WHY DESIGN MATTERS: COMPARING THREE PASSIVE COOLING STRATEGIES IN SIXTEEN DIFFERENT CLIMATE ZONES

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ABSTRACT

In order to compare the performance of three different cooling strategies (External Operable Shades, Internal Operable Shades, or a Whole-House Fan) in all 16 California climate zones, hourly performance data was recorded in a pair of full height test cells.

The results were used to validate HEED (Home Energy Efficient Design), a whole-building energy simulation program. HEED automatically designed two 2000 sq.ft. houses, one to Meets the Energy Code, (California's Title24), and the other that was a More Energy Efficient scheme. The Code requires a slightly different buildings in each of California's 16 climate zones. On a state-wide basis these More Energy Efficient homes designed by HEED use about 35% less energy than the homes that Meet the Energy Code (Title 24).

One of the three cooling strategies was added to each of the two basecase homes in each climate In the Title 24 home the Whole-House fan is only half as good as either of the two Operable Shades. However in the More Energy Efficient home (that has more thermal mass) the Whole-House fan is significantly better than the Operable Shades, even to the point of eliminating the need to install an air conditioner in 10 of California's 16 climate zones.

The External and Internal Shades performed almost the same throughout the state, because in this simulation the more opaque External Shade required more indoor lighting along with its accompanying load on the air conditioning system. This modifies the traditional belief that External Shades are always more efficient.

This study demonstrates once again why design matters. Small changes in the way a building is designed can make a significant difference in the amount of energy it uses.

1. INTRODUCTION

California is divided into 16 climate zones, and the California Energy Code (Title-24) requires a slightly different design for homes in each zone.

HEED (Home Energy Efficient Design) is a user friendly design tool intended to help homeowners, architects, and builders design more energy efficient homes (www.aud.ucla.edu/heed). It is intended for use at the very beginning of the design process, when most of the decisions are made that will affect the buildings eventual energy performance. HEED was validated in this project using experimental data, and has been previously validated using the ASHRAE BestTest procedure (the results are reported on the HEED web site).

HEED starts by asking four questions: the building's location (climate zone), square footage, number of stories, and building type. With this information HEED automatically creates a building design that meets Title 24 (titled Scheme 1, "Meets Energy Code"). Then it automatically creates a second more energy efficient building design (titled Scheme 2, "More Energy Efficient") that is usually about 30% better. This process was repeated for each of California's 16 climate zones, using climate data for every hour of the year.

2. HOW HEED MODELS THESE THREE COOLING STRATEGIES

HEED was expanded to be able to simulate the logic of the experimental microprocessor thermostat used to operate these three different cooling strategies, the External Operable Shade, the Internal Operable Shade, and the Whole House Fan. The performance of these shades is calculated using ASHRAE and ACM algorithms.[1]

The Operable Shades were designed to close whenever there is sun on the window and the indoor air was above comfort low temperature in summer, or more than three degrees below comfort high temperature in winter. All the homes in this study have a 70ºF comfort low temperature and a 78ºF comfort high as specified in Title 24. This means there is a dead band of 8ºF. There is also a 60ºF night setback.

The Whole-House Fan was designed to turn on in summer whenever the indoors was above comfort low temperature, or in winter whenever the indoors was above the comfort high temperature. This meant that in summer the fan acted as a night flusher, cooling down the interior of the house usually in the late afternoon and at night, until the interior fell below outdoor air temperature, or until it was below the bottom of the comfort zone (70ºF). It also means that in winter the fan acts as an economizer cooler, turning on during the day time whenever the indoor air temperature was being raised above the top of the comfort zone because of too much solar radiation,

3. EXPERIMENTAL VALIDATION OF HEED

As part of a 5-year research project on smart controllers, hourly performance data was recorded in a pair of full height test cells. The performance of the Basecase Control Cell was compared to an Experimental Cell which had one of the three different cooling strategies: External Operable Shades, Internal Operable Shades, or a Whole-House Fan (Milne, LaRoche, 2004).

HEED requires a physical description of the building (the test cells), plus climate data that was actually recorded during the days of the test, including the outdoor air temperature, beam and total horizontal solar radiation. HEED can simulate the logic of the microprocessor thermostat used to operate the automatic internal and external louvers, as well as a whole house fan. The performance of the external and internal shades is calculated using ASHRAE and ACM algorithms. A control cell, with no shading or fan, was also simulated

The experimental results were used to validate HEED, by comparing the indoor temperatures measured in the test cell to the corresponding indoor temperatures calculated by HEED.

