LBL-36521
UC-1600

What is a Low-Energy House?*

Barbara R. Litt and Alan K. Meier

Lawrence Berkeley Laboratory
Energy & Environment Division
University of California
Berkeley, CA 94720

August 1994

---

* This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Technologies, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

What Is a Low-Energy House?

Barbara R. Litt and Alan K. Meier, Lawrence Berkeley Laboratory

Traditionally, a "low-energy" house has been one that used little energy for space heating. But space heating typically accounts for less than half of the energy used by new U.S. homes, and for low heating energy homes, space heating is often the third largest end use, behind water heating and appliances, and sometimes behind cooling. Low space heat alone cannot identify a low-energy house. To better understand the determinants of a low-energy house, we collected data on housing characteristics, incremental costs, and energy measurements from energy-efficient houses around the world and in a range of climates. We compare the energy required to provide thermal comfort as well as water heating, and other appliances.

We do not have a single definition of a low-energy house, but through comparisons of actual buildings, we show how different definitions and quantitative indicators fail. In comparing the energy use of whole houses, weather normalization can be important, but for cases in which heating or cooling energy is surpassed by other end uses, other normalization methods must be used.

Introduction

Most people view low-energy houses as good things, yet differ greatly in their definitions of what exactly a low energy house is. Traditionally, a low-energy house implied a home with low space heating. However, as building practices have improved, space heating energy use has dropped—sometimes to as low as the third largest end use—in new homes located in cold climates. At the same time, energy use for cooling has increased as more homes have become air conditioned and more homes are built in the warmer climates. Clearly, equating low-energy with low-space heating will not apply to a home in Miami or San Diego just as equating low-energy with low-cooling will not apply in Manitoba. Other end uses, such as water heating, can be the largest regardless of the climate.

The absence of a consistent definition of "low energy" is an important issue because policies, at many different levels, have been created to encourage construction of low-energy houses. Some of these policies include

- building energy efficiency standards
- appliance efficiency standards
- home energy rating systems
- utility DSM programs
- single-technology tax credits, subsidies, or incentives
- utility bill leveling options
- rate structures that increase above a baseline usage

Without a consistent understanding of what a low-energy house is the combination of these policies may be unsuccessful or, worse, even counter-productive.

A second need for a consistent definition of low-energy houses arises when comparing energy use of different buildings. These comparisons are useful in identifying technical or design features that result in decreased energy use. Without a definition, it is impossible to conclude that one building or technology is energetically or economically superior to the other. A particularly challenging aspect of the definition is the treatment of buildings whose energy is supplied completely from renewable sources (e.g. photovoltaic). Such homes can now offer virtually the same level of amenities (lighting, refrigeration, heating) as those connected to the grid, albeit at greater first cost. Are these "zero-energy" homes or something in between?

The objective of this paper is to present the elements of a low-energy definition and apply them to actual homes. These homes are part of a DOE-sponsored compilation of new, low-energy houses. Since the goal of the compilation is to identify and assess the performance of low-energy houses, clearly a robust definition is needed.

Every Actor Views Low Energy Differently

A surprisingly large number of actors are involved in increasing residential energy efficiency. Most (but by no means all) have similar objectives, but they differ on the methods to achieve them or the constraints put upon their methods. For example, the objective of building standards is to create a low-energy house through prescriptive insulation levels, because this is often the only energy aspect addressed by them. Similarly, the federal appliance standards seek to improve the air conditioner's efficiency but not the level of insulation or the thermostat. Thus, from their perspective, the low-energy house is one with high-efficiency appliances. A home energy rating system focuses on the low-energy features that can be easily recognized by even a poorly-trained auditor. Thus, some energy-rated low-energy houses are those containing items that fit on a checklist. But home energy rating systems are evolving and the National Energy Policy Act of 1992 requirements for them apparently would not allow a checklist system. Table 1 illustrates the diversity of other actors and their interests.

It is useful to review existing definitions currently in use by these various actors. Most of them do not actually define the term. Utility programs, some raters, and some lenders do have explicit definitions, because such definitions are inputs to rebate decisions, ratings, and loan calculations. Building scientists and architects usually do not, but often implicit definitions are evident in their writings.

