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ABSTRACT

An extensive database of residential energy use has been generated at LBL using the DOE-2.1A computer program for 7 prototype buildings in 45 U.S. locations, covering a wide range of typical conservation measures. We first analyzed the data to determine the energy savings associated with each measure, producing a series of tables giving the delta heating and cooling loads relative to an uninsulated house for each prototype house in each location. We then analyzed this intermediate data using linear regressions to establish the relationship between component loads and key physical characteristics of individual building components, such as ceiling conductivity or infiltration air change volume. We found that the energy savings for typical residential conservation measures can be established with very high accuracy using simple linear regression equations. These regression equations not only reduce the size of the database, but also allow us to extend it to buildings with geometries, conservation measures, and physical characteristics differing from those used in generating the database itself.

INTRODUCTION

The influence of various energy conservation options on residential energy use in typical houses in the United States has been extensively analyzed by the Applied Science Division at Lawrence Berkeley Laboratory (LBL). Over the past five years, the Energy Analysis Program at LBL has compiled a comprehensive residential energy database using the DOE-2.1A computer program for five prototype houses (one-story, two-story, split-level, and two townhouses) with three foundation conditions (slab-on-grade, basement, and ventilated crawl space) in 45 U.S. base locations.

Table 1 gives a list of the 45 base locations and foundation types covered in the residential data base. For each building, foundation type, and location, we did a basic parametric set of 18 to 20 simulations to evaluate the energy impacts of typical conservation measures such as ceiling, wall, and foundation insulation, different window glazings and areas, and varying infiltration rates. The parametric sets differ depending on the foundation type simulated, with higher insulation levels included for basement and crawl space configurations because of their prevalence in colder locations. The conservation packages included in each parametric simulation represent rational combinations of typical measures ranging from single-pane windows and no insulation to R-60 ceilings, R-27 walls, and triple-pane windows (see Table 2).

Table 1. Foundation Types and Locations in DOE-2 Residential Database

(X = complete set, S = short set, other foundation types
estimated using statistical regressions)

City	Slab	Basement	Vent. Crawl
1. Albuquerque NM	X		
2. Atlanta GA	X	X	X
3. Birmingham AL	X	S	
4. Bismarck ND		X	
5. Boise ID		X	X
6. Boston MA		X	
7. Brownsville TX	X		
8. Buffalo NY		X	
9. Burlington VT		X	
10. Charleston SC	S		X
11. Cheyenne WY		X	
12. Chicago IL	S	X	
13. Cincinnati OH	S	X	S
14. Denver CO		X	
15. El Paso TX	X		
16. Fort Worth TX	X		
17. Fresno CA	X		S
18. Great Falls MO		X	
19. Honolulu HA	X		
20. Jacksonville FL	X		
21. Juneau AK		X	
22. Kansas City MO		X	
23. Lake Charles LA	X		
24. Las Vegas NV	X		X
25. Los Angeles CA	X		S
26. Medford OR		S	X
27. Memphis TN	X	S	X
28. Miami FL	X		
29. Minneapolis MN		X	
30. Nashville TN	X	S	X
31. New York NY	S	X	
32. Oklahoma City OK	X		
33. Omaha NB		X	
34. Philadelphia PA		X	
35. Phoenix AZ	X		
36. Pittsburgh PA		X	
37. Portland ME		X	
38. Portland OR		S	X
39. Reno NV	X	X	
40. Salt Lake City UT		X	
41. San Antonio TX	X		S
42. San Diego CA	X		S
43. San Francisco CA	X		S
44. Seattle WA		X	X
45. Washington DC		X	

Table 2. Conservation Options in Parametric Sets

Slab Foundation Options

Option Code	Ceiling Insulation (Nominal)	Wall Insulation (Nominal)	Floor* Insulation (Nominal)	Infiltration (ach)	Glazing Layers 1/2in gap
A01	R-0	R-0	R-0	0.7	1
B01	R-11	R-0	R-0	0.7	1
C02	R-11	R-11	R-0	0.7	1
D01	R-19	R-11	R-0	0.7	1
E01	R-19	R-11	R-5 2ft	0.7	1
F02	R-19	R-11	R-5 2ft	0.7	2
G05	R-19	R-19	R-5 2ft	0.7	2
G01	R-30	R-11	R-5 2ft	0.7	2
H04	R-30	R-19	R-5 2ft	0.7	2
I07	R-30	R-19	R-5 2ft	0.7	3
I06	R-38	R-19	R-5 2ft	0.7	2
J06	R-38	R-19	R-5 2ft	0.7	3
K03	R-30	R-19	R-10 2ft	0.7	3
K01	R-38	R-19	R-10 2ft	0.7	2
L04	R-38	R-19	R-10 2ft	0.7	3
M03	R-38	R-27	R-10 2ft	0.7	3
H54	R-30	R-19	R-5 2ft	0.4	2

Basement Foundation Options †

Option Code	Ceiling Insulation (Nominal)	Wall Insulation (Nominal)	Floor* Insulation (Nominal)	Infiltration (ach)	Glazing Layers 1/2in gap
A01	R-0	R-0	R-0	0.7	1
B01	R-11	R-0	R-0	0.7	1
C02	R-11	R-11	R-0	0.7	1
D01	R-19	R-11	R-0	0.7	1
E01	R-19	R-11	R-5 4ft	0.7	1
F02	R-19	R-11	R-5 4ft	0.7	2
I05	R-19	R-19	R-5 8ft	0.7	2
I03	R-30	R-11	R-5 8ft	0.7	2
J03	R-30	R-19	R-5 8ft	0.7	2
K03	R-30	R-19	R-5 8ft	0.7	3
L04	R-38	R-19	R-5 8ft	0.7	3
M01	R-38	R-19	R-10 8ft	0.7	3
N02	R-38	R-27	R-10 8ft	0.7	3
N05	R-49	R-19	R-10 8ft	0.7	3
O02	R-49	R-27	R-10 8ft	0.7	3
P01	R-60	R-27	R-10 8ft	0.7	3
P02	R-49	R-27	R-19 flr	0.7	3
O52	R-49	R-27	R-10 8ft	0.4	3

† Crawl space options similar.

