RESIDENTIAL ENERGY AND POLICY SIMULATION: ACCURACY OF RESULTS FROM THE ORNL RESIDENTIAL REFERENCE HOUSE ENERGY DEMAND MODEL

Daniel M. Hamblin, Battelle Columbus Division, Laura J. Bibo,
Bonneville Power Administration

ABSTRACT

The ORNL Residential Reference House Energy Demand (RRHED) model is a computer-based engineering-economic end-use simulation model which forecasts energy demand and conservation policy impacts based upon a detailed evaluation of how households use energy for particular appliances. The focus of the current study is the revealed accuracy of model predictions in four areas:

1. aggregate electricity sales over a five-year historical period;

2. new structure penetration projections for space and water heat;

3. aggregate space heat energy use per new building; and

4. costs of conserved energy for shell improvements.

The geographic area for analysis is the Pacific Northwest area of Bonneville Power Administration service.

The RRHED model produces weather adjusted forecasts for historical years. These predictions for Public and Private Rate Pools are compared to actual sales data. The adequacy of the nested logit qualitative choice simulation mechanism is analyzed by comparing 1983 simulations with 1983 Pacific Northwest Residential Energy Survey results. New structure space heat electricity consumption estimates are validated against analysis data available from diverse sources. RRHED predictions for the cost of programmatic initiative conserved energy are evaluated for consistency and accuracy by comparison of output "shadow price" results with external computations.

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1. INTRODUCTION

Public domain end-use energy models were initially developed for one overriding and fundamental purpose--to indicate long-term benefits of programmatic conservation initiatives net of market-induced energy savings in BTU's and constant dollars. However, the "funding source" market for end-use models has matured in the emphatic direction of shorter-term electric load and aggregate forecast uses. A third current of influence upon "public-domain" modelers has been the academic community of reviewers, whose criticisms in support of logical consistency have made blatant the difficulty of sound and defensible attainment of the initial development purpose with funding constrained by the "aggregate" performance needs of load forecasters in the trenches.

The context of crosscurrents defines the environment influencing evolution and development of the ORNL Residential Reference House Energy Demand (RRHED) model. RRHED was preceded by the ORNL Residential Energy Demand Model, originally developed by Eric Hirst and Janet Carney for the purpose of predicting the results of conservation policy.[1] The ORNL model provided forecasts at the national level and for the ten federal Department of Energy (DOE) regions.

The widespread technology transfer and programmatic applications emanating from continuing development of the Hirst and Carney Model led to its targeting for evaluation and validation. These exercises were performed by nationally known economists and statisticians under sponsorship from the National Bureau of Standards,[2] the Energy Information Administration of DOE,[3] the Electric Power Research Institute,[4] and others.[5] The result of such studies was to induce additional technology transfer to private-sector model builders and to stimulate the evolutionary upgrading of the original model. That upgrading has occurred in the context of retaining the identified strengths of the original Hirst and Carney modeling approach.

Primary among those strengths was the emphasis in model structure upon technical characteristics of conventional and advanced energy service technologies. The development struggle for RRHED has been to articulate, define, and defend a more disaggregate approach which would mitigate the logical consistency and aggregation bias problems identified by model reviewers

-- while preserving and enhancing the explicit depiction of actual technologies. At the same time, the Bonneville Power Administration (BPA) Division of Power Forecasting, which has supported model development, has placed priority on model validation and documentation. One measure of validity is the model's ability to accurately portray an aggregate load forecast historical track from the base period (1979) to the current year.

The focus of the current study is the revealed accuracy of model predictions. The results selected for analysis reflect upon the quality of service to the different masters providing stimulus for model development. The RRHED model produces weather adjusted forecasts for historical years. These predictions for BPA service area Public and Private Rate Pools will be compared with actual sales data. A primary outcome of the model review recommendations was the development of a nested logit qualitative choice mechanism[6] for predicting new structure energy service equipment choices. The adequacy of this fuel-and-equipment choice structure will be examined by comparing 1983 RRHED simulations of space and water heat penetrations with 1983 Pacific Northwest Residential Energy Survey (PNWRES)[7] results. The adequacy of initial calibration and consequent model technology choice simulation will be examined by comparing 1983 space heat consumption estimates from several sources. A second test of the technology choice structure has to do with the correctness--given underlying data and assumptions--of costs of conserved energy predicted from it. Validating these calculations is an essential prerequisite to use of the model for comparing programmatic conservation initiatives to electric power generation options. RRHED conservation cost predictions will be evaluated by appeal to "external" computations.

