ENERGY EFFICIENT AFFORDABLE HOUSING;
Validating HEED's Predictions of Indoor Comfort

Murray Milne and Jessica Morton,
Department of Architecture and Urban Design
UCLA
Los Angeles, CA 90095
milne@ucla.edu

Tim Kohut, Project Architect
Los Angeles Community Design Center
315 West Ninth Street, Suite 410
Los Angeles CA, 90015
tkohut@lacdc.com

ABSTRACT

Designing energy efficient affordable housing is especially complex because of the limited budget available for "special" features like air conditioners, the tight timelines imposed on the design team, and the many decision makers whose approval is required. The thermal comfort of the residents is rarely considered, and when it is, features that would enhance comfort are often sacrificed for aesthetic or first-cost considerations. As a result, housing may be affordably built but too often proves uncomfortable and expensive to live in.

The Las Brisas Community Housing Project with 92 units of affordable rental housing in Long Beach, California, was remodeled in 2003 and 2004.[i ii] Issues of thermal comfort and energy affordability were evaluated at the very beginning of the design process by the architect for various design alternatives using HEED, a Home Energy Efficiency Design tool. A prior ASES paper describes the architect's initial design process, and illustrates how HEED's graphic outputs helped decision makers understand complex ideas about their building's thermal comfort and energy costs[iii]. Because of high first costs and because renters must pay for their own utilities, it was decided not to install air conditioners. This paper describes how the project was actually built, and reexamines the accuracy of HEED's Indoor Air Temperature predictions compared to temperatures measured in the field. In the summer of 2005 three months of data was collected in two typical units. A critical factor turned out to be the way the residents used, or failed to use, features that were designed to help them keep their units comfortable
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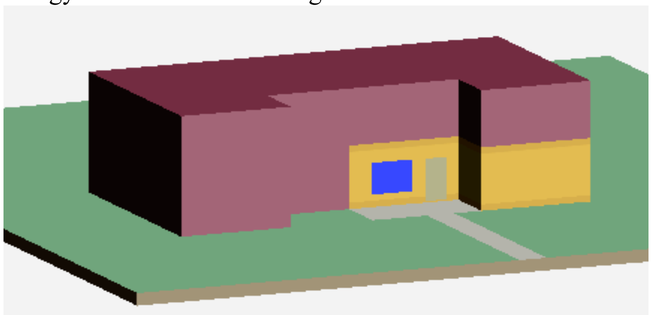
1. INITIAL REMODELING DESIGN DECISIONS:

As part of the rehabilitation of these 23 buildings built in the 1950s, all plumbing, mechanical, and electrical systems were replaced. Additionally, interior plaster was removed and insulation was added to the existing walls. During this process, extensive termite damage was discovered, and as a result, all of the exterior plaster was removed and approximately 50% of the original framing was replaced. Roofs were replaced, insulation added to the attic floors, energy efficient windows installed, and new attic cross-ventilation louvers were oversized to far exceeded code minimum requirements.



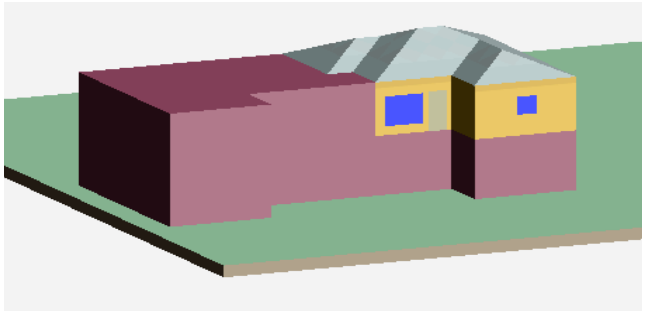


Fig.1: These two schematic drawings produced by HEED show the Window Layout for the First Floor Unit (left) with its slab on grade, and the Second Floor Unit (right) with its attic and pitched roof. The front doors of both units face East.

