Comparison of Calculated and Measured Air Conditioning Design Loads For Alternative Glazing Options in Production Homes in California

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ABSTRACT

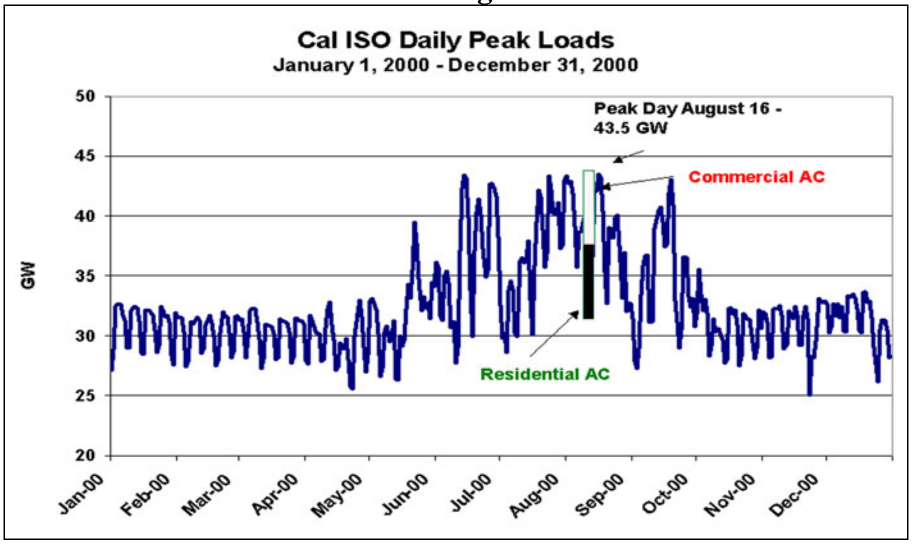
In the spring of 2000 two identical new homes were purchased from a local production builder in a bedroom community near Sacramento California. Both homes came equipped with clear double glass. After a series of careful measurements to ensure the houses were really identical, all the glass in one home was replaced with high performance, low solar gain, low emmissivity (LSLE) glass. During July of 2001, the air conditioning system in the house with LSLE was downsized by one ton (3.5 kW) to demonstrate the real cooling load savings from the glass. The two unoccupied homes were kept comfortable and monitored with extensive hourly data for over a year to document the energy and peak demand savings from the high efficiency glass. The house with LSLE glazing and reduced air conditioning capacity met the cooling load and saved 25% of the cooling kWh and over one third of the air conditioning system peak demand (1.8 kW less) compared to the house with clear double glazing Air conditioning sizing calculations were performed for the houses using a alternative versions of the industry standard sizing approach. Actual design loads were inferred from the capacity and operation of the installed air conditioners and compared with the calculated loads. This analysis shows that the current ANSI Standard sizing approach overestimates the sensible loads by 18% to 25% and the savings from LSLE glass by 38%, but other versions give acceptable results.

Introduction

Residential Air Conditioning

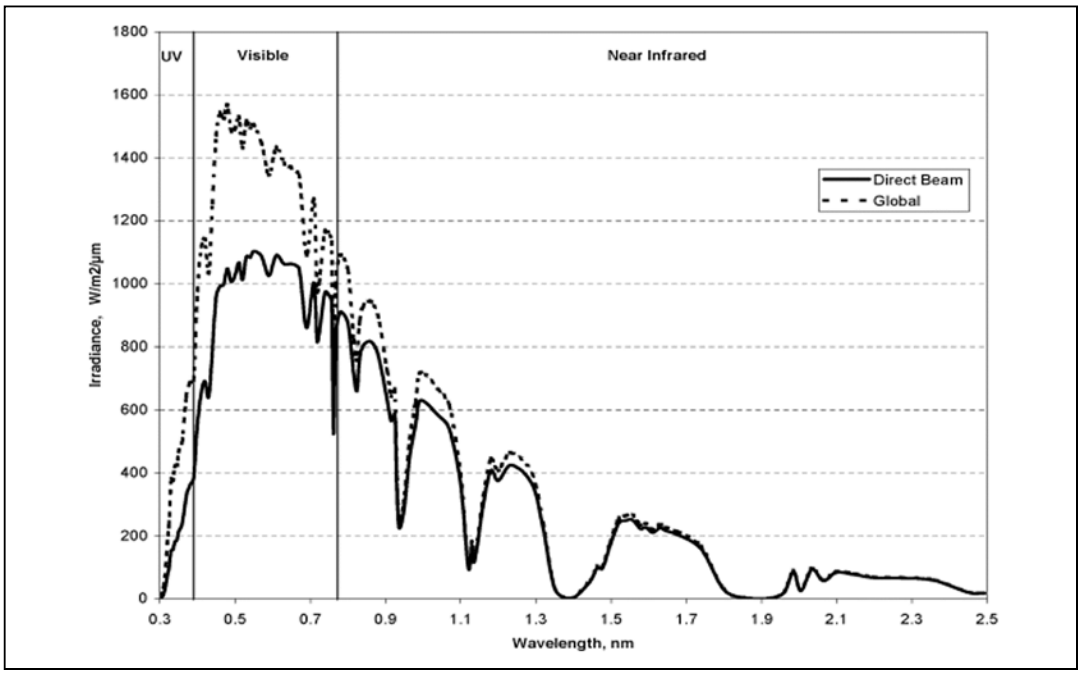
Air conditioning has become a standard feature of new homes built in the United States. A related trend is that new homes are increasingly being built in areas where air conditioning is necessary for summer comfort. As a result, residential air conditioning consumes an increasing amount of electricity and is one of the biggest contributors to peak electricity demand in many areas. Air conditioning consumes about 20% of the annual electricity used in houses built in the hot central valley of California (Wilcox, 1995) but it is all used on hot summer days when residential and commercial air conditioning are the two largest contributers to the electricity peak demand. Figure 1 shows daily peak demand during 2000 for the California Independent System Operator (ISO) which supplies 85% of the state's electricity. Each tooth in the graph is a week and each downward spike is a weekend. The bar in the center shows that residential and commercial air conditioning each contribute about 7 GW or about 30% of the additional demand above the annual base load. For this reason measures that reduce residential peak cooling load and improve peak cooling efficiency are of great interest because they directly impact electricity peak load shortages and the need to build new power plants.

