Title

FINANCIAL IMPACTS ON UTILITIES OF LOAD SHAPE CHANGES. THERMAL INTEGRITY MEASURES FOR RESIDENTIAL BUILDINGS: TEXAS UTILITIES ELECTRIC COMPANY AND NEVADA POWER COMPANY

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Thermal Integrity Measures for Residential Buildings: Texas Utilities Electric Company and Nevada Power Company

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I. INTRODUCTION

Increasingly, electric utilities are being required by regulatory and political authorities to implement demand-side programs in their service territories. Forecasting the effects of demand-side programs is more difficult and less well understood than supply-side interventions. Achieving a least-cost balance between demand- and supply-side activities requires that the differences between these alternatives for the provision of energy services be accounted for in a consistent fashion. As a starting point, the costs and benefits of both activities must be evaluated with a common set of economic and performance assumptions. To date, methods needed to carry out such analyses for demand-side programs have not been generally available.

One central aspect of the difficulties involved in evaluating demand-side programs is that traditional utility planning methods have been influenced by the need to plan for discrete, and often large, generation additions. The generating characteristics and costs of new plants are assumed to be well-defined and the costs of operation can be readily calculated. Demand-side programs, by contrast, consist of many diverse, uncertain and relatively small load shape effects. The evaluation of these effects must consider both their magnitude and timing, and, in addition, account for their non-dispatchability vis-a-vis utility-owned power plants.

A framework for making these trade-offs is beginning to emerge, as utilities develop offers to purchase power from small power producers and cogenerators. Conservation and load management, like non-utility generation of electricity for sale to a grid, represent marginal changes in the demands placed upon the utility's generating system. The value of these changes is properly measured by the utility's marginal cost of generation, which also forms the basis for offers to purchase power. Although the value of non-utility generation is far from settled, the information on utility economics embodied in avoided cost offers provides a logical starting point for the valuation of demand-side activities.

LBL has already made large gains in the compilation and analysis of measured performance data on demand-side activities in buildings [**BED, 1986**]. The goal of this LBL project is to complement existing work by developing analytical tools that bridge the gap between the measured performance of demand-side activities and their financial evaluation within the framework of traditional electric utility planning practice.

The purpose of this study is to demonstrate tools developed at LBL for such an integrated assessment. Specifically, we will report on results for two utility case studies of the load shape and financial impacts of measures that enhance the thermal integrity of residential buildings. The subjects of our case studies are the residential class of the former Texas Power and Light (TP&L) service territory of the Texas Utilities Electric Company (TUEC) and that of the Nevada Power Company (NPC).

The outline of this report is as follows. The background section provides a brief review of LBL's studies of the financial impacts on utilities of load shape changes, summary descriptions of the two utility subjects of this study, and detailed descriptions of the thermal integrity conservation policies examined. The methods section outlines the integrated conservation policy analysis method developed at LBL. The section describes the computer models used and, more importantly, the links between the models used in our analyses. The models include the DOE-2 Building Energy Analysis Program, the LBL Residential Energy Model, the LBL Residential Hourly Load and Peak Demand Model, and the LBL Financial Impacts on Utilities of Load Shape Changes Model. The fourth section contains our results on the load shape and financial impacts of the policies. A fifth section summarizes the entire report and outlines areas of future work. The appendix documents assumptions used to calculate the cost of the thermal integrity

II. BACKGROUND

Since 1980, LBL has been developing tools to assist policymakers and utility planners assess the financial impacts of conservation and other load shape modifying policies. Starting in 1984, LBL began a series of utility case studies of a variety of conservation measures to demonstrate modeling capabilities currently under development. The present study is the latest LBL case study report arising from the Financial Impacts on Utilities of Load Shape Changes project. It is designed to be complementary to recently completed studies on these two utilities [**Kahn, 1986a; Eto, 1986a; Eto, 1986b**]. These studies examined the impacts of increased residential appliance efficiencies on the two utilities and contain extensive documentation of the modeling assumptions and procedures. The present report will refer to these earlier results, but will focus primarily on the overall modeling procedure and results. In addition, we have also performed case studies on the Pacific Gas and Electric Company, the Detroit Edison Company, and the Virginia Electric and Power Company [**Kahn, 1984; Pignone, 1984; Eto, 1984a; Eto, 1984b; Ruderman, 1985**].

The subjects of our case studies are the residential classes of the former Texas Power and Light service territory of the Texas Utilities Electric Company and that of the Nevada Power Company. Table 2.1 summarizes features of the utilities and their residential classes.

