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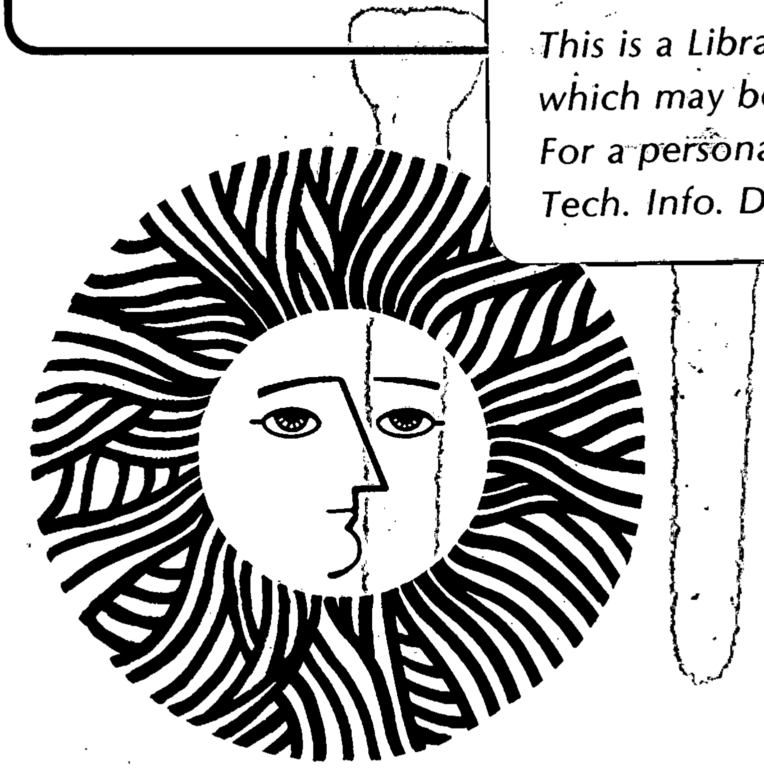

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MONITORED LOW-ENERGY HOUSES IN NORTH AMERICA AND EUROPE: A COMPILATION AND ECONOMIC ANALYSIS*

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ABSTRACT

In our continuing compilation, BECA-A (Building Energy-Use Compilation and Analysis, Part A, New Homes) we have to date analyzed 128 submetered, energy-efficient homes in North America and Europe. Only 59 have acceptable data on additional first cost of conservation measures. Of these, the lowest cost of conserved energy is for the superinsulated category, where the cost of conserved energy is well under the average price of electricity, i.e. 6.2¢/kWh. Only 37 homes have submetering adequate to permit correcting space heating loads for variations in occupant behavior (thermostat setting and internal gains). For these 37, the mean "standardized" thermal integrity is 50.3 kJ/m^2-DD, compared to U.S. 1979 building practice of 100, or U.S. stock of 180. We solicit (and continue to collect) more data.

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CONTENTS

1. INTRODUCTION

In our project, Building Energy-Use Compilation and Analysis (BECA), we are documenting depletable-energy conservation in the building sector.[1] These compilations demonstrate the technical and economic potential of conservation techniques and provide a basis on which policy makers, builders and contractors, commercial building owners, and homeowners can make informed decisions about conservation measures.

In BECA, Part A (BECA-A), we focus on space heating, by far the largest energy end use in new residential buildings We have collected data on 200 low-energy houses throughout North America and Europe, which include active solar, passive solar, superinsulated, and earth sheltered dwellings (and many in combination). The data consist of submetered energy consumption, inside and outside temperatures, number of occu-

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[1] The BECA series is published in Energy and Buildings or is available from the Energy Efficient Buildings program, LBL (Lawrence Berkeley Laboratory), and includes:
Part A = New residential buildings (from which this paper is derived)
Part B = Retrofit residential buildings
Part C = Commercial buildings
Part D = Appliance energy use
Part V = Validation of computer programs

pants, and investment cost of conservation. We perform two levels of analysis: one for all buildings with submetered heating, and one for the subset of homes with submetered heating, appliances, and hot water. In the first analysis we present annual energy use corrected to standard indoor temperature, while in the second we correct the data to reflect "standard" occupancy, internal gains, and inside temperature.

In this paper we present a comparison of the thermal performance and economics of 128 homes (computed July 1982, out of our 200) on the basis of annual heating load and cost of conservation. We discuss the effect of internal gains on performance measures and introduce a method to normalize the heating load to "standard" conditions. We emphasize the importance of normalization to compare building performance accurately, and present the standard heating loads compared with simulation, current building practice, and the national building stock.

2. DEFINITIONS

We have divided the homes into the following five primary categories: active solar, passive solar, hybrid solar, earth sheltered, and superinsulated. The concepts of active solar and earth sheltering are self-evident, but with superinsulation, passive solar and hybrid solar the definitions become hazy. We have defined superinsulated homes as those in which insulation is a major conservation measure, and have allowed passive solar homes to include those with a majority of the glazing on the south. Hybrid solar is passive solar with fans to distribute the hot air. In practice we find that 39 of our 128 houses do not fit neatly into these categories. Thus, we have defined a superinsulated/active solar and a "multi-strategy" category. The "additional cost of conservation" is defined as the cost above conventional construction for conservation or solar measures. The figures we present were derived by the researchers from whom we received data by summing up the added costs incurred (i.e., extra insulation, alternative framing, or solar collectors) and subtracting avoided costs (as in downsizing or eliminating the furnace).

3. BASIC SHELL PERFORMANCE

Our primary goal is to rank low-energy homes by their life cycle cost. To evaluate the quality of the building's thermal envelope, we first derive the annual (non-renewable) heating load, which is the annual thermal energy delivered to the house by the heating system. For each building we have obtained submetered heating-system energy use, average outside temperature and heating degree-days (base 18.3°C [65°F]) during each metered period, a description of construction (including floor area, R-values, and conservation measures), and cost. The metered heating load, Q_{Hm}, is obtained by multiplying the heating energy delivered to the heating system, E_{Hm}, by the heating system efficiency, η_H (or COP in the case of a heat pump).

$$Q_{Hm} = \eta_H E_{Hm} \qquad [1]$$

In the cases of hybrid solar and active solar collectors, we count the parasitic losses (operating electricity for pumps and fans) as equivalent to electric resistance heaters ($\eta_H = 1.0$). The solar contribution from passive and active solar homes is not included in E_{Hm}, but of course is reflected in a reduced E_{Hm} and Q_{Hm}. In treating solar gains this way we are then crediting shell performance with the ability of the house to use solar energy. We have excluded all buildings heated with wood because of large uncertainties in stove and fireplace efficiencies, energy content of wood, and amount of wood burned.