* Dimension refers to depth of insulation along slab perimeter or basement wall.

The complete database consists of over 5,000 DOE-2 runs for the base case parametric simulations. In addition, there is an equal number of DOE-2 runs for a smaller number of locations for sensivity analyses of optional conservation measures such as added south windows, reflective and heat-absorbing glazings, night insulation, whole-house fans, attached sunspaces and night setbacks. We used the information from this large data base to develop the DOE-sponsored energy slide rules and *PEAR*, a microcomputer version of the database.[1,2].

Full descriptions of the methodology and operating assumptions used in generating the data base, and the results of the sensitivity analyses are covered in other technical reports.[3,4,5,] In this paper we describe the analysis of the base case parametrics, and their conversion to simplified calculations for estimating energy use in typical homes. In particular, we will explain the *delta* (Δ) *load* format developed for the residential slide rules, and a more refined *component load* format that has been incorporated into the *PEAR* microcomputer program. We assess the accuracy and appropriateness of the two formats as simplified calculational procedures.

ANALYSIS OF DATABASE

Determination of Δ Loads

The DOE-2 database provides annual heating and cooling loads for selected packages of conservation measures in a prototype house for any of the 45 climate locations.* We define Δ loads as the change in loads due to the addition of conservation measures. We have calculated them by comparing simulations in the database differing only by a single measure. We derive cumulative Δ loads for each component, e.g., ceilings or walls, by summing individual Δ loads for the same component. These cumulative Δ loads are actually composite values that assume all building components are being tightened simultaneously. For example, the Δ load for R-0 to R-38 ceiling is the sum of the Δ load from R-0 to R-19 ceiling on an uninsulated house, plus the Δ load from R-19 to R-38 ceilings on a moderately insulated house. For typical conservation packages, this procedure produces the most accurate Δ loads and minimizes interactions between different building components.

The Δ load approach is a convenient and easy to understand format for presenting the data. For each prototype and location, we have transformed the database into a series of Δ loads spanning the conservation measures simulated. For the energy slide rules, we show the Δ loads as linear distances on a series of tabs (see Fig. 1). By aligning tabs, the user can calculate the total building load for any combination of measures by subtracting in analog fashion the Δ loads from a worse case base house. The Δ loads are also printed in tabular form in an accompanying technical support document (see Table 3 for a sample).[6] The Δ heating and cooling loads for each

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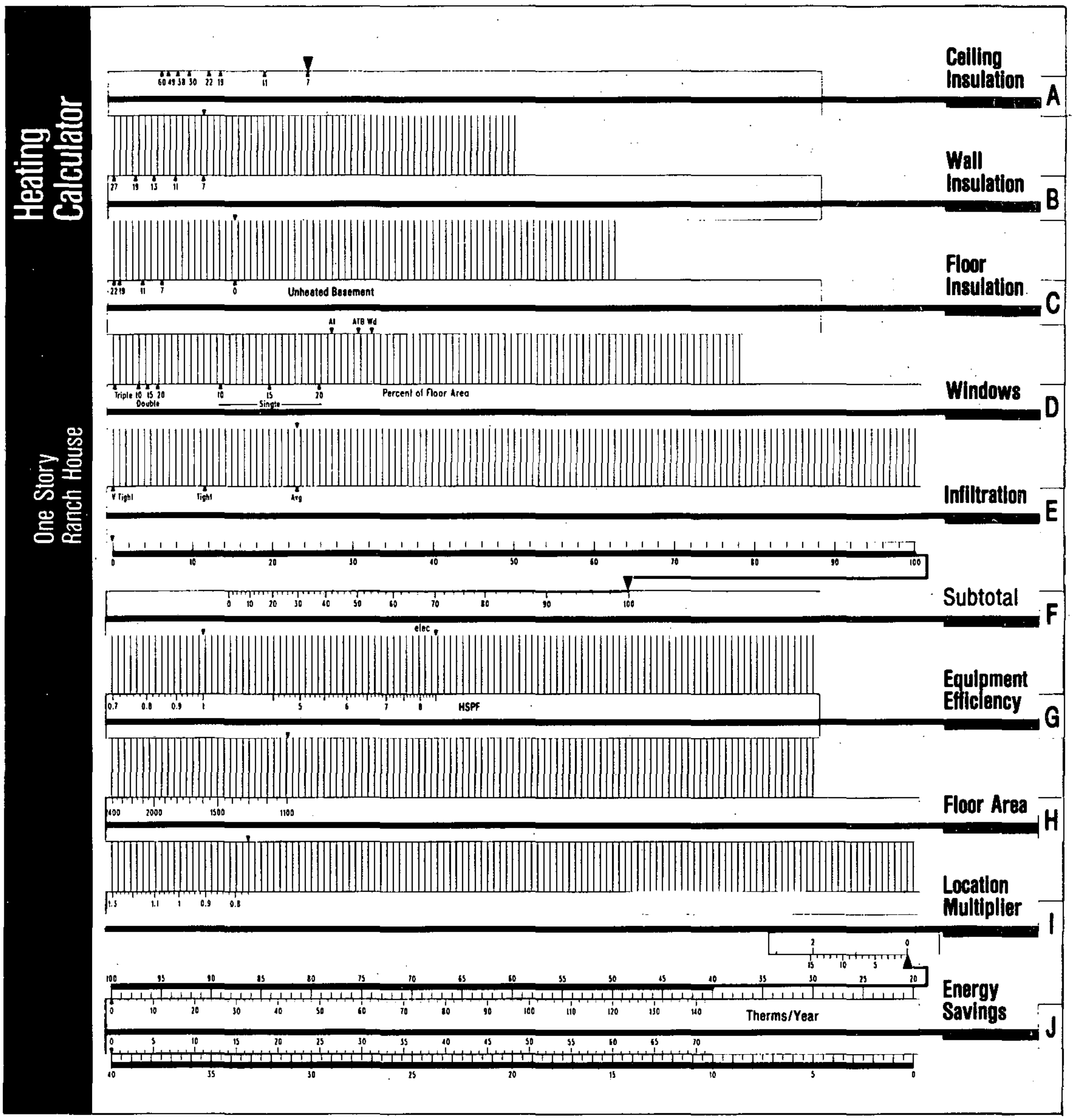
* Although the complete output from the database includes detailed summaries of monthly and peak loads and energies and other information, to date we have analyzed only total annual loads.

