they do not demand compressive cooling. This heavier house will also deliver increased comfort during typical summer conditions due to high mass and cooler radiant surfaces indoors. Increased fire-proofing with lower insurance rates, a well as increased sound proofing will also result from the increased mass. The necessity for shading allows the house to present more sheltering overhangs, porches and trellises which present images of small town, turn of the century houses that are becoming increasingly popular in both the custom house and merchant housing industry.

Acknowledgements

The research reported here was funded by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor. We also want to thank the Center for Environmental Design Research (CEDR) at the University of California, Berkeley for administrative support and research assistants Nick Anderson and Martha Bush for their work on the project.

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