

CROSS-COMPARISONS OF NEW ENERGY-EFFICIENT HOUSES

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INTRODUCTION

We have compiled energy performance data on 431 *low-energy* homes in the U.S., Canada, and Europe as part of the Buildings Energy-Use Compilation and Analysis project (BECA-A). Measured data on the actual performance of occupied buildings provide an essential form of feedback to architects and builders on how well calculations and computer models actually predict energy performance and dollar savings. Such data need to be systematically collected and compared in a meaningful way. However, differences in weather, operating characteristics, and measurement techniques complicate the process of making performance comparisons among houses. In this summary, we present preliminary results based on an analysis of the *heating* performance of homes in the data base.

We gathered information on building physical characteristics, energy-related behavior of occupants, energy consumption for heating and other end uses, actual and normal-year weather, and the incremental construction costs associated with conservation design features. Results reported in this study are based on a selected sample of 343 homes. Roughly 90 houses were deleted from the initial sample either because of inadequate data inputs (e.g. wood stove use) or problems with the parameter estimates generated by the the energy analysis model. Approximately 100 homes were well-monitored, (i.e. the houses had measured indoor temperatures and we were able to calculate internal gains), while furnace energy use was sub-metered in 148 homes. For analysis purposes, we categorized each home into one of four broad groups by primary conservation strategy, based on a review of its design features: superinsulated, passive solar, active solar, and earth-sheltered. Seventy percent of the 343 homes are classified as superinsulated. We have relatively few examples in the data base of well-monitored active solar and earth-sheltered homes.

APPROACH

We designed the BECA-A energy analysis model, SUBMET, to utilize the most frequently monitored quantities in new, low-energy houses. Typically, these include furnace consumption and efficiency, indoor and outdoor temperatures, and appliance energy usage. The metered time increments vary in duration from 1 to 60 days, but are typically one month. One week is optimal because it is often suggested that the typical family "operates" on a weekly cycle, and data from anomalous periods (like vacations) are more easily identified and discarded.

The complete derivation of this model can be found in Busch et al. (1985). From the basic equation for the heat balance across a building envelope, we have

$$H = k (T_b - T_o). \quad [1]$$

where H is the furnace output, k is the overall heat loss coefficient, and T_b and T_o are the balance temperature and outdoor temperature, respectively. Where possible, we adjust actual indoor temperature measurements and internal gains to a "standard" condition based on the BECA-A sample. We then perform a least-squares fit of H' (which reflects the adjustment to standard internal gains) as a function of

the T_o' (which reflects the adjustment to standard indoor temperature), yielding "standardized" performance parameter estimates for T_b and k .

$$H' = k \left[T_b - T_o' \right] \quad [2]$$

We use the derived parameters, k and T_b , from equation (2) to calculate furnace output, H' , summed over the entire year, adjusted from the actual year's weather to a "typical" year. This yields a normalized annual performance factor, H'_{annual} , expressed as,

$$H'_{annual} = \sum_{m=1}^{12} \sum_{h=1}^{24} H' (m, h) \quad [3]$$

where m is each month of the year and h is each hour of the typical day of that month. The normal monthly outdoor temperature, $T_{o,m}$, is decomposed into hourly increments by fitting a sin curve to the normal daily maximum and minimum temperatures for each month,

$$T_{o,h} = \left[\frac{(T_{max,m} - T_{min,m})}{2} \right] \sin \left(\frac{\pi h}{12} \right) + T_{o,m} \quad [4]$$

RESULTS

Comparisons with conventional new houses.

In this study, we analyzed metered data on the annual energy use of new, single-family detached houses built since 1975 (from the 1982 Residential Energy Consumption Survey). Our objective was to estimate a performance indicator (i.e., annual furnace output in a "typical" year) for conventional new homes similar to that produced by SUBMET for BECA-A homes. This process involved several analytic steps, principally due to the level of aggregation of RECS measured data (i.e., whole-building annual consumption). In previous studies (Busch et al., 1985), we estimated baseline energy consumption of conventional new houses using the building energy simulation program, DOE-2, on a prototypical new house in each major climate zone. Preliminary results using the metered data indicate that roughly 80 percent of the BECA-A houses have lower annual furnace energy output than the stock of new houses built since 1975. However, the "best-fit" regression line of furnace energy output for conventional new houses has fairly large standard errors; thus, at the 90% confidence level, annual furnace output is ± 50 to 80% of the mean value.