Fig. 1 Heating Calculator for One-Story Ranch House



XBL 8312-2463

Table 3. Δ Loads Version of Database Matrix

WASHINGTON 1 STORY RANCH HOUSE BASEMENT

HEATING

Base Load = 110.709 MBtu/Yr

Ceiling		Wall		Foundation	
R-0	0.	R-0	0.	R-0	0.
R-11	-28.03	R-11	-13.41	R-5 4ft	-3.76
R-19	-31.15	R-13	-14.12	R-5 8ft	-5.78
R-30	-33.67	R-19	-16.34	R-10 8ft	-8.21
R-38	-34.60	R-24	-17.67	R-11 Flr	-7.25
R-49	-35.39	R-27	-18.11	R-19 Flr	-9.06
R-60	-35.89				

Infiltration	
Hi (1.0 ach)	0.
Med (.7 ach)	-7.50
Low (.4 ach)	-15.00

Window	Sash	10% area	15% area	20% area
1 pane	Alum	-7.77	-3.92	0.
	Alum+TB	-9.26	-6.15	-2.98
	Wood	-10.00	-7.25	-4.45
2 pane 1/2"	Alum	-14.05	-13.26	-12.34
	Alum+TB	-15.48	-15.41	-15.20
	Wood	-16.16	-16.42	-16.55
3 pane 1/2"	Alum	-16.26	-16.25	-16.09
	Alum+TB	-17.43	-17.99	-18.42
	Wood	-18.07	-18.96	-19.70

Area Multipliers

1000	.679	1700	1.091	2400	1.480
1100	.739	1800	1.147	2500	1.535
1200	.798	1900	1.204	2600	1.590
1300	.857	2000	1.260	2700	1.645
1400	.917	2100	1.315	2800	1.700
1500	.976	2200	1.370	2900	1.755
1600	1.034	2300	1.425	3000	1.809

COOLING

Base Load = 39.302 MBtu/Yr

Ceiling		Wall		Foundation	
R-0	0.	R-0	0.	R-0	0.
R-11	-7.82	R-11	-2.24	R-5 4ft	-.70
R-19	-8.74	R-13	-2.37	R-5 8ft	-1.04
R-30	-9.43	R-19	-2.76	R-10 8ft	-1.45
R-38	-9.69	R-24	-2.96	R-11 Flr	-.81
R-49	-9.94	R-27	-3.03	R-19 Flr	-1.01
R-60	-10.08				

Infiltration	
Hi (1.0 ach)	.0
Med (.7 ach)	-.54
Low (.4 ach)	-1.08

Window	Sash	10% area	15% area	20% area
1 pane	Alum	-8.32	-4.09	0.
	Alum+TB	-8.35	-4.13	-.05
	Wood	-8.36	-4.15	-.07
2 pane 1/2"	Alum	-9.39	-5.75	-2.11
	Alum+TB	-9.42	-5.79	-2.16
	Wood	-9.44	-5.81	-2.18
3 pane 1/2"	Alum	-10.03	-6.57	-3.20
	Alum+TB	-10.05	-6.60	-3.23
	Wood	-10.06	-6.62	-3.25

Area Multipliers

1000	.786	1700	1.059	2400	1.315
1100	.825	1800	1.096	2500	1.352
1200	.865	1900	1.133	2600	1.387
1300	.905	2000	1.170	2700	1.422
1400	.944	2100	1.206	2800	1.457
1500	.984	2200	1.243	2900	1.492
1600	1.022	2300	1.279	3000	1.527

building prototype and city appear as negative values to be subtracted from *base loads* for a worst case house with no insulation, single-pane aluminum windows, and an infiltration rate of 1.0 ach.

To account for floor area differences, we have done DOE-2 sensitivity runs for each prototype with varying house sizes while keeping aspect ratios and ceiling heights constant. Because of the graphic constraints of the slide rule format, we use a single *floor area multiplier* based on correlations of this sensitivity analysis to scale the resultant loads for house size differences. The resulting calculation procedure using the complete Δ load format can be summarized as:

$$\begin{aligned} \textit{Total Load} = \; & (\textit{Base Load} - \Delta Load_{ceiling} - \Delta Load_{wall} \\ & - \Delta Load_{foundation} - \Delta Load_{infiltration} \\ & - \Delta Load_{windows}) * (\textit{Floor area multiplier}) \end{aligned}$$

Determination of Component Loads

The Δ loads format gives an accurate representation of the database, but lacks flexibility for extending that data to building geometries and component characteristics different from those assumed in generating the data base. The Δ loads and *base loads* are prototype specific. The *floor area multiplier* is not only prototype specific, but also ignores changing surface-to-volume ratios for varying sizes within one prototype. This may cause significant errors in estimating Δ loads for houses where the ratios of wall-to-roof, window-to wall, etc., differ significantly from those of the prototype house, leading to serious difficulties when the data is used for assessing tradeoffs.

To increase the flexibility of the database in handling different measures and prototypes, we developed the concept of component loads. We define *component loads* as the net annual contribution of each building component to the heating or cooling loads of the building. We have calculated them from regressions correlating the Δ loads to key physical parameters terms associated with the various building components. For insulation measures, we have regressed them against either ceiling and wall conductivity or total foundation conductance. For infiltration, we have regressed against air changes per hour; and for windows, against window area (see Figs. 2 through 9).

Where the regression line meets the y-axis (y-intercept) the component loads can be assumed to be zero (zero conductance for ceiling, walls, and floors, zero air changes for

Figure 2.