Figure 1. Contribution of Air Conditioning to California Peak Electrical Demand



Source: Borenstein, et al. 2002

Figure 2. Spectral Irradiance of Incident Direct Beam and Global Solar



Source: ASTM 1987

Spectrally Selective Glazing

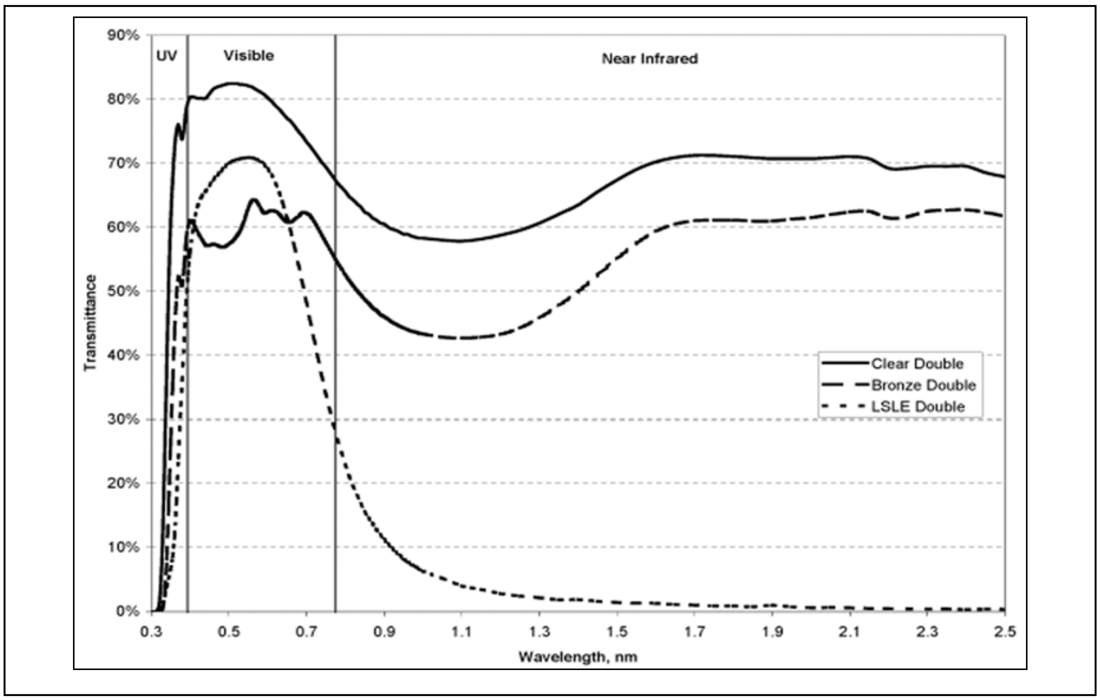
Low solar, low emmissivity (LSLE) glazing can be defined by its performance in the following 3 areas:

1. It provides a window Solar Heat Gain Coefficient (SHGC) that is 0.40 or less.
2. It has a visible transmittance of 0.70 or greater (nearly as clear as regular glass).

3. It reduces window U-factor by 15-30% compared to clear double glazing in the same frame.

LSLE glazing uses a thin film coating that selectively transmits and reflects different wavelengths of solar energy to reduce solar heat gain transmittted through windows without reducing visibility and daylight. Figure 2 shows the spectral distribution of incident direct and global radiation at the ground. About 35% of the energy in the global irradiance is in the near infrared wavelengths between 0.85 and 2.5 nm. Figure 3 shows the spectral transmittance at normal incidence for clear, tinted and LSLE double glazing calculated by Optics5. The LSLE glazing has a relatively high transmission in the visible region and a very low transmission in near infrared region compared to the other two glazing types.

Figure 3. Spectral Transmittance of Clear, Tinted and LSLE Double Glazing



Source: Arasteh, et al, 1998

Alternative Glazing and Air Conditioner Sizing

Previous studies have shown that high performance glazing along with other measures can reduce cooling energy use, cooling peak loads and peak electricity demand (Anello et al, 2001; Farrar, Hancock, & Anderson; Farrar et al, 2000; Reilly& Hawthorne, 1998). Previous studies have also shown that air conditioner sizing impacts the electrical peak load in houses (Peterson & Proctor 1998, Proctor 1997, 1998). The Roseville experiment was designed to extend the previous work by for the first time providing a long term, unoccupied experiment with identical side by side homes where the only variable was glass type.

Roseville Experiment

Roseville

Roseville is a bedroom community in California's central valley east of Sacramento (lattitude 38.7, longitude 121.2, elevation 160 ft (49 m)). The central valley has hot dry summers with clear sunny skies almost every day. The cooling design conditions for Roseville are summarized in Table 1.