Table 2.1 Summary of TUEC and NPC

Year	System Peak Demand 1984 (MW)	Projected Growth 85-99 (%/yr)	System Sales 1984 (GWh)	Projected Growth 85-99 (%/yr)	1984 Residential Sales (% of system)	1984 Res. Avg Use per Cust. (kWh/yr)
Texas Utilities	15595	2.9	77049	3.3	33	12073
Nevada Power	1502	3.8	6572	3.7	44	13445

Sources: PUC of Texas, 1984
NPC, 1984

1. Texas Utilities Electric Company

Texas Power and Light was incorporated into the Texas Utilities Electric Company on Jan. 1, 1984. Prior to the merger, TP&L served 51 counties in north-east Texas (see Figure 2.1). TUEC is a summer-peaking utility that expects continued strong demand growth into the 1990's. The demand growth is driven primarily by the commercial and residential sectors. The company anticipates improved load factors resulting from the increased penetration of electric heating. TUEC has a diversified industrial load composed of oil, electronics, and other industries. The company also serves a large agricultural customer class. Costs are lower than the national averages. In 1985, residential rates averaged 0.070 $/kWh for a customer using 1 MWh/month. The national average, for that year was 0.076 $/kWh [**DOE, 1985**]. The company's costs may fall further below the national average as planned coal capacity is brought on line. TUEC expects its generation mix to fall from over 50% oil and gas in 1985 to less than 20% in 1999. These falling costs have important consequences for our financial analyses.

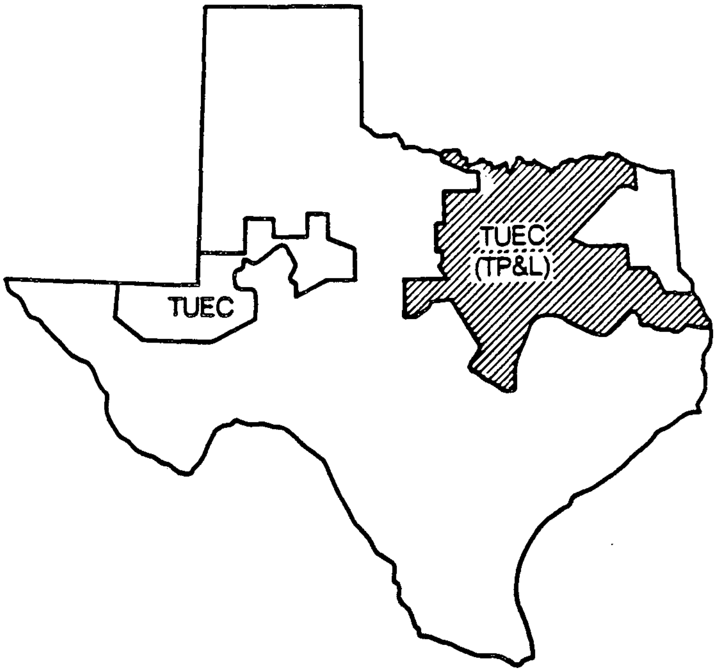

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Figure 2.1 Texas Utilities Electric Company service territory. Shaded region is the former Texas Power & Light service territory.

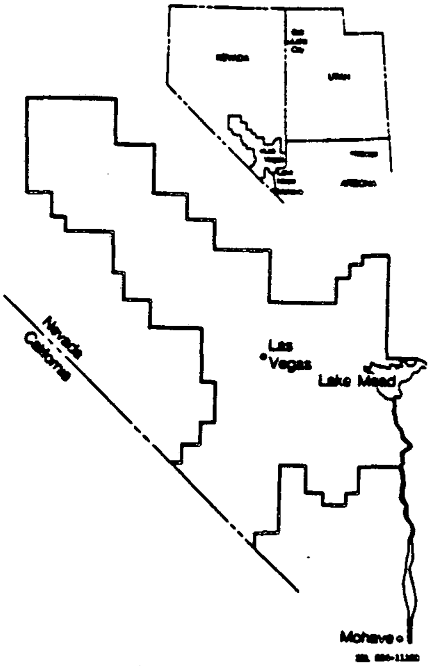

Figure 2.2 Nevada Power Company service territory.

2. Nevada Power Company

The Nevada Power Co. serves the southern part of Nevada, primarily the city of Las Vegas (see Figure 2.2). It is a relatively small investor-owned utility with a peak load of about 1.5 GW. NPC is experiencing growing load and a declining load factor. This situation is caused by the low industrial baseload demand. The commercial and residential sectors represent 86% of all sales, and this load is driven by the heavy air conditioning needs of this hot area. Like TUEC, Nevada Power plans to reduce its dependence on oil and gas generation (from 14% to 6%), but its planned coal additions are not as economical as those of TUEC.

3. Thermal Integrity Conservation Policies

For each utility, we examine the load shape and financial impacts of five policies to reduce energy use in residential buildings. The policies are implemented by assuming that all residential buildings are modified to the policy levels in 1987 and that the measures have a twenty year lifetime. Across the board implementation is programmatically unrealistic, but serves to illustrate the maximum potential impact of each policy.