Ground floor units had concrete slab on grade construction, while its ceiling was protected by the upstairs neighbor. The upper units had plywood subfloors and newly insulated ceilings with a naturally ventilated attic above (Fig.1). All the units also benefited from the reconfiguration of interior spaces, remodeled kitchens and baths, and installation of all new interior finishes.

1.1 Annual Energy Costs:

Installing new dual pane Low-e windows and adding insulation to the walls and attic spaces helped bring these buildings up to code, but also reduced annual gas heating costs. HEED showed that the original units averaged over $800 Annual Energy Costs, while the proposed re-designs averaged about $500 Yearly.

1.2 Whole-House Fans:

The original buildings were built very close together. In the courtyards, they are twenty feet apart, while in the side yard there is only eight feet of separation. The architects felt that this would allow for only minimal natural ventilation. Whole-house fans were introduced as a solution to try to bring indoor air temperatures into a more comfortable range.

Traditional whole-house fans vent directly into an attic. For the upper floor unit the fans affix to the ceiling rafters, a spring loaded shutter opens when the fan is running, and the fan exhausts air from the unit interior into the attic where it helps to cool the attic before it is exhausted through large louvers. Outdoor air is pulled through the unit via open windows or doors. At 2500 CFM, the upper floor whole house fans provide 20 air changes per hour, enough to quickly cool down hot units or at least provide the residents with the psychological cooling effect of good air motion.

On the other hand, installing the ground floor whole house fans was more complicated. Without attic space available, a plenum type side-wall whole house fan[iv] was used. Only a 1250 CFM whole-house fan was available for a plenum installations. The fan with its mushroom shaped cover, was placed on the rear wall of the unit, and was connected to an interior plenum over a hallway. It could provide only half the power as the second floor units, giving 10 air changes per hour.

HEED demonstrated that these whole house fans were one of the most important features for improving indoor comfort. Using HEED's graphic plots, the architects were able to make a convincing argument that more than any other feature, whole house fan would help keep indoor air temperatures more comfortable during the hottest months of the year. It also allowed the architects to demonstrate that whole house fans introduced natural cooling at extremely economical costs. For Example HEED showed that it costs just $ 36 per year to run the 2500 CFM whole house fan.

1.3 Exterior Shading:

From the onset, increasing exterior window shading to the south and west elevations was also thought to be the key to reducing indoor air temperature. However using HEED, the architects found that in the upper unit averaged 4 degrees hotter with window shades alone , compared with a whole house fan alone. The unit with the whole-house fan cooled off more quickly in the evening, compared to the unit with the extra shading. Through this trial and error process using HEED, the architects realized that exterior shading did not make quite as much impact on indoor air temperature as first thought. HEED helped the architects place a dollar value on the introduction of exterior shading in relationship to other building features. The architects still feel this is an important feature, but overall, the developer, and the occupants, would get more 'bang for the buck' from the whole house fan than from exterior shades

1.4 Thermal Mass:

The upper unit behaves like a low-mass building, with very little thermal storage and only a few hours of time lag between the peak outdoor and peak indoor air temperatures. The lower unit with its slab on grade behaves more like a high mass building, with much more thermal capacity to store up nighttime 'coolth', and a longer time lag between peak outdoor and indoor air temperatures. This longer time lag gives the fan more time to bring in cooler outdoor air to cool down the interior thermal mass. HEED showed that the peak temperatures will be much lower in the ground floor unit.

1.5 Final Overall Predicted Performance:

The fact that air conditioners were eliminated from this affordable housing project means that energy cost is not a good measure of design quality, because the best schemes all use about the same amount of energy for furnace, lights, fans, and appliances. Thus minimizing peak indoor air temperatures was the only objective way to identify the best design.