There are between 4 months and 4 years of energy consumption data per home, with the majority of data in the form of monthly metered readings. For each home, we perform a least squares fit to the basic heat equation:

$$Q_{Hm} = k(T_b - T_o) \qquad [2]$$

where

Q_{Hm} = heat delivered by the heating system (furnace output),

k = heat loss coefficient (slope) = effective UA (conduction plus infiltration)

T_b = balance temperature = x-intercept

T_o = outside temperature

Equation 2 implies a constant indoor temperature, T_i. Nonetheless, for some of our homes we have monthly measured T_i, and they fluctuate. We can improve our fit by adjusting the outside temperature to an effective constant indoor temperature. While making this correction we also adjust all of the homes to a standard indoor temperature of 20°C for comparison of homes with each other (see section on standardization, p. 9). This effective outside temperature is calculated as follows:

$$T_o' = T_o + T_i - 20^{o}C \qquad [3]$$

where

T_o' = effective outside temperature

T_i = measured inside temperature

$20^{o}C$ = standard inside temperature

The adjustment of T_o to T_o' before the fit yields a balance temperature for a home normalized to 20°C inside temperature.

To calculate heating energy for each period with $T_o < T_b$,

$$Q_H = k(T_b - T_o) \qquad [4]$$

The annual heating load is

$$AQ = \frac{1}{Y}\left[\sum_{m=1}^{n} Q_H^m\right] \qquad [5]$$

where

Q_H = heating energy (calculated from parameters of fit),

AQ = annual heating load

m = month

n = number of months in metered period

Y = number of years (always in integral numbers)

When there is less than a full winter's data the annual heating load is derived by extrapolating from available months. Thus Q_H for the missing months uses k and T_b from the fit, and the average outdoor temperature, T_o, from each missing month. For homes having only annual data, we simply report the measured annual consumption.

Figure 1 is a scatter plot of actual thermal intensity (annual heating load per unit area) versus degree-days for 67 buildings (including 4 small low-rise apartment houses) totaling 128 single-family units. The points are all identified by conservation category symbols, and by the identification number for a home or group of n homes. Building descriptions and a summary of results can be found in Tables 1 and 2 respectively (pages 16 and 17).

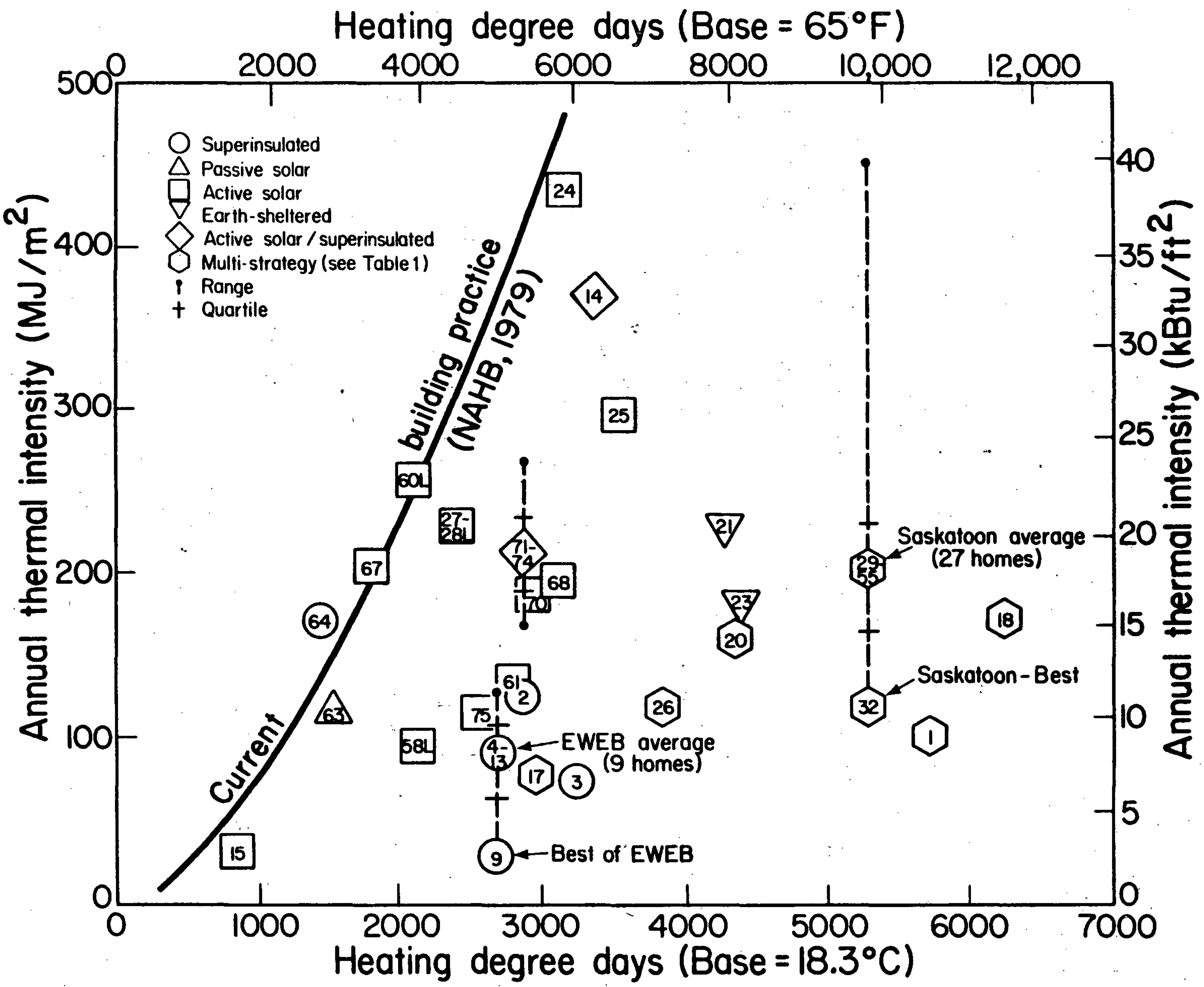

Fig. 1. Scatter plot of annual heating load/m^2 vs. climate for 28 points representing 128 submetered energy-efficient new homes. The solid curve is NAHB's 1979 survey of U.S. building practice, taken from Fig. 2.

