Energy and Buildings, 8 (1985) 291 - 294

Research Communication

Measuring The Energy Efficiency of Manufactured Homes

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(Received November 6, 1985)

BACKGROUND

The Lawrence Berkeley Laboratory is attempting to broaden the scope of the Building Energy-Use Compilation and Analysis (BECA) data bases to include measured energy performance of new and retrofitted manufactured homes [1]. Progress has been limited by the scarcity of good data.

Even though manufactured homes represent only 7% of the existing U.S. housing stock, new additions in 1983 numbered nearly 440 000, or 29% of all new single-family housing starts. Judging by purchase price, mobile homes (2/3 of manufactured home starts) represent a large fraction of 'affordable' new housing, yet energy consumption is higher and their occupants pay over $3.5 billion in annual energy bills. Average annual energy intensity is 1043 MJ/m^2, compared with 830 MJ/m^2 for site-built homes [2]. In addition, energy prices are often higher (due in part to greater reliance on electricity and liquid propane gas) than those paid by occupants of site-built homes. Survey data show that many mobile homes are located in the South and have a higher saturation of electric appliances than site-built homes. This may make energy used for cooling and water heating a more significant fraction of total energy consumption for mobile homes.

There are several reasons why it is important to focus on manufactured housing as a subsector distinct from site-built single-family homes. Thermal construction characteristics are regulated by an independent federal standard; industry and prospective buyers are especially cost-sensitive, and hence less likely to accept the added cost of efficiency improvements; and construction details often differ from those of site-built homes. In the U.S., mobile homes are built to a Department of Housing and Urban Development (HUD) thermal code which preempts local building codes. Site-assembled manufactured homes (panelized, modular, precut) must meet local codes.

The 1977 HUD thermal standards designate only two climate design zones in the continental U.S., and require minimum ceiling resistances of only 2.5 m^2 °C/W, wall resistances of 1.9 m^2 °C/W, and storm windows or fixed dual glazing in the colder zone. Two previous studies found that this lack of climate specificity in the standards can cause heating and cooling system sizing errors and the selection of suboptimal levels of insulation [3, 4]. Important energy-related technical issues include the effect of highway transport on shell integrity and ductwork, high surface area-to-volume ratios, extensive thermal bridging, insulation compression, appliance specification, and difficulty incorporating thermal mass (weight and cost constraints).

Another energy-related construction issue is indoor air quality. Limited field data suggest that recommended safety levels are sometimes exceeded [5, 6]. A recent revision to the HUD code sets maximum allowable formaldehyde emission rates for sheathing materials. Yet, while this may alleviate the formaldehyde problem in new homes, conditions in the 4 million existing homes will be unaffected.

Energy performance in manufactured homes is poorly understood. Extensive energy-use simulation studies have been conducted, yet little has been done to compare them to actual energy performance data [7, 8]. As a result, it is difficult for policy makers to assess the condition of the existing stock or the potential for efficiency improvements in new homes. The Bonneville Power Administration (BPA), for example, has excluded HUD-code homes from its planned Model Conservation Standards (MCS) and from

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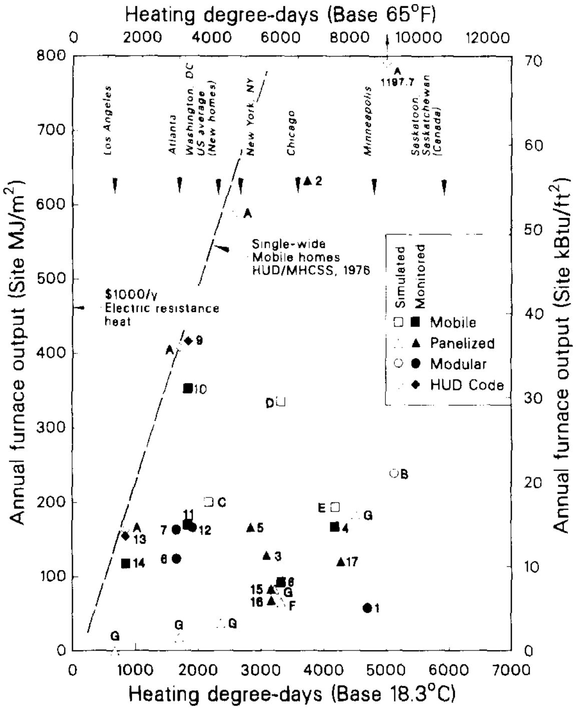

