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APPROPRIATE CONSERVATION MEASURES FOR SINGLE-FAMILY BUILDINGS IN HOT, HUMID CLIMATES[1]

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ABSTRACT

The effectiveness of a number of energy conservation measures for homes located in hot, humid climates was analyzed using the DOE-2.1B building simulation model. Measures having the greatest benefits to the homeowner are predicted to be the addition of ceiling insulation only if the house is not already insulated, weatherization, and reduction of the wall outer surface solar absorptance. The weatherization and solar absorptance reduction measures should be do-it-yourself installations to be cost-effective.

Replacement of an air-conditioning unit with a new high-efficiency unit was very effective in reducing peak demand and annual cooling energy. Unless the energy efficiency ratio of the existing unit is low (<6), replacement is generally not cost-effective.

The measures were predicted to result in slightly increased indoor humidities, but their effect on human comfort was predicted to be small. However, this conclusion should be considered preliminary since the simulation models used for these predictions have limitations. The amount of energy that can be saved by these measures is very dependent on the occupant's lifestyle, such as the degree to which the occupants will alter clothing to achieve comfort.

INTRODUCTION

The purpose of this study was to examine and evaluate the most cost-effective conservation measures and their related energy savings for existing single-family dwellings located in hot humid climates. The effectiveness of retrofit measures in such climates is not well understood and may not be accurately predicted by present energy audit procedures, such as the Residential Conservation Services (RCS) procedures (1). This is because other sources, in addition to the air temperature difference, contribute to the air conditioning load, as illustrated in Fig. 1. Solar radiation and moisture removal requirements are large parts of the cooling load. Adding insulation to the building shell reduces the cooling load, but does little to reduce the latent heat portion of the load.

The scope of this study was to identify building and equipment measures and to analytically evaluate them, individually and in combinations. They were examined with respect to their costs, expected energy savings, effect on air conditioning performance, humidity control, and human comfort. Specific measures analyzed are summarized in Table 1, and they include building shell retrofit measures, reduction of internal loads, and replacement of existing air conditioning units.

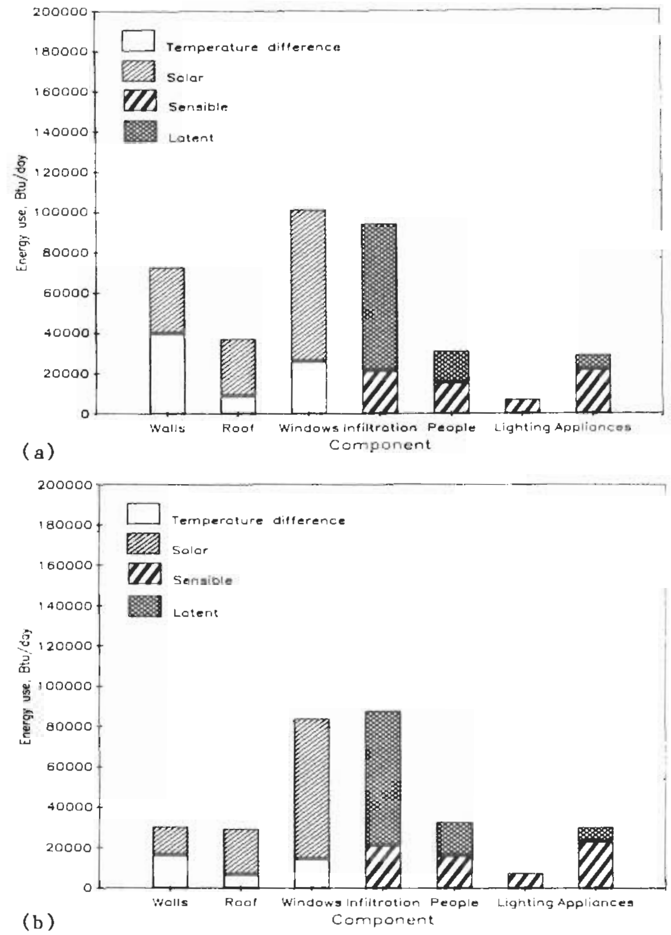

Fig. 1. Predicted cooling load components for a frame ranch house located in Orlando, FL, on a warm summer day: (a) R-11 ceiling insulation, no wall insulation, single pane windows, (b) R-19 ceiling insulation, R-11 wall insulation, double pane windows.

Table 1. Retrofit energy conservation measures investigated.