Washington Ceiling Heating Loads

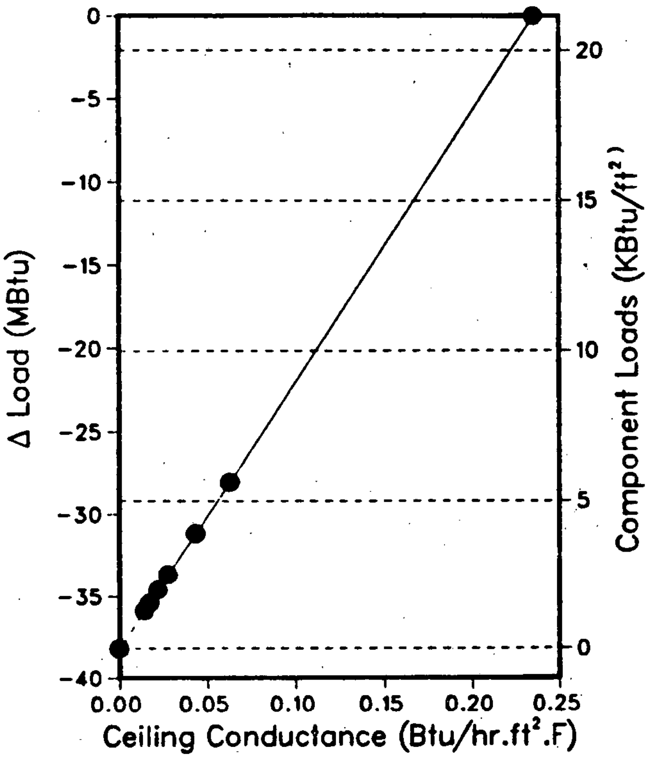


Figure 3.

Washington Ceiling Cooling Loads

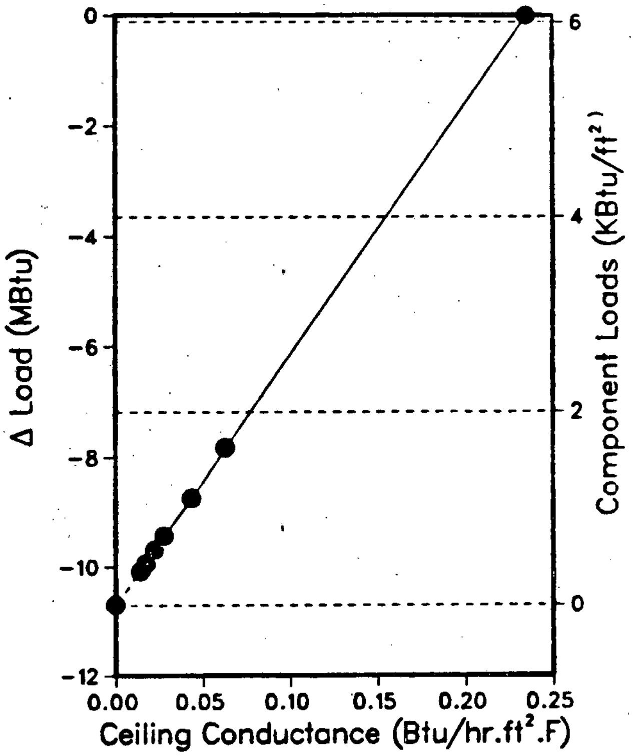


Figure 4.

Washington Wall Heating Loads

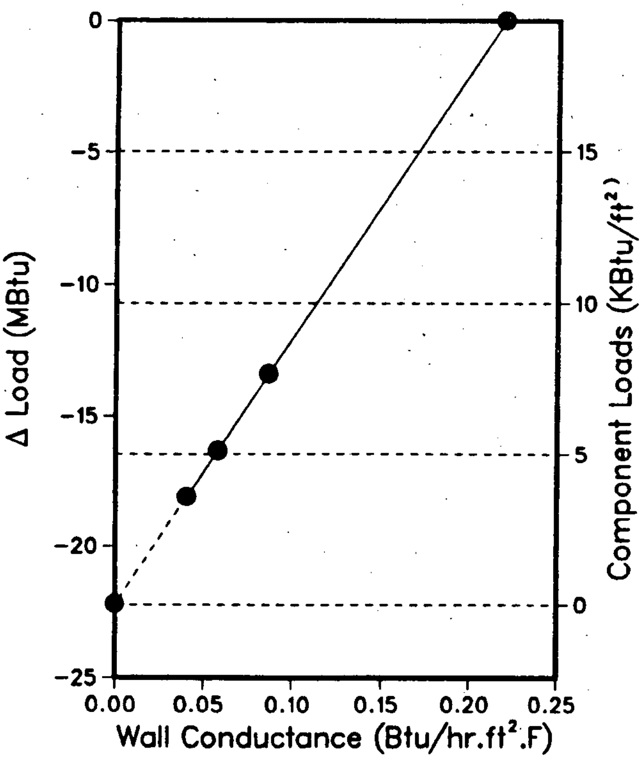


Figure 5.

Washington Wall Cooling Loads

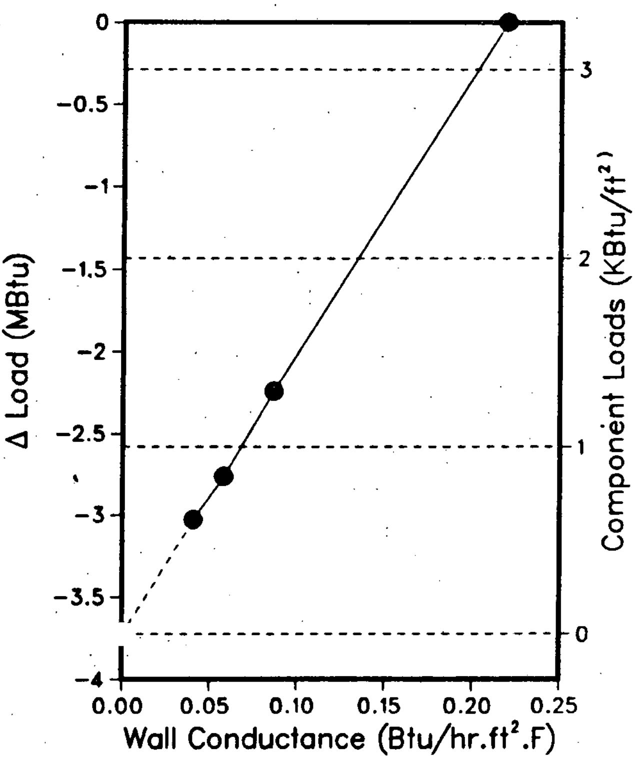


Figure 6.

