ELIMINATING AIR CONDITIONERS IN NEW SOUTHERN CALIFORNIA HOUSING

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ABSTRACT:

If we are to drastically cut carbon emissions from residential sector, one of the primary ways to achieve this is to design homes will can be comfortable without the need for air conditioners. In a prior ASES paper we showed that this would be possible in at least half of California's 16 climate zones. This paper reports a field study that validates these results. The defining issue in this study is the comfort of the residents during the hottest days of the year.

Architects at the Los Angeles Community Design Center felt it should be possible to design Energy Efficient Low Income Housing in Southern California that does not need air conditioning. The Orange Grove project in Pasadena incorporated a number of features designed to keep indoor air temperatures within the comfort range. Critical to this were Whole House Fans which would bring in up to 20 air changes per hour during the cooler evenings whenever daytime temperatures were above the comfort range. During the early design phase a careful analysis was made of indoor air temperatures calculated by HEED (Home Energy Efficient Design) that showed they would always fall within the comfort range as defined by ASHRAE Standard 55. This data was presented to the city, but in the end LACDC was told they must include air conditioners, at which point the whole house fans were value engineered out of the project.

Because the units were designed with high mass first floors and cross ventilation at each level plus some stack ventilation up the stairwell, it was thought that they still might be comfortable without air conditioning. To test this hypothesis we instrumented four units during the three hottest months of the summer of 2007.

HOW THE UNITS WERE INSTRUMENTED:

Of the four units we instrumented, two faced east-west, and two faced north-south. One unit in each orientation did not use their air conditioner (we paid them $50 per month) and the other unit used their air conditioner as they wished. We used HOBO data loggers to record indoor air temperatures and the current on the Air Conditioner circuit every 10 minutes. We also recorded outdoor air temperature and global and diffuse radiation.

The results were quite surprising. During the hottest periods the residents in the two air conditioned units kept their units around 80ºF which apparently they considered comfortable. The residents in the un-air conditioned East-West unit used a number of strategies which usually also held their unit around 80 ºF. This recorded data was used to evaluate in detail the effect of natural ventilation and the effect of indoor air motion on the resident's comfort.

PROJECT DESIGN

Orange Grove Gardens, Pasadena: New construction completed 2005

- 38 Units – Multi-Family Housing
- Chosen units: three bedroom townhomes (1050 SF)
- Slab-on-Grade Construction for East-West units
- Reinforced Concrete slab over parking for North-South units
- City required Air Conditioners in each unit
- Whole-house fans were eliminated

Fig.1 Floor plans for the 2-story townhouses

CLIMATE FACTORS FOR PASADENA, CA

The California Energy Code says to use as the Outdoor Design High the temperature after excluding 1.0% of the hottest hours, which means that the hottest 88 hours are excluded. Thus it is assumed that for these 88 hours the indoor design temperatures can exceed the required design high. The ASHRAE Handbook says the Outdoor Design High for Glendale/Burbank is 95°F Dry Bulb with 69°F Wet Bulb at 1.0%. The NOAA all time Record High recorded for Burbank 113°F. To be conservative we decided to use 95°F as 0.5% Outdoor Design High.

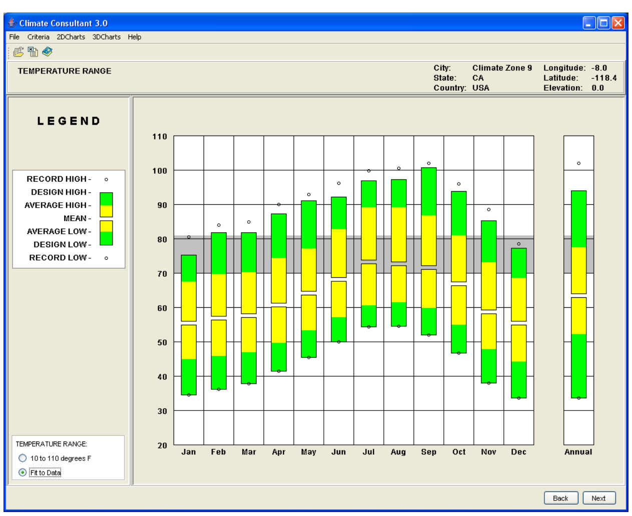


Fig.2: Energy Plus climate data evaluated by Climate Consultant 4 for Pasadena (Climate Zone 9) showing 102 ºF record high and about 30 ºF (yellow) diurnal temperature swing.