Fig. 1. Monitored and simulated annual furnace output versus heating degree-days (base 18.3 °C). Energy is counted as heat *delivered* by the heating equipment in order to normalize for heating system efficiencies. The symbols differentiate between building type. The results for 40 monitored homes (17 numbered data points) show the potential for savings when compared with simulations of homes built to HUD standards for mobile homes (points labeled "A"). Findings from various simulation studies are presented in 14 additional lettered data points. Of the measured buildings, the best home (point 1) uses only 12 kJ(m^2 °C-day) annually while standard practice for mobile home construction is roughly 230 kJ/(m^2 °C-day). Energy use is normalized to floor area but variations in operating conditions are not adjusted for. An annual operating cost benchmark of $1000 is given, based on 100 m^2 floor area and electric resistance heat at $0.08/kWh. Descriptions of each home are provided in Table I.

eligibility for retrofit assistance. In both cases BPA lacks adequate field data to formulate an energy policy.

MEASURED DATA

We have compiled heating energy use data for 40 energy-efficient manufactured homes built in the U.S. and abroad to compare them with each other and to standard practice (Fig. 1). We have separated the buildings into classes of mobile, modular, and panelized homes to distinguish among the respective construction types and standards. As a group the most successful house uses only 12 kJ/(m^2 °C-day), versus 230 kJ/(m^2 °C-day) for homes built to meet the HUD code. The efficient homes use superinsulation (points 1 and G), solar (points 2 - 7, 12, B, C, and D) or zone-heating techniques (points 15 and 16) to achieve the energy savings. Points 9 - 11, 13, and 14 provide an opportunity to compare HUD-code homes with more highly insulated counterparts at the same site and under similar experimental conditions — annual heating savings range from 25 - 60%.

We have identified only one study of pre- and post-retrofit energy use in manufactured homes [9]. The small sample of 35 homes allows no general conclusions but we note that they received different measures and saved less energy at a greater cost than site-built homes treated in the same retrofit project.

PROSPECTS

Despite the lack of good data there is evidence that the energy efficiency of manufactured housing can be improved with the existing industry framework. For example, the least energy-intensive home in Fig. 1 (point 1) is the manufacturer's *standard* model and includes triple glazing, high insulation levels, and an air-to-air heat exchanger.

Innovative construction methods from abroad include masonite web "I-beams" for wall and roof framing from Sweden [10], which nearly eliminate thermal bridging, and lightweight sintered ceramic walls with high thermal resistance from Japan. Unfortunately, energy use data from these countries is either inadequate or unavailable. In Sweden, energy consumption is ordinarily tabulated on an annual basis (not monthly), space heating is rarely submetered, and indoor temperature measurements are normally unavailable. The Japanese claim that their new construction materials increase a building's efficiency, yet they provide no documentation. The most thorough experiments have been conducted by U.S. manufacturers designing and building marketable and efficient homes (points B - F in Fig. 1) [11]. Although these buildings have been instrumented for a heating season or more,