Table 1. Roseville Cooling Design Conditions

Design Values of Dry-Bulb (DB) with Mean Coincident Wet-Bulb Temperature (MCWB)

	Annual Percentage Values								Mean
	0.1%		0.5%		1.0%		2.0%		Daily
Units	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	Range
IP, F	105	71	102	70	100	70	96	68	36
SI, C	41	22	39	21	38	21	36	20	20

Source: CEC, 2002

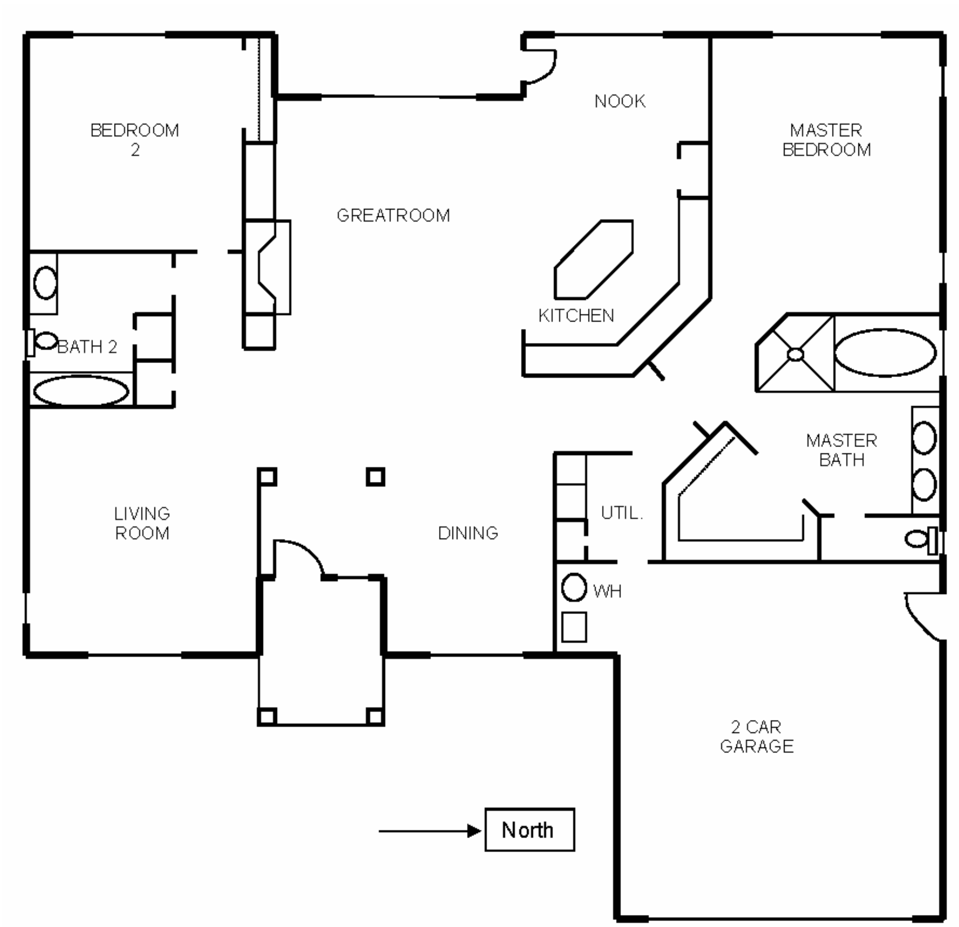
Experimental Houses

The 2 houses were identical single story 1854 ft2 (172 m2), 3 bedroom production homes located on the same block with identical orientation, colors and solar exposure. Figure 4 shows the front of the house which faces East. The lots were selected to demonstrate performance in the most important and demanding orientation with about 50% of the glass in the rear facing West (Figure 5). This orientation is critical because production builders typically size air conditioning for a model in the worst orientation and install the same size air conditioning unit in every instance of that model regardless of its orientation. As in many of California's current production homes there were 10 ft (3.0 m) ceiling heights, R-13 (R-2.3) stud walls with synthetic stucco over R-4 (R-0.7) foam sheathing and uninsulated slab on grade floors that were carpeted except in bath and kitchen. Concrete tile roofs were installed over ventilated attics with R-38 (R-6.7) loose fill insulation. The air conditioning systems featured 3.5 ton (12.3 kW), SEER 11 split system air conditioners with air handlers and ducts located in the attic. Figure 6 shows the floor plan of the house.

Figure 4. Front Facing East

Figure 5. Back Facing West

Figure 6. Floor Plan



Commissioning

Particular care was taken during construction and commissioning to eliminate differences between the houses that would affect the comparison of the glazing:

1. An experienced construction supervisor inspected weekly during construction and worked with the builder to achieve identical framing, insulation and finishes.
2. Blower door tests verified that infiltration air leakage was low and both houses were within 2% of each other (3.95 air changes per hour at 50 Pa (ACH50) for the clear glass house and 4.02 ACH50 for the LSLE house).
3. Air conditioning ducts in both houses were sealed using the aerosol sealant technique to achieve total duct leakage of less than 5% of air handler fan flow.
4. Air conditioner charge was checked and air flows were measured to make sure the systems were operating according to specifications.
5. After commissioning all the systems, with clear double glass in both houses, the cooling energy consumption of the two houses was within 1%, with the eventual clear glass house using slightly less cooling energy.