The first policy retrofits all existing residences in 1987 to the levels found in new construction during the base year (1980 for NPC and 1981 for TUEC). This policy primarily affects the levels of insulation. The second policy is a package of weatherization measures that exceeds the levels of insulation found in new houses and, in addition, significantly reduces infiltration rates. The third policy examines the effects of floor insulation in isolation. For residences in Nevada, this policy involves placing insulation underneath the floor above the crawlspace. For residences in Texas, which typically have slab floors, the policy involves installing perimeter insulation around the base of the foundation to a depth of two to four feet. The fourth policy examines the individual effect of installing triple glazing on all homes. The final policy is an extreme one that would be difficult to realize in practice. We refer to this policy as a passive solar policy, since thermal mass and the placement of southfacing windows are included in addition to high levels of insulation, low infiltration rates, and triple glazing.

Table 2.2 and 2.3 compare the measures mandated in each policy with the current characteristics of new and existing homes in each utility's service territory. The tables express each conservation policy as a change in thermal integrity ratios for new and existing buildings. Thermal integrity ratio is defined as the annual heating (or cooling) load of a building including the conservation measure divided by the annual heating (or cooling) of an existing building in the base year. The thermal integrity ratio is also used to specify the efficiency of new buildings relative to the stock of buildings in a service area. Thus, the measures are described separately for the stock-average or existing residence and for new residences. New residences may already incorporate components of several of the policies. In these cases, only measures that exceed existing levels in new residences are incorporated.

Table 2.2 Summary of Conservation Policies - Texas Utilities Electric Company

		Conservation Measures					Thermal Integrity Ratio	
Policy Case		Ceiling (R-value)	Wall (R-value)	Floor (Btu/hr.F.lin ft)	Infiltration (ACH)	Glazing (number)	Heating	Cooling
Base	existing	15	7.8	1.18	0.7	1	1.000	1.000
	new	22.1	11.8	0.40	0.7	1	0.802	0.917
New Construction	existing	22.1	11.8	0.40	0.7	1	0.802	0.917
	new	22.1	11.8	0.40	0.7	1	0.802	0.917
Weatherization	existing	38	19	1.18	0.4	1	0.661	0.872
	new	38	19	0.40	0.4	1	0.550	0.819
Floor Insulation	existing	15	7.8	0.18	0.7	1	0.819	0.910
	new	22.1	11.8	0.18	0.7	1	0.734	0.879
Triple Glazing	existing	15	7.8	1.18	0.7	3	0.784	0.932
	new	22.1	11.8	0.40	0.7	3	0.589	0.847
Passive Solar	existing	38	19	0.18	0.4	3	0.168	0.619
	new	38	19	0.18	0.4	3	0.168	0.619

Table 2.3 Summary of Conservation Policies - Nevada Power Company

		Conservation Measures					Thermal Integrity Ratio	
Policy Case		Ceiling (R-value)	Wall (R-value)	Floor (Btu/hr.F.sqft)	Infiltration (ACH)	Glazing (number)	Heating	Cooling
Base	existing	20.5	8.5	0.208	0.7	1	1.000	1.000
	new	31.7	12.5	0.067	0.7	2	0.434	0.674
New Construction	existing	31.7	12.5	0.067	0.7	2	0.434	0.674
	new	31.7	12.5	0.067	0.7	2	0.434	0.674
Weatherization	existing	38	19	0.208	0.4	1	0.777	0.942
	new	38	19	0.067	0.4	2	0.281	0.628
Floor Insulation	existing	20.5	8.5	0.067	0.7	1	0.603	0.763
	new	31.7	12.5	0.067	0.7	2	0.434	0.674
Triple Glazing	existing	20.5	8.5	0.208	0.7	3	0.847	0.947
	new	31.7	12.5	0.067	0.7	3	0.402	0.656
Passive Solar	existing	38	19	0.067	0.4	3	0.255	0.599
	new	38	19	0.067	0.4	3	0.255	0.599

III. METHOD

LBL has developed an integrated method for evaluating the load shape and financial impacts of residential conservation and load management policies. The method is composed of four distinct modeling tools. The models are:

- The LBL Residential Energy Model
- The DOE-2 Building Energy Analysis Simulation Model
- The LBL Residential Hourly and Peak Demand Model
- The LBL Financial Impacts on Utilities of Load Shape Changes Model

The links between the models are as follows. First, the effect of the policy on a single house is estimated using DOE-2. Second, the total energy effect of the policy is estimated by use of the LBL Energy Model. The model outputs describe not only the electricity demand but the full household energy consumption, since any interfuel substitution is already accounted for in the model. Third, the electricity consumption component of the forecast of total energy demand is expanded to a full annual load shape by the Hourly Model. Fourth, the financial impacts of the load shape changes are calculated by the Financial Model. This section provides an overview of the method of analysis with descriptions of the models and the flows of information between them (see Figure 3.1).