Energy performance of BECA-A houses

Table 1 summarizes the results generated by SUBMET disaggregated by primary conservation strategy. The first two entries, k-value and balance temperature, are the two regression performance parameters. The mean k-value for the entire sample is $98.7 \text{ W/}^\circ\text{C-100m}^2$ while the mean balance temperature is 14.0°C . Superinsulated homes have the lowest k-values. Earth-sheltered houses also have low k-values and balance temperatures, but a general conclusion for this type of construction is difficult given the small sample size (4 houses). As a group, active solar houses in the data base have higher and more variable k-values and balance temperatures than homes that utilize other design strategies.

To facilitate comparisons among buildings, we segmented the selected sample into four climate zones. The motivation for our climate regionalization was a sense that radically different climates might demand different design solutions. We view the climate zone breakdown as a first step to more detailed future analysis. Because we examine heating performance only, our characterization included only readily available climate variables relevant to heating loads: heating degree days and average annual solar radiation. We chose HDD to base 13°C instead of the traditional 18.3°C because the former more closely reflects the kind of loads BECA-A houses "see" as evidenced by the sample average 14°C balance temperature. We created four climate zones based on natural groupings of BECA-A houses. Houses falling along the boundaries were allocated to specific zones using the concept of "climatic distance" (Andersson

et al. 1986).

Figure 1 shows energy performance versus heating degree days plotted by climate zone. Houses aligned vertically on a plot usually are from the same monitoring project. Zone 1 is a high solar energy zone (with annual solar radiation $>180 \text{ W/m}^2$) and all the homes within it utilize passive solar designs. In the coldest regions (Zone 4; $>3100 \text{ HDD}_{13}$), our results suggest that earth-sheltered houses can achieve heating performance comparable to superinsulated houses in the data base (although a much larger sample of earth-sheltered houses would be required to confirm this observation). It also appears that, on average, superinsulated houses in the compilation have lower annual furnace output than passive solar homes in zone 3 (HDD_{13} between 1700 and 3100). No conclusion regarding active solar houses is possible from this analysis because only the one U.S. active solar house in the compilation had normal heating degree day data to the proper base. Though the intent of the regional analysis is to discourage comparisons across drastically different climates, identical vertical scales allow us to observe that the range of performance tends to increase with increasing coldness.

DISCUSSION

Additional analysis is planned in four broad areas: 1) correlation of actual performance with the presence of specific design features (e.g., triple glazing, trombe wall, heat exchanger) using multivariate analysis techniques, 2) comparison of measured energy performance with design predictions, 3) refinement of baseline energy use analysis for conventional new houses (incorporating monthly billing data and larger sample size), and 4) examination of the incremental costs associated with and cost-effectiveness of design strategies utilized in new, low-energy houses. This is an ongoing effort; we welcome data and analytic contributions from our readers.

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	Super-Insulated	Passive Solar	Active Solar	Earth-Sheltered
Number of Houses	244	79	15	4
k-value ($\text{W}/^\circ\text{C}\cdot 100\text{m}^2$)	85 ± 3	119 ± 7	150 ± 26	86 ± 17
Balance Temperature ($^\circ\text{C}$)	14.7 ± 0.5	12.6 ± 0.5	13.8 ± 0.6	12.2 ± 2.9
Annual Furnace Output (MJ/m^2)	280 ± 9	183 ± 12	202 ± 29	209 ± 13
Annual Furnace Output ($\text{kJ}/\text{m}^2\text{-HDD}_{13}$)	81 ± 3	111 ± 9	184^\dagger	65 ± 4

* All entries are mean \pm standard error of the sample mean.

† Only one house in this subsample.

Figure 1. Annual furnace output versus heating degree days (base 13°C) for low-energy homes disaggregated into four climate zones.