Table 2. Glazing System Properties

Glazing	U-factor, Btu/ft^2-hr-F (W/m^2-K.)	Solar Heat Gain Coefficient (SHGC)
Clear Double (CLR)	0.49 (2.8)	0.65
Low Solar Low E (LSLE)	0.34 (1.9)	0.31

The Windows

The builders provided clear double glazed windows in vinyl frames (CLR). Based on a coin flip,we selected one of the houses and replaced all the glazing with about 300 square feet of LSLE glazing units in frames identical with the original units. Table 2 compares the area weighted properties of the 2 window systems according to the industry standard rating system (NFRC 2001). There was no interior shading in either house.

Experimental Operation

The unoccupied, unfurnished houses were operated to simulate normal residential occupancy. Thermostats were set to maintain 68 F (20 C) for heating and 75 F (24 C) for cooling. There was a data logger in each house which recorded hourly temperatures and electricity and gas use for cooling and heating. The system also included a complete weather station with outdoor temperature, relative humidity, wind and solar measurements. Electric heaters controlled by the data loggers simulated sensible heat generated by occupants using the California Energy Commission standard internal gain profiles. Data was downloaded daily by telephone to remote computers for analysis and archiving.

Results

First Summer

The experiment started in September of 2000 just in time to catch the end of the intense California central valley cooling season. Table 3 summarizes the data for the 50 days from September 6 through October 26, 2000. Daytime temperatures were regularly over 100 F (38 C) and the skies were clear almost every day. The average outdoor temperature was 75F (24 C) with a maximum of 106 F (41 C). The total air conditioning electricity use in the LSLE house was 29% less during that period than in the otherwise identical house with normal double glass.

Table 3. First Summer Results

	Glazing type		Comparison
Conditions	**CLR**	**LSLE**	**LSLE/CLR**
Average Indoor Temp	74.4 F (23.6 C)	74.2 F (23.4 C)	
Maximum of Average Indoor Temp	78.7 (25.9)	77.6 (25.3)	
Maximum Indoor Temp Any Room	80.7 F (27.1 C)	78.8 F (26.0 C)	
AC Runtime, hr	197	141	0.72
Energy			
AC Outdoor Unit, kWh	649	453	0.70
AC Air Handler, kWh	170	124	0.73
Total AC kWh	818	577	0.71
Demand			
Peak Outdoor Unit kW	4.02	3.86	0.96
Peak Air Handler kW	0.83	0.80	0.97
Peak Total AC kW	4.85	4.67	0.96

Second Summer Downsizing

The experimental results during the first year showed that the LSLE glass significantly reduced the cooling load. The air conditoner in the LSLE house ran fewer hours and used less energy. For hours when the clear glass house air conditioner ran full on just meeting the load, the LSLE air conditoner ran about 2/3 of the time. Based on this data we decided to install a smaller air conditioner in the LSLE house to demonstrate the reduced loads. In July of 2001 we replaced the air handler and outdoor unit of the low SHGC house with a similar 2.5 ton (8.8 kW) nominal system from the same manufacturer. It would have been ideal if the downsized system was identical to the original system in every way, just smaller, but unfortunately this was not possible due to several practical issues:

1. The cooling capacity of the new system as installed was less than we had expected and it therefore ran about 7% more hours than the system in the clear glass house.
2. Since we did not replace the ducts, they were oversized for the new smaller system and the losses from the extra surface area reduced the efficiency of the new smaller system.
3. The peak demand of the smaller system was less than we had expected, probably related to the lower than expected capacity.

In spite of the reduced capacity and efficiency of the new downsized system it maintained temperatures in the LSLE house that were slightly lower than those in the clear glass house, even at peak conditions, and demonstrated the load savings we expected.

Table 4. Second Summer Results

	Glazing type		Comparison
Conditions	**CLR**	**LSLE**	**LSLE/CLR**
Average Indoor Temp	75.3 F (24.1 C)	75.0 F (23.9 C)	
Maximum of Average Indoor Temp	77.8 (25.5)	77.3 (25.2)	
Maximum Indoor Temp Any Room	82.6 F (28.1 C)	79.6 F (26.4 C)	
AC Runtime, hr	329	353	1.07
Energy			
AC Outdoor Unit, kWh	1095	800	0.73
AC Air Handler, kWh	279	207	0.74
Total AC kWh	1374	1007	0.73
Demand			
Peak Outdoor Unit kW	4.0	2.48	0.62
Peak Air Handler kW	0.82	0.56	0.68
Peak Total AC kW	4.9	3.0	0.63

Table 4 compares the results for 50 days of post downsized data during August and September of 2001. Both houses maintained indoor temperatures that on average were near the set point, with the LSLE house slightly cooler. The indoor temperatue floated up in both houses during peak periods when the outdoor temperature was high, but the maximum temperature in the LSLE house was lower than the corresponding temperature in the clear glass house. The energy savings were about the same as the first summer with the LSLE house using 27% less cooling electricity. The big change was in the electricity demand where the smaller air conditioning sytem in the LSLE house used a maximum of 3 kW and saved 1.8 kW compared to the original system in the clear glass house.

Calculated Cooling Loads

Sensible cooling loads were calculated for both houses with several variants of the widely-used ACCA Manual J method, as implemented in an ACCA-approved software package (Wrightsoft, 2004). In general, standard procedures were used for all building elements except "custom" characteristics were defined for the clear and LSLE glazings. The following sections describe the procedures with variant names created for the purposes of this analysis.

Method 7. Manual J 7th Edition (ACCA 1986). All calculations performed were performed using standard MJ7 procedures except for glazing. MJ7 pre-dates fenestration ratings (SHGC) and does not directly handle arbitrary glazing materials. The software package used has been extended to incorporate Manual J 8th Edition procedures for custom glazing.