1. LBL Residential Energy Model

The LBL Residential Energy Model is the integrating engine that drives our policy analyses. It incorporates engineering, economic, and demographic data to produce an end-use forecast of energy use. Purchase decisions for appliances and fuel choice are simulated according to economic criteria, while operation of the appliance stock is simulated according to engineering criteria and prevailing weather conditions. The model forecasts consumption of all the domestic fuels, except wood, based on input projections of inflation, future energy prices, numbers of households, incomes, and housing thermal integrity.

The model is the product of a long development effort that began at Oak Ridge National Laboratory in the mid-1970's. The intent of the early ORNL work was to create a residential energy use model that incorporated both engineering and economic principles. [**Hirst, 1978**] After the model was adopted by LBL, numerous improvements were made. [**McMahon, 1986**] For example, the modelling of appliance retirements has been appreciably enhanced. Where the original model annually retired a fixed fraction of appliances in each age category, the revised model maintains a full distribution of appliance ages and only retires appliances in existing homes after a fixed service lifetime. Therefore, the model has available a complete description of the stock at any time, including the distribution of efficiencies. Further, the model was adjusted to account for the effect of retirements of older (and hence less efficient) appliances on energy use. Another modification has been the creation of a specific appliance category for heat pumps, which were originally subsumed under central air conditioning.

Perhaps the most significant change in the model, however, has been in the way it has been used by LBL researchers. We have used the model to address specific policy issues, such as the proposed appliance efficiency standards, *at the local utility level* [**Levine, 1984**]. The principal task in using the model at the level of individual electric utility service territories is the re-specification of the input data based on local conditions.

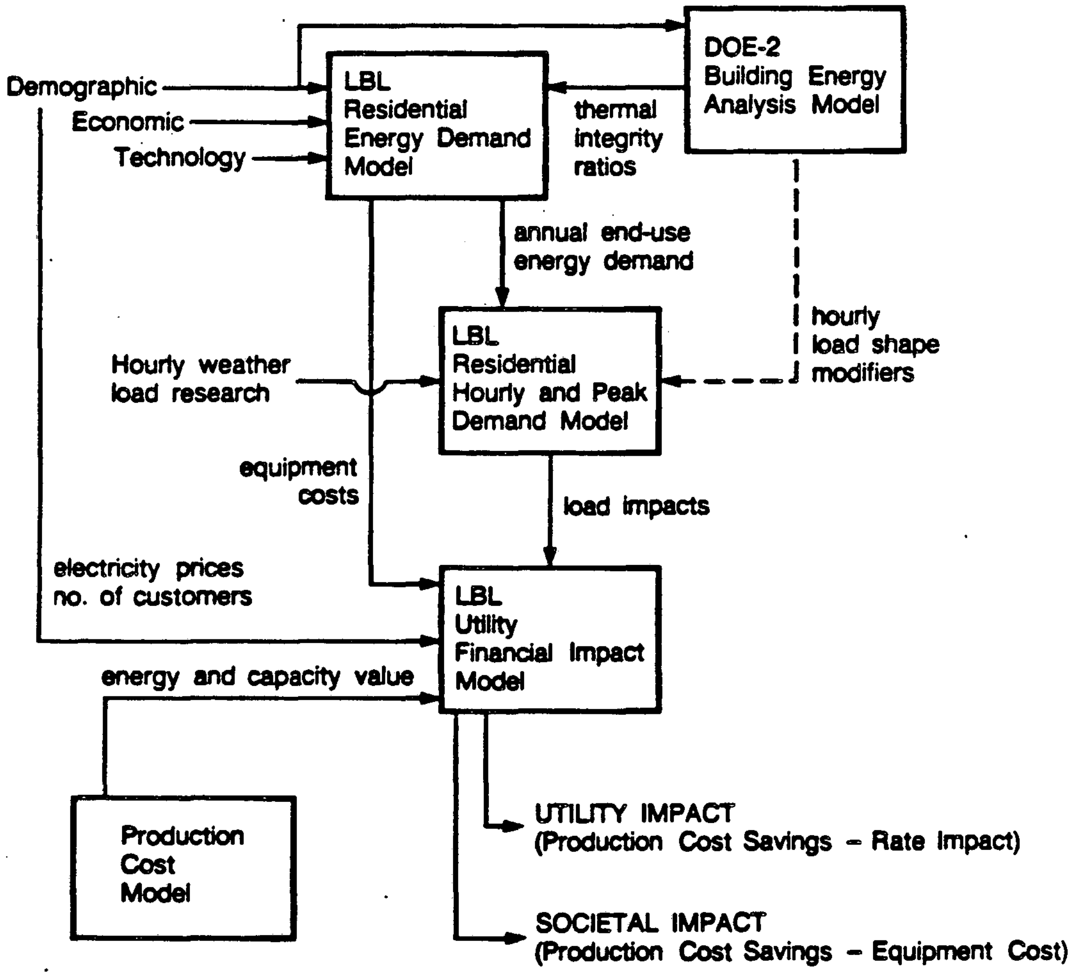
LBL Integrated Conservation Policy Analysis Method

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Figure 3.1 LBL integrated conservation policy analysis method.