A.	**Shell conservation measures**	
	1.	**Added insulation (including double-pane windows)**
	2.	**Weatherization (reduced infiltration)**
	3.	**Reduced solar absorptance**
	4.	**Window shading**
	5.	**Drape closing**
B.	**Internal load measures**	
	1.	**Refrigerator replacement**
C.	**Equipment measures**	
	1.	**Air conditioner replacement**

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In addition to the energy savings, the effect of the measures on the peak hourly average cooling loads was investigated. Although this may not affect the homeowner directly, it could affect the owner indirectly by charges for the utility capacity and possible time-of-day rates.

METHODOLOGY

The approach used was to define a prototype ranch house and predict its cooling energy use and hourly interior temperatures and humidity ratios using the DOE-2.1B building simulation model (2). Human comfort was then evaluated from these predicted conditions using the International Organization for Standards Predicted Mean Vote (PMV) relation (3). Initial costs of the measures were estimated primarily from the RCS residential retrofit data base (4). The analysis concentrated on the house being located in Orlando, FL, with supplemental calculations for the house being located in Miami, FL, and Houston, TX. Typical Meteorological Year (TMY) weather data were used for these calculations.

PROTOTYPE HOUSE

The prototype house selected for this study was a 28-ft by 56-ft ranch house built on a concrete slab, which is typical of one-story houses currently built in southeastern United States. Both frame and masonry construction were considered since many houses in that region are constructed of concrete block. The house has a gable roof with 2-ft overhangs. It has 178 ft^2 glazing, which is about 11% of the floor area. This is slightly greater than the 8-10% national average (5), and reflects the inclusion of a sliding glass door on the rear wall and windows on the end walls.

A family of four was assumed to occupy the house. The internal load generated by this family was about 76,300 Btu/day, of which 25,100 Btu/day is latent. This is a slight modification of the internal load profile developed by the Florida Solar Energy Center (6), but the hourly load distribution was assumed to be essentially that developed by the Center.

Cooling and heating of the house were done by a central air conditioning unit and electric resistance heaters, which is common in hot humid climates. Only air conditioning units currently on the market were considered in this study. Capacities of these units varied from 23,400 Btu/h to 42,000 Btu/h, and the energy efficiency ratios (EERs) of the units varied from 6 to 11.8. Data that were obtained from the manufacturers were used to describe the performance of these units. It was assumed that these units had a degradation coefficient of 0.2 to account for the cycling losses.

DOE-2.1B PROGRAM

The DOE-2.1B program is a public domain computer assisted model that describes the flow of heat in a building and the associated space-conditioning equipment on an hourly basis (2). The program uses detailed data of the building geometry and construction, the space-conditioning equipment, and the weather to predict the energy flow. Internal loads in the form of people, lights, and equipment, as well as any infiltration and ventilation air, are incorporated in the energy flow description. Heat flow through all internal and external building surfaces is assumed to be one-dimensional.

The program uses a sequential approach to calculate the energy consumed by the heating and air-conditioning equipment. It first determines the heating or cooling loads in each zone of the building, assuming that the interior temperature in each zone is fixed. These fixed temperature loads are then passed on to the next part of the program, where the actual zone temperatures and the amount of heat added or extracted by the heating and cooling equipment are calculated.

Moisture removal is an important aspect of air conditioning in hot humid climates. For residential cooling systems, the program assumes that the air-conditioning unit is temperature controlled. It first calculates the sensible heat extracted by the unit each hour and the fraction of the hour that the unit is operating. For each hour that the unit does operate, a steady state moisture balance is performed for each zone and across the unit's cooling coil. If the dewpoint of the air leaving the cooling coil is above the coil's surface temperature, the excess moisture is assumed to condense on the coil.

There are two major assumptions in this moisture removal procedure. The first is that the moisture balance is the average for the hour and does not account for changes in the humidity as the air conditioner cycles within the hour. Thus, the impact of cycling in the humidity change during the hour cannot be ascertained. The second is that the effect of moisture absorbed and desorbed in the building surfaces and furniture on the cooling energy use is neglected. Recent work by Fairey et al., indicates that this may be an important parameter, particularly when windows are opened daily to conserve energy (7). Some caution, therefore, must be used in interpreting the results predicted by this program.

During the hours when air conditioning is not required, it was assumed that the interior air humidity ratio equaled the outdoor air humidity ratio. This is reasonable, although it may be higher than this at times because of the internal moisture load.

PMV COMFORT INDEX

The DOE-2.1B predicted interior conditions were converted into the PMV comfort index using the relation published in International Standard ISO 7730 (3). This relation, developed by Fanger (8), is basically an energy balance on the body. It assumes that a person's skin temperature and sweat rate at comfort are linearly related to that person's metabolic rate.