Method 8A. Manual J 8th Edition version 1.10 Average Load Procedure (ALP) (ACCA, 2003a). The ALP is the base MJ8 procedure, intended for stand alone, single-family houses having Adequate Exposure Diversity (AED). AED is an MJ8 concept that characterizes the distribution of glazing on building facades. If glazing gains occur reasonably evenly throughout the day, then the MJ8 method uses the sum of 8 hour average loads as an estimate of the peak load. In initial versions of MJ8, AED assessment was subjective. In 1.10, a building is defined as having AED if the peak hourly fenestration load does not exceed 130 % of the average of the hourly fenestration loads.

Method 8P. Manual J 8th Edition version 1.10 Peak Load Procedure (PLP) (ACCA, 2003a). For buildings that do not meet the AED criteria, MJ8 provides alternative (generally higher) gain factors for fenestration and walls. These factors are close to the peak gain expected from those elements. Summing them yields a sum-of-the-peaks total that is conservative (i.e. too large) in any situation where maximum gains do not occur simultaneously.

Method 8B. Manual J 8th Edition modified by ACCA Technical Bulletin 2003-001a (ACCA, 2003b). In MJ8 1.10 (our methods 8A/8P), the AED threshold introduced a "trigger" effect – small changes in fenestration area could result in large load changes. In response to this, ACCA has published an amended procedure that introduces the "AED Excursion", defined as the amount that the peak fenestration load exceeds 130% of the hourly fenestration load. The AED Excursion is added to the ALP (method 8A) result. The PLP has been dropped for equipment sizing purposes.

It is not clear which of these methods is currently recommended by ACCA. Manual J 8th Edition version 1.10 (Method 8A/8P) has been approved as an ANSI standard and would thus appear to be the sanctioned procedure. However, the AED "trigger" inherent in this approach can produce excessive load estimates for many buildings (including the Roseville houses). The 8B method mitigates this problem, but it is not currently part of the ANSI standard method.

For all methods, input data were selected in accordance with ACCA procedures. The blower door results were used to specify infiltration rates. Internal gain was based on the power of the electric heaters operated in the buildings. Outdoor design conditions were the 1 % conditions listed in Table 1. Duct losses were estimated assuming attic location, R-4 insulation, and full sealing. In MJ7 this resulted in a 15% sensible duct gain and in MJ8, 17.1 %. A quirk of 8B procedure is that the AED Excursion adjustment is added after duct gains are calculated. The effective duct gain percentage in the 8B cases is thus about 15%.

Table 5 summarizes the calculated sensible loads and various load components. Note that under MJ8 version 1.10 procedures, the Roseville houses do not have AED – the large amount of west glass results in a significant afternoon peak.

Table 5. Calculated Sensible Design Cooling Loads (Btuh)

Meth	House	Envelope Components					Infil	Internal	Building total	Ducts	Total
		Opaque	Fen base	AED exc	Fen total	Env total					
7	CLR	4904	21046	0	21046	25950	2311	1852	30113	4517	34630
	LSLE	4904	11966	0	11966	16870	2311	1852	21033	3155	24188
8A	CLR	4051	21091	0	21091	25142	1557	1852	28551	4878	33429
	LSLE	4051	11988	0	11988	16039	1557	1852	19448	3323	22771
8P	CLR	3961	31108	0	31108	35069	1557	1852	38478	6575	45053
	LSLE	3960	16920	0	16920	20880	1557	1852	24289	4150	28439
8B	CLR	4051	21091	3508	24599	25142	1557	1852	32059	4878	36937
	LSLE	4051	11988	1410	13398	16039	1557	1852	20858	3323	24181

Table 5b. Calculated Sensible Design Cooling Loads (kW)

Meth	House	Envelope Components					Infil	Internal	Building total	Ducts	Total
		Opaque	Fen base	AED exc	Fen total	Env total					
7	CLR	4904	21046	0	21046	25950	2311	1852	30113	4517	34630
	LSLE	4904	11966	0	11966	16870	2311	1852	21033	3155	24188
8A	CLR	4051	21091	0	21091	25142	1557	1852	28551	4878	33429
	LSLE	4051	11988	0	11988	16039	1557	1852	19448	3323	22771
8P	CLR	3961	31108	0	31108	35069	1557	1852	38478	6575	45053
	LSLE	3960	16920	0	16920	20880	1557	1852	24289	4150	28439
8B	CLR	4051	21091	3508	24599	25142	1557	1852	32059	4878	36937
	LSLE	4051	11988	1410	13398	16039	1557	1852	20858	3323	24181