2. DOE-2

The DOE-2 building energy analysis model simulates the thermodynamics of a building and estimates non-linear flows of heat among all of the building's enclosed spaces and surfaces on an hourly basis. The model uses response factors to calculate heat conduction and radiation through the building envelope. Through a detailed and flexible input-processor, the user can specify building location, orientation, construction, material properties, HVAC and lighting systems, central plant equipment, and schedules of operation, occupancy, and utilization. All inputs are specified by a Building Description Language that permits the user's building description to either be exceptionally detailed or to rely on extensive defaults. It was developed by LBL, Argonne National Laboratory, and Los Alamos National Laboratory to provide building designers, engineers, and researchers with a well-documented, state-of-the-art tool for analyzing the energy performance of buildings [**Curtis, 1984**].

DOE-2 simulates the hourly energy performance of buildings on an annual basis. The weather inputs to DOE-2 are in the form of hourly weather tapes. For this study, typical meteorological year (TMY) data for Fort Worth and Las Vegas were used for TUEC and NPC, respectively.

The DOE-2 program forms the engineering foundation for our analysis of conservation measures. We use the outputs of the program to complement information obtained from utility-specific sources on the heating and cooling requirements of existing and new buildings as well as those of buildings modified by our conservation policies. For example, utilities often have estimates of heating and cooling energy use for a stock-weighted average residence in the service territory. A complementary appliance saturation survey will provide information regarding other characteristics of this residence [**TPL, 1984; NPC, 1985**]. We use these characteristics to simulate energy use for two housing types with DOE-2. The first simulation calculates annual heating and cooling energy use for the average residence. The second calculates these values for a modified version of this residence, which includes the energy conserving features of a particular policy. Next, the ratio of heating or cooling loads between the average and the policy-modified house is calculated. This thermal integrity ratio is used to modify the original, utility-supplied estimate of average heating and cooling loads to produce a utility-specific estimate of the effect of the conservation policy on houses in the service territory. Thus, we are using a ratio derived from DOE-2 simulations, not the absolute values from the simulations. In addition, the hourly load information for the modified house will be saved and pre-processed for use by the LBL Residential Hourly and Peak Demand Model.

3. LBL Residential Hourly and Peak Demand Model

The Residential Hourly and Peak Demand Model is coupled directly to the outputs of the LBL Residential Energy Model [**Verzhbinsky, 1984**]. The model distributes annual electricity usage data by end-use into annual hourly demand profiles. Dealing, as it does, with every single day of the year, it operates at a very high level of detail compared to most load simulation models, which characterize the year in a summary form, such as periodic load duration curves, or "typical days." The origin of the model's load-spreading capability is primarily metering data that have been collected by load research studies. Adjusting space-conditioning load profiles for local weather conditions is achieved by a matrix that relates consumption in a given hour to climatic conditions. The matrix contains estimates of the fraction of the appliance stock that would be running under the conditions specified by an hourly weather tape and other input data. We have modified the algorithm, which uses these matrices, to also incorporate processed hourly load data from DOE-2 runs. Thus, the final hourly load shapes include data from both empirical observations and simulated performance.

Before making forecasts for a base and policy case, both LBL energy forecasting models undergo an extensive calibration and benchmarking process. The calibration process relies heavily on data supplied by the utility and, in the absence of such data, publically available sources are consulted. The goal of the benchmarking process is to reconcile model forecasts for past years to sales recorded by the utility in those years. We have described these efforts for each utility in previous reports [**Eto 1986a; Eto 1986b**]. We reproduce from these reports our calibrated benchmark results for winter and summer peak day hourly energy use for each utility (see Figures 3.2-3.5).