To simulate the performance of these units we used the Energy Plus Weather (EPW) data for Pasadena which shows 102ºF as the peak temperature, which is 7ºF above the California Energy Code Design High of 95ºF. However when we excluded the hottest 88 hourly temperatures it matched the required 95ºF Design Temperature (Fig.2).

Evaluating this EPW data also shows almost 30 ºF diurnal temperature differences which means that average night-time temperatures fall into or below the Comfort Zone, which is defined by the California Code as 70 ºF to 75 ºF.. This means that if a house has sufficient thermal mass (like a slab on grade) and sufficient air flow at night, it should be able to store up enough "coolth" to coast through the next day.

HOW SUMMER COMFORT IS DEFINED:

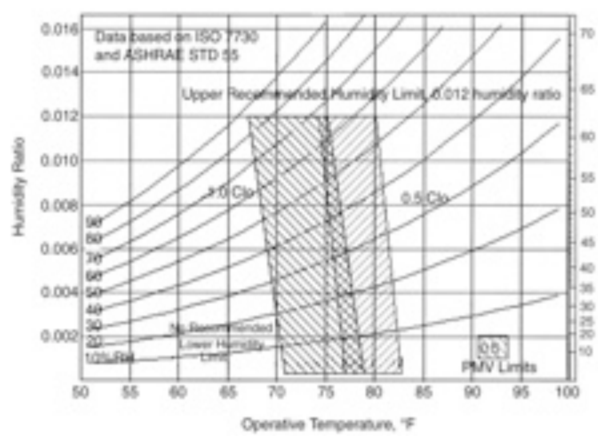


Fig.3: Winter and Summer comfort zones as defined by ASHRAE Standard 55.

The ASHRAE Standard 55 definition of Comfort (Fig.3) provides a Summer comfort zone (0.5 Clo) and a Winter comfort zone (1.0 Clo). The difference between summer and winter comfort zones is primarily how people dress. In residential applications, in winter men might wear a long sleeve shirt with a T-shirt and long pants, which is about 1 Clo,. In summer men might wear a single weight short sleeved shirt, open at the collar, with shorts or about 0.5 Clo. Using this chart the summer design high is 80ºF at higher humidity to 83ºF in less humidity.

The California Alternative Calculation Manual says that hourly Thermostat Set Points for Cooling shall be 78ºF at night to 83ºF at mid-day.

For this project, to be safe we assumed 81ºF as the upper level for Indoor Comfort Temperature.

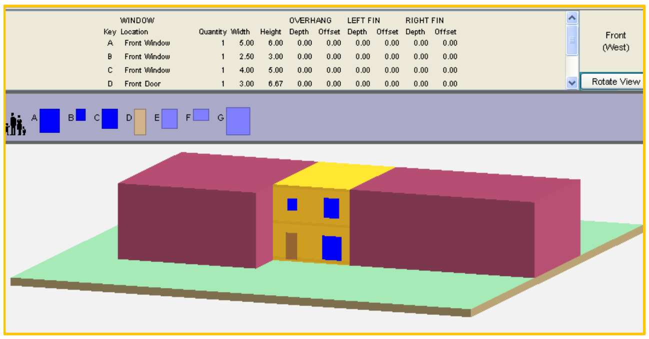


Fig.4: The HEED model of the West facing townhouse (left) compared with the as-built photograph of the same unit.

HOW ORANGE GROVE GARDENS WAS DESIGNED FOR PASSIVE COOLING

During the very earliest phases of the design process HEED (Home Energy Efficient Design) was used to predict the performance, because it can accurately calculate indoor air temperatures for all 8760 hours per year.