Section 2 is a cursory discussion of the theory-based approach to modeling. The Section 3 "criteria for Evaluating Model Performance" includes description of a strategy for model validation, accompanied by delineation of performance criteria. Section 4 is a display of model performance with respect to the results selected for analysis and the Section 3 criteria. Section 5 is a conclusion which summarizes the successes and failures comprising model performance.

2. THEORY-BASED APPROACH

A model is theory-based if it relates cause and effect by an appeal to hypotheses about behavior. The relationship may have an historical origin if it is characterized by econometric parameters estimated from data describing past decisions and values of economic variables. The relationship may also be current and dynamic if decisionmaker optimization--in conformity with a particular notion or theory--is explicitly depicted by algorithms in the model.

The ORNL Residential Reference House Energy Demand Model is theory-based in both senses. It combines logically consistent economic hypotheses or paradigms, which characterize household decision making, with energy service production possibilities, stemming from engineering technological process analyses. The intertemporal utility maximization hypothesis which underlies fuel and equipment choice is implemented through the application of econometric parameters to predicted "current" values of endogenous and exogenous variables. In part, these values are produced by a life-cycle-cost minimization hypothesis which underlies the capital stock usage/efficiency/capacity decision. The decision results from an explicit dynamic optimization process depicted in RRHED. The boundary conditions for the optimization are set by the engineering process analyses which generate shell and energy service equipment isoquants. These isoquants are economic constructs for displaying the energy performance and embodied capital costs of different energy service technologies which provide the same type and level of amenity. They are consistent with a broad family of underlying household energy service production functions or correspondences developed and utilized by economists for discerning relationships between output and cost, and underlying inputs and input prices.

Analysis of policy affecting new structures can be done in a constrained optimization framework. This produces cost-of-conservation shadow prices which the underlying theory predicts may alter the builder or homeowner decisions for technology and fuel.

It should be noted, for comparisons made below, that a theory-based approach may penalize model performance over a short observation period, relative to accounting-based energy projections obtained by modifying economic and engineering data exogenously over time and using the end-use model fundamentally as an adding-up tool.

3. CRITERIA FOR EVALUATING MODEL PERFORMANCE

3.1 Strategy for Model Validation

Daniel McFadden recommends model validation via a backcast over years prior to the calibration period.[8] This strategy is plausible for RRHED, given existence of the 1983 PNWRES and the model's 1979 base period. However, resources have not permitted systematic validation following the McFadden recommendation. The significant aspect of that recommendation is to be able to validate model performance at an arm's length from the outputs and time frame employed for calibration. Otherwise, the model is simply reporting the calibration wires installed in it. And, as McFadden further points out, if a model is over-fit in a calibration sense, it may lose the parametric response from its theory-based structure and thereby go astray over the longer-term forecast period.[9]

RRHED was subjected to a systematic and comprehensive model calibration, primarily with respect to the 1979 base period. For the results reported below, two aspects of the calibration are worthy of note. First, relationships among inputs (e.g., new structures vs. average existing stock) are calibrated via recourse to a set of personal-computer-based parameter-development and calibration programs.[10] Calibration was performed within the broader context of aggregating Rate Pool specific RRHED forecast results to a BPA service area total. Fundamental to this calibration are the underlying assumptions about the relative "tightness" (and resultant space-conditioning consumption characteristics) of the average existing stock in the "Publics" and "Privates." These assumptions, which result in data employed for calibration, were developed by Hamblin and Kenton R. Corum of the Northwest Power Planning Council. The fundamental calibration methodology employed in the PC software is a Gauss-Jordan simultaneous equations solution algorithm. This utilizes space heating consumption characteristics of stock and technical characteristics of new buildings to develop technology curves (isoquants) and RRHED simulation model calibrating data.