Actual Sensible Cooling Loads

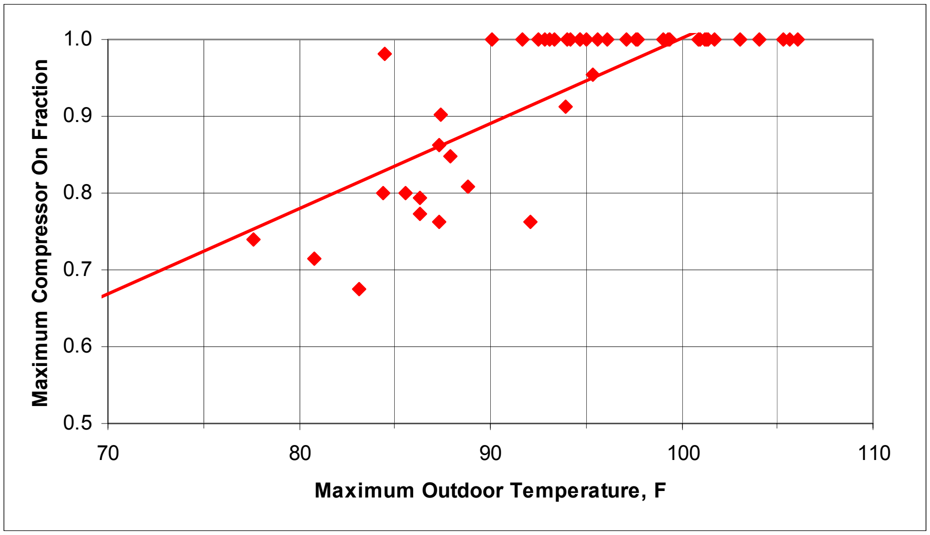
Sensible cooling loads were not directly measured during the Roseville experiment, but they may be inferred from the capacity and run time of the air conditioning systems which was monitored. When the air conditioner runs for the full hour the, load during that hour is equal to or greater than the capacity of the air conditioner during the hour. The total capacities of the units at design conditions were estimated based on the manufacturer's detailed cooling capacities, corrected to the monitored evaporator fan heat input and field tests of all three units. Since this experiment did not provide for any latent internal gain and the climate in Roseville is very dry we believe the evaporator coils were dry at design conditions. The all sensible capacities at 100 F (38 C) for the three units are displayed in Table 6.

Table 6. Calculated Sensible Cooling Capacity at Design Conditions

Unit Rated Capacity	Net Sensible Capacity, BTUH	Net Sensible Capacity, W
3.5 ton units	36,142	10,590
LSLE, 2.5 ton unit	24,164	7,080

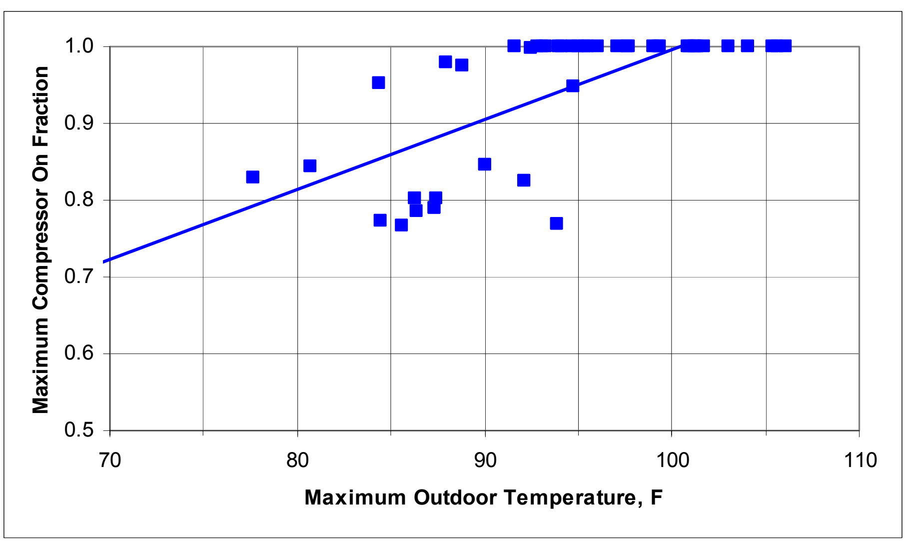
Figures 7 and 8 show the air conditioning compressor peak hourly run time versus maximum daily outdoor temperature for clear days in the post down sized period of 2001. The line represents a simple regression of part load as a function of outdoor temperature. There is a large scatter in the data due to variations in solar over the day and other weather parameters. However, the overall pattern for both houses is similar. In particular, both houses had a substantial number of days when the air conditioners ran full on for at least 1 hour.

Figure 7. Maximum Daily Compressor on Fraction versus Daily Maximum Temperature for the Clear Double Glazed House



Air conditioner sizing can also be assessed by measuring the ability of the system to maintain indoor temperature. A common specification is that the indoor temperature should not float up from the set point more than 3 degrees F (1.7 C) at the design conditions. Table 4 shows that the maximum indoor average temperature of the LSLE house was 77.8 F (25.5C) which is less than the criteria even though the outdoor temperature reached 106 F (41 C) significantly above the design temperature. By this measure the system sizing in both houses is at least adequate for the test occupancy.

Figure 8. Maximum Daily Compressor on Fraction versus Daily Maximum Temperature for the LSLE Glazed House with Reduced Size Air Conditioner



For the 2001 data, the percent on time of the air conditioners in the hours between 3 PM and 7 PM were regressed against the west vertical insolation, the horizontal insolation, and the outdoor temperature from one hour earlier. The effects of the LSLE glass were captured in slope corrections for the delayed ambient temperature and the west vertical insolation. The regression excluded any hours where the percent on time was 100%. This produced a predicted compressor on time for any combination of the above variables. The resulting regression equation had an adjusted R2 of 0.74. The regression results are shown in Table 7.