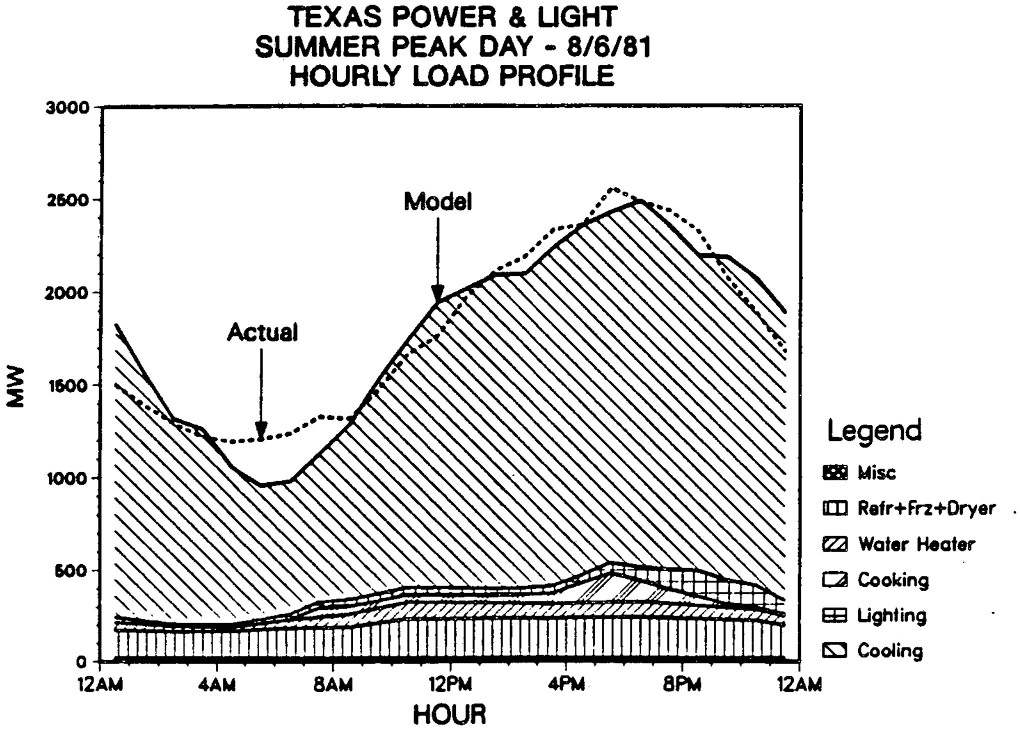

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Figure 3.2 Summer peak day calibration for the TP&L service territory of TUEC.

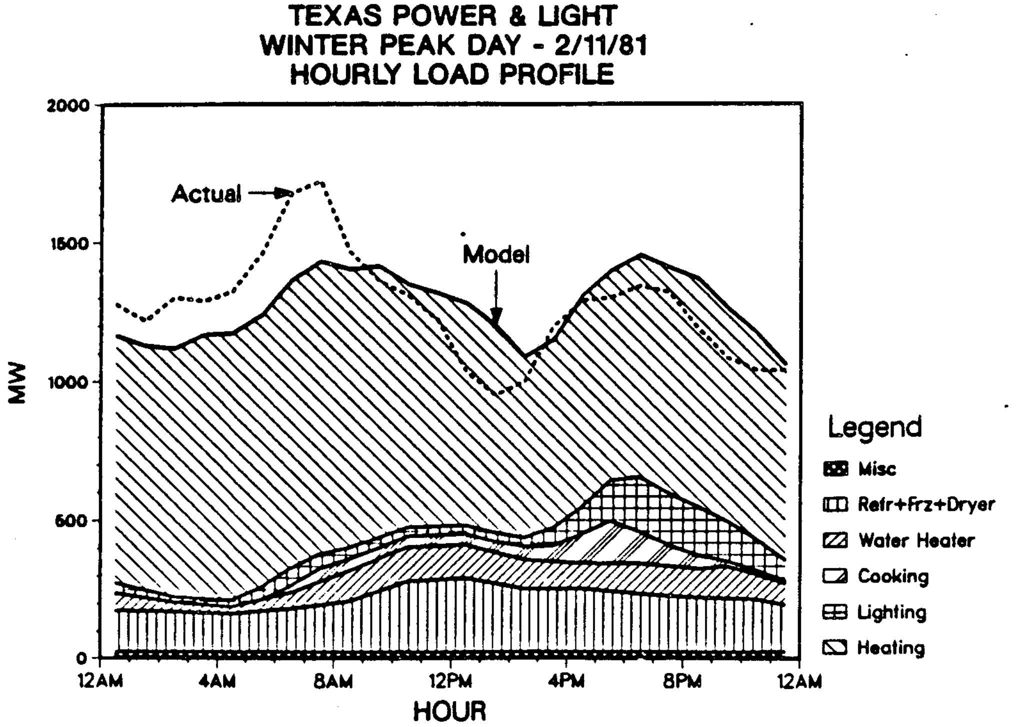

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Figure 3.3 Winter peak day calibration for the TP&L service territory of TUEC.