This East-West Townhouse Unit (fig.4) has a number of design features that contribute to Thermal Comfort including:

- Slab on grade (high thermal mass)
- Good glass (dual glazed, .32 U, 0.35 SHGC)
- Wall and roof insulation to meet or exceed code
- Party walls on two sides
- Whole-house fan for night flushing
- Possibility of stack and cross ventilation with two exposed elevations (if the residents open windows)

HOW NIGHTTIME VENTILATION HELPS CREATE COMFORT ON HOTTEST DAY

HEED can not only show plots for the annual performance, but can show each individual hour's performance during any selected 12-day period. In this case (Fig.5) for the hottest 12 days in the EPW climate data for Pasadena, it shows when the whole house fan turns on and off (left). It also can calculate the amount of cooling this incoming ventilation air will produce, in this case up to 14.4 kBTUh, or over one ton of "free" cooling. In theory the occupants could create this same amount of "free" cooling by opening and closing windows at the same times, assuming there was enough wind velocity to create 20 air changes of cross ventilation flow through their unit.

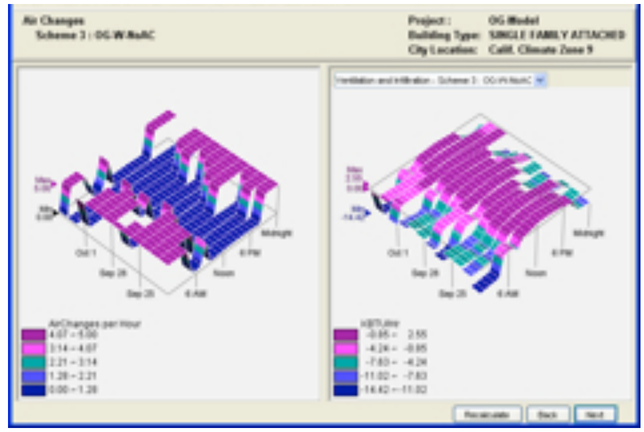


Fig.5: HEED printout shows (left) how the whole house fan turns on at night and (right) the amount of "free" cooling this ventilation air produces, up to -14.42 KBTU

CALCULATED TEMPERATURE IN THIS UNIT AS DESIGNED ON HOTTEST DAY

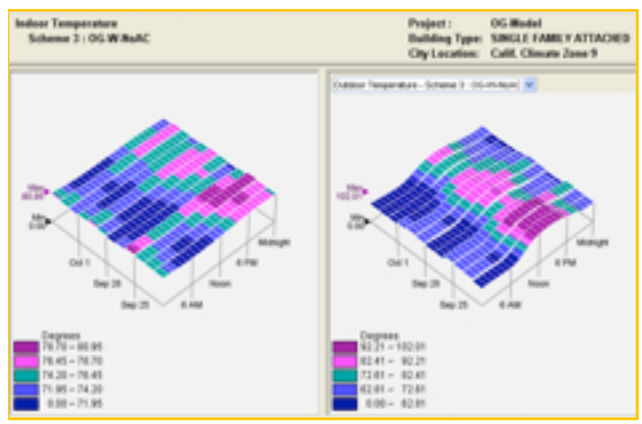


Fig. 6: This printout from HEED show the calculated indoor air temperature for this east-west unit (left) peaking at 80.95°F, compared to the corresponding outdoor air temperature which peaked at 102.81°F

HEED showed that for this unit with a whole-house fan, when outdoor air hits the 102°F High (Fig.6), indoor temperatures reached only 80.7°F. Note that this outdoor temperature is 7°F hotter than ASHRAE design high. To find these particular days, the EPW climate data file was searched for the hottest 12 day period. In this case it happened to fall between September 22 to October 4.

The Bottom Line: This unit as designed should be quite comfortable without Air Conditioning

HOW THE AIR CONDITIONING DECISION WAS MADE

The LACDC presented the original design that included a whole house fan to achieve at least 5 Air changes per hour to city officials showing that air conditioners were not needed. The City, which was contributing construction financing, said they were very impressed with the presentation, but they decided that Air Conditioners must be installed anyway!!!

And then Whole House Fans were Value Engineered out !!!

Part 2 Monitored Data:
PASSIVE COOLING VS. AIR CONDITIONING

After construction was completed we still believed that natural ventilation should be adequate to maintain comfortable indoor temperatures because the double sided townhomes were designed for cross ventilation and some stack ventilation.