The 12 pure active solar homes, with an average "thermal integrity" (thermal intensity per degree-day), TI, of 80 kJ/(m^2-°C-day) [3.9 Btu/ft^2-°F-day][2], generally perform worse than the 11 superinsulated homes, TI = 39, or the 31 which combine insulation and passive solar features, TI = 42. Home 14 exhibits high consumption, probably because it is unoccupied and thus the heating is not supplemented at all by internal gains (this will be corrected for in later sections). Home 18 also has zero occupancy; however, since it was a demonstration project, appliances were used and the heating consumption is not far above what might be expected if it were occupied. The common threads between the best buildings (1, 2, 3, and 4 - 13) are extremely low infiltration (ranging from 0.12 air changes per hour to 0.37 ach) and high insulation levels. These homes have an average thermal integrity, TI, of only 30.6.

4. INTERNAL GAINS

Comparison of homes on the basis of annual heating load gives only a first approximation of shell performance. To obtain a closer approximation it is necessary to account for internal gains as well as indoor temperature. Heating-energy consumption for a building may be described with the following basic heat-balance equation:

$$E_H \eta_H = Q_H = (Q_T - Q_I - Q_S) \qquad [6]$$

where

Q_T = total thermal energy losses from building shell (conduction and infiltration),

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[2] 1 Btu/(ft^2-°F-day) = 20.4 kJ/(m^2-°C-day)

Q_I = internal gains from people and appliances, and hot water, and

Q_S = solar gains.

We make no correction for Q_S because variation from year to year is small,[3] and of course the architectural dependency is already included in our concept of the shell. Thus, the variable of concern to us is Q_I.

The homes surveyed show internal gains ranging from 15 to 60 GJ/year [14.2 - 57 MBtu/year][4] and average 35 GJ/year (perhaps 15 GJ during the heating season), compared to an average annual heating load AQ = 33 GJ for our sample. Homes with identical shells and furnaces may have different annual heating loads due to such differences in internal gains. Since internal gains during the heating season can be as large as 100 - 150% of the heating load, considerable error will result if internal gains are not properly included. (For calculation of Q_I see Appendix A).

5. STANDARDIZED PERFORMANCE

For a subset of 27 buildings we have measured indoor temperature, submetered data on heating, hot water, and appliance energy use, and number of occupants. For these homes, we can correct the heating energy for both indoor temperature and internal gains. An important aspect of our work is to generate a basis on which to compare buildings with each other, with simulations, and with mass-metered building stock data. To compare buildings it is imperative to normalize internal gains and indoor temperature, T_i, to standard conditions, T_{is}. We selected a

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[3] Variation in solar radiation is typically less than 10 - 15% (personal communication with Frank Quinlin, NOAA, 1982).

[4] 1 MBtu = 1.054 GJ.

standard inside temperature, T_{is}, of 20°C [68° F], and standard internal gain, Q_{Is}, of 32 GJ/year (1 kW)[5] (assumed constant over the 12 months).

To normalize for internal gains we first calculate the balance temperature for the house with internal gain = Q_{Is}:

$$T_{bs} = T_b - \left(\frac{Q_I - Q_{Is}}{k} \right) \qquad [7]$$

where

T_{bs} = standard balance temperature, and

Q_{Is} = standard internal gains.

The standard annual heating load (SAQ) is calculated as follows (analogous to equations 3 and 4):

$$Q_{Hs} = k(T_{bs} - T_o) \qquad [8]$$

$$SAQ = \frac{1}{Y} \left(\sum_{m=1}^{n} Q_{Hs}^{m} \right) \qquad [9]$$

where

Q_{Hs} = heating load normalized for internal gains, i.e. standardized Q_H), and

SAQ = standard annual heating load.

This correction is equivalent to adding the difference between standard and actual internal gains ($Q_{Is} - Q_I$) to the heating energy for each period. However, this procedure allows extrapolation to months where

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[5] This figure is in common use among researchers as the U.S. average. California Energy Commission, "Staff Presentation Outline for Committee Proposed Standards," April 1981; Oak Ridge National Laboratory, "ACES: Final Performance Report," December 1978 through September 1980," April 1981.

$(T_b - T_o)$ is less than zero and $(T_{bs} - T_o)$ is positive. Of course, in calculating both the AQ and the SAQ, negative values of Q_H or Q_{Hs} are never counted.

Since T_i was normalized to 20°C in calculating T_b, SAQ is now corrected for both internal gains and indoor temperature.

6. BUILDINGS IN CONTEXT

In Figure 2, a plot of SAQ/m^2 versus heating degree-days, homes are compared under "standard conditions," free of variation in occupant effects. Here we compare the homes with 1) the new residential Building Energy Performance Guidelines (BEPG, 1981),[6] 2) new building practice (NAHB, 1979),[7] and 3) the national building stock (RECS, 1980).[8] The BEPG curves were generated with internal gains equal to Q_{Is} (1 kW).

The most salient feature of Figure 3 is the demonstration of a tremendous potential for conservation. Dividing each point by its degree-days, we find the mean standard thermal integrity of our energy-

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[6] BEPG was developed at LBL as an extension of the research on the federal Building Energy Performance Standards (BEPS, 1979). John Ingersoll et al., "Methodology and Assumptions for the Evaluation of the Heating and Cooling Energy Requirements in New Residential Buildings," LBL Report 13767, Berkeley, CA, 1981.

[7] Derived by simulation on DOE 2.1 from "Single Family Construction Practices 1973, 1976, 1977;" NAHB Research Foundation, Inc., Rockville, MD, 1974, 1977, and 1980.

[8] Note that the lowest three curves of Figure 2 have a reasonable shape, but the "stock" curve (RECS 1979) is an unreasonably straight line. This is due to the fact that we have not yet plotted RECS points for many locations and fitted a curve to them. Instead we took the U.S. average intensity and average degree-days calculated for the RECS data by Stephen Meyers (in his unpublished master's thesis, Residential Energy Use in the United States: A New Look at How Americans Use Energy in the Home, Lawrence Berkeley Laboratory, 1981), and simply drew a straight line through the origin and through that point. We will provide a curve in the next edition of BECA-A.