TABLE 1

Descriptions of monitored and simulated manufactured homes*

ID	Project Name	Bldg. Type	Location	No. Of Bldg.	SH Fuel	Cond. Floor Area (m²)	South Glaz. Area (m²)	NR. Glazings (SI)	R-Wall (SI)	R-Ceil. (SI)	R-Sub-Floor	Cons. Strat -egy	Site Furnace Output (MJ/m²-y)	Degree Days (18.3 C°)
MONITORED														
1	B1	Mod.	BUTTE, MT	1	er	99	8	3	7.9	10.6	3.3	s,x	58	4701
2	A1	Pan.	CONCORD, MA	1	er	130	9	---	2.3	3.3	---	a	632	3738
3	SERI	Pan.	BOULDER, CO	1	ef	200	27	---	---	---	---	p	128	3089
4	SERI	Mob.	SPENCER, WI	1	g	94	8	---	---	---	---	p	167	4188
5	SERI	Pan.	BOLTON, MA	1	ef	140	16	---	---	---	---	p	166	2842
6	RYMARK I	Mod.	FREDRICK, MD	1	er	149	8	2	2.5	5.3	---	p,c	124	1659
7	RYMARK II	Mod.	FREDRICK, MD	1	er	149	15	3	2.5	5.3	---	p,c	163	1659
8	LANL	Mob.	LOS ALAMOS, NM	1	ef	98	9	2	---	---	---	a	93	3326
9	LITTLE ROCK	Mob.	LITTLE ROCK, AK	3	h	98	---	1	1.9	2.5	1.9	HUD-I	416	1845
10	LITTLE ROCK	Mob.	LITTLE ROCK, AK	3	h	98	---	2	1.9	3.5	1.9	c	352	1845
11	LITTLE ROCK	Mob.	LITTLE ROCK, AK	4	h	98	---	2	3.5	6.7	3.9	c	170	1845
12	TECH V	Mod.	KNOXVILLE, TN	1	er	111	14	2	3.3	6.7	3.3	p,c	167	1914
13	T1	Mob.	TALLAHASSEE, FL	1	ef	91	---	1	1.2	2.5	1.9	HUD-I	154	851
14	T2-HUD	Mob.	TALLAHASSEE, FL	1	ef	91	---	2	2.3	3.9	3.2	c	117	851
15	KEMNAY	Pan.	N. SCOTLAND	8	er	109	---	2	3.7	4.6	6.0	c	82	3164
16	KEMNAY	Pan.	N. SCOTLAND	10	er	99	---	2	3.7	4.6	6.0	c	67	3164
17	IMPALA	Pan.	MADISON, WI	1	er	158	---	3	8.5	10.0	4.8	c,x	120	4277
SIMULATED														
A	HUD STD.	Mob.	PHOENIX, AZ	1	er	70	4	1	1.9	1.9	1.2	HUD-I	162	844
A	HUD STD.	Mob.	ATLANTA, GA	1	er	70	4	1	1.9	1.9	1.2	HUD-I	408	1702
A	HUD STD.	Mob.	SEATTLE, WA	1	er	70	4	2	1.9	2.5	1.9	HUD-II	589	2608
A	HUD STD.	Mob.	BISMARK, ND	1	er	70	4	2	1.9	2.5	1.9	HUD-II	1198	5007
B	D1	Mod.	FARGO, ND	1	g	161	13	2	3.9	8.8	3.9	a,s	239	5132
C	U1	Mob.	RICHMOND, VA	1	h	109	17	2	1.9	5.3	3.3	p,c	200	2171
D	U2	Mob.	DENVER, CO	1	h	109	17	2	1.9	5.3	3.3	p,c	345	3324
E	W1	Mob.	SPENCER, WI	1	g	89	8	3	3.5	5.8	3.9	c	193	4188
F	A2	Pan.	BOULDER,CO	1	ef	226	27	3	3.3	5.3	3.3	a	66	3324
G	SWEDISH	Pan.	LOS ANGELES, CA	1	er	124	7	3	5.8	8.3	4.9	s,x	0	673
G	SWEDISH	Pan.	ATLANTA, GA	1	er	124	7	3	5.8	8.3	4.9	s,x	18	1702
G	SWEDISH	Pan.	ALBUQUERQUE, NM	1	er	124	7	3	5.8	8.3	4.9	s,x	37	2367
G	SWEDISH	Pan.	BOISE, ID	1	cr	124	7	3	5.8	8.3	4.9	s,x	83	3223
G	SWEDISH	Pan.	MINNEAPOLIS, MN	1	er	124	7	3	5.8	8.3	4.9	s,x	184	4515

*The ID numbers correspond to monitored buildings, the ID letters to simulated performance. The seventeen numbered data points correspond to 40 homes. A variety of manufactured building types are represented here — mobile, modular, and panelized homes. Most of the homes employ a mixture of solar strategies and increased envelope efficiency. The energy consumption data are normalized for floor area and adjusted for the reported heating system efficiencies to annual furnace output. Annual energy intensities, in MJ/(m^2 °C-day), are plotted against heating degree-days in Fig. 1 and primary sources of the data are cited in [1]. Type: Pan. = panelized home, Mob. = mobile home, Mod. = modular home. Strategies: s = superinsulated, p = passive solar, a = active solar, c = extra insulation, x = heat exchanger, HUD = conventional HUD home and climate zone no. SH Fuel: er = electric resistance heat, ef = electric furnace, g = gas furnace, h = heat pump.

delays in reporting the results and poor data capture force us to rely on estimated performance at this time.

Future work will emphasize collection of more performance and cost data and analysis according to our BECA-A weather and occupancy normalization methodology [12]. This work is part of an ongoing compilation and we welcome contributions of performance data for new or retrofitted manufactured homes and for buildings of all types.

ACKNOWLEDGEMENT

The work described in this report was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building, Building and Community Systems, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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