Utility DSM programs are good sources of practical definitions, since the programs must determine which houses qualify for incentives. Some programs label a new house efficient if simulations show that it should use less than a certain percentage of the maximum energy budget allowed by code. Other programs accept the house based on the presence of components and systems that are more efficient than those used in standard construction. Another approach is to provide explicit heating and cooling budgets which must be met. Usually these take into account the building size and climate zone.

Researchers often frame their goals for new energy-efficient demonstration houses in terms of building a house that uses a small fraction of the energy consumed by a typical house. Usually they focus on the house's energy intensity rather than absolute energy consumed, so the energy use is normalized by living area. A fifty percent reduction is a popular goal. For example, a Canadian program aimed to build demonstration houses using less than half of the total purchased energy that new houses meeting the R-2000 program requirements would use (CANMET undated). A California utility's demonstration program requires that a house's total predicted energy use is 50% less than that mandated under California's energy code (PG&E 1992). Even more ambitious projects aim for a 75% reduction in total energy use, or zero purchased energy used for heating.

Strictly speaking, it is possible to build houses that use no purchased energy. An alternative definition could be based on how close a house and its occupants come to using completely renewable energy, generated at the site. While such a definition could apply to low-energy homes, obviously this would be only one of many criteria used to decide whether the house was environmentally friendly.

These definitions ignore interests of some actors and oppose those of others. Focusing on efficiency rather than absolute energy use ignores environmentalist and forecaster concerns. None of the definitions mention cost-effectiveness. Stating goals in terms of a fixed percentage decrease seems arbitrary. Why not aim for a 55% decrease? Labeling a house "low-energy" because it includes several more efficient components gives builders little incentive to include additional conservation measures which are cost-effective but invisible. Also it fails to take account of synergisms, that is, possible increases in efficiency or decreases in costs due to interactions between a building's systems (Lovins and Lovins 1991). We have seen such effects in houses in our compilation. For example, superinsulated houses can now be built for effectively the same cost as conventional houses (Andrews 1994). The added costs of extra insulation, sealing, and low-emissivity windows are offset by eliminating ductwork and downsizing heating and cooling equipment. An analytical framework that gives credit for this kind of comprehensive approach is needed.

To illustrate these problems, we created three generic definitions, to be applied to a sample of houses from the USDOE's ongoing compilation of measured performance data for recently built, new, low-energy houses. These generic definitions are (1) meeting or exceeding a fixed percentage reduction from a baseline energy intensity, (2) presence of required conservation measures, and (3) absolute purchased energy use below a maximum. The baseline for type 1 or maximum for type 3 could be with respect to either measured energy used in new conventional homes or simulated consumption for a conventional prototype house. Within each of these categories, what qualifies will depend on whether site energy or primary energy is considered. In practice, the baseline energy intensity and the list of conservation measures required for the first two definitions should be determined locally, and we do not yet have sufficient local baseline data. We do know that at least one of the rammed earth houses in the compilation did not qualify for a rebate because its