Washington Foundation Heating Loads

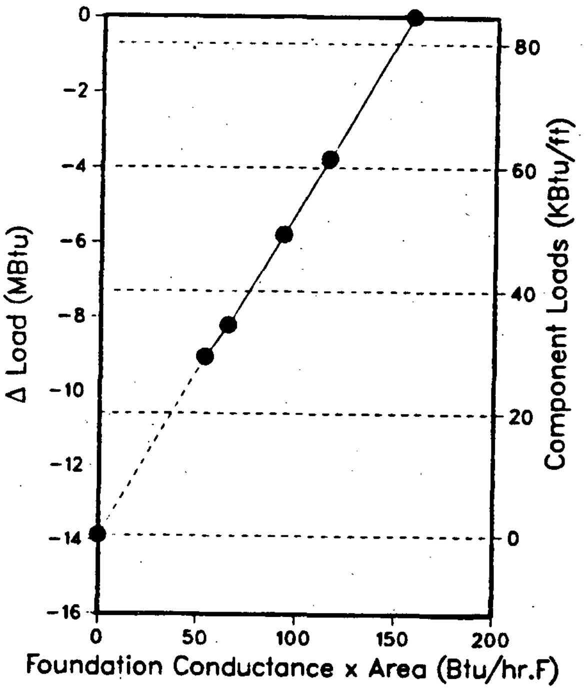


Figure 7.

Washington Foundation Cooling Loads

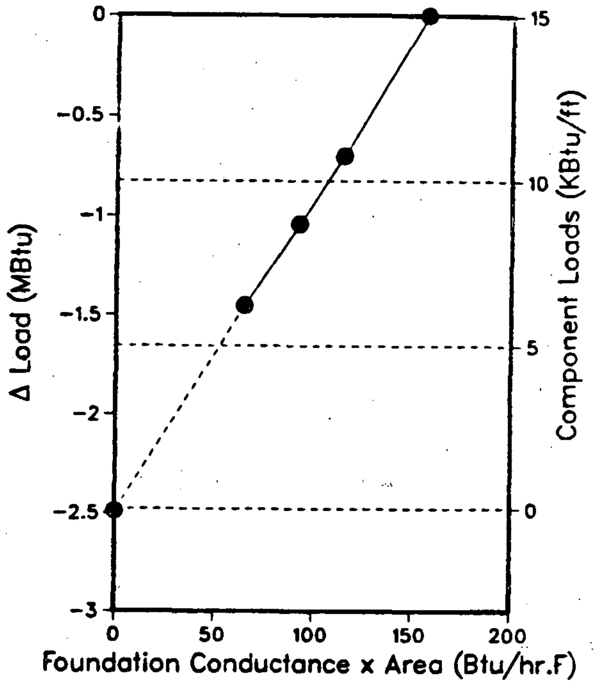


Figure 8.

Washington Window Heating Loads

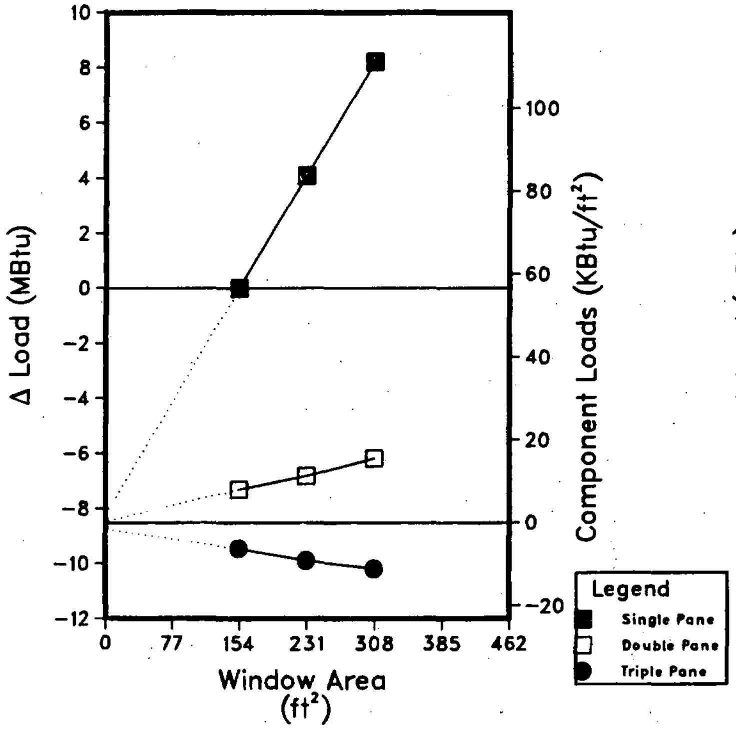
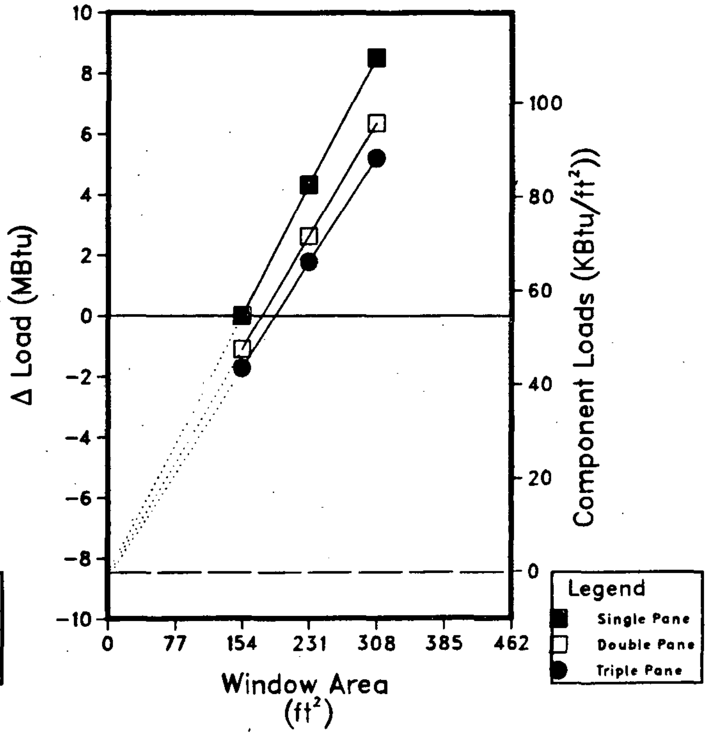