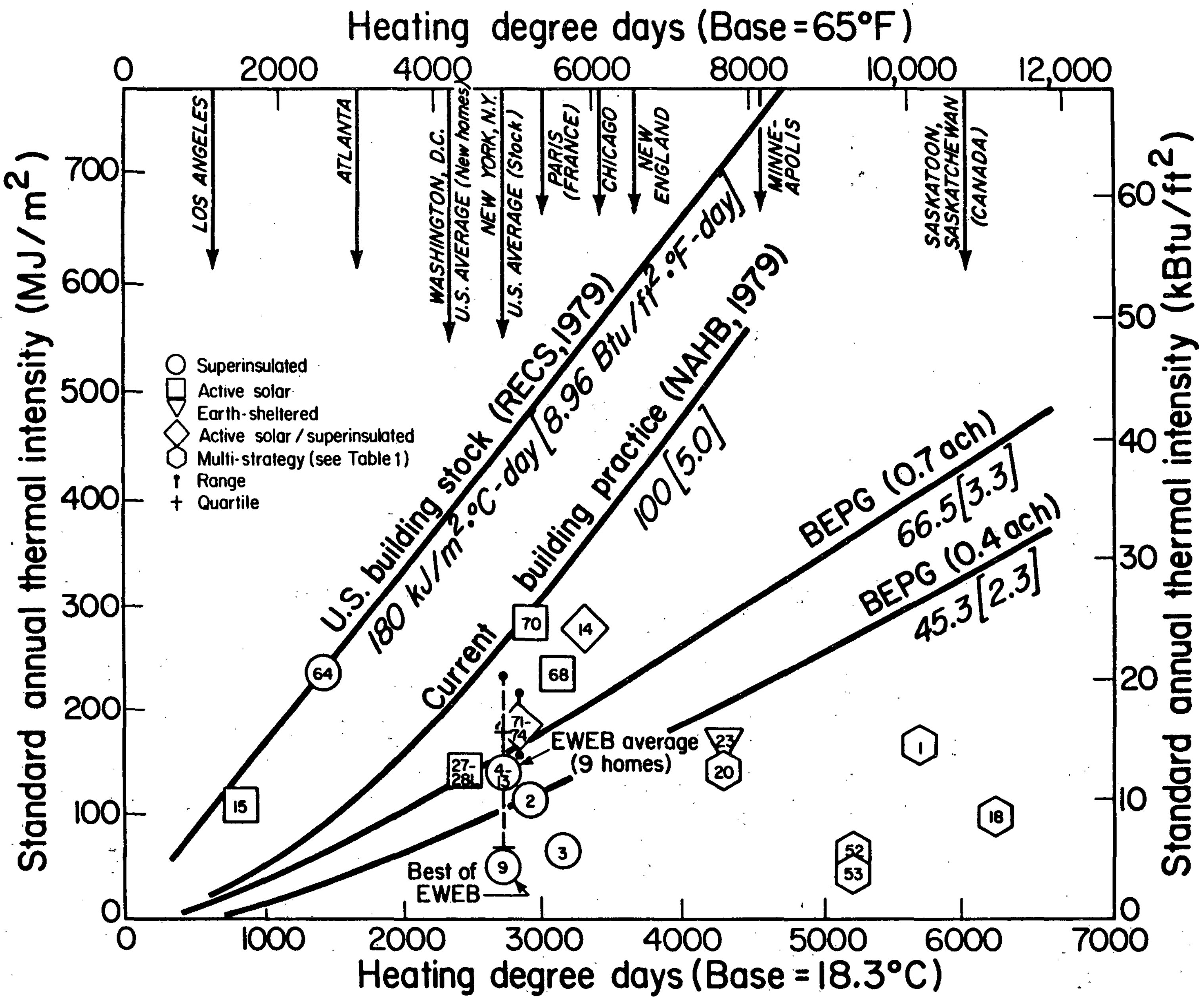

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Fig. 2. Thirty-seven home scatter plot of "standardized" thermal intensity vs. climate. The various comparison curves are defined in the text. The average thermal intensity per degree-day for our 37 homes is 50 kJ/(m^2-°C-day), or half of the current building practice.