Table 1. Differing Perspectiveness About a Low-Energy House

Actor	Interests	Implications for Definition
Occupant	Amenities; quality construction; resale value; affordable; low utility bills; sustainable use of resources	Don't trade off services for low energy use
Builder	Profit; differentiation from other builders; provide a quality product; keep incremental costs down; lower operating costs can increase low income demand for housing; public opinion; no call backs	Consider incremental costs; should not be too easy, nor too difficult for a house to qualify
Utility DSM Program Manager	Avoid need for new generating capacity; provide service at an acceptable cost; cost-effective for the utility; recover revenue losses due to decreased sales	Consider time of use; address energy provided by the utility; include credit for load shifting; should be verifiable
Rater (HERS)	Energy saving technologies must be simple to assess; keep cost of rating down; context is real estate transactions	Focus on the house, eliminating occupant influence
Lender (EEM)	Reduce defaults; accuracy and reliability of energy ratings; increase the number of people who can qualify for a loan; context is real estate transactions	Consider the predictability of actual energy savings, including occupant influence
Community	Location and appearance of new development; use of public services; compliance with codes and zoning	Consider not just the structure, but its place within the community
Environmentalist	Decrease environmental damage (e.g., greenhouse gas emissions, acid rain, damming of rivers, nuclear waste and risk of accidents); maximal savings; sustainable (i.e. 100% renewable) energy	Not just low-energy, but "green" buildings; renewable energy is OK; not just the house, but its occupants and their lifestyle; consider transportation energy
Advocate for the Poor	Low operating costs; low first costs; equity implications	Include houses affordable by low-income people
Health Regulator	Healthy indoor environment	Include indoor air standards
Politician	Avoid making enemies while appearing proactive	Fuel neutrality; don't antagonize the construction industry
Government Forecaster	Future patterns of energy use and greenhouse gas emissions; international commitments to cut emissions	Consider fuel mix, source of electricity, and choice of materials
Architect	Aesthetics; good design; energy not a major consideration	Consider whole house as a system
Building Scientist	Individual technologies; monitored consumption	"If it isn't monitored, then it wasn't used."
Social Scientist	Interaction of occupants, technologies, and society	Consider occupants, and larger societal implications

construction so radically differed from the norm. Only the third definition can be easily applied to a national or international sample of houses in a broad range of climates.

Compilation Methodology

We are compiling performance data for recently built houses around the world which were explicitly intended by their designers to be low-energy homes. The project is partly a replication of the DOE's original compilation done in the early 1980s (Rosenfeld et al. 1981, Busch and Meier 1986), using houses built from 1987 on. The goals are to identify and assess the performance of low-energy houses, and to assess progress in building low-energy homes since the previous compilation. We compile monitored data for energy performance (submetered when available), outdoor temperatures, housing characteristics such as living area and use of various appliances, energy design strategy and specific measures used, occupancy, thermostat settings, and incremental costs. Few houses have data available for all categories. We identify houses through journal and trade articles, reports (CANMET 1993), phone interviews with many actors shown in Table 1, and personal contacts. We then obtain energy consumption data from primary sources. At present, we have data for more than 50 houses, and are actively seeking more.

There are many types of houses in the compilation. Some have been built as research and demonstration projects, some custom designed and built but not studied, and others effectively mass produced for relatively high volume sales. Single-family detached, duplexes, townhouses, and multifamily buildings are included. At present there are no manufactured houses but we intend to include them soon. Similarly, there are no off-the-grid houses now, but we would like to include some in the future. All houses have been occupied as a primary residence for at least one year for which we can obtain consumption data. For houses which have not been studied, we ask the occupants to fill out a questionnaire specifically designed for this project. We then cross check responses with the builder. So far there has been good correspondence between people's responses and what the builder claims to have built.

Given the heterogeneity of housing types and available data, we use a wide variety of analytical methods to compare houses. For houses with whole house utility bills only we use PRISM (Fels 1986) to calculate the normalized annual consumption (NAC), slope, and intercept. Many houses use gas heat and electric central air conditioning, so separate parameters can be calculated for heating- and cooling-dominated consumption. The use of energy signature models such as PRISM on houses with significant passive solar gains can be problematic (Flouquet 1992), but it may be the best method of weather normalization available for such limited input data. While the physical interpretation of the slope and intercept should not be taken too far (Minehart and Meier 1994), the NAC is robust. For houses with submetering we also apply PRISM, but the slope and intercept parameters have more physical relevance. If besides submetering we also have information on thermostat settings and internal gains then we apply SUBMET (Meier et al. 1988, Meier and Nordman 1988) to obtain normalized annual heating and cooling energy use.

Methods such as PRISM and SUBMET are helpful in comparing energy required to maintain thermal comfort in different climates. But if a goal of the compilation is to compare whole house energy use, major issues of aggregation and disaggregation arise. To compare thermal performance of houses of different sizes, in different climates, with different occupants, normalization must be done. If we broaden the focus from space conditioning to total energy use, then how and what to normalize become less clear. For example, for comparative purposes water heating energy use is more appropriately normalized by number of occupants (and perhaps by water temperature) than by degree days and/or living area. The question of what kind of normalizations are "fair" also arises. In particular, how or whether to normalize energy used for special amenities such as pools or hot tubs is unclear but non-trivial. For example, the hot tub in house H used 870 kWh in one year—almost as much as the refrigerator.