We decided to monitor pairs of units to see if they would remain comfortable without AC.

We instrumented 4 identical units: 2 North-South facing, and 2 East-West facing. In each pair one of the owners agreed not use their air conditioning (residents were paid $50/month to allow us to shut off their AC, while the other two units used their air conditioning as they wished.

We installed HOBO data loggers in all four units to recorded temperatures every 12 minutes, then averaged this data hourly

Bottom Line: 81°F seems to be considered a comfortable temperature by all the participating residents (thus confirming ASHRAE Standard 55 parameters for summer conditions: 81 to 83°F peak indoor comfort temperature). We also recorded the current on the Air Conditioner circuits, and the outdoor air temperatures.

RECORDED OUTDOOR VS. INDOOR TEMPERATURES IN AIR CONDITIONED UNITS

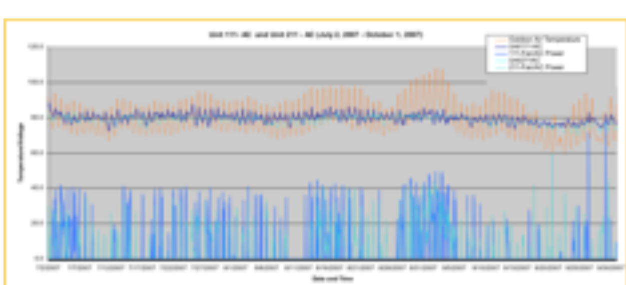


Fig.7: Recorded outdoor air temperature (red) overlaid by the temperatures in the two air conditioned units (dark blue and lighter cyan), also showing at the bottom the electrical power used by the air conditioner circuits.

In the two air conditioned units the recorded indoor air temperatures (Fig.7) show that the residents always kept their homes at or below 81°F, which they apparently considered comfortable. Along the bottom of this chart it shows the amount of time when they ran their air conditioners were operating.

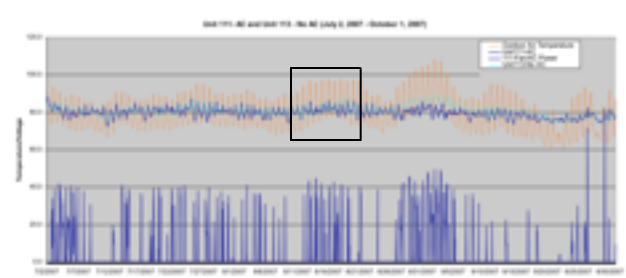
Bottom Line: 81°F seems to be considered a comfortable temperature by these residents, which agrees with the ASHRAE 55 summer upper comfort limit of 80°F to 83°F and confirms our assumption about using 81°F as the design comfort temperature)

COMPARING A PASSIVELY COOLED UNIT TO ONE WITH AIR CONDITIONING

The data recorded in the north-south facing unit without air conditioning showed a shocking pattern. On many afternoons the indoor air temperatures reached into the 90s. Upon interviewing this resident we found they believed they should manage their house like their car, that is crack open the windows in the daytime to prevent overheating, then close it up at night. This strategy turns out to be exactly opposite the optimum way to manage passive cooling.

The resident in the east-west facing unit more closely followed out suggestions for how to maintain indoor comfort conditions. They tried to keep windows closed and shades drawn during the daytime. They opened some of their second floor bedroom windows when it was cooler outside, but they did not open doors between bedrooms for cross ventilation because of the need for acoustic privacy. They also kept all the lower floor windows closed at night for security.

But this resident had a number of large stand fans that they ran during the hottest periods of the day. Note that air motion alone will not reduce dry bulb temperature, but will increase comfort.



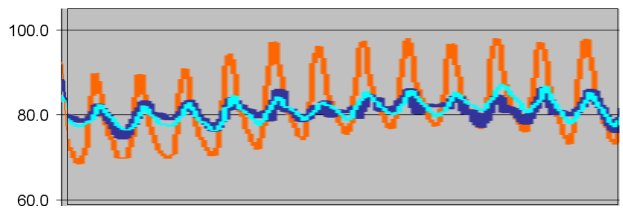


Fig.8: Comparing recorded temperatures in the two east-west units shows the unit without air conditioner (light cyan) compared to the unit that ran air conditioning daily for most of the summer (dark blue). The lower chart shows a blowup of a 12 day period used in HEED calculations.