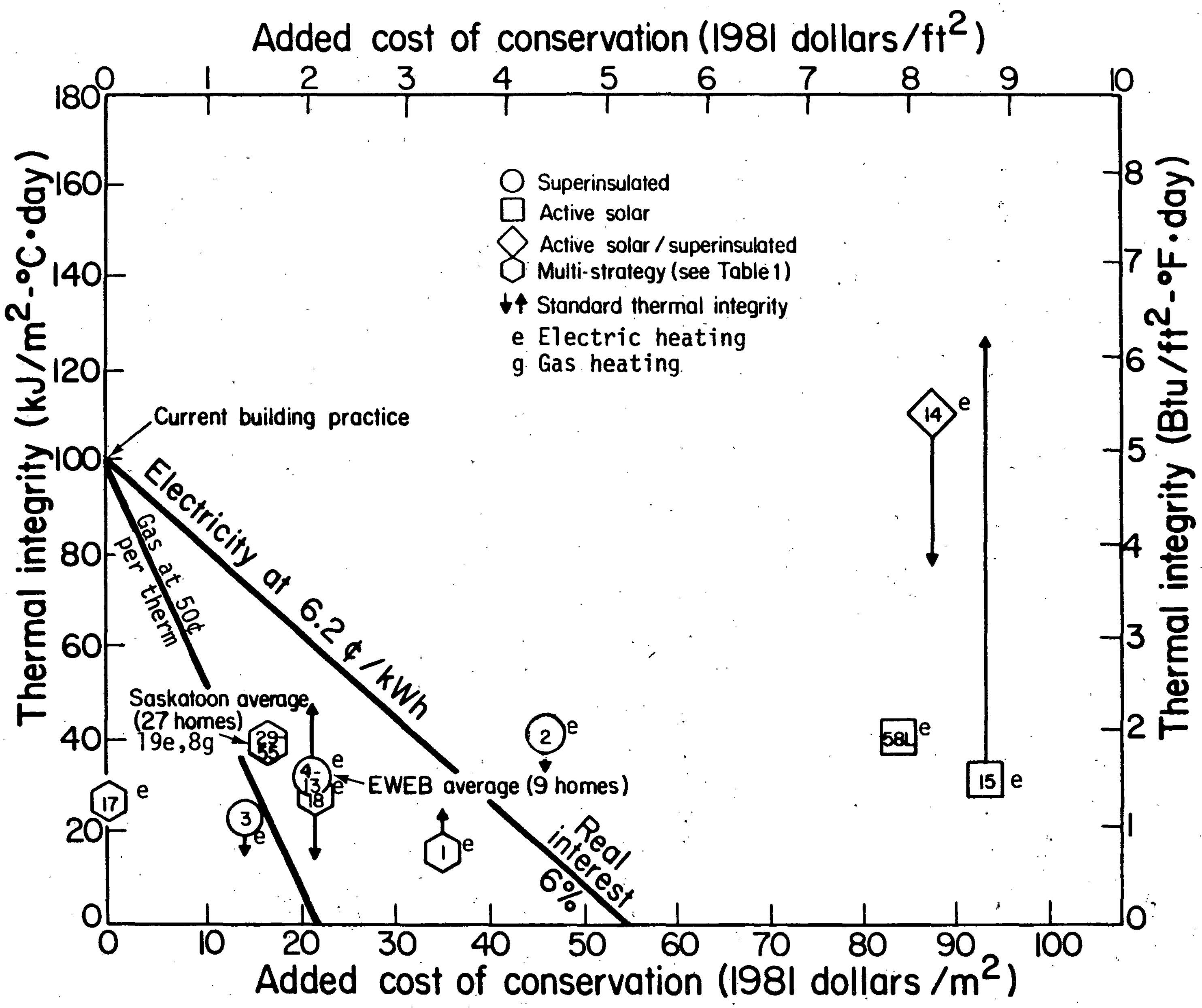

Fig. 3. Fifty-nine-home scatter plot of thermal integrity vs. added first cost per square meter of conservation-and-solar features. The heating loads of Fig. 1 and Fig. 2 (represented by the arrows) have been divided by floor area and degree-days. The point on the y-axis at 100 kJ/(m^2-°C-day) represents average U.S. current practice (see Fig. 2); the sloping lines descending from it are the boundaries of cost effectiveness for the 1981 average residential energy price of 6.2¢/kWh for electricity, and 50¢/therm for gas. Since conservation investments are typically "one-time," the future stream of energy savings for 30 years are converted to a single present value, assuming a 6% real interest rate (yielding a capital recovery rate of 7.25% per year). The home is cost effective if its point lies below the line in question.

7. ECONOMICS

Figure 2 shows thermal integrity versus additional cost of conservation per unit area for the 59 homes for which we have cost data. The sloping reference line represents the boundary of cost effectiveness against the 1981 average residential energy price for electricity at 6.2¢/kWh.[9] The slope was calculated as follows. Since conservation investments for new residential buildings are typically "one-time," the future stream of energy purchases for 30 years (the assumed time horizon of the houseowner) is converted to a single present value assuming a 6% real discount rate. The conservation measure is cost-effective if the data point lies below the purchased energy line.

Superinsulation and insulation with passive solar or earth-sheltering are the only generally cost-effective measures, with the cost of conserved energy well below 6.2¢/kWh. (In the construction of building 17, the builder offset the extra cost of insulation by savings on the heating system. The net cost of conservation was $0 in this particular house, since the load was so small that the builder replaced the central furnace with small resistance heaters.)

8. CONCLUSION

We have assembled data for 200 homes and have so far critically reviewed and entered 128 of these into our data base. Of these 128 homes 59 had data on additional first cost, and 37 were monitored in enough detail to standardize. We invite other researchers to contribute their data to further this research.

We have compared the 128 homes by building type, heating

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[9] Monthly Energy Review, May 1982, DOE/EIA-0035082/05.

performance, and added cost for conservation and solar measures. We found that active solar buildings used the most heating energy, 80 kJ/(m^2-°C-day) [3.9 Btu/(ft^2-°F-day)] and that those with superinsulation, or passive solar and superinsulation combined, consumed considerably less -- 39 [1.9] and 42 [2.1] respectively. Those homes with both low infiltration and superinsulation performed extremely well with an average thermal integrity of 30.6 [1.5]. We also observed that the superinsulated homes had the lowest cost of conserved energy, far below 6.2¢/kWh.

We have introduced a method to correct for occupant effects on heating energy performance measurements by substituting a standard internal gain and indoor temperature. We compare our standardized buildings with the BEPC, current building practice, and with U.S. building stock data. On a scale where U.S. building stock averages 180 kJ/(m^2-°C-day) [8.9 kJ/(ft^2-°F-day)], current practice is 100 [5.0], and BEPC are 66 [3.3] (high infiltration) and 45 [2.3] (low infiltration), solar and conservation homes average 50 [2.5] (ranging from 9.8 [0.5] to 160 [7.8]).

9. ACKNOWLEDGEMENTS

We would like to thank John Flaherty, Françoise Flouquet, Jeffrey Harris, John Ingersoll, Wolfgang Lührsen, Virginia Magnus, and Patricia Marraro for their assistance.