Figure 9.

Washington Window Cooling Loads



infiltration, and zero area for windows).[*] We base the component loads for the simulated measures on their Δloads from the y-intercept (indicated on the right-hand scales of Figs. 2 through 9). To facilitate scaling, we have normalized the component loads either per square foot (for ceiling, walls, and windows), per perimeter foot (for foundations), or per cubic foot (for infiltration).

Since component loads correspond to the net loads effect for each component, they can be scaled by the actual amounts of ceiling, foundation, window, etc, thus making the data base relatively prototype-free.[†] The functional form of the regression equations also makes it very easy to interpolate component loads for intermediate component conditions using either adjacent component loads or general regression equations to describe the entire range.

The component loads calculation procedure can be summarized as :

$$
\begin{aligned}
\mathit{Load} \;=\; & [\,(\,\mathit{Component\ Load}_{ceiling} \;*\; \mathit{Area}_{ceiling}) + (\mathit{Component\ Load}_{wall} \;*\; \mathit{Area}_{wall}) \\
& + (\mathit{Component\ Load}_{foundation} \;*\; \mathit{Length}_{foundation}) \\
& + (\mathit{Component\ Load}_{windows} \;*\; \mathit{Area}_{windows}) \\
& + (\mathit{Component\ Load}_{infiltration} \;*\; \mathit{Volume}_{air\ change/hr}) + (\mathit{Residual\ Load})\,] \\
& *\; [\,\mathit{Floor\ area\ adjustment,}]
\end{aligned}
$$

where the component loads can be either in tabular format (see Table 4) or further reduced to regression slopes times the various scalar terms (see Table 5).

In Table 4, the increasing Δ loads for added conservation measures of Table 3 have been replaced by decreasing component loads normalized per unit length, area, or volume. For the prototype building and base conservation options, the two tables will give the same results. However, Table 4 is more flexible for extrapolating the data to different house geometries.

There are two additional terms used in the component loads calculations, the ***residual load*** and the ***floor area adjustment***. The ***residual load*** is the difference between the sum of the component loads and the total loads from the actual DOE-2 database. It represents the net effect of

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[*] We use this extrapolation only for computing the component loads and not for extending the range of the database. Significant interactions between the Δ loads can be expected in super-insulated houses with extremely high insulation levels beyond those covered in the simulation database. We should mention, however, that test DOE-2 runs showed very little interaction and very good agreement to extrapolated Δ loads in houses for which we changed only a single building component (i.e., ceiling or wall) to infinite resistance.

[†] A certain amount of bias still exists because of minor building characteristics such as roof tilt, overhang length and location. The additional work necessary to incorporate such terms into the regression analysis is probably not warranted.

Table 4. Component Loads Version of Database Matrix

WASHINGTON 1 STORY RANCH HOUSE BASEMENT

HEATING						COOLING					
Ceiling ($KBtu/ft^2$)		Wall ($KBtu/ft^2$)		Foundation (KBtu/ft)		Ceiling ($KBtu/ft^2$)		Wall ($KBtu/ft^2$)		Foundation (KBtu/ft)	
R-0	21.15	R-0	19.32	R-0	84.28	R-0	6.07	R-0	3.25	R-0	14.58
R-11	5.63	R-11	7.70	R-5 4ft	61.63	R-11	1.62	R-11	1.31	R-5 4ft	10.36
R-19	3.85	R-19	5.16	R-5 8ft	49.46	R-19	1.09	R-19	.86	R-5 8ft	8.31
R-30	2.42	R-27	3.61	R-10 8ft	34.70	R-30	.70	R-27	.62	R-10 8ft	5.84
R-38	1.89			R-19 Flr	29.70	R-38	.55			R-19 Flr	8.49
R-49	1.44					R-49	.40				
R-60	1.15					R-60	.33				

Infiltration ($KBtu/ft^3$)		Windows ($KBtu/ft^2$)		Infiltration ($KBtu/ft^3$)		Windows ($KBtu/ft^2$)	
Hi (1.0 ach)	2.03	1 pane Plain	53.38	Hi (1.0 ach)	.15	1 pane Plain	55.20
Med (.7 ach)	1.42	2 pane 1/2" Plain	7.40	Med (.7 ach)	.10	2 pane 1/2" Plain	48.47
Low (.4 ach)	.82	3 pane 1/2" Plain	-4.71	Low (.4 ach)	.06	3 pane 1/2" Plain	45.03

Residual Load = -5.99 MBtu/Yr

Residual Load = 3.63 MBtu/Yr

Table 5. Regression Coefficients for Washington

		Heating (KBtu/yr)	Cooling (KBtu/yr)
Ceiling Component Load		$88.27 * UA_{ceiling}$	$25.33 * UA_{ceiling}$
Wall Component Load		$88.18 * UA_{wall}$	$14.83 * UA_{wall}$
Foundation Component Load		$89.00 * UA_{foundation}$	$15.40 * UA_{foundation}$
Window Component Load	single pane	53.38 * Window area	55.20 * Window area
	double pane	7.40 * Window area	48.47 * Window area
	triple pane	-4.71 * Window area	45.03 * Window area
Infiltration Component Load		2.03 * ach * volume	0.15 * ach * volume
Residual Load		-5.99 MBtu/yr	3.63 MBtu/yr

internal loads and interactions ignored in the component-by-component regression analysis.[*] The predominant influence of internal loads on the residuals is evident in that they are always negative for heating and positive for cooling loads.