During the design phase HEED predicted that the final overall average peak monthly indoor air temperature would be 84ºF in the upper unit and 76ºF in the lower unit. Looking at an actual 12-day heat wave (Fig. 4 and 5) showed that when it was 95ºF degrees outside the upper unit would peak at 86ºF and the lower unit would peak at 82 F. On the theoretical worst peak hour of the year when it was 98ºF outdoors, the upper unit would peak at 91ºF

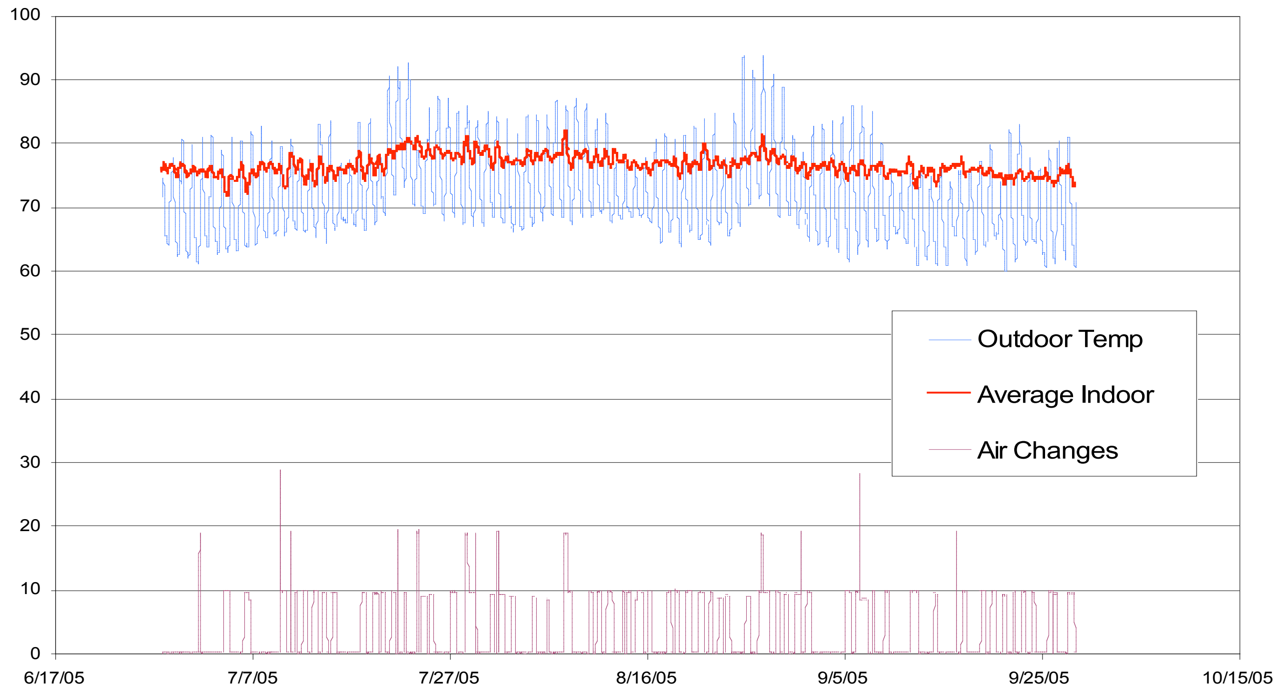


Fig. 2: The First Floor slab-on-grade unit shows very little change in Average Indoor Air Temperature compared to Outdoor Air Temperature. The spikes in Fan Power indicate that occasionally the owner also turned on the furnace fan to help circulate air in addition to the whole house fan. Note that the indoor air temperature exceeded 80ºF on only three days