Table 1. Input Data

A	B	C	D	E	F FUEL/SYSTEM TYPE (SEE KEY)				G	H	I	J NO. OF GLAZINGS;	J-1	K	K-1	K-2	L	M	N	O	P
ID NO.	SITE NAME	LOCATION	NO. OF BLDG	NO. OF METERED UNIT PER BLDG	SPACE HEAT 1	SPACE HEAT 2	HOT WATER	COOLING	YR. BUILT	HEATED FLOOR AREA PER UNIT (m^2)	SOUTH GLAZ. AREA PER UNIT (m^2)	SOUTH	E,W,N	R-WALL (SI)	R-CEIL (SI)	R-FLOO (SI)	INFILTRATION (AC/H)	HOW INF. MEASURED (SEE KEY)	CONSERVATION MEASURES (SEE KEY)	ADDED COST OF CONS. 1981 $	NO. OF OCCUPANT PER UNIT
1	PASQUA	REGINA SA CANADA	1	1	ER		ER		803	247	8			7.0	9.2	1.8	.13		HI X	8637	4
2	HUD-EER I	MT. AIRY MD	1	1	ER	ER	ER	C	773	117	14	3	3	3.2	6.8		.19		I	5429	4
3	PHELPS	LERNA IL	1	1	ER		ER		794	160	3	3	3	6.9	8.9	5.3			I	2281	2
4	EWEB-A	EUGENE OR	1	1	EH		ER		773	107		2	2	3.4	6.8	3.4	.36	B	I	3454	2
5	EWEB-B	EUGENE OR	1	1	ER		ER		773	107		2	2	3.4	6.8	3.4	.30	B	I	1961	4
6	EWEB-C	EUGENE OR	1	1	ER		ER		773	102		2	2	3.4	6.8	3.4	.26	B	I	1866	5
7	EWEB-D	EUGENE OR	1	1	ER		ER		773	102		2	2	3.4	6.8	3.4	.21	B	I	1866	4
8	EWEB-E	EUGENE OR	1	1	ER		ER		773	107		2	2	3.4	6.8	3.4	.16	B	I	1968	2
9	EWEB-F	EUGENE OR	1	1	ER		ER		773	102		2	2	3.4	6.8	3.4	.12	B	I	1866	2
11	EWEB-H	EUGENE OR	1	1	ER		ER		773	83		2	2	3.4	6.8	3.4	.37	B	I	1527	1
12	EWEB-I	EUGENE OR	1	1	ER		ER		773	83		2	2	3.4	6.8	3.4	.30	B	I	1527	1
13	EWEB-J	EUGENE OR	1	1	EH		ER		773	133		2	2	3.4	6.8	3.4	.22	B	I	3936	2
14	ACORN	CONCORD MA	1	1	ER	EA	ER		753	130	9	1	1	2.3	3.4				A I	11333	0
15	LYNN-SDG+E	SAN DIEGO CA	1	1	ER	EA	ER	C	763	185		2	2	2.0	3.4				A	17311	5
17	LA VIGNE	CAMANO ISLAND WA	1	1	ER		EP		763	142	19	2		2.2	3.4				E IP	0	2
18	SASK.CONS	REGINA SA CANADA	1	1	ER	EA	ER		774	188	11	2	2	7.3	10.6		.60	T	A IP	4010	0
20	USC CAMDEN	CAMDEN STATE PARK MN	1	1	ER	EP	ER		793	167				3.6	4.5				EH		3
21	USC SEWARD	MINNEAPOLIS MN	1	1	ER		ER		793	98				2.7	3.6				E		1
23	USC WILLMA	WILLMAR MN	1	1	ER		ER		793	195				3.6	3.6	0.			E		3
24	CENTOFTE	CENTOFTE DENMARK	1	1	OB	EA	OB		783	133		2	2	1.3	1.7				A		4
25	CREVE	CREVE DENMARK	1	1	OB	EA	OB		783	108	16	3	3	3.7	3.4	2.5			A		4
26	FJARAS	FJARAS SWEDEN	1	1	ER	EA	ER		793	160	15	3	3	7.1	9.1	8.3	.20		AD I		3
27	BOURGOIN W	BOURGOIN FRANCE	1	6	ER	EA	ER		773	95		2	2	2.3	2.4	1.8			A		4
28	BOURGOIN E	BOURGOIN FRANCE	1	6	ER	EA	ER		773	95		2	2	2.3	2.4	1.8			A		4
29	SASK A1	SASKATOON SA CANADA	1	1	ER		ER		803	179				5.1	10.6	0.	1.70	B	IP	3412	1
30	SASK B1	SASKATOON SA CANADA	1	1	ER		ER		793	199				7.8	10.6	3.5	2.20	B	IP	4886	2
31	SASK B3	SASKATOON SA CANADA	1	1	GB		ER		793	300				7.9	10.6	0.	1.50	B	IP	4653	3
32	SASK B5	SASKATOON SA CANADA	1	1	GB		GB		793	306				7.0	12.3	1.3	.60	B	IP	4653	4
33	SASK B6	SASKATOON SA CANADA	1	1	ER		ER		783	287				7.0	10.6	5.3	1.00	B	IP	4037	4
34	SASK B7	SASKATOON SA CANADA	1	1	ER		ER		803	164				5.3	8.8	0.	2.20	B	IP	3412	2
35	SASK D1	SASKATOON SA CANADA	1	1	GB		GB		803	284				6.3	7.0	0.			IP	4265	2
36	SASK F1	SASKATOON SA CANADA	1	1	GB		GB		803	297				5.1	7.0	0.	1.60	B	IP	4265	3
37	SASK G2	SASKATOON SA CANADA	1	1	ER		ER		793	218				7.8	4.7	0.			IP	3722	3
38	SASK G3	SASKATOON SA CANADA	1	1	GB		GB		793	265		2	2	5.3	10.6	0.		B	IP	4653	2
39	SASK G4	SASKATOON SA CANADA	1	1	ER		ER		793	241				7.8	10.6	4.9			IP	3722	2
40	SASK G5	SASKATOON SA CANADA	1	1	ER		ER		793	297				7.0	10.6	1.8	1.40	B	IP	3722	2
41	SA H1 BEST	SASKATOON SA CANADA	1	1	ER		EP		793	225				5.3	8.8	0.	1.70	B	IP	3722	2
42	SASK K3	SASKATOON SA CANADA	1	1	ER		ER		803	210				5.3	8.8	0.			IP	3412	4
43	SASK L2	SASKATOON SA CANADA	1	1	ER		ER		783	163		2	2	6.3	10.6	0.			IP	4037	1
44	SASK L6	SASKATOON SA CANADA	1	1	GB		GB		803	226				5.3	8.8	0.	2.50	B	IP	4265	2
45	SASK R1	SASKATOON SA CANADA	1	1	GB		GB		793	217		2	2	4.8	7.0	0.			IP	4653	4
46	SASK S1	SASKATOON SA CANADA	1	1	ER		ER		793	167				6.4	10.6	3.5			IP	3722	1
47	SASK S2	SASKATOON SA CANADA	1	1	ER		ER		793	328				5.3	8.8	0.			IP	3722	4
48	SASK T1	SASKATOON SA CANADA	1	1	ER		ER		803	250				10.6	10.6	4.9	.80	B	IP	3412	1
49	SASK V1	SASKATOON SA CANADA	1	1	ER		ER		793	495				5.3	8.8	0.	2.50	B	IP	3722	2
50	SASK W1	SASKATOON SA CANADA	1	1	GB		GB		801	212				4.9					IP	4463	4
51	SASK W4	SASKATOON SA CANADA	1	1	ER		ER		783	242				7.8	10.6	0.	1.30	B	IP	4037	5
52	SASK AA2	SASKATOON SA CANADA	1	1	ER		ER		801	219				5.3	8.8	0.	2.30	B	IP	3570	0
53	SASK AA3	SASKATOON SA CANADA	1	1	ER		ER		793	200				5.3	8.8	0.	1.60	B	IP	3722	0
54	SASK AA4	SASKATOON SA CANADA	1	1	ER		ER		793	204				5.3	8.8	0.			IP	3722	4
55	SASK AA5	SASKATOON SA CANADA	1	1	ER		ER		793	200				5.3	8.8	0.	2.80	B	IP	3722	2
58	ROUSSET	MARSEILLE FRANCE	1	16	ER	EA	FP		766	91	0	1	1	1.8	1.7	1.6			A	7621	3
60	CARCASSONE	CARCASSONNE FRANCE	4	10	ER	EA	ER		773	90		1	1						A		3
61	LE HAVRE	LE HAVRE FRANCE	1	1	ER	A	ER		763	116									A		4
63	SUNCATCHER	DAVIS CA	1	1	GB		A	N	773	150	12	2	2	3.4	5.3		.75		P		3
64	ANSW-HOU-3	AUGUSTA CA	1	1	ER		ER	C	761	153		2	2	3.4	5.3	2.5			I		4
67	ARAMON	MONTPELLIER FRANCE	1	1	ER		ER		753	150									A		5
68	EINDHOVEN	EINDHOVEN NETHERLAND	1	1	GB	EA	GB		783	220	9	2	2	2.5	2.5	2.0			A		4
70	MILTON KEY	BRADVILLE ENGLAND	1	1	GB	EA	ER		743	85									A		3
71	ZOETERME 3	THE HAGUE NETHERLAND	1	1	GB	EA	ER		783	130	12	2	2	1.7	2.7	1.4	.60		A I		3
72	ZOETERME 4	THE HAGUE NETHERLAND	1	1	GB	EA	ER		783	130	12	2	2	1.7	2.7	1.4	.60		A I		2
73	ZOETERME10	THE HAGUE NETHERLAND	1	1	GB	EA	ER		783	130	12	2	2	1.7	2.7	1.4	.60		A I		2
74	ZOETERME 2	THE HAGUE NETHERLAND	1	1	GB	EA	ER		783	130	12	2	2	1.7	2.7	1.4	.60		A I		4
75	BRADVILLE	BRADVILLE ENGLAND	1	1	GB	EA	ER		743	85	8	1	1	1.2	1.8	.6	1.00		A		4