The *floor area adjustment* is a secondary correction based on the same sensitivity analysis of house size variations mentioned earlier for the Δ load procedure. Although the two floor area modifiers seem superficially similar, the *floor area adjustment* is a much smaller correction since differences in skin-to-volume ratio, etc., have been already accounted for in the component loads calculations. Table 6 shows the regression equations developed to calculate different floor areas for the one-story ranch prototype. These floor area adjustments relate to the changes to internal loads intensities for different house sizes. Thus, the slopes are positive for houses smaller, and negative for houses larger than the prototype.

Table 6. Floor Area Regression Equations for 1-Story Ranch Prototype

	Heating		**Cooling**	
House Size (ft^2)	Slope	Intercept	Slope	Intercept
1000	.015774	-.179999	.023151	-.547235
1176	.013235	-.276697	.034155	-.909189
2000	.007042	-.276997	.88346	-.022931
2500	-.016606	.564084	.94197	-.042022
3000	-.023329	.965105	.93566	-.066706

The component loads calculation requires a series of simple calculations which are too complex to incorporate into a mechanical slide rule, but are ideally suited for a microcomputer. We have incorporated this format into *PEAR*. The component loads approach allows *PEAR* to adjust for different roof areas, wall areas and heights, perimeter lengths, and window areas to the point where the geometries of the original prototypes are of only incidental concern.[†] At the same time, the regression coefficients allow *PEAR* to interpolate for intermediate component conditions.

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[*] We did not do component regressions for internal loads because we did not treat them as a variable. We held them constant for all database simulations.

[†] The input for window areas is further divided into the amounts facing north, south, east, and west to incorporate analytical results on the impact of various window orientations. For discussion of that analysis, refer to Turiel, et al. (5).

ACCURACY OF THE Δ LOAD AND COMPONENT LOAD CALCULATIONS

For a prototype house with base case options, the Δ and component loads calculations give identical numbers. For non-prototype houses, the results differ. To compare their accuracy for varying house sizes, we did parametric DOE-2 simulations for houses with floor areas 35% smaller (1000 ft^2) and 95% larger (3000 ft^2) than the 1540 ft^2 prototype house in four locations (New York, Phoenix, Atlanta, and Washington). Since we have not changed the building aspect ratio, the test runs are conservative in testing the sensitivity of the calculation procedures for changes in building geometry. We then compared the results for total and incremental building loads to extrapolated values from the database using the Δ loads and the component loads procedures. For brevity, we show only the results for New York (see Tables 7 and 8), but the relative accuracies are similar in all four cities.

Table 7. Comparison of DOE-2 Results to Δ Loads and Component Formats for 1000 ft^2 New York Test House

	Heating (MBtu)			Cooling (MBtu)		
	DOE-2.1A test run (load)	Δ loads format (error)	Component format (error)	DOE-2.1A test run (load)	Δ loads format (error)	Component format (error)
Total Loads†						
A01 (00-00-FM0-.7-1)	72.22	-0.38	-0.05	12.05	-1.32	-0.07
B01 (11-00-FM0-.7-1)	52.91	+1.16	+0.04	9.24	-0.34	-0.07
C01 (19-00-FM0-.7-1)	50.50	+1.32	+0.04	8.92	-0.21	-0.06
C02 (00-11-FM0-.7-1)	40.43	-0.86	-0.07	8.34	-0.42	-0.19
D01 (19-11-FM0-.7-1)	38.01	-0.71	+0.06	8.00	-0.32	-0.21
E01 (19-11-FM1-.7-1)	35.15	-0.52	+0.10	7.76	-0.30	-0.18
D02 (19-11-FM1-.7-1)	29.42	-0.87	+0.13	7.46	-0.34	-0.10
J03 (30-19-FM3-.7-2)	23.26	-0.75	-0.29	6.92	-0.33	+0.25
K03 (30-19-FM3-.7-3)	21.69	-0.86	-0.30	6.82	-0.42	+0.30
Δ Loads						
R0 → R19 Ceiling	21.72	+1.49	+0.09	3.13	+1.11	+0.01
R0 → R11 Wall	12.48	-2.02	+0.03	0.90	-0.08	-0.04
R0 → R5 (4) Fdn	2.86	-0.19	-0.04	0.24	-0.02	-0.03
1 pane → 2-pane	5.73	-0.35	-0.03	0.30	-0.06	-0.08
2 pane → 3-pane	1.57	+0.11	-0.01	0.10	+0.07	+0.05

† Code in parenthesis identifies conservation measures in the folloing order: ceiling, wall, and foundation insulation, infiltration rate, and number of glazings. FM0 = uninsulated foundation, FM1 = R-5 4ft., and FM3 = R-5 8ft.