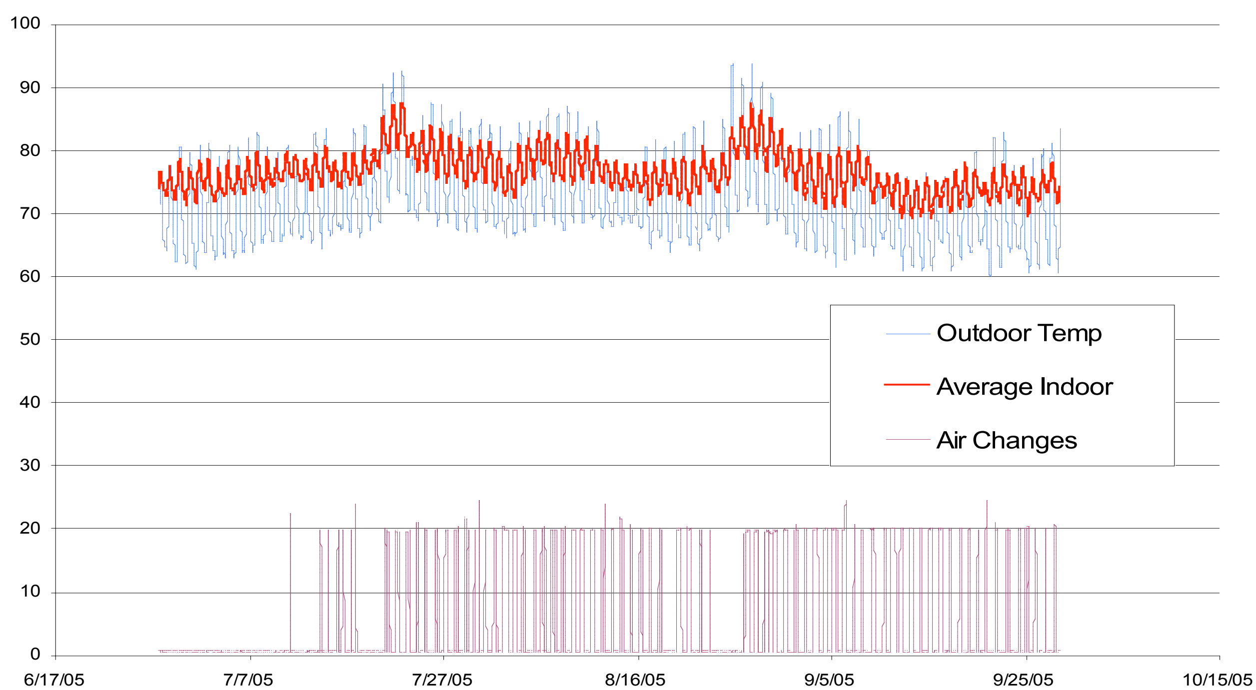


Fig. 3: The Second Floor low-mass unit with the attic shows much greater diurnal change in Average Indoor Air Temperature compared to the first floor unit. This second floor unit also experienced higher peak indoor temperatures in spite of regular use of the whole house fan. However at night minimum temperatures were always much cooler than the first floor unit. (Note the heat wave between August 22 to September 3 is analyzed in more detail in Figs 4 to 6 below.)

and the ground floor unit would peak at 87 F. While all these peak daytime temperatures are still uncomfortable, indoor temperatures will be noticeably cooler than outdoors.

2. THE PROJECT AS BUILT:

Much to the surprise of both architect and developer, the majority of the energy features identified by HEED survived the bidding process and were included in completed project. Only exterior shading at bedroom windows was eliminated, at the behest of the fire department who wanted no obstructions protruding from the building where rescue ladders might be needed.

As constructed each unit has shading by a porch roof and one-foot roof overhangs, a whole house fan, increased insulation, and new low-E dual glazed windows. Of these, the whole house fan was seen as the one feature that would most dramatically impact resident thermal comfort. When used correctly in Southern California's temperate climate, whole house fans could take advantage of wide diurnal fluctuations in outdoor temperatures to help cool the building through evening and nighttime flushing. However, because the whole house fans were manually operated; it was up to the residents to decide when outdoor temperatures were cool enough to turn them on.

2.1 Occupant Training:

Orientation meetings were held with incoming residents to inform them how to operate their heating and ventilation systems. Since the whole house fans were manually operated, large thermometers were placed on the front porches at each unit and residents were told to check that outdoor were below the interior temperatures before turning on the whole house fans and opening a window or door to allow the fan to flush the unit with cooler air.

3.0 REVISITING THE DESIGN ASSUMPTIONS – HOW THE BUILDINGS PERFORM:

In the summer of 2005, the LACDC decided that a more detailed analysis of the environmental strategies implemented at Las Brisas was needed to determine if these were worth repeating at other affordable housing projects. Working with the Department of Architecture and Urban Design at UCLA, two units were field tested. HOBO data loggers loaned by the Agents of Change project at the University of Oregon, recorded three indoor air temperature and fan power. One data logger recorded outdoor air temperature.