KEY FOR TABLE IS ON PAGE 18.

Table 2. Results

A	Q	R	S	T	U	U-1	U-2	V	V-1	V-2	W	X	Y	Z	A
ID NO.	-K-[a] (W/K)	NO. OF PO- INTS IN FIT	R SQU	BALANCE TEMP. T-SUB-B (C)	-AQ- ANNUAL HEATING LOAD (GJ)	THERMAL INTENS. (10^{6}J/ SQM)	THERMAL INTEG. (KJ/SQM DD-C)	-SAQ- STD. ANNUAL HEATING LOAD (GJ)	STD. THERMAL INTENS. (10^{6}J/ SQM)	STD. THERMAL INTEG. (KJ/SQM DD-C)	AVERAGE ANNUAL INTER- NAL FREE HEAT (GJ)	ANNUAL HEATING DEGREE- DAYS (18.3C)	DEFAULT VALUES (SEE KEY)	ANNUAL SOLAR RAD. (MJ/ SQM)	ID NO.
---	*****	****	***	*******	*******	*******	*******	*******	*******	*******	*******	*******	*********	------	---
1	88.8	8	.96	8.6	24.1	9.8	17.1	37.0	15.0	26.3	55.7	5700	L R	5100	1
2	111.6	8	.46	11.6	14.2	12.1	40.8	12.2	10.3	34.9	25.9	2953	V E		2
3	65.9	7	.84	12.7	11.1	6.9	21.4	8.1	5.1	15.7	26.9	3233	VRT		3
4	276.5	19	.49	9.4	13.9	13.0	46.4	19.5	18.1	64.9	41.7	2795	LVRTE I	4671	4
5	96.9	26	.84	14.1	13.2	12.3	43.8	22.4	20.9	74.6	42.1	2795	LVRT I	4671	5
6	90.2	18	.87	10.9	6.6	6.5	23.1	23.6	23.1	82.5	52.8	2795	LVRT I	4671	6
7	118.9	24	.80	11.6	10.3	10.1	36.1	13.7	13.4	47.8	35.3	2795	LVRT I	4671	7
8	71.0	8	.94	11.9	6.1	5.7	20.7	5.5	5.1	18.8	29.1	2734	P VRT	4671	8
9	48.8	7	.83	11.3	3.6	3.6	13.0	4.9	4.8	17.7	32.1	2734	P VRT	4671	9
11	80.3	8	.97	12.3	7.4	8.8	32.3	4.8	5.7	20.8	23.9	2734	P VRT	4671	11
12	100.7	9	.72	11.5	7.8	9.3	34.0	8.1	9.6	35.2	29.5	2734	P VRT	4671	12
13	184.0	5	.97	11.5	14.3	10.7	39.2	24.4	18.2	66.7	47.1	2734	P VRTE	4671	13
14	308.6	11	.91	11.0	48.0	36.9	109.3	34.7	26.7	79.0	0.	3379	LVRT	4579	14
15	161.5	7	.59	16.3	5.0	2.7	32.2	19.7	10.6	128.1	59.1	827	I	6857	15
17					11.1	7.8	26.9					2894		4370	17
18	105.6	6	.95	8.4	33.2	17.7	28.1	17.5	9.3	14.8	0.	6284	LVRT I	5100	18
20	165.4	4	.94	8.5	27.7	16.5	38.2	22.9	13.7	31.6	24.0	4332	PLVRT I	4851	20
21	156.5	5	.89	7.8	24.2	24.6	57.5					4283	P I	4851	21
23	168.7	4	.88	10.7	35.0	17.9	41.4	32.2	16.5	38.1	29.5	4332	PLVRT I	4851	23
24	307.4	24	.93	15.0	57.9	43.6	139.5					3122	E	3690	24
25	199.4	23	.84	11.9	31.5	29.2	83.3					3499	E	3690	25
26	111.7	12	.78	11.8	19.6	12.2	31.7					3855		3690	26
27	146.5	25	.78	15.2	21.7	22.7	91.9	13.6	14.3	57.8	14.7	2473	R	5041	27
28	131.7	26	.90	15.7	21.0	22.0	89.4	14.5	15.2	61.8	18.4	2461	R	5041	28
29					48.9	27.3	52.3					5216		5000	29
30					41.6	20.9	40.1					5216		5000	30
31					61.5	20.5	39.3					5216	E	5000	31
32					37.9	12.4	23.8					5216	E	5000	32
33					36.7	12.8	24.5					5216		5000	33
34					26.2	16.0	30.7					5216		5000	34
35					52.1	18.3	35.2					5216	E	5000	35
36					80.7	27.2	52.1					5216	E	5000	36
37					37.3	17.1	32.8					5216		5000	37
38					72.0	27.2	52.1					5216	E	5000	38
39					36.9	15.3	29.3					5216		5000	39
40					45.1	15.2	29.1					5216		5000	40
41					33.3	14.8	28.4					5216		5000	41
42					41.8	19.9	38.2					5216	P	5000	42
43					74.2	45.5	87.2					5216		5000	43
44					32.1	14.2	27.2					5216	E I	5000	44
45					64.9	29.9	57.3					5216	E	5000	45
46					43.9	26.3	50.4					5216		5000	46
47					68.9	21.0	40.3					5216		5000	47
48					39.8	15.9	30.5					5216		5000	48
49					76.2	15.4	29.5					5216		5000	49
50					42.3	20.0	38.2					5216	E	5000	50
51					45.7	18.9	36.2					5216		5000	51
52					48.0	21.9	42.0	14.3	6.5	12.5	1.8	5216	LVRT	5000	52
53					40.2	20.1	38.5	10.3	5.1	9.8	4.6	5216	LVRT	5000	53
54					35.3	17.3	33.2					5216		5000	54
55					38.0	19.0	36.4					5216		5000	55
58	59.2	8	.80	16.1	7.9	8.6	40.0					2151		5753	58
60	155.7	8	.93	16.9	23.1	25.4	124.6					2040		4296	60
61	280.3	8	.86	12.4	26.1	22.5	79.2					2838			61
63	185.1	8	.68	16.0	16.5	11.0	72.3					1518	P E	5562	63
64	195.0	7	.66	18.7	25.4	16.6	115.8	34.9	22.8	159.4	48.7	1429	LVRTE	5644	64
67	385.6	8	.89	14.4	29.7	19.8	111.3					1781			67
68	479.7	8	.55	10.8	42.8	19.5	62.1	51.9	23.6	75.3	51.7	3136	LVR E	3412	68
70	179.6	16	.76	10.6	15.7	18.4	63.5	23.9	28.2	97.0	44.3	2903	LVR E		70
71	240.9	9	.94	11.9	25.2	19.4	68.3	21.6	16.6	58.3	24.6	2844	L R E	3510	71
72	266.4	11	.94	13.3	34.9	26.8	94.9	28.2	21.7	76.6	19.6	2829	L R E	3510	72
73	365.5	8	.91	10.4	28.6	22.0	77.9					2829	E	3510	73
74	233.5	7	.92	11.8	21.8	16.7	66.2	20.1	15.5	61.3	27.8	2529	L R E	3510	74
75	90.2	12	.58	12.4	9.6	11.3	42.9	6.7	7.9	29.9	23.4	2635	R	3446	75