Comparing the indoor temperatures of the two east-west units (Fig.8) shows that the unit without air conditioning stayed as cool as (and sometimes even cooler than) the air conditioned unit. The only time this does not occur is when outdoor air temperatures exceeded 100°F for five days in a row. These outdoor air temperatures exceed the 102°F peak in the EPW climate data file used to design the units, and also greatly exceeded the ASHRAE design high of 93°F for this location.

The question is did this residents strategy of increased air motion produce effective indoor air temperatures within the comfort range?

Part 3:
PASSIVE COOLING – WHAT WE LEARNED

HOW ACCURATE ARE THE DESIGN MODELS?

Using this actual recorded outdoor air temperature data a file was re-created in the EPW format, and HEED was re-run but without the whole house fans. It was assumed conservatively that this unit would achieve only about 1.0 air change per hour with the limited night time ventilation strategy that they employed. During this 12-day period when the peak outdoor dry bulb temperature peaked at 98°F, the recorded peak indoor temperature was 87°F inside the unit (Fig.9). Using these same recorded outdoor temperatures HEED calculated the indoor Dry Bulb would peak at 86.06°F during this same period.

Bottom Line: HEED calculates indoor air temperatures that are within 1ºF of actual recorded indoor air temperatures

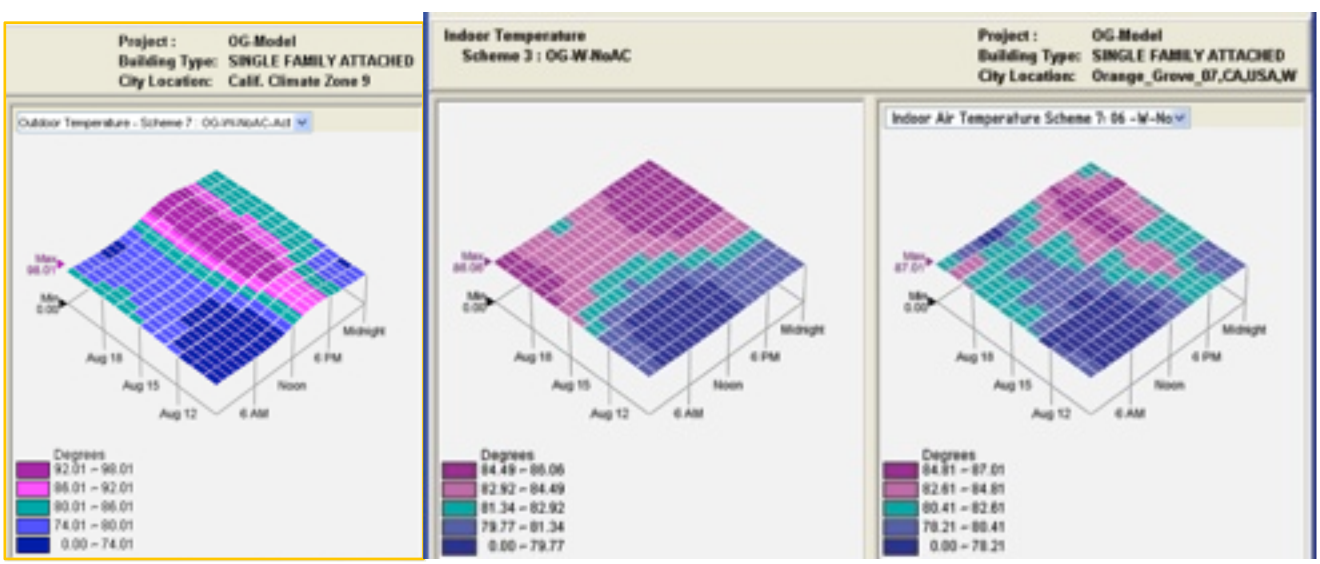


Fig.9: Using actually recorded outdoor air temperatures peaking at 98.01°F (left), HEED predicted indoor maximum temperature at 86.06°F (center) while the actual recorded indoor max was 87.01°F (right)