The PMV relation contains a term converting the energy balance to a comfort index. This index ranges from -3 for a person feeling very cold, to 0 for a person feeling minimum thermal discomfort, and to 3 for a person feeling very hot. Generally, it is desirable to maintain the PMV index between -0.5 and 0.5 (3).

RESULTS

Both the homeowner and the utility can benefit from the installation of the conservation measures. The homeowner can realize energy cost savings and the utility can have a lower delivered power level. A simplified evaluation using the predicted energy and peak power savings and typical retrofit measure costs was done in this study. Its purpose was to indicate which measures are most promising. Measure installation and electrical energy costs vary, and the results presented must be interpreted with this in mind.

It was predicted that the energy conservation measures would not result in human discomfort for any of the measures. There were some increases in the PMV indices, but they were not sufficiently large to result in discomfort (PMV > 0.5). The energy savings presented in this paper are approximate values predicted in the study. Details of the predicted energy consumption and savings for the different measures will be presented in the report for this study (9).

TEMPERATURE SETPOINTS

The prototype house thermostat setpoints were 70°F for heating and 78°F for cooling. Typically, air conditioner thermostats in hot humid regions are set at about 78°F to 80°F (10). An average person at normal activity level will have to limit his or her clothing to a tropical ensemble (light, open-neck shirt with short sleeves, shorts, and sandals) at times to maintain comfort at these temperatures.

The setpoints have a great influence on energy consumption, as illustrated in Fig. 2a. For a frame prototype house in Orlando having only R-11 ceiling insulation, the cooling energy requirement is increased 19% by lowering the cooling temperature setting from 78°F to 76°F.

Increased cooling temperature settings could result in thermal discomfort to the occupants. If the occupants are wearing light summer ensembles (short-sleeve shirt, long, lightweight trousers, light socks and shoes), they may suffer discomfort at times when the setpoint is 78°F. This is illustrated in Fig. 2b, where there are a few (15) hours where the PMV index exceeds 0.5. Changing the tropical ensembles, the occupants can be comfortable at 78°F, but will begin to be uncomfortable at 80°F (Fig. 2c). This shows the importance of lifestyle, such as the amount of clothing worn, on cooling energy consumption.

HOUSE ENVELOPE MEASURES

Typical energy savings and simple payback times for the conservation measures applied to the prototype house are listed in Table 2. Values are presented for both only the cooling season and for the combined cooling and heating seasons. In Orlando and Houston, the heating season energy savings exceed the cooling season energy savings. The opposite is true for Miami.

If the house has no insulation, installing ceiling insulation is attractive at all locations with payback times ranging from 2 to 4 years. Once the house has some ceiling insulation, R-11 to R-19, further addition of insulation is not cost effective to the homeowner. The addition of wall insulation is somewhat attractive for frame houses in Orlando and Houston, but not in Miami. It is not attractive for masonry houses in all three cities because of the expense of adding insulation and covering it with stucco or brick.

Houses in hot humid climate regions generally have single-glazed windows. Energy savings can be realized by adding storm windows, but they are relatively expensive, having simple payback times of 14 years or greater.

Weatherization (reducing air infiltration) is attractive if it is a homeowner do-it-yourself project, because material costs are relatively inexpensive. This measure is labor-intensive, so payback times for contractor installation are higher. In Orlando and Houston, most of the savings is for heating energy, while in Miami, most of the savings is for cooling energy. This measure is more attractive for houses located in cooler climates. For the prototype house located in Houston, for example, even contractor weatherization is attractive (about 5 years simple payback).

Painting the walls of the house with a light color (white or light green) is an attractive energy saving option if it is a homeowner do-it-yourself project. This measure is also labor intensive, thus, having a contractor to paint the walls is expensive. Exterior wall surfaces are generally painted periodically, even if a contractor is employed. Selecting a light color paint at the time of painting will result in lower energy costs with very little, if any, additional cost to the homeowner. Light color paints have lower solar absorptances, which means lower heat gains through the walls. This measure is then most attractive in regions where cooling energy use is relatively large. For cooler regions, however, there is little or no advantage in using light color paints, since this will also result in increased heating energy cost.

Additional cooling energy savings can be obtained by using roofs with low solar absorptance. Roofing is generally installed by contractors, which makes this measure unattractive for energy savings alone. Roofing has to be replaced periodically, and, at that time, consideration should be given to using light color material in hot humid climates.