The second calibration aspect -- which violates the McFadden "arm's length" admonition -- has to do with "wires" installed to control model behavior in areas for which data (and resultant parameterization) are conflicting, or to a large extent, non-existent. These wires exist in the area of wood and "other" non-conventional space heat. In light of conflicting data on both the incidence and the impact of wood heat,[11] the penetration of "other" space heat systems is wired to judgmentally reflect (high, medium, low) scenario-specific market success for these systems. In other words, the RRHED model is never <u>validated</u> for "other" space heat. Rather, any particular historical simulation may attempt to replicate actual penetrations for "conventional" systems and scenario assumptions for "other" systems. Of course, this strategem -- in a fingernail's length sense -- could provide a free parameter for ensuring that RRHED aggregates replicate historical sales. The results reported below do <u>not</u> reflect any such historical fine tuning. Rather, they embody a conservative assumption of relative constancy of "other" systems -- which does not permit year-to-year penetrations to vary by more than 1/32 from the previous period's result. The result of this assumption for the space heat aggregate is consistent with a finding for the Pacific Northwest of J. A. Hausman and J. Mackie-Mason[12] -- that the endogenous impact of wood heat upon electricity consumption is not significant.

Given the calibration described subject to the arm's length caveat, the validation strategy reflected in the results reported below is to compare model performance to actuals and alternative - source estimates. These comparisons are made for an historical period for which weather fluctuations (i.e., changes in Rate-Pool-specific annual heating and cooling degree days) are assumed to impact upon space-conditioning usage with a unitary elasticity.

3.2 Delineation of Performance Criteria

The performance criteria employed are simple and direct. For comparisons of predicted and actuals or alternative-source estimates, three criteria will be employed:

1. A "visual" comparison and explanation of likely source of differences;

2. A Mean Absolute Percent Error (MAPE) or Mean Absolute Error (MAE) for cases in which an actual observation is zero; and,

3. A Root Mean Square Percent Error (RMSPE) or Root Mean Square Error (RMSE) for cases in which an actual observation is zero.

These performance measures avoid the problem of positive and negative errors canceling; further, the RMSPE (or RMSE) penalizes individual errors more heavily.[13]

The criterion employed for validating model projections of the cost of energy conserved because of programmatic initiative is demonstration that model results are comparable to estimates derived manually from a simple approximation formulation.

4. MODEL PERFORMANCE

4.1 Aggregate Electricity Forecasts

Table I compares predicted and actual electricity sales by Rate Pool, for the 1980-1985 period. Because the 1985 sales data are preliminary and 1985 projections do <u>not</u> include space conditioning weather adjustment, performance statistics are separately reported for 1980-1984 and 1980-1985.

Table I. Actual versus RRHED predicted electricity sales for the Pacific Northwest (Average Megawatts).

Year	Public Rate Pool		Private Rate Pool	
	Actual	Predicted	Actual	Predicted
1980	2474	2493	2987	3023
1981	2390	2430	2921	2976
1982	2451	2481	3084	3082
1983	2277	2324	2925	2991
1984	2368	2390	3075	3087
1985	2523	2372	3106	3106
80-84 MAPE		1.33%	1.16%	
80-84 RMSPE		1.42%	1.43%	
80-85 MAPE		2.11%	0.97%	
80-85 RMSPE		2.76%	1.31%	

4.2 Fuel-and-Equipment Penetrations

Tables II and III compare projected and "PNWRES-Survey-indicated" actual penetrations for space and water heat in 1983, respectively. A caveat is in order for these comparisons. Because the nested-logit qualitative choice framework does not include projection of an "other-" or wood-heat choice, the penetrations are normalized to exclude "non-conventional" system choice. Performance statistics are computed cross-sectionally--across the possible choices. Comparisons are by building type and Rate Pool.

The preceding discussion concerning survey "actual" versus predicted space heat penetrations raises significant questions about reconciling large errors in "individual" disaggregate predictions with the very small error revealed in aggregate load forecast projections. As noted, model performance may benefit from compensating errors -- some of which may be the deliberate consequence of calibration strategy which, in the face of conflicting data on wood heat impacts, associates a smaller predicted incidence of electric systems with larger usage per system than is indicated by the scant evidence. The results on electric space heat usage displayed below indicate how inconclusive is the available evidence -- in support of any particular calibration strategy.