3.1 Post Occupancy Evaluation:

During the course of three months, data was downloaded every two to three weeks, and observations recorded, and residents were asked how they were using their building features, principally the whole house fan, and how well they felt the system was working.

The most striking difference was between the first floor unit with its slab-on-grade and ceiling protected by the unit above, compared to the second floor unit with its plywood floor and ceiling under the attic. Even though the first floor unit had half the air changes (Fig 2), its average indoor temperature remained very stable, fluctuating only three degrees per day and averaging 78ºF while topping 80ºF on only three days (but always remained about eight degrees less than peak outdoor air temperature). The second floor unit (Fig 3) fluctuated about seven degrees per day and topped 80ºF on 28 days during this period. Note however that it was always four degrees cooler at night than the first floor unit.

3.2 Twelve-Day Analysis:

Looking in detail at the hottest 12 days of recorded data (August 23 to September 4) explains some of these results for the upper unit (Fig.6). For comparison HEED was run for a similar 12-day heat wave from September 3 to 15 that had a peak temperature that was one degree higher (Fig 5).

The results showed that HEED accurately predicted the peak indoor air temperature to within one degree (86.82 vs. 87.43). Note that HEED predicted that nighttime temperatures would fall to 66.18ºF but the recorded low was 72.17 F. Probably the recorded temperatures would have been lower if the occupants had used their whole house fan in a more optimum pattern. For example they did not turn on their fan during the first day of the heat wave, usually kept it running after sunrise when it was actually heating the unit, and once kept it running during the heat of the afternoon.

4. OCCUPANT PROBLEMS OPERATING THE SYSTEM:

The Post Occupancy Evaluation showed some unanticipated problems. First, the thermostat was designed for both heating and cooling with a switch allowed users to switch from one mode to another. However, because an air conditioner was not included this confused residents. During the first months, on hot days residents would switch their thermostat to cooling mode which only turned on their furnace fan blowers.

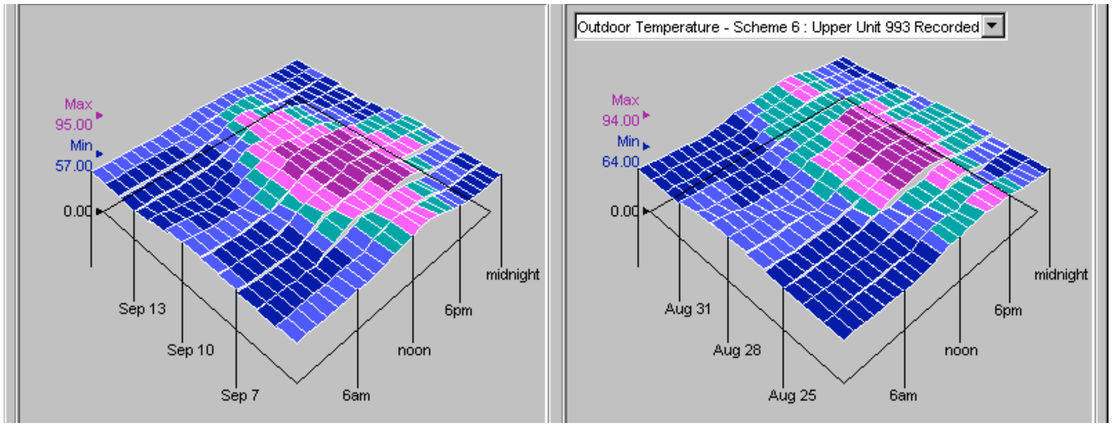


Fig.4 The peak Outdoor Air temperature recorded on site was 94ºF (right) between August 22 through September 3. In order to compare this actual performance with HEED's predictions during the design phase, using EPW climate data for this climate zone a similar temperature pattern was found that peaked at 95ºF between September 4 through 15 (left).