There are several possible approaches to comparing whole houses. The first is to consider disparate uses of energy separately, and to normalize each of them by the level of service provided. A second approach is to determine which end-use is dominant, calculate a normalized consumption for that component, and add the remaining consumption without normalization, to come up with an effective NAC. A third approach, applicable to houses without submetering, is that of PRISM, which normalizes not only heating (or cooling) energy by degree-days but also other energy use which is correlated with outdoor temperature variations (e.g., lighting) regardless of whether the correlation is due to a causal relationship (Fels et al. 1986). Finally, one can completely ignore normalization and simply compare monitored data.

Example Houses

The variety of houses and types of data in the compilation are illustrated in Figure 1. Most of these houses are actually hybrids, rather than relying on a single energy design strategy. Two broad categories of data availability are apparent—houses without submetering for which we

House	Whole-House		Sub-metered	Incremental Costs	Occupancy	Amenity Levels	Indoor Air Quality
	Elect.	Other					
A	✓	✓			✓	✓	
B	✓	✓			✓	✓	
C	✓	✓			✓	✓	
D	✓	✓			✓	✓	
E	✓	✓		✓	✓		
F	✓	✓		✓		✓	
G	✓	✓		✓			
H	✓		✓				✓
I	✓		✓			✓	✓
J	✓		✓				
K	✓		✓	✓		✓	
L	✓		✓	✓		✓	✓
M	✓				✓	✓	
N	✓	✓	✓			✓	✓

A. 7 superinsulated and passive solar single-family houses (suburban Chicago, Illinois)
B. 6 superinsulated single-family houses (suburban Chicago, Illinois)
C. 5 superinsulated duplexes (Hanover Park, Illinois)
D. 3 superinsulated townhouses (Aurora, Illinois)
E. 19 superinsulated low-rise 15- or 24-plex apartment buildings with efficient appliances, each building master metered (West Des Moines, Iowa)
F. Completely passive solar hydronically heated earth-bermed house with efficient appliances (Caspar, California)
G. Passive and active solar-assisted superinsulated house with efficient appliances (Tallahassee, Florida)
H. Superinsulated passively shaded house with a ground-coupled heat pump and efficient appliances (Tampa, Florida)
I. Superinsulated passive solar house with an integrated mechanical system and efficient appliances (Brampton, Ontario)
J. Superinsulated all-electric house with load leveling (Sapporo, Japan)
K. Superinsulated house with a heat pump (Halifax, Nova Scotia)
L. Low-heating-energy passive solar superinsulated duplex with seasonal hot water storage and waste heat recovery from water and air (Waedenswil, Switzerland)
M. 5 rammed earth passive solar houses, some with active solar water heating (Tucson, Arizona)
N. Superinsulated house with oil central hot water radiant panel heating system (Sendai, Japan)

Figure 1. Data Available for Example Houses

have information about the occupants' use of the house, and houses with submetering for which we know little about the occupants.

Houses A, B, C, D, and M were built simply to be lived in, and were not studied prior to this compilation. We know the number of occupants, when they took long vacations, activities expected to influence energy use, and their impressions and concerns about their houses. Such information is helpful in removing unoccupied periods from the data analysis.

Houses H, I, K, L, and N are research and demonstration houses, with extensive submetering. House J is not submetered in the normal sense of the term, but the residents use three different prices of electricity, regular, nighttime, and snow-melting, although not all the "snow-melting" electricity is used for that purpose (Kudo 1993). Most of these houses are all electric. For these houses we have not had direct contact with the occupants, and have generally not had access to the same kinds of information collected with our questionnaire.