Either interior or exterior shading of windows against direct solar radiation will reduce the cooling energy requirements. Simply closing the drapes at these times is, of course, a cost-effective way of reducing cooling energy costs. Additional savings can be realized by using light color, close weave drapes, but window drape replacement is expensive relative to the cost of saved energy. However, drapery liners are available at a reasonable cost that can be hung from the same hardware as the drapes. Simple payback times for these liners are about 5 to 6 years for the prototype house located in the three cities investigated.

Awnings can be used to reduce cooling energy use, but they are expensive relative to the cost of the saved energy. Unless there are other reasons for installing awnings, such as rain

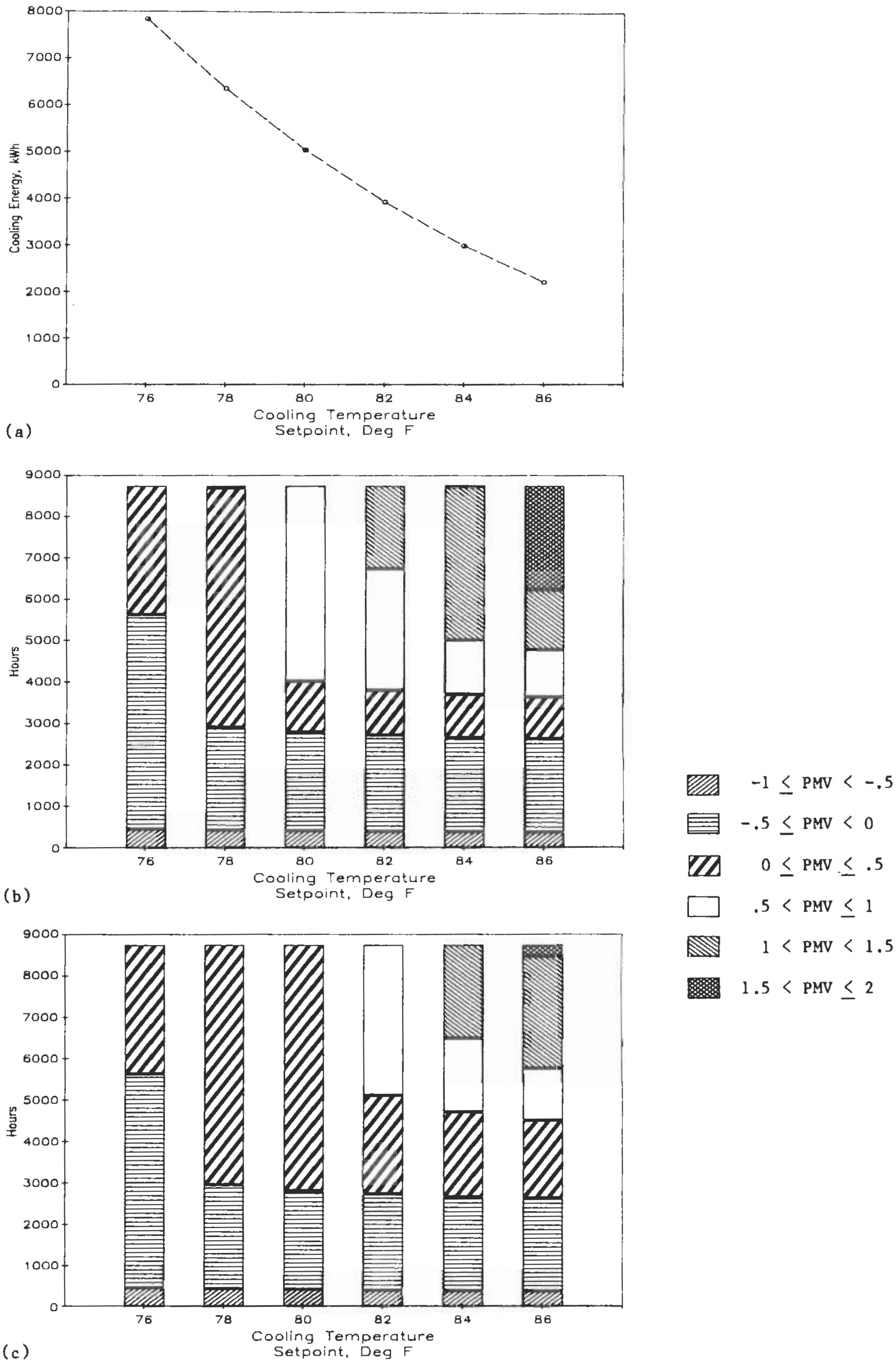

Fig. 2. Effect of cooling temperature setpoint and clothing on cooling energy use and comfort for a frame prototype house in Orlando, FL: (a) cooling energy use, (b) comfort indices for light summer ensemble minimum clothing, (c) comfort indices for tropical ensemble minimum clothing.