THE EFFECT OF VENTILATION ON COMFORT

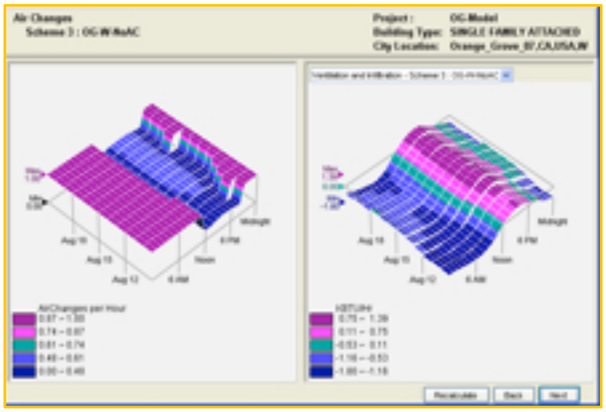


Fig.10: Using these same outdoor temperatures, and assuming that the owner's actual nighttime window management strategy produced only about one air change per hour (left), HEED calculated that this would produce only about 1.8 kBTUh of cooling at night, but normal .35 air changes of infiltrating would create 1.39 kBTU h of daytime heating gain.(right).

If residents opened only their upstairs windows as soon as outdoor dry bulb temperature was cooler than indoors, we estimate there would be 1.0 air change per hour (Fig.10, left). Using the actually recorded outdoor air temperatures, the result of this ventilation strategy (right) shows heat loss about -1.80 kBTUh at night from the few open windows, but 1.39 kBTUh heat gain during the hottest part of the day from infiltration alone

Bottom Line: Relying on residents to open and close their windows at exactly the right time is probably too much to expect. Thus thermostat controlled mechanized ventilation would probably be more reliable and could manage greater air changes per hour.

THE EFFECT OF AIR MOTION AND CLOTHING ON COMFORT

The resident in the east–west unit without air conditioning had many fans running indoors. According to ASHRAE Standard 55, air velocities of about 140 fpm are the limit of the comfort range in office settings. If we assume that the mean radiant temperature is the same as the recorded indoor temperature, this air velocity would provide for a reduced effective temperature of 4.6°F. When this is subtracted from the recorded peak of 87.01°F it produces an effective maximum comfort temperature of approximately 82.4°F. When the SET (Standard Effective Temperature) is calculated more accurately (Fig.12) it shows 80.2°F is accurately which is slightly below the 81°F, which was the average ASHRAE comfort high we were seeking.

So now the question is how many people would find this peak temperature with this amount of air motion to be uncomfortable? Again ASHRAE Standard 55 provides an algorithm that calculates the Predicted Percent Dissatisfied (PPD) and the Predicted Mean Vote (PMV).

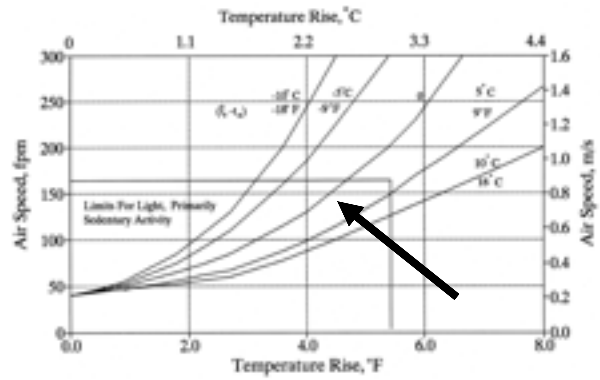


Fig.11: Air speed required to offset increased temperatures (ASHRAE 55)