Table II. 1983 PNWRES versus RRHED predicted space heat penetration (%).

Fuel and Equipment Type	Public Rate Pool: Single Family Survey	Public Rate Pool: Single Family Predicted	Public Rate Pool: Multi-Family Survey	Public Rate Pool: Multi-Family Predicted	Public Rate Pool: Mobile Home Survey	Public Rate Pool: Mobile Home Predicted	Private Rate Pool: Single Family Survey	Private Rate Pool: Single Family Predicted	Private Rate Pool: Multi-Family Survey	Private Rate Pool: Multi-Family Predicted	Private Rate Pool: Mobile Home Survey	Private Rate Pool: Mobile Home Predicted
Electric												
Central	43.4	26.9	22.8	0.4	93.8	33.8	15.7	21.9	8.0	4.7	92.2	29.4
Non-Central	44.6	31.7	60.5	99.2	0.5	37.2*	53.7	26.2	87.2	71.1	0.0	32.6*
Hydronic	0.0	4.3	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.1	0.0	0.0
Heat Pump	9.1	11.1	16.7	0.0	5.0	12.6	3.4	10.2	4.8	18.5	7.8	10.8
Gas												
Central	2.9	12.9	0.0	0.3	0.9	9.5	26.8	23.3	0.0	4.3	0.0	23.3
Non-Central	0.0	0.4	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.0	0.4
Hydronic	0.0	4.9	0.0	0.0	0.0	0.0	0.4	5.5	0.0	0.5	0.0	0.0
Oil												
Central	0.0	5.3	0.0	0.0	0.0	6.4	0.0	6.1	0.0	0.7	0.0	3.4
Non-Central	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Hydronic	0.0	1.5	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.1	0.0	0.0
Mean Absolute Error	5.88		7.81		5.16		6.2		3.88		6.70	
Root Mean Square Error	7.85		15.09		8.46		9.66		6.91		12.8	

* Fire regulations which effectively prohibit baseboard installations in mobile homes are not depicted in the fuel choice predictions. For this reason, summary statistics are computed with central and non-central electric in mobile home considered as one category.

Table III. 1983 PNWRES versus RRHED predicted water heat penetrations (%).

Fuel	Public Rate Pool: Single Family Survey	Single Family Predicted	Multi-Family Survey	Multi-Family Predicted	Mobile Home Survey	Mobile Home Predicted
Electric	97.8	94.9	100.0	100.0	99.6	99.4
Natural Gas	2.2	5.1	0.0	0.0	0.4	0.6
Oil	0.0	0.0	0.0	0.0	0.0	0.0
Mean Absolute Error	1.93		0.0		0.13	
Root Mean Square Error	2.37		0.0		0.027	

Fuel	Private Rate Pool: Single Family Survey	Single Family Predicted	Multi-Family Survey	Multi-Family Predicted	Mobile Home Survey	Mobile Home Predicted
Electric	82.3	87.6	100.0	99.5	100.0	97.5
Natural Gas	17.7	12.4	0.0	0.5	0.0	2.5
Oil	0.0	0.0	0.0	0.0	0.0	0.0
Mean Absolute Error	3.53		0.33		1.67	
Root Mean Square Error	4.33		0.17		2.04	

4.3 Electric Space Heating Usage

Table IV summarizes estimates of electric space heating usage for new single-family dwellings from various sources. A variety of analysis techniques were used to develop these estimates. Associated use per square foot and total square footage are listed also. Estimate 1 is derived from the 1983 PNWRES. For new primary electric space heating households (who claimed to use electricity most of the time), usage is about 8,600 kWh/year, region average. A simple seasonal approach was used to break annual consumption into space heat and non space heat use. Average summer monthly use per household was multiplied by 12 to approximate non space heat annual use, and subtracted from total annual use to get the space heat figure. This approach implicitly assumes summer period space heating and air conditioning loads compensate for the fact that other non space heating loads (water heating, lighting, clothes drying) are higher in winter. It was initially thought that this approach would overstate space heat use (understate non space heat use); but, this simple technique gave reasonable approximations of end-use metered space heat use for the Albany-Bend households which are discussed below.