Table 2. Some typical energy cost savings and simple paybacks for prototype house envelope retrofit measures (electricity cost 6¢/kWh).

Measure and Location	Approximate Annual Savings		Cost of Measure, $		Simple Payback Time, years	
	kWh	$	Contractor	Do-It-Yourself	Contractor	Do-It-Yourself
1. Added ceiling insulation						
R-0 to R-11, Cooling						
Orlando and Miami	1000	60	540	270	9.0	4.5
R-0 to R-11, Cooling and Heating						
Orlando	2800	168	540	270	3.2	1.6
Miami	1600	96	540	270	5.6	2.8
R-0 to R-19, Cooling						
Orlando and Miami	1100	66	870	450	13.2	6.8
R-0 to R-19, Cooling and Heating						
Orlando	3000	180	870	450	4.8	2.5
Miami	1700	102	870	450	8.5	4.4
R-19 to R-38, Cooling						
Orlando	170	10	870	450	87	45
Houston	130	8	870	450	109	56
R-19 to R-38, Cooling and Heating						
Orlando	390	23	870	450	38	19.6
Houston	540	32	870	450	27	14.1
2. Added wall insulation						
R-0 to R-11, Cooling						
Orlando	490	29	590	–	20	–
Houston	410	25	590	–	24	–
R-0 to R-11, Cooling and Heating						
Orlando	1400	84	590	–	7.0	–
Houston	2100	126	590	–	4.6	–
3. Storm windows						
1 to 2 Panes, Cooling						
Orlando	320	19	720	640	38	34
Houston	130	8	720	640	90	80
1 to 2 Panes, Cooling and Heating						
Orlando	650	39	720	640	18.5	16.4
Houston	770	46	720	640	15.7	13.9
4. Weatherization						
1 to 0.57 AIF,[a] Cooling						
Orlando	230	14	650	210	46	15.0
Miami	350	21	650	210	31	10.0
Houston	260	16	650	210	40	13.1
1 to 0.57 AIF,[a] Cooling and Heating						
Orlando	630	38	650	210	17.1	5.5
Miami	480	29	650	210	22	7.2
Houston	1100	66	650	210	9.9	3.2
1.43 to 0.57 AIF,[a] Cooling						
Orlando	430	26	650	210	25	8.4
Miami	630	38	650	210	17.7	5.5
Houston	480	29	650	210	22	7.2
1.43 to 0.57 AIF,[a] Cooling and Heating						
Orlando	1100	66	650	210	9.9	3.2
Miami	900	54	650	210	12.0	3.8
Houston	2200	132	650	210	4.9	1.6
5. Reduced wall solar absorptance						
0.7 to 0.3 Absorptance, Cooling						
Orlando	600	36	1200	120	33	3.3
Miami	870	52	1200	120	23	2.3
Houston	470	28	1200	120	43	4.3
0.7 to 0.3 Absorptance, Cooling and Heating						
Orlando	500	30	1200	120	40	4.0
Miami	810	49	1200	120	24	2.4
Houston	230	14	1200	120	86	8.6
6. Shading						
Drape Replacement, Cooling						
Orlando	350	21	–	105	–	5.0
Miami	400	24	–	105	–	4.4
Houston	300	18	–	105	–	5.8
Awnings, Cooling						
Orlando	240	14	700	500	50	36
Miami	280	17	700	500	40	24
Houston	170	10	700	500	70	50

[a]AIF is air infiltration factor defined as:

$$ACH = AIF\ [0.252 + 0.0218\ V + 0.0084\ \Delta T\ ],$$

where ACH = air changes per hour, V = wind speed, mph, and T = temperature difference, °F. Typically, annual average ACH = 0.6 for AIF = 1.0.

protection, they do not appear to be cost effective.

REPLACEMENT REFRIGERATORS

Air-conditioning energy use is very dependent on the magnitude of the internal load. A large portion of this load is due to the heat and moisture generated by the occupants, themselves. Assuming that the number of occupants remain the same, the refrigerator generates an appreciable part of the remaining sensible heat load.

The efficiency of American-made refrigerators has been improving during the recent years, although there has been little improvement during the last 2 to 3 years. Depending on the age of the existing refrigerator, up to 800 kWh per year direct savings and up to 200 kWh per year combined heating and cooling energy savings could be realized by purchase of a new average efficiency refrigerator. Thus, the homeowner could save up to $60 per year energy cost (6¢ per kWh). Typical initial costs of new refrigerators are about $650 to $850 (11). These are not sufficiently low to warrant replacement.