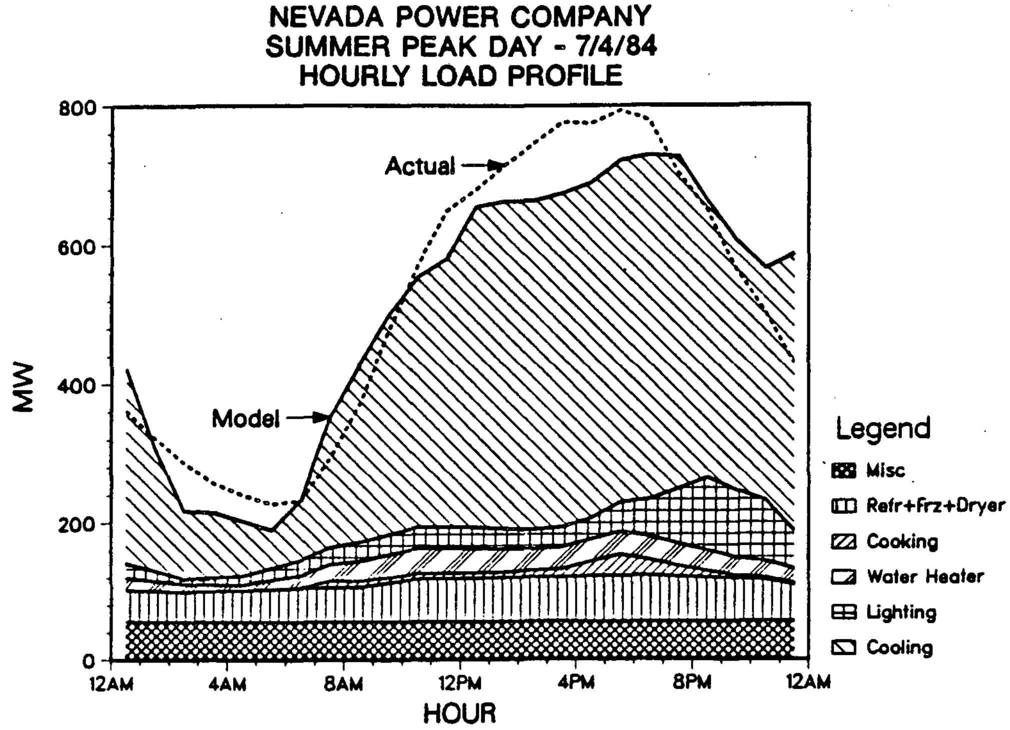

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Figure 3.4 Summer peak day calibration for NPC.

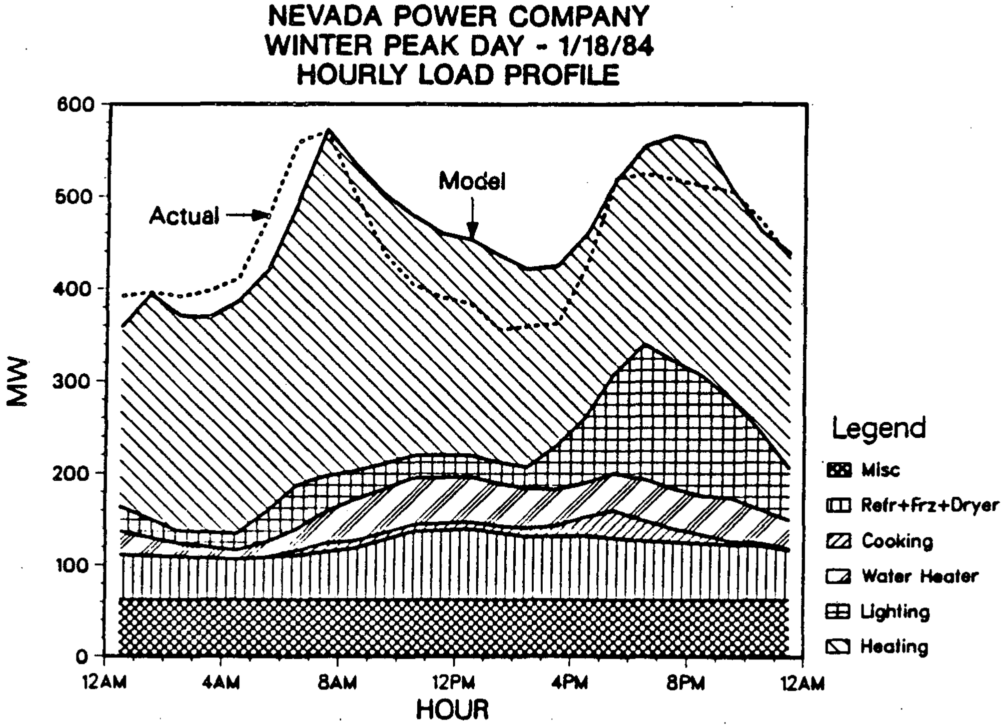

Figure 3.5 Winter peak day calibration for NPC.

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4. LBL Financial Impacts on Utilities of Load Shape Changes Model

The final component of the LBL analysis method calculates the financial consequences of differences in load shapes between base and policy cases. The model relies on financial data characterizing avoided production costs and retail electricity rates to determine financial impacts on both the utility and society. While the methodology employed is not specific to one customer class, the current version has been developed to accomodate the load shapes forecast by the Residential Hourly and Peak Demand Model.