Table 7. Compressor On-Time versus Outdoor Temperature and Insolation

Source	SS	df	MS		Number of obs	188
					F(5, 182)	107.84
Model	3.32537336	5	0.665074672		Prob > F	0
Residual	1.12240025	182	0.006167034		R-squared	0.7476
					Adj R-squared	0.7407
Total	4.44777362	187	0.023784886		Root MSE	0.07853
	Coef.	Std. Err.	t	P>|t|	95% Conf. Interval	
West Vertical Insolation	0.0008254	0.0000503	16.4	0	0.0007261	0.0009247
West Vertical LE effect	-0.0001044	0.0000514	-2.031	0.044	-0.0002059	-2.97E-06
Horizontal Insolation	-0.0007316	0.0000574	-12.74	0	-0.000845	-0.0006183
Outside Temperature 1 hr. earlier	0.0124424	0.0010878	11.438	0	0.0102961	0.0145887
Outside T-1 LE effect	0.0007139	0.0003782	1.888	0.061	-0.0000323	0.00146
Constant	-0.6619849	0.0907445	-7.295	0	-0.8410315	-0.4829383

Design temperature for Roseville is 100 F (38 C). However outdoor temperature is not the only and in fact not the most important driver of design load for these houses. The data for the hours with an outdoor temperature above the design temperature were examined. The minimum west vertical insolation and horizontal insolation (for days when there was significant insolation) were determined. The design condition was thus defined as outdoor temperature of 100 F (38 C), West vertical insolation 632 W/m2, and horizontal insolation 165 W/m2. Substituting those design conditions into the regression equation the percent on times (and estimated loads at design are shown in Table 8.

Table 8. Estimated Sensible Load at Design Conditions (from monitored units)

	Percent On Time	Sensible Load, BTUH (W)
Clear Double Glass	98.3%	35,528 (10,410)
LSLE	98.9 %	23,898 (7,002)

Comparison of Calculated to Actual Cooling Loads

Figure 9 compares the calculated sensible loads with the sensible loads inferred from the data for the clear glass and LSLE glass houses. Method 8B, Manual J 8th Edition modified by ACCA Technical Bulletin 2003-001a (ACCA, 2003b, provides the best overall fit. Method 8P, Manual J 8th Edition, which is now an ANSI standard, overestimates the sensible loads by 18% for the LSLE house and 25% for the clear double house.

Figure 9. Calculated versus Measured Sensible Cooling Load

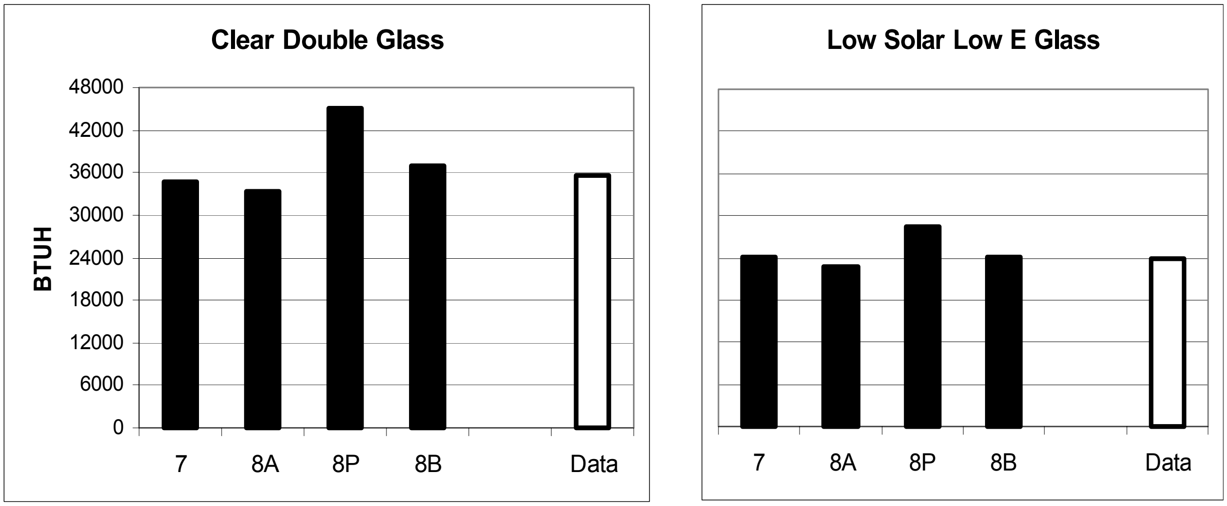


Figure 10. Calculated versus Actual Sensible Cooling Load Savings for LSLE Glass

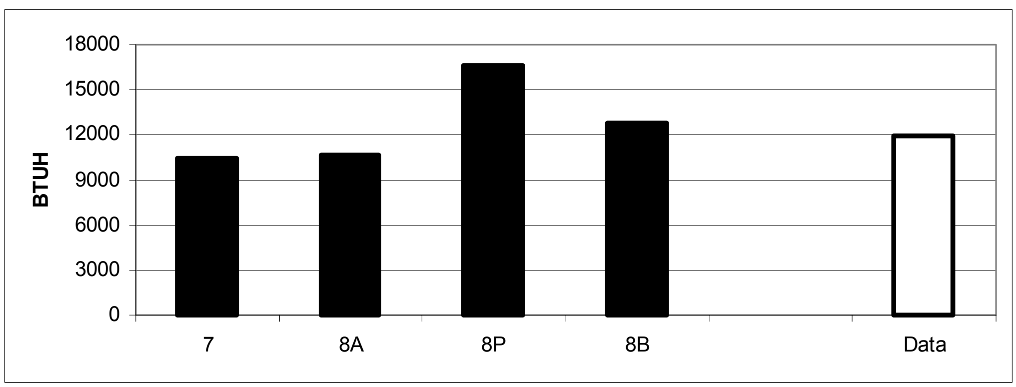


Figure 10 compares the calculated with actual load savings from using the LSLE glazing. Method 8P, Manual J 8th Edition, the ANSI Standard, overestimates the savings by 38%. Method 8B, Manual J 8th Edition modified by ACCA Technical Bulletin 2003-001a (ACCA, 2003b, provides the best estimate, overstimating savings by 6%.