TABLE 1: HEED VALIDATION TESTS

HEED Validation Tests For Summer	**Temperature Difference between Data Recorded in the Experimental Cell vs. Temperatures Calculated by HEED**		
Experimental Test Series	Peak Hottest Hour	Peak Coldest Hour	Average all Hours
1. External Shades Experimental Cell	-.12ºC (-.21ºF)	.66ºC (1.18ºF)	.24 ºC (.44ºF)
2. Internal Shades Experimental Cell	-.62ºC (-1.11ºF)	.22ºC (.40ºF)	-.14ºC (-.26ºF)
3. Whole House Fan Experimental Cell	1.30ºC (2.34ºF)	-.57ºC (1.03ºF)	.58ºC (1.04ºF)
C. Control Cell No Shades No Fan	-.72ºC (-1.31ºF)	-.82ºC (-1.47 ºF)	-.30ºC (-.54ºF)
Mean Temperature Difference	**-.16ºC (-.29ºF)**	**-.51ºC (-.92ºF)**	**.38ºC (.68ºF)**

The results of these validation studies (Table. 1) shows how well HEED predicts the actual measured indoor summer temperatures. HEED is most accurate at predicting the indoor maximum hottest hour to within -.29ºF. HEED is slightly less accurate at calculating the indoor minimum coldest hour to within -.92ºF. On average for all hours HEED is quite accurate at predicting the indoor temperature to within .68ºF over all hours of all tests for summer climate conditions.

In summary, HEED was shown to accurately calculate the indoor air temperature to within one degree compared to the measured indoor air temperatures for the Control Cell (with no shades or fan) and for the Experimental Cell with each of the three different types of cooling strategies (LaRoche, Milne 2004).

4. USING HEED TO MODEL COOLING STRATEGIES IN EACH CLIMATE ZONE

Once HEED was shown to accurately predict the performance in these test cells, then HEED was used to model two 2000 sq.ft. occupied houses, one that Meets the Energy Code (Title24), and a More Energy Efficient version. HEED uses the California Energy Commission's 8760 hour annual climate data for each of these 16 California climate zones.

TABLE 2: DIFFERENCES BETWEEN THE TITLE 24 AND THE ENERGY EFFICIENT DESIGNS

Scheme 1: MEETS ENERGY CODE (Title 24) Design	Scheme 2: MORE ENERGY EFFICIENT Design
Square floor plan	Rectangular floor plan facing South
Equal area of glass on each wall	Most glass on South, least on E &W
Windows tinted as required by code	Clear glass on South and North
No window shading	Overhangs shading South Windows
Stud and Stucco walls	High mass walls, exterior insulation
Raised wood floor	Slab on grade floor, carpet or tile
1/2 air change infiltration	Whole-House Fan to 10 air changes/hr
Lights are mostly incandescent	Lights are mostly fluorescent
BOTH DESIGNS HAVE THE SAME: Floor area, Window area, Climate	

5. DESIGN DIFFERENCES BETWEEN TITLE-24 HOME AND MORE ENERGY EFFICIENT HOME

HEED automatically designs both a Meets Energy Code (Title 24) house (Scheme 1), and a More Energy Efficient house (Scheme 2) for the given climate and latitude. The difference between the designs is shown in Table 2.

For each of the 16 climate zones in California, the Energy Code requires a slightly different house. It has different amounts of insulation, different types of glazing, and different maximum window areas as defined by Title 24 (the California Energy Code) and by the ACM (Alternative Calculation Method). But in all cases it is a low-mass home with a square floor plan and the window area distributed equally on each of the four sides. Obviously this is not the best passive solar design strategy for all of these different climates. In each climate it is quite possible for HEED to design a more energy efficient home that uses much less energy than the basecase Title 24 design.

6. PASSIVE COOLING SYSTEMS PERFORMANCE

Comparing the Meets Energy Code home (Fig.1) with the More Energy Efficient home (Fig.2) for the Basecase plus the three cooling strategies, within each of the 16 climates, shows many interesting differences. These two figures show loads on the furnace or air conditioner, and account for energy saved if the passive system can keep the interior within the 8ºF dead band.

6.1 Fan vs. Shades:

The External and Internal Shades are a better cooling strategy for the Title 24 (low mass) building, while the Whole-House Fan is a dramatically more effective cooling strategy for the More Energy Efficient (high mass) building. This difference is so significant that the Whole-House fan essentially eliminates the need to install an air conditioner in this high mass More Energy Efficient home, in 10 of California's 16 climate zones. Note also that in the More Energy Efficient building the automatic operable External or Internal Shades also essentially eliminates the need for air conditioning in 5 of California's climate zones.

