



The guidelines were then employed to design and construct a home that was comfortable and energy conserving. That home was monitored and analyzed for comfort and energy use. A primary intent of the research/design team was to positively impact the low-income housing approach in Hawaii. The Department of Hawaiian Homelands (DHHL) will be one of the highest volume homebuilders in the state within the next decade. Its prime goal is to develop housing for low-income Hawaiian families. This was an opportunity to introduce these design concepts to this large developer, to have their client families experience more comfort and substantial monthly savings and by demonstrating these principles, this project, in the long-run, has the potential to create local jobs, add money to the state economy, reduce Hawaii's dependence on fossil fuel and effect large-scale energy conservation by increasing the use of solar hot water systems and maximize the energy use in other areas of the home.

#### DESIGN GUIDELINES

The design guidelines were entitled, "Field Guide for Energy Performance, Comfort and Value in Hawaii Homes". See Figure 1.

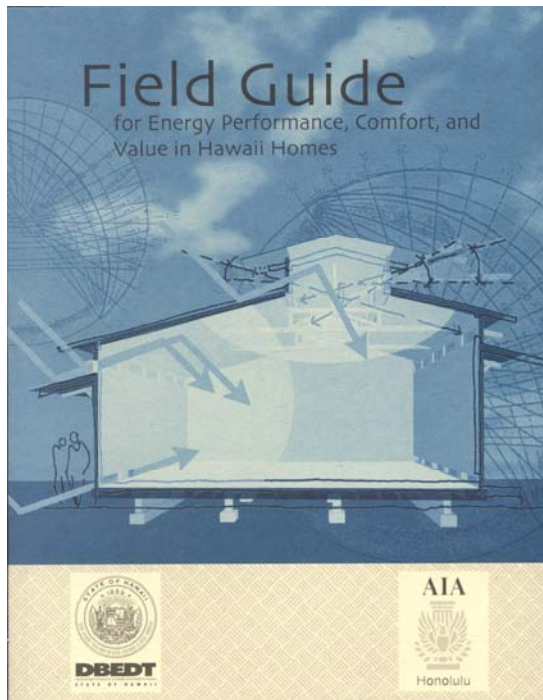


Figure 1. Design Guidelines- Cover

The Field Guide is divided into four basic sections. The first section provides an introduction to the issues of human comfort, thermal transfer methods, an overview of climatic and site analysis

and initiates the combined concepts of comfort, building design and energy savings. The second section of the guideline offers specific design strategies for orientation, envelope design, glazing and material choices for thermal and solar control, and natural ventilation strategies. See Figure 2.

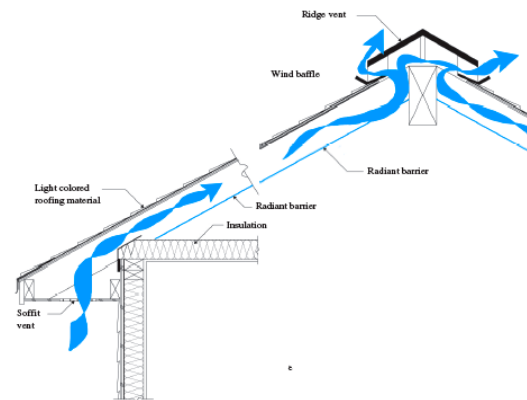


Figure 2. Integrating Roof Design Illustration From Guidelines

Section three presents further energy conservation methods such as solar hot water applications and articulates the benefits of utilizing energy efficient lighting and appliances. Section four offers information on energy efficiency financial incentives, provides information for federal and state tax rebates and utility incentive programs and discusses some of the larger benefits of energy and resource efficient residential design and construction. The Field Guide was designed to be very user friendly. It is graphically rich and accessible to a variety of audience types. The prime target groups are architects, contractors, developers, policy makers and homeowners. The research and design team, through a series of outreach efforts, made attempts to get the Field Guide information to the potential home buying sector, hoping that that group, once more aware of the principles, would verbalize their informed opinions to developers and thereby elevate the quality of housing coming to the market. It should also be noted, that at this point the research team realized that there was a fundamental disconnect between the local lending institutions and the benefits of energy conserving residential design. The group catalyzed discussions between the local electric utility, EPA's Energy Star program and the local banks. From this effort an energy efficient mortgage program was established for Hawaii. This allowed homeowners that were building or buying homes to qualify for a higher mortgage amounts, since the monthly savings from energy conservation in the home would give them more cash to invest every month.