Discussion and Conclusions

The primary purpose of the Roseville experimental program was to demonstrate the energy and demand savings resulting from replacement of clear glazing with high performance low solar low-E glazing (LSLE). The measurements on the two buildings show essentially equivalent air-conditioning performance. The LSLE house has 1 ton less sensible capacity at actual design conditions, so that capacity savings can be attributed to the high-performance glazing. Several observations can be made about the loads calculation methods as applied to these buildings:

- With the exception of method 8P (MJ8 PLP), all methods gave reasonably good loads estimates.

- MJ7, Manual J 7th Edition (ACCA 1986), requires the use of "custom glazing" extensions to achieve a reasonable result. Features introduced in MJ8 allow it to directly handle high-performance glazing that is now the norm.
- Method 8P, Manual J 8th Edition, now an ANSI Standard, produces results that are clearly too high for these cases and should not be used.
- Method 8B, Manual J 8th Edition modified by ACCA Technical Bulletin 2003-001a (ACCA, 2003b), gives the most accurate estimate of sensible load and savings and should now be the method of choice among the ACCA procedures

Finally, this work brings into focus the fact that there is not an unambiguous criterion for identifying the correct size for a cooling system from measured data, even in this relatively simple sensible-only situation. There is normally some amount of temperature variation in a residential building served by a single zone system, so adequate performance must be defined in some statistical sense. Actual cooling requirements are generally less than would be expected assuming a fixed set point throughout the building. Residential loads calculation methods must recognize these effects to avoid selection of over-sized equipment.

Future Work

A new experimental project is exploring heating and cooling performance of LSLE glazing in a climate with colder winters and humid summers. Improved instrumentation in the new project will allow direct measurement of sensible cooling delivered to the house.

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References

ACCA. 1986. *Load Calculation for Residential Winter and Summer Air Conditioning – Manual J 7th Edition*, Air Conditioning Contractors of America, Arlington, VA.

ACCA. 2003a. *Manual J Residential Load Calculations*, 8th Edition. Fourth Printing, February, 2003. Air Conditioning Contractors of America, Arlington, VA.

ACCA. 2003b. Using Hourly Heat Gain Data for MJ8 Equipment Sizing Loads. Technical Bulletin 2003-001a, December, 2003. Available at www.acca.org.

Anello, M., Parker, D., Sherwin, J., Richards, K. 2001. Measured Impact of Advanced Windows on Cooling Energy Use, FSEC-PF364-01. Florida Solar Energy Center, Cocoa, FL

Arasteh, D., Finlayson, E., Huang, J., Huizenga, C., Mitchell, R., Rubin, M., 1998. *State-of-the-Art Software for Window Energy-Efficiency Rating and Labeling.* Proceedings of the

ACEEE 1998 Summer Study on Energy Efficiency in Buildings. http://windows.lbl.gov/materials/optics5/default.htm

ASTM 1987. *Standard Tables for Terrestrial Direct Normal Solar Spectral Irradiance at Air Mass 1.5.* ASTM Standard. American Society for Testing and Materials; ASTM E 891 - 87. http://rredc.nrel.gov/solar/standards/am1.5/#about

Borenstein, S., Jaske, M., and Rosenfeld, A. 2002. "Dynamic Pricing, Advanced Metering and Demand Response in Electricity Markets," *The Hewlett Foundation Energy Series Foundation monograph.* http://www.ef.org/energyseries_dynamic.cfm

CEC, 2003. *2005 Building Energy Efficiency Standards, Joint Appendices, P400-03-001JAETF, California Energy Commission, Sacramento, CA.* http://energy.ca.gov/2005_standards/documents

Farrar, S., C.E. Hancock, and R. Anderson. 1998. "System Interactions and Energy Savings In a Hot Dry Climate." ACEEE 2000, Vol. 1:79-92.

Farrar-Nagy, S., Anderson, R., Reeves, P., Hancock. C. 2000. "Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate," ACEEE 2000, Vol. 1, p. 63.

James, P.W., J. Cummings, J. Sonne, R. Vieira, and J. Klongerbo. 1997. "The Effect of Residential Equipment Capacity on Energy Use, Demand, and Run-Time." In *ASHRAE Transactions*, Vol.103, Part 2, 297-303, 4082. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

NFRC., 2001. *NFRC 100-2001 and NFRC 200-2001*, National Fenestration Rating Council, Silver Spring, MD. http://www.nfrc.org

Peterson, G. and J. Proctor. 1998. "Effects of Occupant Control, System Parameters, and Program Measures on Residential Air Conditioner Peak Loads." In *Proceedings from the ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* 1:253-264. Washington, D.C.: American Council for and Energy-Efficient Economy.

Proctor, J. 1997. "Field Measurements of New Residential Air Conditioners in Phoenix, Arizona." In *ASHRAE Transactions*, Vol.103, Part 2, 406-415. BN-97-2-2. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Proctor, J. 1998. "Monitored In-Situ Performance of Residential Air-Conditioning Systems." In *ASHRAE Transactions*, Vol.104, Part 1. SF-98-30-4. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Reilly, S. and Hawthorne, W. 1998. "The Impact of Windows on Residential Energy Use," ASHRAE Transactions.

Wilcox, B., 1995. "Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses." Sacramento. California Energy Commission and California DSM Measurement Advisory Committee (CADMAC).

Wrightsoft, 2004. Right-J module of Right-Suite Residential. See www.wrightsoft.com.