Tables 2 and 3 illustrate the influence of different normalization methods on the outcome of energy intensity calculations. Note that we have not normalized for the effect of different climates. Houses F and L use relatively little energy so they perform well regardless of the normalization framework (although House F might compare less favorably if climate were addressed). The two Japanese

Table 2. Comparison of Annual Energy Use and Selected Normalizations

House[a]	Living Area (m^2)	Electricity (kWh)	Other	Site Energy (GJ)	Site Energy (MJ/m^2)	Primary Energy (GJ)	Primary Energy (MJ/m^2)
A (7)	280	9235	104[b]	140	550	200	830
B (6)	204	6947	102[b]	130	670	180	970
C (5)	147	5970	34.7[b]	100	740	150	1000
D (3)	110	6358	46.9[b]	70	640	120	1100
E (19)	1822	17670	617[b]	680	370	810	450
F	374	3761	10.9[c]	24	65	52	140
G	140	2488	30.5[c]	39	280	58	410
H	204	12700	0[d]	46	220	140	680
I	408	18129	6.1[e]	71	180	200	530
J	136	13284	0[d]	48	350	130	920
K	213	23045	0[d]	83	390	250	1200
L	150	2500	4.5[e]	14	88	32	210
M (2)	188	11215	missing wood	40	210	120	640
N	165	3483	31.7	44	270	70	420

---

a. The number of buildings included in the values is shown in parentheses, unless it is a single building.
b. Natural gas
c. Propane
d. All electric houses
e. Wood

houses and the efficient apartments use the least energy per person. Not surprisingly, houses for which only space heating energy was targeted (for example A, B, C, D, and K) tend to perform less well in this total energy comparison.

We have used energy performance indicators arising from various perspectives shown in Table 1 to rank these houses. Each indicator is subdivided into two categories, one considering site energy, and one primary energy. The focus on site energy favors electric heat over gas and is consistent with builder concerns since it allows them to install less expensive electric resistance heating. The focus on primary energy is more consistent with environmental interests. The focus on total energy use addresses environmental concerns about sustainability. Energy per unit area is consistent with builder concerns because it allows them to build bigger houses and helps consumers of those houses feel good. Normalization by the number of occupants allows a focus on broader issues of equity. As expected, which houses are ranked highest (and lowest) depend on which definitions we use.

Discussion

Although cost-effectiveness of energy-efficiency measures is a key concern for many actors, data regarding incremental costs are not available for many houses. Even when researchers or builders provide such data, they cannot be taken at face value. Often only capital costs are considered. Many design features do not require more capital but require attention to design, for example proper placement of windows. What is the cost of putting a window on the south side rather than somewhere else? An action may cost no more in building materials, but it requires planning. This type of expense is not captured by the incremental cost framework. The value of experience is also left out of the incremental cost framework. It has taken some builders many years of on-the-job learning to be able to scale up production of superinsulated houses, so

Table 3. Ranking of Example Houses According to Different Definitions

	Total Energy		Energy per Unit Area		Energy per Person	
Rank	Site	Primary	Site	Primary	Site	Primary
1	L	L	F	F	L	L
2	F	F	L	L	J	N
3	G	G	I	G	N	E
4	N	N	H	N	F	G
5	H	D	N	E	G	J
6	J	J	G	I	E	F
7	D	H	J	H	H	D
8	I	C	E	A	I	B
9	K	B	K	J	D	C
10	C	I	A	B	B	H
11	B	A	D	C	K	I
12	A	K	B	D	C	A
13			C	K	A	K

if a builder without the experience tried to duplicate the design, the incremental cost data would greatly underestimate the actual cost. In other cases it is possible to obtain data on the total cost of construction, but difficult to determine what baseline costs to subtract. Houses for which the incremental cost data can be considered accurate are houses that are not very different from conventional ones, with an energy-efficient upgrade here and there. In the examples above, K is the only house which fits this profile, and that only because the R-2000 construction methods have nearly become standard practice in Canada (Sinha et al. 1993).

Once the focus broadens from space conditioning to total energy use, many other questions arise, such as whether we can adequately describe a house without reference to its occupants, whether we should include embodied energy, and whether we should consider use of other resources besides energy. Answers to these questions differ, depending on the reasons that energy efficiency, or indeed, the comparative analysis, is desired.