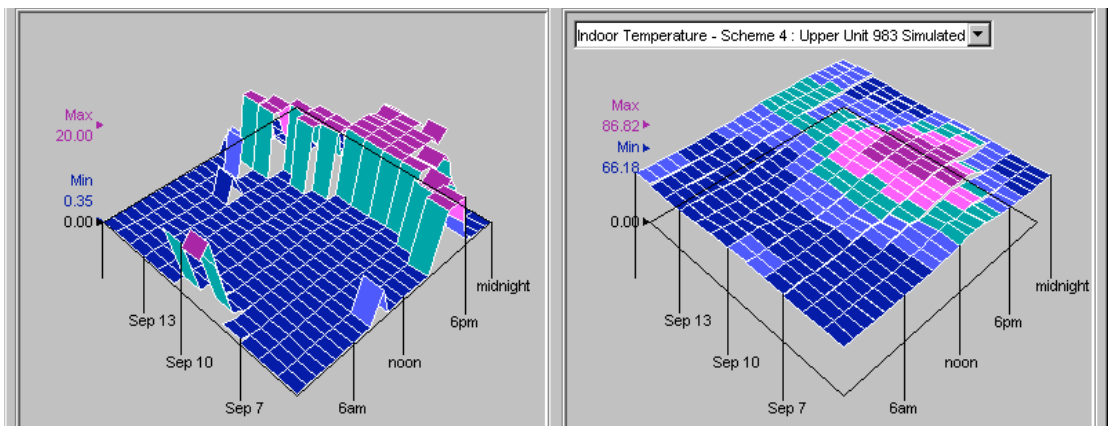


Fig.5 During the design phase HEED predicted that the peak Indoor Air Temperature (right) would be 86.82ºF in the low mass upper unit. The ventilation patter for the 20 Air Change whole house fan (left) needed only a few hours each night to being minimum indoor temperatures down to the high 60's, which was below the bottom of the comfort range.

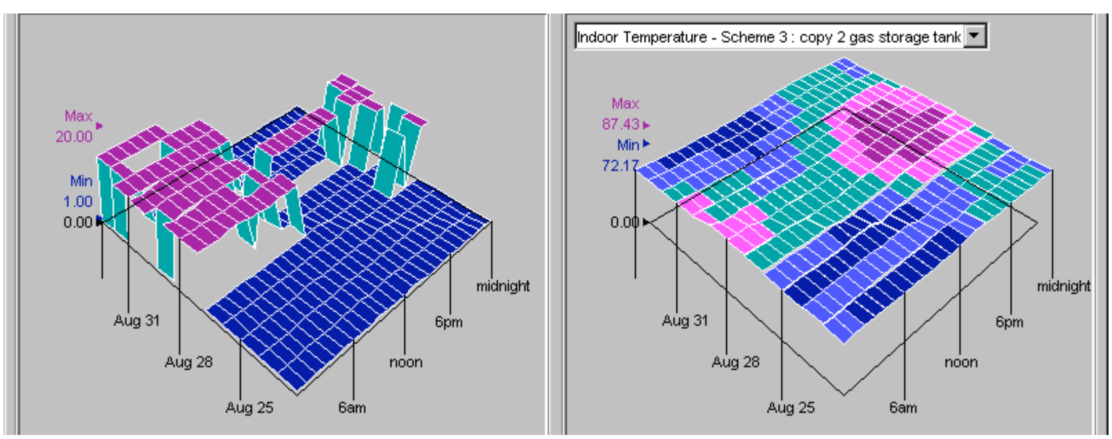


Fig.6 The recorded data in this same upper floor unit shows that the occupants experienced a peak Indoor Air Temperature of 87.43ºF (right), which is within 1 degree of HEED's predicted peak temperature (see Fig.5). Note that the occupants did not use their whole house fan during the first day of the heat wave, and two days later they kept the fan running during the increasing heat of midday (left).

This recirculated the indoor air, but did not reduce indoor air temperatures. A number of complaints were lodged by residents frustrated because their ‘air conditioning’ systems didn’t work. This was cleared up with the help of the architect, and the on-site property management team was able to further educate residents on their equipment and how to use it.