[a] For those homes where k could not be calculated, AQ and SAQ were calculated with an approximation method. See Ribot et al., "Monitored Superinsulated and Solar Houses in North America: A Compilation and Economic Analysis," PASSIVE '82, the National Passive Solar Conference, Knoxville, TN, September 1982.

KEY FOR TABLE IS ON PAGE 18.

Key to Table 1: Input Data

Column F: Fuel/System Type

space heat 1 = primary (purchased) space heating type and fuel
space heat 2 = secondary space heating type and fuel
hot water = fuel and type

fuel (first letter)	type (second letter)
G gas	B burner
O oil	H heat pump
E electricity	R resistance
	A active solar

cooling (if applicable)

C central
N other

Column M: How Infiltration Is Measured

B blower door
T tracer gas

Column N: Conservation Measures

A active solar
D double envelope
E earth-sheltered
H hybrid solar
I superinsulated
P passive solar
X air-to-air heat exchanger

Key to Table 2: Results

Column Y: Defaulted Values

P number of occupants
L water heater location
V water heater volume
R water heater insulation R-value
T water heater thermostat setting
E furnace efficiency
I inside temperature

(for default values see Appendix B)

Appendix A: Internal Gains

Internal gains, Q_I, are defined as the thermal energy generated inside the building shell other than that specifically for heating.

$$Q_I = Q_p + Q_a + Q_w$$

where

Q_p = gains from people,

Q_a = gains from appliances, and

Q_w = gains from water heating system.

1) People: Gains from people equal 7.6 MJ/person-day. This is 88 W per person, for 16 hours per day.[1]

2) Appliances: Q_A is equal to the total appliance energy consumption minus the dryer energy use. Dryer energy use is calculated as a function of the number of people.

$$Q_D = (3.6 \text{ MJ/person-day})(0.8) = 33 \text{ W/person}$$

where Q_D is dryer energy and 0.8 is average dryer efficiency.[2,3] Dryer energy is never counted as latent gains since any gains are lost via evaporation and infiltration.

3) Hot water: Gains from the water heating system are calculated from water heating energy consumption, tank volume, tank insulation,

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[1] Default value from Computerized Instrumented Residential Audit: CIRA. Lawrence Berkeley Laboratory Pub-442, Version 1.0, March 1982.

[2] Special run, Pacific Northwest Residential Survey (Washington, Oregon, Idaho and Montana only). Elrick and Lavidge, Inc., 1980.

[3] Though we have used 0.8 in our program, recent tests run at LBL have shown the latent load to be closer to 0.5. We will change the figure to 0.5 in the next edition of BECA-A.

tank location, set temperature, and heating type (i.e. gas or electric).

$$S = \left(\frac{1}{R_T + R_I}\right) \left(1.25V^{2/3}\right) \left(T_{set} - T_L\right),$$

where

S = standby losses,

R_T = average DHW tank R-value,

R_I = added tank insulation R-value,

V = volume (1.25 is a shape factor),

T_{set} = set temperature, and

T_L = location dependent room temperature (a function of outside or inside temperature depending on location).

$$Q_w = SL + 0.05(\eta_w E_w - SL) = 0.95\,SL - 0.05\eta_w E_w$$

where

L = location factor (fraction of standby losses which enter the conditioned space),[4]

E_w = water heater energy consumption,

η_w = efficiency (1.0 for electric, and 0.7 for gas).[5]

0.05 is the fraction of the energy which is assumed to enter the house via conduction from pipes and drains. No latent gains are included since they are only temporary (they are offset by evaporation into dry infiltrating air).

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[4] CIRA (see footnote 1).

[5] Clear, Robert D., and David B. Goldstein; "A Model for Water Heater Energy Consumption and Hot Water Use: Analysis of Survey and Test Data on Residential Hot Water Heating" (draft). LBL-10797, May 1980.

Appendix B: Defaults

1. (P) Number of occupants = 0.02 people/m^2. This was derived by dividing the U.S. population by the number of homes and by the average floor area of U.S. homes.

2. (L) Water heater location = living space.[1]

3. (V) Water heater volume = 150 liters = 40 gallons.[2]

4. (R) Water heater tank insulation $R_{SI} = 1.6$, $R_{British} = 9$.[3]

5. (T) Hot water set temperature = 60° C = 140° F.[4]

6. (E) Space heating efficiency, η_H: gas burner = 0.7 (assuming new furnaces in new homes).[5] Heat pump COPs are generated as a function of heating degree-days for each metered period.[6] Electric resistance η_H = 1.0.

7. (I) Inside temperature = 20° C = 68° F.[7]

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[1] CIRA (see footnote 1 of Appendix I).

[2] Clear and Goldstein (see footnote 5, Appendix I).

[3] Clear & Goldstein.

[4] CIRA.

[5] BEPS. Ingersoll *et al*. (see footnote 6 of main text, p. 10).

[6] DOE-2 simulations, private communication, John Ingersoll, LBL.

[7] CIRA.

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