The second BPA estimate comes from the residential model. The model shows new single-family space heating usage for resistance-based systems at 9249 kWh/year for public and 9528 kWh/year for private utilities. If the estimates are extended to include heat pumps at incidences predicted by the nested logit fuel-choice mechanism, then the projections are 8329 and 8486 for Publics and Privates respectively. These estimates are 1983 predictions. They follow from base-period values emanating from the 1979 regional survey and heat loss modeling results reflecting current building practice in 1980.

The conditional demand study was performed on the 1983 PNWRES data. Annual and monthly estimates were made that yielded stock average usage from 11,000 to 13,000 kWh/year respectively. Because of small sample size, the conditional demand model was not run for new dwellings. Analysis of new construction versus stock average dwelling characteristics indicates current practice dwellings use roughly 79 percent of 1983 stock average space heat usage. Applying this to the conditional demand stock average estimates yields new dwelling space heat use of 8,690 to 10,270 kWh/yr.

The Northwest Power Planning Council's (NPPC) estimate is 13,200 kWh/yr, current practice in 1983, from their engineering heat loss model. This number is used as a basis for the Model Conservation Standard (MCS) analysis of savings. The regional average house considered as a prototype for current practice

Table IV. Estimates of average annual space heat usage in 1983 new single-family structures.

SOURCE	(kWh/yr)	kWh/ft.^{2}	Square Feet
1. BPA 83 PNWRES	8600	5.47	1573
2. RRHED Model			
Public Resistance Only	9249	6.68	1385
Public Including Heat Pumps	8327	6.01	1385
Private Resistance Only	9528	6.88	1385
Private Including Heat Pumps	8486	6.13	1385
3. BPA Conditional Demand			
Annual Estimation Technique	8690	6.08	1430
Monthly Estimation Technique	10270	7.18	1430
4. NPPC Heat Loss Model	13200	8.00	1650
5. NPPC Residential Model			
Public	9600	6.93	1385
Private	9200	6.64	1385
6. PNGC 83 Survey	6220 (Stock Average)	3.65	1704
7. Albany-Bend (PP&L) Metered Data	9414 (Stock Average)	6.47	1456
Mean	9232	6.34	1463
Mean Absolute Percent Error	10.6%	10.4%	6.15%
Variance	2,351,735	1.04	11,990
Standard Deviation	1534	1.02	109.5
Root Mean Square Percent Error	16.6%	16.1%	7.48%

assumed all electric total house space heating and internal gains from appliances at 2005 efficiencies.

The NPPC residential model, estimate 5, shows publics at 9,600 kWh/year and privates at 9,200. The reasons for the differences between the NPPC engineering and forecasting models are the planning assumptions noted above for the pre-MCS house. The regional average new house in 1983, represented in the forecast model estimates, most likely did use backup heating with electric (primarily wood), some rooms were closed off, and internal gains were greater owing to less efficient appliances. Also, the dwelling sizes in square feet are different as noted in Table IV.

The NPPC and BPA models were calibrated to similar, if not identical, starting values for 1979. The predicted differences by 1983 may be primarily attributed to two factors. First, the RRHED results are weather-adjusted; the NPPC results are not. The region average heating degree days of 5465 for the Privates versus 5382 for the Publics, would, ceteris paribus, engender more space heat consumption in the Privates than in the Publics. Second, the BPA RRHED and NPPC models embody different structural mechanisms in the prediction of discount rates implicit in selection of new structure thermal integrity. The BPA RRHED model projects that discount rates are sufficiently high and fuel prices sufficiently low for base period building codes in place to define building practice throughout the "historical" forecast period. Alternatively, the NPPC model projects new structure shell improvements over this period -- in response to real price movements in the Publics and Privates.

The Pacific Northwest Generating Company's (PNGC) estimate 6 is derived from a 1983 mail survey of PNGC members (4,500 responses), similar in design and purpose to the 1983 PNWRES. PNGC made assumptions on other space heat usage, back-up space heat, and non space heat seasonality of load to arrive at 6,220 kWh/year for stock average single-family households in the PNGC service territories. If the assumption that new dwellings are 30 percent more efficient than stock average holds, this figure drops even lower.