The information in Field Guide became the basis of design for the model demonstration home that was built on Hawaiian Homelands in Honolulu, Hawaii.

#### MODEL HOME

Hawaiian Homelands typically builds single-family developments with a density of around 10 units per acre. This model home was one of the larger units that DHHL provides. The lot area is 8,146 sq. ft and the home is a 4 bedroom, 2 ½ bath with 1,259 sq. ft. enclosed, and 586 additional square feet of porch, laundry and garage. Additional partners were required to materialize and construct the building. Honsador Lumber Corporation contributed much of the building materials. The Building Industry Association of Hawaii and Randy Lau of design Built Systems Inc., contributed construction expertise and labor. Nick Huddleston provided architectural services beyond the grant amount and the Hawaiian Electric Company Inc provided additional support. The modest single story home is compatible with the neighborhood in both scale and aesthetics. The building design followed the guidelines. See Figure 3.



Figure 3. Model Home

The design includes positive orientation to improve natural ventilation, solar control and daylighting opportunities. It utilized reflective exterior surfaces and radiant barrier in the walls and roof to mitigate radiant solar heat gain. There was no insulation used in the envelope to reduce conductive heat gain except for the 1/8" air space provided by the air bubble layer between the two foil surfaces of

the radiant barrier. For the purposes of the building performance analysis this 1/8" layer was not separately calculated. Windows were strategically sized and placed to maximize cross ventilation. Solar hot water panels were placed on the South facing slope of the garage roof. Energy Star and energy efficient appliances and lighting were used throughout the residence. For the month between the completion of construction and the owner moving in, the residence was open as a demonstration home to the public. The model home got a lot of airplay on local radio and television shows. During the open house period it was visited by many state agency department heads, policy makers, architects, developers and close to 5000 members of the public.

#### BIOCLIMATIC ANALYSIS OF THE MODEL HOME

The purpose of the monitoring process was to quantify the effectiveness of the design strategies that were incorporated into the model demonstration house. With very few exceptions, all of which are in less populated areas at higher elevations, Hawaii, across the state, is completely a cooling climate. In the winter, the Honolulu temperatures rarely dip below 70<sup>0</sup> F at their lowest and the highest temperatures in August and September do not typically rise above 90<sup>0</sup> F. The relative humidity hovers year round between 68 to 78% and the Northeast trade winds are relatively constant between 9 to 12mph. A monitoring study was conducted to quantify the physical comfort levels within the home. The demonstration model home was compared to a reasonably identical home one block away. The second home is referred to as the "control house". Onset Computer's HoboXT and H8 data loggers were used to record temperature, relative humidity and light levels. Anemometers from Solomat were used to collect instantaneous wind velocity readings. Temperatures were logged externally and at five interior locations in each of the homes over a three-month period from September 19th to December 15th see figure 4.