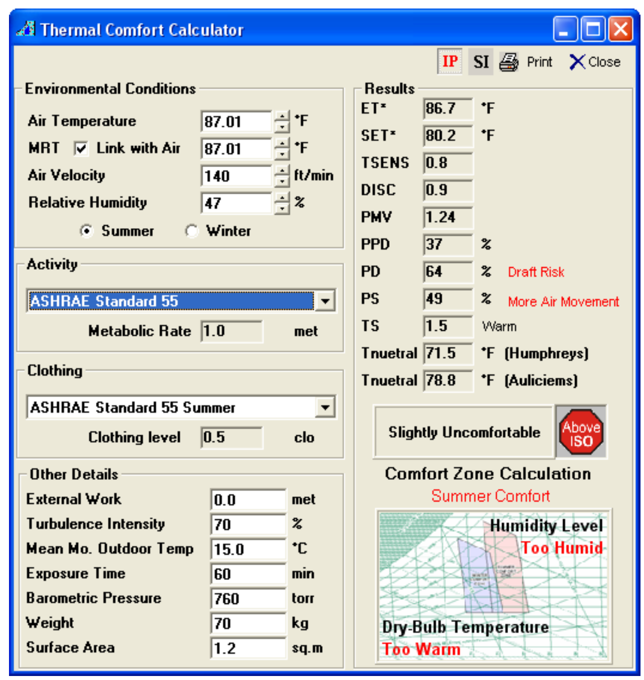


Fig.12: Using the recorded indoor temperature of 87.01°F, and 140 FPM air velocity, the Standard Effective Temperature is 80.2°F and the PPD (Predicted Percent Dissatisfied) is 37% (Calculated using Handsdown Software's Thermal Comfort Calculator – Based on ASHRAE Standard 55)

Using the Thermal Comfort Calculator (from Hands Down Software) under these conditions the Predicted Percent Dissatisfied is calculated at 37% (Fig.12). In other words about 63% of the occupants would probably at least not find these conditions uncomfortable. This means that the according to ASO standards this is rated at "Slightly Uncomfortable". The PPM (Predicted Mean Vote) is 1.24 on a scale that runs from 0=neutral, 1=slightly warm, 2=warm, 3=hot. The SET (Standard Effective Temperature) at this air velocity and clothing is 80.2°F.

If this had been one of the worst 88 hours of the year these hot temperatures would have been excluded if the design comfort range was set at the 1% level. This resident's home probably would have met the 81°F upper comfort limit for all but 88 hours, thus would not need an air conditioner.

Bottom Line : Even though residents did not use the optimum nighttime natural ventilation strategy and indoor temperatures peaked at 87°F, this temperatures was effectively reduced 4.6°F by indoor fans and by the use of summer clothing (.5 Clo), which produced a Standard Effective Temperature of 80.2°F which is within ASHRAE's upper comfort temperature limit.

WHAT WOULD WE DO DIFFERENT NEXT TIME?

Initially the logic behind this project was that these low income residents must pay their own utilities. Some of them do not run their air conditioners because they simply cannot afford the cost. However they are entitled to be comfortable in their own home, and they should not have to endure great discomfort because of lack of the best possible administrative and design decision making. The task for architects should be to design units that will be passively cooled so that the occupants will not need air conditioners for thermal comfort.

If we had it all to do over, instead of installing Air Conditioners, we would install a large whole house fan. We also would have installed an additional amount of thermal mass in the form of a second layer of drywall in ceilings. We also would have installed ceiling fans in all the major rooms capable of velocities of up to 140 fpm.

Part 4:

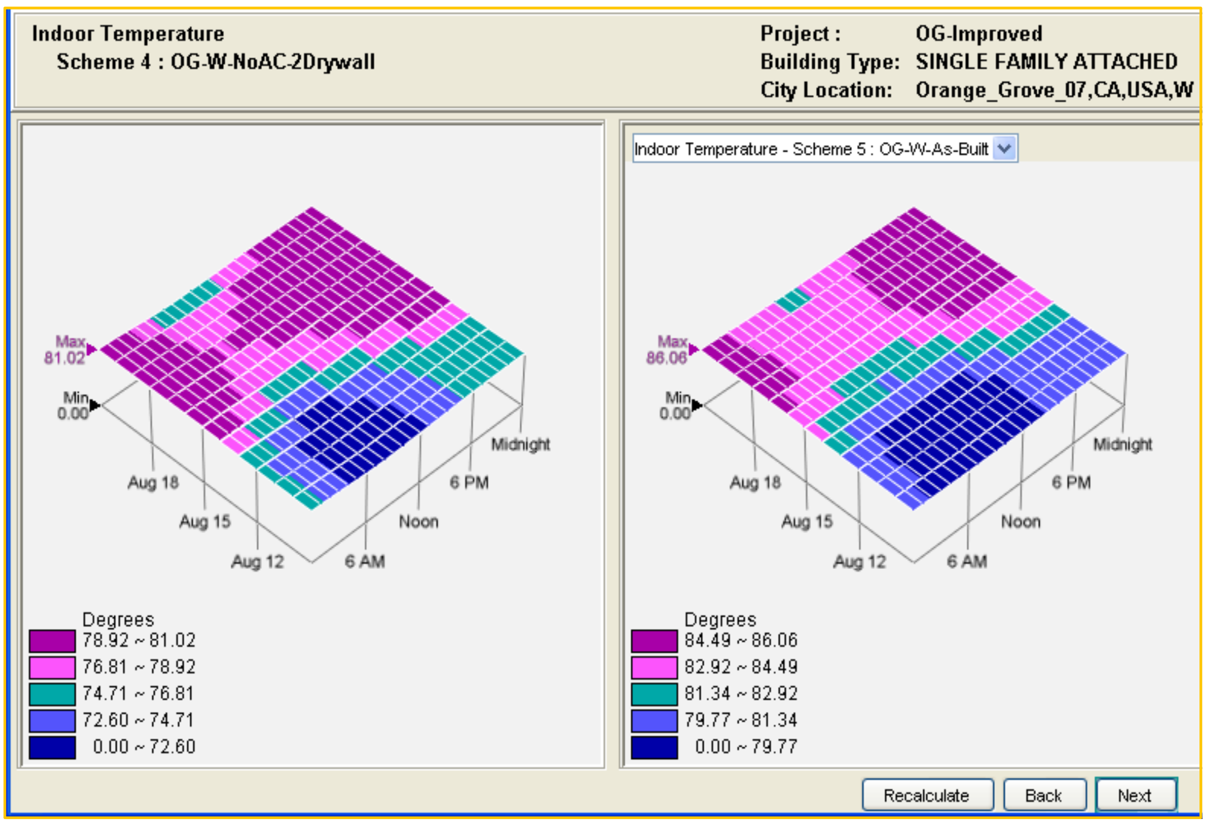


Fig.13: Making the passive design changes listed above, the calculated indoor dry bulb temperature falls to 81.02°F (left), and the availability of ceiling fans would bring the effective temperature down to 76.4°F compared to the measured indoor temperature of 86.06°F (right).

Re-running HEED with these simple design changes would reduce the indoor dry bulb temperature to no more than 81.02°F during these 12 hot days (a peak temperature the residents found acceptable). The availability of ceiling fans would have reduced effective temperatures by an additional 4.6°F for an effective temperature of 76.4°F. This means these passive design strategies can reduce peak indoor effective temperatures by almost 10°F.

Bottom Line: By simple design changes like installing a whole house fan for night flushing, plus a second layer of drywall on the ceiling, and installing ceiling fans for daytime air motion would reduce effective indoor effective temperatures to 76.4°F which is well within the comfort range

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References:

"Why Design Matters: Comparing Three Passive Cooling Strategies in Sixteen Different Climate Zones," Murray Milne, Carlos Gomez, Donald Leeper, Pablo LaRoche, Jessica Morton, Solar 2005 Conference Proceedings, American Solar Energy Society

HEED can be downloaded at no cost from: www.energy-design-tools.aud.ucla.edu/heed

ClimateConsultant can be download at no cost from www.energy-design-tools.aud.ucla.edu

HandsDown Software. www.handsdown.com

Standard 55: Thermal Environmental conditions for Human Occupancy, ASHRAE, American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc, www.ashrae.org

ASHRAE Handbook of Fundamentals, 2005, American Society of Heating Refrigeration and Air Conditioning Engineers

Building Energy Efficiency Standards, CEC-400-2005-001, California Energy Commission

Residential Alternative Calculation Method (ACM) Approval Method, CEC 400-2005-001, California Energy Commission