If the refrigerator does need major repair or replacement, purchase of a high-efficiency unit is a good investment. A high-efficiency refrigerator costs about $60 to $100 more and uses about 200 kWh less energy than an average unit currently being marketed (11). In hot humid climates, the high-efficiency unit will result in small (20 kWh to 80 kWh) combined heating and cooling energy savings. For 6 cents per kWh electricity cost, this translates to a typical annual cost savings slightly greater than $18 per year, which implies simple payback times of 2.3 to 6 years. These savings are in addition to those obtained by replacing an old unit.

REPLACEMENT AIR CONDITIONERS

Very significant cooling energy savings can be realized by replacing an existing air-conditioning unit with a higher efficiency unit (Table 3). If the existing unit has an EER of about 6, about one-third of the cooling energy requirements can be saved by replacing it with a unit having an EER of about 8. If it was replaced with a unit having an EER of about 11.5, about one-half of the cooling energy requirements could be saved. For the prototype house, these percentages translate to be 2000 kWh to 4000 kWh annual savings for Orlando and Houston, and 2500 kWh to 5000 kWh for Miami.

Oversizing the air-conditioning unit will result in some penalty in the annual energy use, but the effect is relatively small. For example, a prototype house in Orlando requires 86 kWh more electricity per year if it has a 28,200 Btu/h capacity, 9.17 EER air conditioner instead of a 23,800 Btu/h capacity, 9.12 EER air conditioner. The results demonstrate that unless the unit is greatly oversized, the EER is much more important than the unit's capacity for the cooling energy use.

Although there are substantial cooling energy savings, air conditioner replacement is not attractive to the homeowner because of the initial cost of the new unit (Table 3). For the prototype house, annual energy cost savings of $100 to $200 per year can be readily obtained, but the simple payback times are generally greater than 10 years. Much depends on the capacity of the installed units, since the initial cost increases rapidly with the capacity of the unit. Because of this, there is a serious cost penalty for oversizing.

If the existing air-conditioning unit needs or is close to needing replacement, then the homeowner should investigate purchasing a high-efficiency unit. Typical central air-conditioning units being purchased today have rated EERs of about 8 (11). Purchase of still higher efficiency units is warranted because of the relatively small additional costs for the higher efficiency units. For the cases investigated in this study, simple payback times of 2 to 4 years were predicted for a homeowner installing a unit having an EER of 11.8 instead of one having an EER of 8 (Table 3).

Table 3. Some typical energy cost savings and simple paybacks for prototype house replacement air conditioners.

Rated Efficiency Change	Approximate Annual Savings kWh	Approximate Annual Savings $	Unit Cost, $	Differential Cost, $	Simple Payback Time, years
EER 6 to 8					
Orlando	2000	120	2000	–	16.7
Miami	2700	162	2000	–	12.4
Houston	2000	120	1000	–	16.7
EER 6 to 9					
Orlando	3000	180	2250	–	12.5
Miami	3700	220	2250	–	10.2
EER 6 to 11.8					
Orlando	4500	270	2400	–	8.9
Miami	5800	350	2400	–	6.9
Houston	3700	220	2400	–	10.9
EER 8 to 11.8					
Orlando	2500	150	–	400	2.7
Miami	3100	190	–	400	2.1
Houston	1700	100	–	400	4.0

PEAK POWER SAVINGS

The retrofit energy conservation measures that would result in the greatest peak power savings are listed in Table 4. Reduction of peak power demand is of interest to the utility, since the addition of generating capacity is expensive. The initial cost of a generating unit depends on its type and size. Typical costs of units starting operation at the present time are $400 per kW capacity for gas-oil turbines (12), $1200 per kW capacity for coal-fired plants (13), and $1500 per kW capacity for nuclear plants (14). (Although gas-oil turbine units are less expensive, the cost of electrical energy generated by these units is high because of high fuel costs.)

During the cooling season, the measure resulting in the greatest peak power savings is replacement of the air-conditioning unit. As stated previously, replacement of existing units that are in good operating condition is not necessarily cost effective to the homeowner. When the units do need replacement, however, the extra cost for high-efficiency units appears to be warranted (Table 3). The homeowner could be encouraged to purchase the higher efficiency replacement unit by some initial monetary assistance from the utility, since the utility would realize a peak load reduction.