Conclusions

Many financial and institutional incentives exist or are being proposed to encourage the construction of low-energy houses. However, the definitions of low-energy are often implicit or incomplete. No single definition of a low energy house will be universally applicable. We have demonstrated that different—but reasonable—definitions can yield very different energy rankings. The core of any ranking scheme is an energy normalization procedure. We proposed several normalization procedures to enable comparisons among houses. No procedure is entirely suitable, but we favor normalizing a house's largest end use (typically space heating in the north and cooling in the south). As we compile more examples of low-energy houses, we will refine our normalization procedures while documenting the actual performance of these houses.

Acknowledgments

People who contributed or made it possible for us to collect data for the houses discussed above are gratefully acknowledged here: Cynthia Cocchi (Bigelow Homes), Keith Denner (Professional Property Management), Stephen Heckeroth (Homestead Enterprises), Danny Parker (Florida Solar Energy Center), Frank Varnedoe, John Putnam (Tampa Electric Company), Masatoshi Kudo (Tsuchiya Twoby Home Company), Ismet Ugarsal (Technical University of Nova Scotia), Peter Suter (ETH Zürich), Tom Wuelpern and Anne Helwig (Rammed Earth

Solar Homes) and Hiroshi Yoshino (Tohoku University). Brian Pon of Lawrence Berkeley Laboratory provided invaluable help with many telephone calls, and Bill Golove provided helpful comments. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

Andrews, S. 1994. "Perry Bigelow: Energy Efficiency Maestro." *Home Energy*, 11(2):13-18.

Busch, J.F., and A.K. Meier. 1986. *Monitored Performance of New, Low-Energy Homes: Updated Results from the BECA-A Data Base*. LBL-18306, Lawrence Berkeley Laboratory, Berkeley, California.

CANMET (Canada Centre for Mineral and Energy Technology). 1993. *Comparison Analysis Report on Advanced Houses Around the World*. Energy, Mines and Resources Canada, Ottawa, Ontario.

CANMET. Undated. "Technical Requirements for Advanced Houses." Brochure of the Advanced Houses Program, Energy, Mines and Resources Canada, Ottawa, Ontario.

Fels, M.F. 1986. "PRISM: An Introduction." *Energy and Buildings*, 9(1):5-18.

Fels, M.F., J. Rachlin, and R.H. Socolow. 1986. "Seasonality of Non-heating Consumption and Its Effect on PRISM Results." *Energy and Buildings*, 9(1):139-148.

Flouquet, F. 1992. "Local Weather Correlations and Bias in Building Parameter Estimates from Energy-Signature Models." *Energy and Buildings*, 19(2):113-123.

Kudo, M. 1993. "Japan Two by Four Architecture Association President's Prize: Sumiya House." *Institute of Building Energy Conservation*, 14-1(76):34-37. (in Japanese)

Lovins, A.B., and L.H. Lovins. 1991. "Least-Cost Climatic Stabilization." *Annual Review of Energy and the Environment*, 16:433-531.

Meier, A.K., J.F. Busch, and C.C. Conner. 1988. "Testing the Accuracy of a Measurement-based Building Energy Model with Synthetic Data." *Energy and Buildings*, 12(1):77-82.

Meier, A.K., and B. Nordman. 1988. "A Thermal Analysis of the Model Conservation Standards for New Homes in the Pacific Northwest U.S.A." *Energy*, 13(11):833-844.

Minehart, D.L., and A.K. Meier. 1994. "Using Synthetic Data to Explore the Usefulness of PRISM's Parameters at Inferring Causes of Changes in Normalized Annual Consumption." *Energy*, 19(2):135-148.

PG&E (Pacific Gas and Electric). 1992. "New Construction: EnergyWise Showcase Home Program." Brochure, San Francisco, California.

Rosenfeld, A.H., W.G. Colborne, C.D. Hollowell, S.P. Meyers, L.P. Schipper, B. Adamson, B. Hidemark, H. Ross, N. Milbank, M.J. Uyttenbroeck, and G. Olive. 1981. "Building energy use compilation and analysis (BECA): An international comparison and critical review." *Energy and Buildings*, 3(4):315-332.

Sinha, R., K. Cooper, W. Mayhew, and B. Sibbit. 1993. "Results of Level B Monitoring of Seven R-2000 Houses." *Proceedings of the 1993 Conference on Innovative Housing*, in press.