The only More Energy Efficient building in which shades are better than the fan is in Zone 16, Mt. Shasta, because the optimum home for this climate (as designed by HEED) has low mass.

6.2 External vs. Internal Shades:

Internal and External Shades performed almost the same in all climates, and for both building types. This is because in this simulation the External Shades were assumed to be more rugged and thus slightly more opaque than the Internal Shades. Because HEED calculates the amount of artificial lighting needed, the Externally Shaded building used slightly more lighting energy plus its accompanying cooling energy. These internal loads in this case were higher than the thermal savings of the external shade. This adds a qualifier to the traditional belief that External Shades are always more efficient.

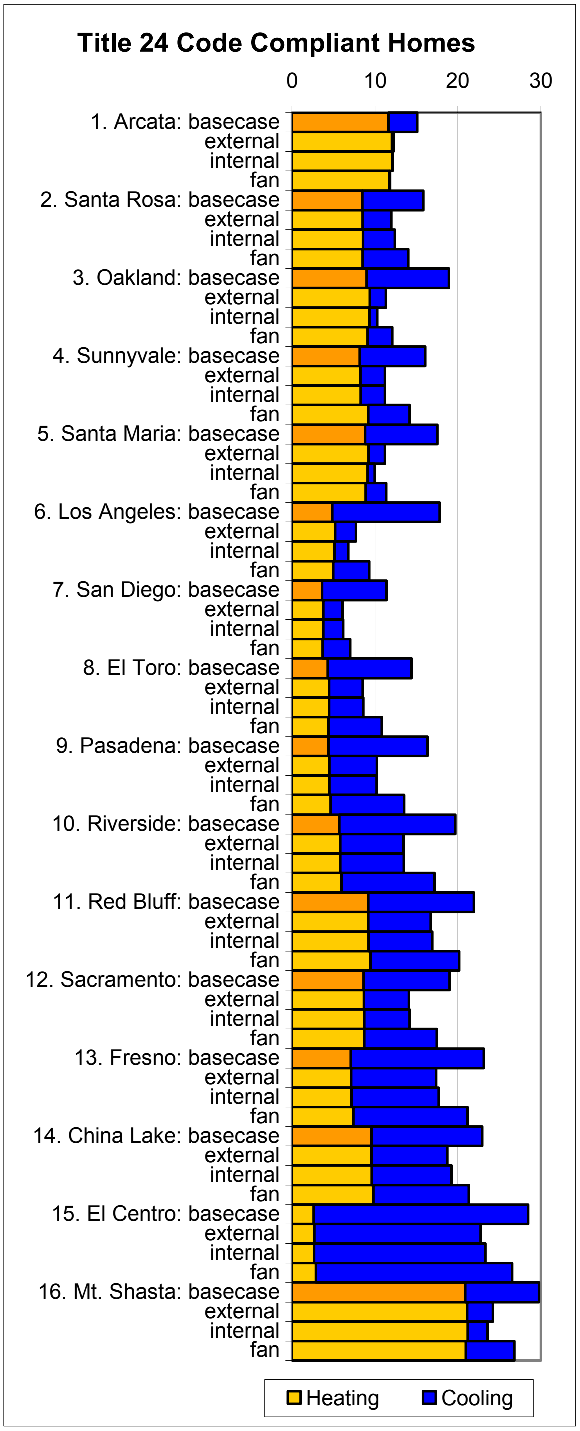

Fig.1: Heating and Cooling Loads for a 2000 sq.ft. Home that Meet the Energy Code (Title 24), Designed Specifically for Each Climate (kBTU/sq.ft.year).

