12 Oct 1978

Assessment of Residential Energy Use: Some Results and Methodologies

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ASSESSMENT OF RESIDENTIAL ENERGY USE: ANALYSIS OF RESULTS AND METHODOLOGIES

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Abstract

This paper addresses the problem of determining residential energy use. Specifically, it discusses some of the estimation methods, selected results, and potential errors in the estimates.

1. INTRODUCTION

The recent excess of energy demand over energy supply and the accompanying pressures to conserve energy has generated interest in the identification of the distribution of energy use. One such distribution is by major sectors of the economy, residential, commercial, and industrial. This paper addresses the problem of determining residential energy use. Specifically, it discusses some of the estimation methods, selected results, and potential errors in the estimates.*

2. ENERGY ASSESSMENT METHODS

Three basic methods are applicable to the estimation of residential energy use. They will be denoted (1) Control Total Methods, (2) Expenditure/Consumption Methods, and (3) Inventory/Use Methods. Most often, one finds that the three methods are used in conjunction with one another.

2.1 CONTROL TOTAL METHODS

These methods have the common denominator that they accept Edison Electric Institute (EEI), American Gas Association (AGA), and Personal Consumption Expenditure (PCE) statistics as accurate for a given subpopulation of the residential sector. The aggregate use estimates take the following general forms:

residential electricity use=

$$RES_{EEI}\left[1 + \frac{\text{calculated master-metered}}{\text{calculated individually-metered}}\right],$$

residential natural gas use=

$$RES_{AGA}\left[1 + \frac{\text{calculated master-metered}}{\text{calculated individually-metered}}\right], \text{ and}$$

residential petroleum product(i) use=

$$PCE\left[\frac{\text{calculated use product (i)}}{\text{calculated use all petroleum products}}\right],$$

where RES_{EEI}, RES_{AGA}, and PCE are the EEI, AGA, and PCE statistics for residential use of electricity, natural gas, and petroleum products, respectively. The necessity for the modification of the EEI and AGA statistics arises because these two sources fail to consider master-metered use.** The PCE statistics must be modified since they are not fuel specific.

2.2 EXPENDITURE/CONSUMPTION METHODS

These methods directly estimate residential energy use on the basis of either expenditure census/sample data to which fuel prices are applied, or significantly smaller samples for which actual energy use is encoded.

$$\text{use} = \text{expenditure/price}$$

*Certain of these results have appeared in expanded form in the *Buildings Energy Use Data Book, Edition I*(8) and others will appear in *Buildings Energy Use Data Book Supplement I: Appliance Inventory, Efficiency, and Energy Use in Residential Sector*.(9)

**Master-metered use is generally included in commercial use.

2.3 INVENTORY/USE METHODS

These methods estimate the inventory of appliances and average appliance energy use, and calculate total energy use as the product of the terms.

use = inventory × average use

Each of the above methods has certain advantages and disadvantages: none is exact, though the Control Total Method judiciously applied is thought by this author to yield the best results. The potential errors for each method are detailed in Table 1.

Table 1. Error Sources in Energy Use Estimates

Type of Error	Method Affected	Example
Accuracy of control totals	CT	RES_{EEI}
Measurement error	CT, EC	Expenditures for electricity
Nonrespondent bias	CT, EC, (IU)[a]	Missing expenditure data
Sampling error	CT, EC, IU	Samples to determine master-metered use
Average price	CT, EC	Use = expenditure/average price
Bias towards preselected results	IU	Average appliance use statistics

Key: CT = Control Total, EC = Expenditure/Consumption, IU = Inventory/Use

[a]The errors in this method are suspected to be considerably smaller than for the other methods.

For further details see G. E. Liepins, "Conditional Rate Structures: A Unique Statistical Approach to Energy Use Assessment," to appear in the 1978 proceedings of the Business and Economic Statistics Section of the American Statistical Association.(7)

3. ENERGY USE STUDIES

Two of the more successful energy use studies are Cohn, S., *Fuel Choice and Aggregate Energy Demand in the Commercial Sector*,(2) and Environmental and Energy Analysis Incorporated (EEA), *Energy Consumption Data Base*.(3) The Cohn study basically used a Control Total Method in conjunction with an Inventory/Use Method, and the EEA study used a Control Total Method in conjunction with an Expenditure/Consumption Method. A comparative listing of features is given in Table 2 below.