The envelope energy conservation measures have relatively small impact on the peak power during the cooling season. This is because the peak power demands in a home usually occur during late afternoon. At that time, the daily peak heat energy has penetrated through the walls and ceiling to the interior, and the internal loads increase due to returning occupants and meal preparation. These measures do result in some reduction in the peak power, however, which would allow the use of smaller air-conditioning units. Since the initial capital cost of the units is quite sensitive to the rate capacity, the envelope measures will reduce the payback times for the replacement air conditioners to the homeowner.

During the heating season, the peak power savings are realized primarily through the envelope conservation measures. Houses in hot humid climates often have very little insulation and relatively high air infiltration rates. If the house has no insulation, it is very beneficial to add ceiling and wall insulation, even in Miami. For the prototype house, peak power savings of about 2.5 kW and 1.3 kW could be obtained by adding ceiling and wall insulation, respectively. Adding

Table 4. Retrofit measures having significant peak power savings.

	Cooling		Heating	
Location	Measure	Typical Savings kW	Measure	Typical Savings kW
Orlando	Replacement Air Conditioner		Added Ceiling Insulation	
	EER 6 to 8	1.0	R-0 to R-19	2.6
	EER 6 to 11.8	2.0	R-11 to R-19	0.3
	EER 8 to 11.8	1.0	R-19 to R-38	0.4
			Added Wall Insulation	
			R-0 to R-11	1.4
			Storm Windows	0.7
			Weatherization	
			1 to 0.57 AIF[a]	0.8
			1.43 to 0.57 AIF[a]	1.5
Miami	Replacement Air Conditioner		Added Ceiling Insulation	
	EER 6 to 8	1.0	R-0 to R-19	2.5
	EER 6 to 11.8	2.0	R-11 to R-19	0.3
	EER 8 to 11.8	1.0		
			Weatherization	
			1 to 0.57 AIF[a]	0.7
			1.43 to 0.57 AIF[a]	1.4
Houston	Replacement Air Conditioner		Added Ceiling Insulation	
	EER 6 to 8	1.0	R-0 to R-19	0.3
	EER 6 to 11.8	2.0	R-19 to R-38	0.4
	EER 8 to 11.8	1.0	Added Wall Insulation	
			R-0 to R-11	1.6
			Storm Windows	1.3
			Weatherization	
			1 to 0.57 AIF[a]	1.1
			1.43 to 0.57 AIF[a]	2.2

[a]AIF is air infiltration factor defined as:

$$ACH = AIF\ [0.252 + 0.0218\ V + 0.0084\ \Delta T\ ],$$

where ACH = air changes per hour, V = wind speed, mph, and T = temperature difference, °F. Typically, annual average ACH = 0.6 for AIF = 1.0.

more insulation to houses in hot humid regions that already have wall and ceiling insulation results in only limited peak power savings.

Weatherizing (reducing air infiltration) the house will reduce the peak power demand during the heating season. For the prototype houses in Orlando and Miami, peak power savings of 0.7 kW to 1.5 kW, depending on the initial air infiltration rate, were calculated. Greater savings were calculated for Houston.

It should be noted that the peak power values, as calculated by the DOE-2.1B program, are those averaged over each hour. As such, the predicted peak power values are independent of the heating and cooling equipment capacities. At any instant, the peak power rate for each individual home is really a function of the equipment capacity. However, as averaged over many homes, the DOE-2.1B values are more representative.

CONCLUSIONS

The most important parameter affecting the energy required to air condition single-family residences in hot, humid climates is the thermostat setpoint. Typically, air-conditioner thermostats in this region are set at about 78°F to 80°F. An average person at normal activity level will have to limit his or her clothing at times to a tropical ensemble to maintain comfort at these temperatures. Otherwise, the setpoint will have to be set lower to maintain comfort. The amount of energy to cool a house would increase about 10% for every degree decrease in the setpoint.

It was predicted that installing the retrofit energy conservation measures in a house would cause the occupants to feel slightly warmer, but not to the extent where they would be uncomfortable.

During the cooling season, the measure generally producing the greatest energy savings is the replacement of the air conditioner. However, this measure is not cost effective to the homeowner unless the existing unit needs major repair or replacement. At that time, purchase of a high-efficiency unit was predicted to be a wise investment. Peak power demand is also reduced by installing a high-efficiency air conditioner, and there may be some incentive for the utility to aid the homeowner in purchasing the high-efficiency unit.

Cooling energy demand also can be reduced by reducing the internal load such as replacing the existing refrigerator with a high-efficiency unit. Again, this is not cost effective unless the refrigerator needs major repair or replacement. At that time, purchase of a high-efficiency refrigerator was predicted to be a viable option.