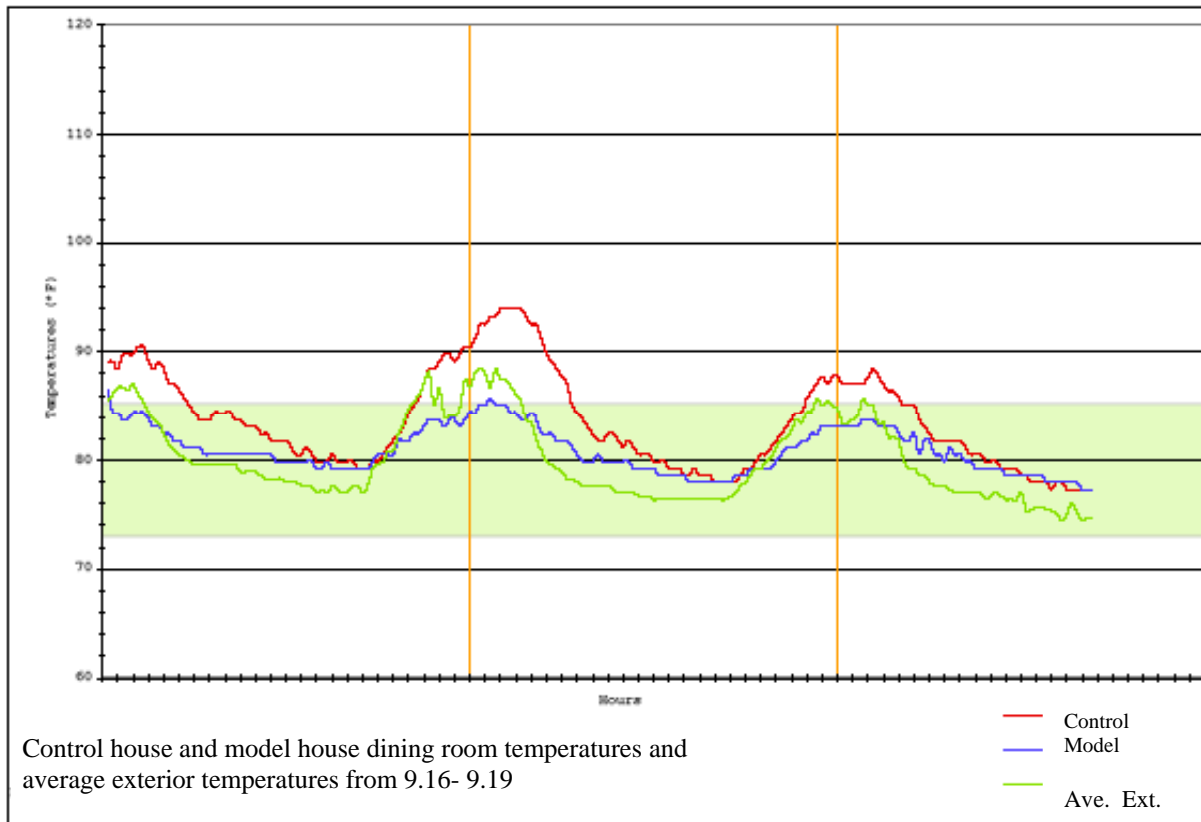


Figure 4. Temperature Monitoring Data of Exterior and Both Test Houses

In addition to the temperature readings, relative humidity and instantaneous air movement recordings were taken and illumination levels in the living room areas were also logged.

The heat mitigating and natural ventilation components that were designed into the model house and absent from the control house, are generally passive technologies, relatively inexpensive and have shown, through this study, to be quite effective. Neither the model nor the control house has any insulation in the roof or the walls. The roof and the South, West and East walls of the model home include a layer of radiant barrier. The exterior surfaces of the roof and walls of the model unit are of lighter colors and are therefore less heat absorbing.

The model's exterior wall surfaces have a reflectance of just over 60% and the control house's walls have a reflectance of 40%. Both homes ventilate the attics with venting in the blocking between the roof rafters just above the wall top plate, but the model home increases the ventilation with a continuous ridge vent that runs the length of the roof. Natural ventilation in the occupied areas is improved

in the model home due to the increase of window openings and the availability of ventilation paths throughout the occupied spaces. A skylight has been installed at the end of the hallway in the model house. It has a fixed evacuation-venting screen. The skylight is responsible for some direct heat gain but does encourage the evacuation of collected hot air in the house and provides illumination to what would otherwise be a darkened hallway. The model home does also include ceiling fans. Reports from the owner indicate that the ceiling fans are used only during the hottest times. It was impossible to determine, through the analysis of the logged data, when the ceiling fans were in use. The results of the testing indicated that the model home consistently outperformed the control house for providing a comfortable environment for the inhabitants. The exterior temperatures and the relative humidity are the same for both homes. The control house's attic space consistently heated up and quickly exceeded the exterior temperatures on a diurnal basis. The attic temperatures in the control house were more than 26 °F above the outside temperatures where the model home's attic never exceeded 6.03°F increase over the outside. Therefore there was a 20°F difference

between the two attic spaces during the hottest times of the day. During the hottest times of the day, the temperatures in the model house's living area were cooler than the outside temperature and as much as nearly 9°F cooler than the living room of the control house. The graphs show that the control house's living room temperatures are typically running 6-9 °F above the high range of the bioclimatic comfort zone whereas the model home's living room temperatures run in the middle and in the high range of the comfort zone and only slightly and infrequently do they exceed the comfort zone during the active hours of the daytime or evenings. The increased air movement in the model house expands the comfort zone for the inhabitants there while the lack of ventilation in the control house leaves the residents feeling uncomfortable due to the increased temperatures.

The bedroom located in the west corner of each house yielded impressive data. Both bedrooms are the same size, configuration and location. The control house bedroom was consistently warmer than both the exterior temperatures and the model house's bedroom temperatures. The greatest difference in both cases was that the control bedroom was nearly 17°F hotter than the exterior and the model bedroom temperature. Furthermore, the model bedroom consistently stayed cooler than the exterior temperatures when they increased above an equilibrium point of 82°F. The difference is attributed to the higher reflective exterior surfaces, use of radiant barrier, increased ventilation and reduced attic heat gain in the model home. See Figure 5.