A second problem was that despite the porch thermometers and the digital thermostats, residents turned on their whole house fans or kept them running even when outdoor temperatures were hotter than indoor temperatures. Others would not use their whole house fans at all, but would open front doors and windows during the hottest hours of the day. Under these conditions, indoor temperatures quickly rise to outdoor levels. Some of these actions might be attributed to culture or habit. For example the on-site maintenance supervisor who lived in this upper unit, would leave his front door open because residents were accustomed to shouting up to him when there was a problem or when he was needed somewhere. Other residents would under-ventilate their homes. Blinds would be drawn during the day, which would actually help cut down on solar heat gain, but when outdoor temperatures fell below indoor temperatures, these same residents would not open their blinds and windows, and would not use their whole house fans. Still others, apparently for perceived security reasons, would not open their windows or doors at night.

A third problem was the high turn-over of residents within the first year. The LACDC has strict lease requirements, and residents who are uncooperative, disruptive, or break the rules, are asked to leave. Half of the resident population at Las Brisas is also classified as “special needs”, families who were formally homeless, or who are recovering from a substance abuse problem. Many of these residents could not make the adjustment to permanent housing and left within the first year. As a result, three years after completion, a different, but more permanent population now resides in the Las Brisas neighborhood. Burdened by day to day maintenance issues, the property management team has not been able to educate all the incoming residents on how to use their building systems.

5. CONCLUSIONS:

A prior ASES paper described the architect’s design process using HEED to show how indoor temperatures respond to different passive design options. This tool not only helped him design more energy efficient units, but at the same time produced graphics that helped the developers and property managers understand complex ideas about their building’s performance. HEED made it possible to quantify exactly how much more comfortable and energy efficient each unit could be. For example, it showed that indoor peak temperatures could be brought down as much as 12 degrees below outdoor peaks on the hottest days in the first floor unit by virtue of various passive design options.

Now that the project has been completed and occupied, the design team revisited it to find out how good the predictions of indoor air temperatures proved to be and to check the validity of the assumptions about occupant behavior. Two units were instrumented to record indoor air temperatures and fan control behavior over a three month period. These results were compared with HEED’s design phase temperature predictions. At this point a number of conclusions have emerged:

- Reliance on low tech controllers and resident involvement to determine when to turn on whole-house fans is not working well (residents turn them on and off at the wrong time).
- Maintenance of equipment affects use (some of the fans was found to be in need of repair and the resident did not seem to realize it and did not report it).
- An aggressive educational component needs to be implemented to train residents on how to use their passive cooling systems (but it is not clear how the on-site management team will fund this).
- Cultural habits, social patterns, attitudes about security, and expectancies about thermal comfort all influence the kind of actions residents take to modify indoor temperatures.
- HEED’s predictions during the design phase showed that indoor temperatures were within one degree of temperatures actually recorded in each unit.
- Summer temperatures in the lower (slab floor) unit were judged to be acceptable without air conditioning, however the higher temperatures in the upper (low mass) unit shows that in the future additional design refinements need to be made to insure better occupant comfort.
- A “smarter” thermostat that reads both indoor and outdoor temperatures is badly needed to automatically control whole house fans[v].

[i] Using HEED to Design Energy Efficient Affordable Housing, Murray Milne, Tim Kohut, et al. Proceedings of the American Solar Energy Society Conference, June 2002, Reno, Nevada.
[ii] “Using HEED to Design Energy-Efficient Affordable Housing”, with Tim Kohut, Home Energy Journal, Spring 2004.
[iii] HEED, Home Energy Efficient Design, was developed by the UCLA Energy Design Tools Group under contract to the California Public Utilities Commission, and is available free at www.aud.ucla.edu/heed
[iv] Manufactured by Kool-o-matic Corporation, 1831 Terminal Road, Niles Michigan 49120
[v] “Effects of Window Size and Mass on Thermal comfort Using an Intelligent Ventilation Controller”, with Pablo LaRoche, Proceedings of the American Solar Energy Society 2003, June 2003, Austin, Texas