Table 2. Comparative Features of the Cohn and EEA Study

Feature	Cohn Study	EEA Study
Data source	Census	Mathematica Inc. tape (based on Census)
Primary data	Appliance ownership	Energy expenditures
Methodology for handling missing data	Not applicable	Regression analysis
Central parameters	Average use by appliance, housing type, region, and fuel	Average price

3.1 ESTIMATION PROCEDURES

For each of the housing types studied, the following flow charts (Figures 1 and 2) indicate the estimation procedures for electricity use:

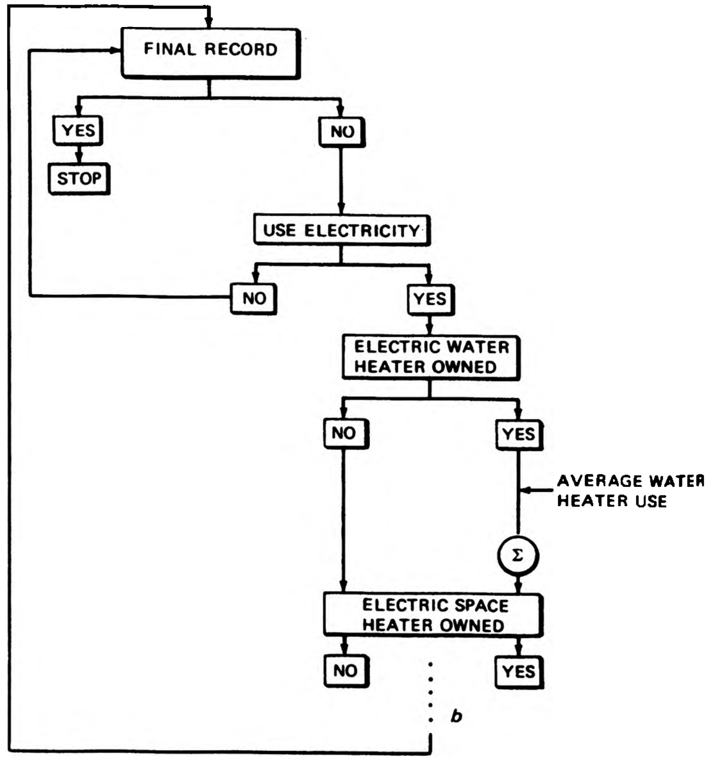

Fig. 1. Cohn Study Electricity Use Flow Chart.

[a]The average use statistics were taken variously from studies by: S. H. Dole, Hittman Associates, or A. D. Little.

[b]Electrical appliances considered were: (1) space heater, (2) water heater, (3) refrigerator, (4) stove, (5) air conditioner, (6) freezer, (7) clothes dryer, and (8) electric lights,

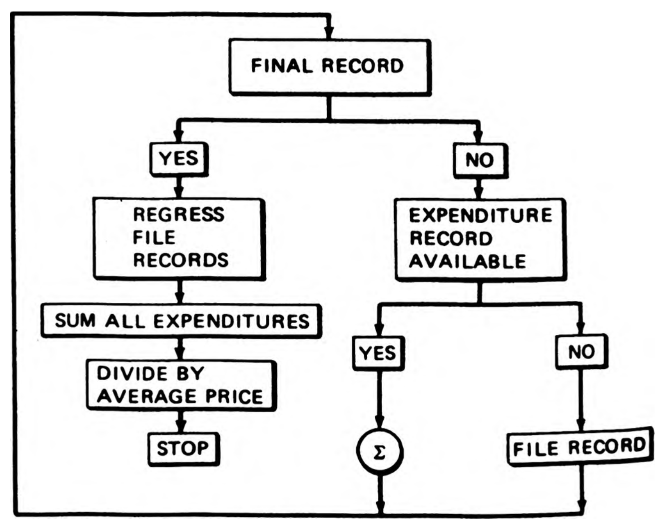

Fig. 2. EEA Study Electricity Use Flow Chart.

3.2 RESULTS

Selected results from several studies including each of the above are presented below in Table 3.

Table 3. Residential Fuel Consumption as Estimated in Selected Studies[a] (10^{15} Btu)[b]

	National Energy[(1)] Accounts 1972	ORNL[(2)] 1975	EEA [ECDB][(3)] 1974	Rand[(4)] 1970	SRI[(5)] 1968	Arthur D. Little[(6)] 1970
Electricity	1.8370	2.0805	1.9994	1.5315	1.3874	1.5162
Natural gas	5.6451[c]	5.2726	5.2985	5.2533	4.6032	5.5860
Coal	0.4988					
Coke	0.0030[d]					
Coal and coke	0.5018			0.3904		
Wood						
Kerosene	0.5159	0.3412	0.3666			
Fuel oil	3.9501	2.0995	2.7236			3.4770
LPG	0.4130		0.7109			0.8208[e]
Petroleum products	4.8790	2.4407	3.8011	2.8529	3.1882	4.2978
Total	11.0259	9.7938	11.1080	10.0100	9.1880	11.4000
Master-metered electricity, %	5.2	4.0	5.6	0.21	10.56	-0.79
Mastered-metered gas, %	22.0	11.8	18.91	16.43	2.96	33.01

[a]Years in headings refer to years to which data pertain.