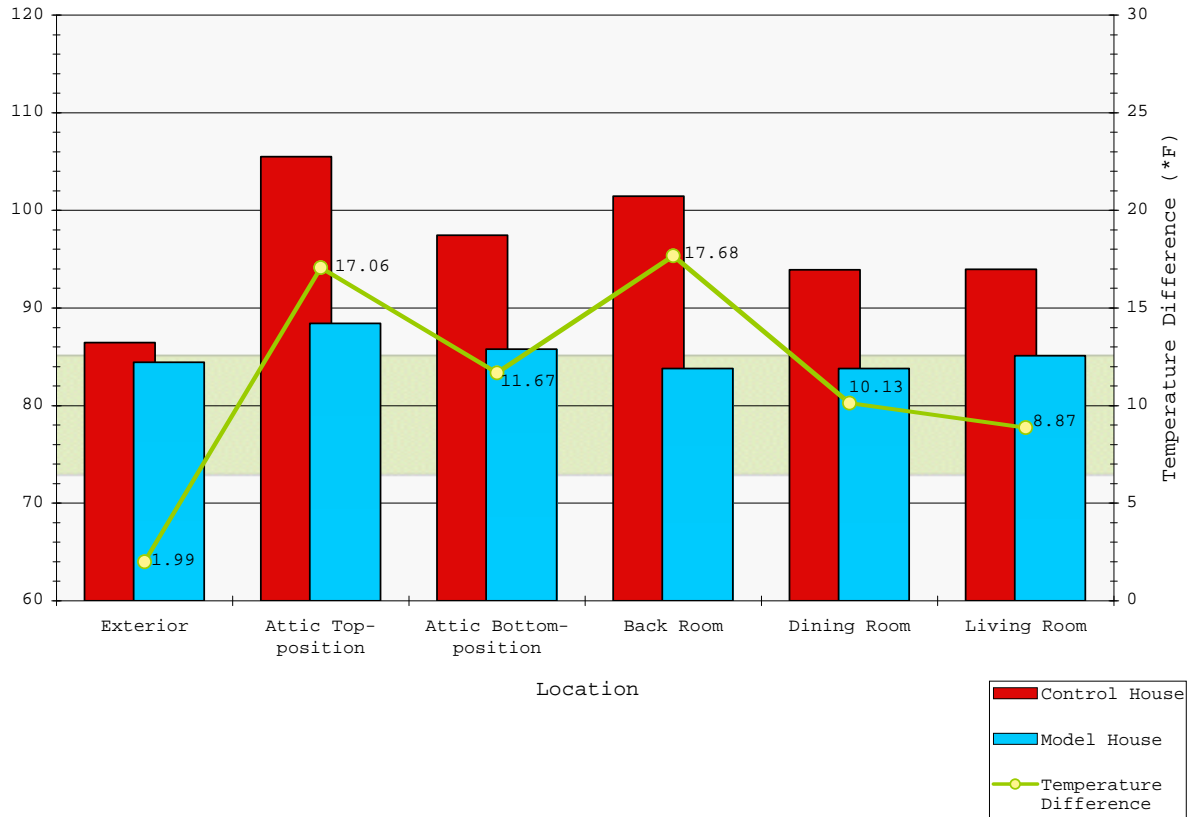


Figure 5. Comparison of Control House Temperatures versus Model House Temperatures for September 17<sup>th</sup> at 5:15PM

The time of the data in figure 5 was selected because it is the time of the day that the respective families arrive home and gather. The “backroom” on the chart is referring to the bedroom on the Southwest corner of each of the houses. The lighter band running

horizontally behind the bars on the chart represents the comfort zone.

## CONCLUSION

This is quantitative evidence that the model home is providing a more comfortable environment due to the design approach than a typical house on Hawaiian Homelands or in most of Hawaii's residential subdivisions. The building's envelope is performing as designed. The model is mitigating heat gain, encouraging natural ventilation, and is allowing more, useful natural light to penetrate the interior.

Overall the model house is an effective demonstration of passive design strategies in Hawaii's warm, humid climate. Temperature differences between the control and model house are as high as 20°F in the attics, nearly 6°F in the living room and as much as 17°F in the bedroom. The model home provides a cool, bright and airy residential experience. Even when the temperature exceeds the comfort zone, the natural ventilation airflow across the skin cools the inhabitants. The design strategies that the model home demonstrate are reducing this family's monthly utility bill by about 40%, creating more comfortable interior spaces and improving their overall quality of life.

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