Table 8. Comparison of DOE-2 Results to Δ Loads and Component Formats for 3000 ft^2 New York Test House

	Heating (MBtu)			Cooling (MBtu)		
	DOE2.1A test run (load)	Δ loads format (error)	Component format (error)	DOE-2.1A test run (load)	Δ loads format (error)	Component format (error)
Total Loads[†]						
A01 (00-00-FM0-.7-1)	192.87	-4.49	-1.81	26.81	+4.19	+0.22
B01 (11-00-FM0-.7-1)	132.71	+4.57	-1.45	17.61	+1.40	+0.06
C01 (19-00-FM0-.7-1)	125.30	+3.51	+1.34	16.76	+3.30	-0.31
C02 (00-11-FM1-.7-1)	111.96	-2.43	-0.51	16.08	+1.60	+0.20
D01 (19-11-FM0-.7-1)	104.56	+2.05	-0.14	15.24	+0.71	-0.19
E01 (19-11-FM1-.7-1)	96.99	+1.94	-0.21	14.50	+0.88	-0.07
J01 (30-19-FM3-.7-2)	65.52	-1.88	+0.78	12.43	-0.25	+0.12
K01 (30-19-FM3-.7-1)	60.62	-1.43	+0.76	11.71	+0.12	+0.32
Δ Loads						
R0 → R19 Ceiling	67.57	-6.00	+0.47	10.05	-0.89	+0.53
R0 → R11 Wall	20.75	+7.00	+0.06	1.52	+0.26	-0.12
R0 → R5 (4) Fdn	7.57	+0.11	+0.07	0.74	-0.17	-0.12
2 pane → 3-pane	4.90	-0.44	+0.02	0.72	-0.37	-0.20

[†] Code in parenthesis identifies conservation measures in the following order: ceiling, wall and foundation insulation, infiltration rate, and number of glazings. FMO = uninsulated foundation, FM1 = R-5 4ft., and FM3 = R-5 8 ft.

For total loads, the Δ load procedure is generally within 3% of the test runs in heating, and within 7% for cooling, with one case of 20% error. In absolute magnitude, the heating errors are larger, up to 1.3 MBtu for the 1000 house, and 4.5 MBtu for the 3000 house. We found that the errors for the component procedure are better by at least a factor of two, being negligible in the small house, and within 1% for the larger house. In terms of total loads, one can argue that although the component approach may be better, the 7% error in Δ loads approach is still insignificant and the procedure is adequate as a simplified calculation.

The difference between the two approaches becomes much more dramatic when one looks at their ability to predict the incremental changes in loads due to added conservation in specific building components. While the component procedure maintains the same relative accuracy in Δ loads as for total loads (i.e., about 1%), the Δ loads procedure produces values that may differ by as much as 30-40%. The primary cause for these errors can be traced to the inability of the Δ load approach to adjust for changes in building surface ratios. For example, note that in Table 8 the wall Δ load for the 3000 ft^2 house is overpredicted by 34%, about the same as the percent decrease in the wall-to-floor ratio from the 1540 ft^2 prototype, which is 31%.

We note that the accuracy reflected in Tables 7 and 8 apply to the house types and range of conservation levels covered in the DOE-2 database, i.e., typical wood-frame houses with up to R-

60 ceilings, R-27 walls, R-10 basement wall insulation, and triple-pane windows. We expect that, for superinsulated houses with insulation levels and infiltration rates beyond this range or for houses with large amounts of thermal mass, there will be significantly larger interactions between building components than those assumed in the two simplified methods described. For such cases, the accuracy of either the delta load or the component load methods is open to question. Therefore, at the present, we have constrained the PEAR program to the range of measures covered in the database, At the same time, we are compiling a database for houses of heavy mass construction and for superinsulated houses. We intend to analyze this additional data using multi-linear regressions and expect to develop a refined simplified calculation procedure that accounts for interactions between component loads.

CONCLUSIONS

The residential energy database developed by LBL in support of several DOE-sponsored programs provides benchmark numbers for determining the energy savings potental of typical conservation measures. Although databases are inherently considered to be less flexible than actual simulation programs, we describe a procedure to extend the database with good accuracy to the range of parametric options and designs found in typical houses. The procedure, which is based on the relationship between building component loads and key physical parameters, results in a set of regression equations that allow us to extend the simulation results to buildings with different geometries, conservation measures, and physical characteristics from those of the base case prototype. The results of our regression analysis also make it possible to compress the size of the data set, and to use it in novel ways. For example, if the relationship between the component loads and conductivities is known, it is easy to calculate the exact R-value necessary to achieve a certain reduction in load.

In our comparison of two approaches for recreating the results of actual DOE-2 simulations of varying house sizes from an existing data base, we found the component loads method to be superior. This was especially true for incremental changes in loads due to added conservation in individual building components, such as the change from R-0 to R-11 in the walls. In this case, we found an error of 34% using the Δ loads method compared to less than a 1% difference with the component loads approach. It is this type of incremental change that is usually evaluated by builders or homeowners when assessing tradeoffs between conservation options. We believe that the component loads approach, using simple linear regression equations, provides the most accurate estimation of energy savings for typical residential conservation measures. The regression equations, which can be used in microcomputer programs like PEAR, extend the flexibility of the base case data. Results generated by such an approach lend themselves well to setting thermal performance levels for residential energy guidelines or standards.

This report summarizes the progress to date in making the DOE-2 residential data more flexible and less dependent on specific building prototypes and conservation measures through the use of component loads. This work is continuing with research targeted for the following topics:

1. Investigate the relationships between total, component, and Δ loads for the 45 locations and building-related climate parameters, such as degree- days, latent enthalpy hours, heating and cooling insolation hours, etc. When we find reliable climate determinants, we can reduce the 45 geographical sets of data and develop extrapolation procedures to extend the data to other locations. This climate analysis is nearing completion and will soon be described in a technical report.
2. Identify the relationship between component loads for different prototypes buildings, e.g., one-story versus two-story, detached versus attached. Secondary terms may be added so that a single data base can include all typical residential house types. This topic includes further work on the effects of internal loads, shading, and different surface-to-volume ratios on various component loads.
3 **Expand and modify, if necessary, the simplified calculation procedure for heavy mass construction and for superinsulated houses.**
4. Evaluate the relationship of window conductance, sash, transmission, emissivity, and shading coefficient to window component loads. This work will probably require expanding the data base to cover the parameters mentioned. The goal is a simplified calculation method that will allow users to choose any combination of window characteristics and shading assumptions.

Research in this area supports our overall goal of developing and disseminating simplified calculation methods for residential buildings. We also hope that the results of this research will be used eventually to increase the energy efficiency of the nation's housing stock.

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