PNGC's estimate differs in another respect from other estimates in Table IV in that the definition of single-family used does not include 2-4 units (as does the definition underlying estimates 1, 2, 3, and 5). The NPPC's heat loss model prototype (4) uses the "pure" single-family definition as well. Estimates 1 through 5 are intended to be region average estimates. The PNGC and Albany-Bend Pacific Power and Light (PP&L) estimates are not necessarily regionally representative.

Estimate 7 is the average of end-use metered results from 60 single-family residences in Albany and Bend (PP&L customers). The Albany-Bend data cover the period April 1983 through March 1984. The sample of 60 metered households (30 in Bend, 30 in Albany) all have electric space and water heat. Seven households have wood stoves and an additional 13 have fireplaces. Besides being all electric and having very little wood heat, the metered household sample is predominantly newer dwellings. Major characteristics of the Albany-Bend sample follow in Table V.

The statistics at the bottom of Table IV comprise an inferential indication of the amount of uncertainty in the prediction of space heat usage. Electric space heat in 1983 RRHED projections comprised 38% of total Publics' residential load and 25% of total Privates residential load. The space heat usage uncertainty is mirrored by uncertainty (indicated above) in the projection of new electric system penetrations, and the primary versus back-up role for these systems in the presence of wood heat. The Table IV results do not support the previously mentioned notion of a deliberate calibration strategy by which too few electric systems are predicted to consume too much electricity. It simply cannot be said that RRHED's aggregate precision is linked to compensating errors within space heat, or between space heat and other end uses.

Moreover, review of monthly billing data and metered household electricity use indicate that space heat use cannot be easily and precisely estimated from aggregate household billing data. Metered data obviously provide the best estimates of space heat use, but so little is presently available that generalizations to the region or even to new construction are very risky. Metered data from the BPA End-Use Load and Conservation Assessment Project (ELCAP) project will be available soon to provide much better estimates of new dwelling space heat use.

4.4 Costs of Conserved Energy

The final estimates for validation are RRHED predictions of the cost of conserved energy associated with programmatic conservation initiatives. In this instance, the point of validation is not the statistical correctness of the projection, but rather, whether model calculations can be independently confirmed. Costs of conserved energy are derivative of RRHED shadow prices from a multivariate simultaneous constrained optimization problem. The motivation for producing these results might be consideration of a conservation policy's cost-effectiveness in comparison with power generation alternatives. Hamblin and Vineyard[14] illustrate the model's application for this purpose, and provide numbers compared to external calculations in Table VI. Although the numbers depicted in VI-a result from a complex classical programming (RRHED) solution algorithm, they may be approximately confirmed by external calculations (depicted in VI-b) which consider four factors:

Table V. Albany-Bend sample characteristics.

Sample Size	60
Mean Dwelling Size	1,456 ft^2
Vintage (Year dwelling built)	
Pre-1940	1.7%
1940-1949	8.5%
1950-1959	1.7%
1960-1969	16.9%
1970-1974	15.3%
1975 or later	55.9%
Heating System Type	
Heat Pump	6.8%
Central Forced Air	39.0%
Room Electric	54.2%
Additional Heating Equipment	
None	67%
Wood stove	12%
Fireplace	22%
Air Conditioning	
None	87%
Central	10%
Window	2%
Swamp Cooler	2%
Other Electric Appliances	
Clothes Washer	6%*
Clothes Dryer	97%
Separate Freezer	58%
Microwave Oven	52%
Dishwasher	29%
Electric Well Pump	8%

*This estimate appears to reflect a coding error. Probably should be 94%.

Table VI. MCS-induced marginal social cost of conserved energy.

Public Rate Pool

a. RRHED projected.