[b]Unless otherwise noted, data not originally in Btu's have been converted using conversion factors published by Jack Faucett Associates in National Energy Accounts.

[c]AGA Residential + 0.22 AGA Commercial, 1975.

[d]Conversion used was 1 ton = 2.6×10^7 Btu.

[e]LPG + coal + steam + unallocated.

3.3 ACCURACY

As can be seen, differences in aggregate energy use estimates for the residential sector are substantial, of the order of 10-15%. These differences are not surprising in view of the estimated probable errors* given in Table 4.

Table 4. State and National Probable Errors

Fuel	State Probable Error	National Probable Error
Electricity	±3%	±3%
Natural Gas	±10%	±3%
Fuel Oil	±25%	±15%
Kerosine	±25%	±15%
LPG	±25%	±5%

Source: Energy and Environmental Analysis, Inc., *Energy Consumption Data Base, Household Sector, Final Report*, Vol. III, Arlington, Va., April 1977, Table III-7.5, p. 43.

The relative superiority (in terms of accuracy of estimates) of one method over the other is difficult to determine. For electricity, the error between actual residential energy use and the estimates can be expressed as:

$$S\left(1 + \frac{(y + \tilde{z}) \cdot U}{(x - z) \cdot U}\right) - R\left(1 + \frac{(y \cdot \hat{U})}{(x \cdot \hat{U})}\right),$$

where

S = actual individually metered residential electricity use,

y = the estimated vector (by type of dwelling) of master metered households,

U = the actual average energy use vector (stratified identically to the vector y),

x = the estimated vector (by type of dwelling) of the number of individually metered households,

z = the correction vector such that x − z is the actual vector of the individually metered households,

$\tilde{z}$ = the correction vector such that y + $\tilde{z}$ is the actual vector of master metered households (consistent estimates would yield z = $\tilde{z}$),

R = the EEI residential energy use statistics,

$\hat{U}$ = the estimated average energy use vector (generally estimated by either expenditure/consumption or inventory/use mehtods),

$y \cdot \hat{U}$ = the inner (dot) product, $\sum_i y_i \hat{U}_i$.

*Probable error is defined to be 0.6745 S, where S is the sample standard deviation.

For example, if three dwelling types, type 1, 2, and 3 are being considered, then each of the vectors x, y, z, U, and Û would be a six-tuple. The vector y would be (o, y_1, o, y_2, o, y_3) where y_i represents the number of master-metered households living in dwelling type i. Similarly, the vector x would be (x_1, o, x_2, o, x_3), and the vector U would represent average use by dwelling type for individually-metered and master-metered units separately.

Some apparently justifiable assumptions lead to the conclusion that the percent error is probably greater than, but can approximated by

$$\frac{(y \cdot U)(x \cdot \hat{U}) - (y \cdot \hat{U})(x \cdot U)}{(x \cdot U)(x \cdot U)} .$$

Loosely speaking, the magnitude of the error is roughly proportional to the degree by which Û fails to be a multiple of U, a condition which is not easily analyzed.

4. CONCLUSIONS

Given this range of varying estimates, what can one conclude? The following is a partial list of valid conclusions: (1) Estimates of aggregate residential energy use vary by 10-15%. Disaggregated estimates are even less accurate. (2) Electricity and natural gas estimates are more reliable than those for other energy sources. (3) It is difficult to quantitatively assess the bias in residential energy use estimates, yet the bias needs to be identified. (4) It is difficult to quantitatively assess the confidence intervals associated with energy use estimates, yet such intervals need to be determined. (5) It is strongly suggested that improved estimates of residential energy use cannot be made until more and better data are available. This then, is the note I would like to conclude on: More and better data are required before residential energy use estimates can be substantially improved, and as such data become available, careful analysis, cognizant of potential biases, should be undertaken to obtain improved (energy use) estimates.

BIOGRAPHY

Gunar E. Liepins was born in Germany in 1946. He received his A.B. in mathematics from the University of California, Berkeley in 1969, and pursued graduate work in mathematics at the Rockefeller University and Dartmouth College, where he received his M.A. in 1972, and Ph.D. in 1974. He also has a M.S. degree from Stanford University in engineering-economic systems. He has taught mathematics at Texas Tech University and is currently employed as a Research Associate in the Energy Division of Oak Ridge National Laboratory. His current research interests include mathematical approaches to energy problems.

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