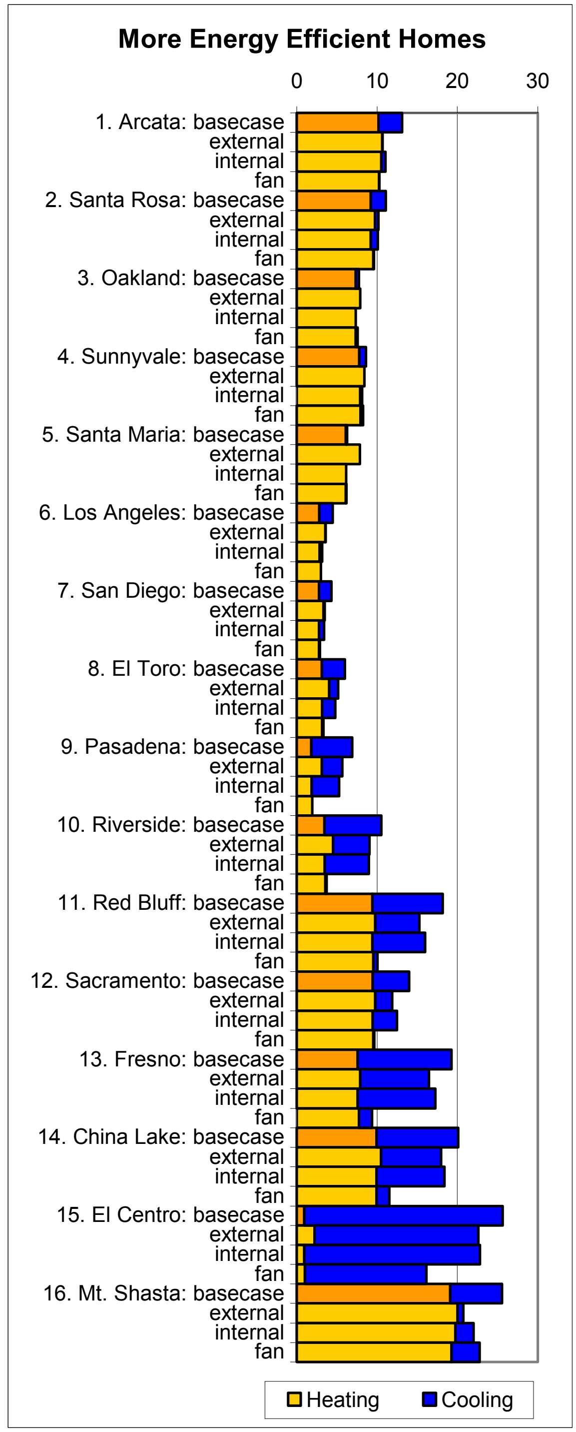

Fig.2: Heating and Cooling Loads for a 2000 sq.ft. Home that is More Energy Efficient, Designed Specifically for Each Climate (kBTU/sq.ft.year).

Note that in the test cells which had no internal loads, the External Shade outperformed the Internal Shade. This points out that there is a delicate balance between the transparency of the shade and its thermal performance when simulating an occupied building's energy performance. If this result is supported by other researchers, it means that automatically controlled internal shades will have a clear advantage because they are much less expensive and are easier to maintain. This illustrates how a single design detail of a building can tip the balance in deciding which cooling strategy to use

6.3 Heating Energy:

Note that the amount of heating energy (left hand yellow bars) used in each climate is essentially the same regardless of cooling strategy. In fact the heating loads sometimes increased by a tiny amount because the cooling strategies occasionally over-cooled the building. But in general, heating loads are not reduced by either of the operable shading strategies, which is counter the expectancy that passive winter heating would be improved. It turns out this is because the operable shades were in their fully open position throughout the heating season and thus essentially did not exist. The same is true of the Whole-House Fan which was off throughout the heating season.

6.4 Climate zone Differences in Performance:

Individual climate zones show interesting differences in performance. For instance Arcata, on the cool overcast northern California coast, shows very little need for cooling, whether it is a low mass or high mass building. Mt. Shasta, California's cold high-altitude climate zone, shows the highest heating needs, but still shows that shading can dramatically reduce the need for air conditioning. This is the only climate zone in which the Whole-House fan in the More Energy Efficient building is less efficient than shading, because the home designed for this cold climate would need much less thermal mass.

6.5 Overall Difference Between Code Compliant Homes and the More Energy Efficient Homes:

On an overall state-wide basis the basecase More Energy Efficient buildings (Fig.2) use less total energy than the Title 24 buildings (Fig.1). These savings are more dramatic when comparing fan cooled buildings. With the two types of operable shades, the More Energy Efficient building still clearly uses less energy than the Title 24 building. This points up the impressive improvements that can be made in a building's energy consumption by single design decisions.

6.6 Design Matters:

The results of this study show dramatically that the way a home is designed can make a significant difference in the amount of heating and cooling energy it uses. It also points up the importance of simulating the performance of every home when establishing the initial design approach and when refining the final design details (which was the motivation for creating the HEED Energy Design Tool).