	1986	1990	1995	2000
Electricity in cents/kWh				
1	11.3	11.8	11.3	10.8
2	12.6	13.6	13.0	12.2
3	12.7	13.4	12.8	12.0
4[a]	36.5	43.5	42.2	41.5
Natural Gas in $/THERM				
1	2.35	2.21	1.99	1.68
2	3.03	3.21	3.23	2.89
3	2.41	2.56	2.55	2.35
Heating Oil in $/GALLON				
1	3.19	3.29	3.05	3.36
2	4.00	4.41	4.08	3.70
3	3.20	3.48	3.42	3.65

b. outside-the-model calculation.

	1986	1990	1995	2000
Electricity in cents/kWh				
1	10.2	10.9	10.4	9.2
2	11.1	11.9	11.3	10.1
3	11.0	11.8	11.2	9.9
4[a]	29.5	31.6	30.6	26.5
Natural Gas in $/THERM				
1	2.38	2.44	2.40	2.22
2	2.80	2.98	3.11	2.89
3	2.33	2.48	2.60	2.50
Heating Oil in $/GALLON				
1	3.30	3.49	3.50	4.05
2	3.91	4.23	4.22	3.92
3	3.25	3.53	3.61	3.98

Key: 1. Central Forced Air 2. Non-Central 3. Hydronic 4. Heat Pump

[a]Predicted heat pump performance under the MCS should be disregarded, because compliance is greatly exceeded under the scenario assumptions modeled.

1. Because, in the presence of projected flat increases in fuel prices, RRHED projects building codes in place to bind through most of the forecast period, it may be (approximately) assumed that none of the MCS first cost is defrayed by "market-induced" conservation.

2. The lifetime or payback period for recovering first cost in energy savings required or expected by the builder or homeowner may be imputed from RRHED discount rates, expected measure durability, and expected rate of fuel price escalation.

3. The energy conservation base is the net of consumption without MCS less consumption under MCS.

4. The cost of conserved energy is then simply

$$\frac{\text{initial incremental MCS cost}}{\text{payback period * conserved energy per period}}$$

5. CONCLUSIONS

The above results reveal a mixed portrait of RRHED performance. They do so, however, within the context of additionally exposing fundamental and unresolved uncertainties in end-use specific detail associated with building space heat consumption and the penetration of wood heat and its "true" impact upon electricity and other fuels' consumption.

The aggregate electricity forecast performance depicted in Table I is an obvious success for the model, and for the aggregate model calibration. It also should attest to the attention paid to the "load forecaster in the trenches master," and the attendant resource dedication to producing accurate forecasts for a short term from a mid-to-long term modeling methodology.

The accuracy of the space and water heat penetrations depicted in Tables II and III -- by the criterion of conformity with the 1983 PNWRES --is generally significantly lower than that for the aggregate consumption results. A primary source of error in space heat is the fuel-choice-mechanism's favor for gas and oil systems, when the 1983 survey indicates little builder preference for gas and <u>none</u> for oil. As previously noted, the preference for electric systems may include preference for electric back-up to wood heat, in lieu of gas or oil back-ups with significantly higher first costs. The large errors in multi-family space heat system choice are owing to a 1979-based calibration, in which electric resistance non-central was indicated to be the predominant-to-unanimous choice for new apartment buildings. Consequently, if the multi-family results are evaluated at the fuel-choice (rather than equipment-choice) level, the mean absolute errors fall to 0.27% and 3.73% for the Publics and Privates, respectively. The root mean square errors fall to 0.33% and 4.28%, respectively. The preeminence of electric water heat -- reflected in so-called "choice-specific" parameter estimates in the nested logit fuel choice -- dilutes the fuel-choice prediction challenge for this end use. Another factor dilutes the "validation" value of the penetration comparisons. The 1983 Survey results are subject to errors which may be expected to increase as sample size decreases. Sample observations for penetrations can be quite small relative to the housing population.

The single family space heat consumption comparisons dilineated in Table IV reveal wide variation in what different sources perceive to be characteristic. The RRHED predictions are in approximate conformity with the 83 PNWRES consumption estimate, with the lower model results perhaps explained by the higher predicted incidence (RRHED vs. survey) of heat pumps (See Table II above.).

Finally, the costs of conserved energy, for a model conservation standard, calculated in Table VI-b conform closely in both absolute and relative magnitude to the RRHED predictions from Table VI-a.

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