Shell conservation measures generally result in both cooling and heating energy savings in hot humid climates. They usually are limited in reducing the peak cooling energy demand, but they are effective in reducing the peak heating energy demand.

If the house does not have insulation, insulating the ceiling is very cost effective. However, if the house already has ceiling insulation (as low as R-11), adding more insulation was predicted to result in only limited monetary savings. Retrofitting a house with wall insulation is generally expensive, and thus usually not cost effective in hot humid climates.

Weatherization and painting to reduce the exterior wall solar absorptance are cost-effective measures if they are do-it-yourself installations. Both are labor intensive measures having low material costs. Greater energy savings can be realized by weatherization in cooler climates, but the opposite is true for reducing the wall solar absorptance.

Reducing cooling energy use by closing window draperies against direct sunlight is effective. Greater savings can be obtained by using light color, close weave drapes, but drapery replacement is generally expensive. There are drapery liners on the market which are cost effective and could be hung from the same hardware as the existing drapes. Awnings also can be used to reduce direct sunlight, but they do not appear to be cost effective because of their initial expense.

The above conclusions must be considered preliminary because of the limitations in the DOE-2.1B model and the PMV relation used in this study. The DOE-2.1B program calculates energy consumption on an hourly average basis, and it does not consider different cycling rates within the hour. Thus, swings in the interior temperature and humidity within an hour cannot be predicted, which can be important in hot humid regions. The program ignores any effect due to moisture absorption-desorption on the interior surfaces. This effect is not completely understood, and because of this, investigation of potential energy savings by opening windows was not done. The program uses a relatively simplistic procedure to calculate moisture removal by the air conditioners. This is really a complex process, and the procedure may be somewhat limited.

The PMV relation is based on the observations that the skin temperature and the evaporative sweat rate correspond linearly to the condition of thermal comfort. This relation appears to be reasonably accurate at neutral comfort conditions, but seems to deviate somewhat from this accuracy in hot and cold stress conditions (15). There are other models that determine human comfort in terms of a person's sweat rate, skin and body core temperatures, and skin wetness, and they should be investigated.

REFERENCES

1. "Residential Conservation Service Model Audit Manual," Oak Ridge National Laboratory, ORNL/CON-103, October 1983.

2. "DOE-2 Reference Manual, Version 2.1A," LBL-8706, Rev. 2, May 1981; "DOE-2 Supplement, Version 2.1B," LBL-8706, Rev. 3, Supplement January 1983.

3. International Organization for Standards, " Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort," ISO-7730, Geneva, 1984.

4. "Residential Conservation Service, Residential Retrofit Specification/Cost Data Base," SERI/SP-254-1788, November 1982.

5. Energy Analysis Program, Lawrence Berkeley Laboratory, "Affordable Housing Through Energy

Conservation, A Guide to Designing and Constructing Energy Efficient Homes," Technical Support Document, DOE/SF/00098-1 Draft, November 1983.

6. P. Fairey, "Passive Cooling Gas Technology Characterization and Development," Quarterly Report, November 1983-January 1984, Florida Solar Energy Center Report, FSEC-CR-103-84, February 25, 1984.

7. P. W. Fairey, Florida Solar Energy Center, personal communication to M. A. Karnitz, Oak Ridge National Laboratory, October 30, 1984.

8. P. O. Fanger, Thermal Comfort, Krieger Publishing Co., Malabar, Florida, 1982.

9. H. A. McLain, J. M. MacDonald, D. Goldenberg, "Appropriate Conservation Measures for Single-Family Buildings in Hot Humid Climates," ORNL/CON report, to be issued.

10. R. Messenger, Florida Atlantic University, "Maximally Cost-Effective Residential Retrofit Demonstration Program," Florida Public Service Commission Report, DE84-900240, October 1982.

11. H. S. Geller, "Efficient Residential Appliances and Space Conditioning Equipment: Current Savings, Potential, Cost Effectiveness, and Research Needs," pp. E-118-E-130, in Proceedings of ACEEE 1984 Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, August 1984.

12. Turbomachinery International, 25(6):10, August 1984.

13. "How Much Do U.S. Power Plants Cost?," Electrical World, 199(3):87-88, March 1985.

14. Pennsylvania Power and Light Company, 1984 Annual Report.

15. L. G. Berland and J. A. J. Stolwijk, "The Use of Simulation Models of Human Thermoregulation in Assessing Acceptability of Complex Dynamic Thermal Environments," pp. 157-191 in J. A. J. Stolwijk, Energy Conservation Strategies in Buildings, Comfort, Acceptability and Health, John B. Pierce Foundation of Connecticut, Inc., 1978.