7. AVERAGE CALIFORNIA STATE-WIDE PERFORMANCE

When the performance of these four buildings are added up and averages for all 16 zones, it gives a rough idea of the state-wide impact of each system (Table 3). Strictly speaking however, because the population is each climate zone is so different, these averages are technically not the same as state-wide averages. For example, Zone 6, Los Angeles, has a great many more people and homes than Zone 1, Arcata.

7.1 State-Wide Performance of the Title-24 Home:

In the Title 24 (Meets Energy Code) home, the average of all 16 climate zones shows that the Exterior or Interior Shades reduce total loads by an average of 69% to 70% compared to the Basecase design (Table 3). The Whole-House Fan is less effective, reducing total loads to about 82% of the Basecase house loads. This means that the operable shades were significantly better than the Whole-House fan for a Title 24 house, which has low Internal mass.

When looking at cooling loads alone, the results are much more dramatic. The Exterior and Interior shades reduce cooling loads by more than half for the Basecase house. The Whole-House fan reduces cooling loads to 68.6% of the Basecase house. Notice that with all three of these cases, the heating loads increased by about 2 %, because the cooling strategies occasionally over-cooled the building.

7.2 State-Wide Performance of the More Energy Efficient Home

The More Energy Efficient building has a more rectangular floor plan with most of the glass facing south, and an overhang shading all south windows. In most zones this was designed as a high-mass building, giving it a much longer thermal time lag. This More Energy Efficient house used only 65% of the energy of the Meets

Energy Code house, on average for all 16 California climates (Table 3). This breaks down to only 50% of the cooling and 87% of the heating compared to the Title 24 house. These dramatic reductions are due only to architectural design differences, and do not include the effect of the automatic Operable Shades or the Whole-House fan.

The three cooling strategies have somewhat less impact on the More Energy Efficient house, because it is already so efficiently designed. The External and Internal Shades reduce total loads to about 85% of the Basecase More Energy Efficient house, while the Whole-House Fan reduces it even more to 64% because night flushing is so much more effective in high-mass buildings. Here also heating loads alone show a slight increase compared to the Basecase home, because the controller occasionally over-cools the building. Cooling loads show a more dramatic reduction, to 71% for Internal shades, to 59% for External Shades, and to a truly impressive 26% of cooling loads for the Whole-House Fan compared to the Basecase building.

TABLE 3: PERCENTAGE DIFFERENCES IN PERFORMANCE AVERAGED FOR ALL CLIMATE ZONES

PERCENTAGE DIFFERENCES IN AGGREGATE LOADS

	Title 24 (T24) Meets Energy Code Home			More Energy Efficient (EE) Home		
	Basecase vs External	Basecase vs. Internal	Basecase vs. Fan	Basecase vs. External	Basecase vs. Internal	Basecase vs. Fan
Total HVAC	69.24%	70.01%	82.34%	85.44%	85.47%	63.81%
Heating HVAC	102.09%	102.13%	102.66%	101.08%	101.24%	101.49%
Cooling HVAC	47.62%	48.67%	68.62%	59.06%	71.43%	26.07%

	EE Basecase T24 Basecase	EE Fan vs. T24 Fan	EE External vs T24 External	EE Internal vs T24 Internal
Total HVAC	65.39%	50.67%	80.69%	79.82%

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(3) Title 24: Energy Efficiency Standards for Residential and Nonresidential Buildings, 2001, California Energy Commission Publication P 400-01-024

(4) ACM: AB970 Low –Rise Residential Alternative Calculation Method Approval Manual, January 3, 2001 California Energy Commission Publication P 400-01-04

HEED is available at no cost on www.aud.ucla.edu/heed It has been validated using the experimental data as described here and also using the ASHRAE BestTest procedure as described on the web site.

ACKNOWLEDGEMENTS:

This project was supported by the Energy Innovations Small Grant Program of the California Energy Commission. The development of HEED was supported by the California Public Utilities Commission. HEED was developed by the Energy Design Tools Group at the UCLA School of Architecture and Urban Planning, in association with CTG Energetics, Malcolm Lewis President.

[1] To calculate the performance of closed internal venetian blinds HEED uses an IAC=.26 (Interior Attenuation Coefficient) described in the 2001 ASHRAE Handbook of Fundamentals, 30.48, Table 19. HEED treats exterior louvers in the closed position as an exterior diffuse shade with a Solar Heat Gain Coefficient (SHGC) =.13 as defined in the California Alternative Calculation Method (ACM) Table 3-3 (CEC Publication P400-01-004), and uses the ACM method to combine SHGCs.