The financial impact on utilities considers both the changes in production expenses resulting from modified loads and changes in the recovery of fixed costs due to changes in revenues. Avoided production costs are based on both long- and short-run measures of marginal cost for a utility. The capacity- and energy-related components of marginal cost are used separately to value the load shape changes [**Kahn, 1986b**]. In our framework, these avoided production costs are the benefit resulting from load shape changes.

The costs, in this framework, are the under-recovery of fixed costs through reduced electricity sales. We refer to this term as the rate impact cost. This term is measured by the difference between lost revenues and avoided variable operating costs. When the utility features tiered or block rates, we use the block-adjustment procedure to calculate revenue losses [**Kahn, 1984**]. Avoided variable costs are estimated using short-run marginal costs.

It is important to distinguish our calculation from more traditional analyses of the costs and benefits of load shape changes. Changes in fixed costs are not true costs in the sense of social cost/benefit analyses; rather, they are a transfer payment that may be borne by either the ratepayers of the utility or its shareholders. The precise allocation is a matter of regulation. It is common for the rate impact to be included in the measurement of utility costs and benefits. Also, our calculation of utility impacts relies on the same discount rate used by the utility to determine the present value of the load shape change. For TUEC, this rate corresponds to the weighted average cost of capital adjusted for the tax benefits on debt (11.5%). NPC, on the other hand, uses the un-adjusted weighted average cost of capital (15.07%).

The financial impact on society more closely resembles traditional cost/benefit analyses. In this calculation, the capital and labor cost of implementing the conservation policy is compared to the avoided production cost benefits. In the case of thermal integrity improvements, direct fuel (non-electricity) savings must also be considered part of the benefit of the policies. In addition, societal cost calculations typically employ lower discount rates. We will continue to use the same discount rate for TUEC, but use the lower, equivalent rate for NPC (i.e. weighted average cost of capital adjusted for tax benefits on debt, 11.89%).

The Financial Model, too, is dependent on information supplied by the utility. These data are typically in the form of tariff sheets for the rate impact effect and offers to purchase power from small power producers and cogenerators for avoided costs. This procedure was employed in the TUEC case study [**TUEC, 1985; Eto, 1986b**]. For the Nevada Power case study, we developed independent estimates of marginal production costs with the Telplan production-cost simulation program developed for the Electric Power Research Institute [**Tera, 1982**]. The interested reader is directed to our technical report for additional details on the development of marginal costs for Nevada Power [**Eto, 1986a**].

IV. LOAD SHAPE AND FINANCIAL IMPACTS

Our discussion of the results of the case studies will start with a review of the load shape impacts of the conservation policies. Then, after describing the intermediate financial results, we will summarize the financial impacts on ratepayers and society.

1. Load Shape Impacts

The energy and demand impacts of the conservation policies are summarized in Tables 4.1 and 4.2 for TUEC and NPC, respectively. The results generally track the increases in thermal integrity mandated by each policy. For both utilities, the passive solar policy yields the largest savings in both energy and demand; Tables 2.2 and 2.3 show that these policies specify the highest levels of thermal integrity. For the other policies, the rankings for each utility diverge, but still follow the increases in thermal integrity. For TUEC, the weatherization policy generates the next largest savings, while for NPC the new construction policy ranks second.

For several policies, the rankings differ between energy and peak demand savings. For TUEC, the floor insulation policy saves more energy than retrofitting existing houses to the thermal integrity of new construction, but reduces peak demand by only a third the level of the new construction policy. A similar reordering is found for the floor insulation and weatherization policies for NPC houses. In this case, the floor insulation policy saves more energy than the weatherization policy, but has a smaller effect on peak demand.

The most concise summary of the load shape impact of the policies is given by the effect on residential class load factors. Load factors measure the relationship between peak and average demands. From a utility perspective, a high load factor is desirable because it indicates that capacity installed to serve peak demands is being utilized relatively more during non-peak demand conditions. For TUEC, Table 4.1 shows that the passive solar, the weatherization, and the triple glazing policies all have progressively smaller positive impacts on the residential class load factor, in that order. For NPC, Table 4.2 shows that only the passive solar policy increases the residential class load factor. The impacts on class load factors have important consequences for our financial impact analyses.

Figures 4.1 and 4.2 show the impacts of each policy on monthly sales for TUEC and NPC, respectively. Figures 4.3 and 4.4 show the respective impacts of each policy on monthly peak demands. These figures illustrate two features common to all the policies. First, the energy impacts of the policies are uniform across seasons; for each policy, the ordering remains the same for both seasons. Second, although the same general result applies to peak demands, for NPC the spread in demands between policies is narrowest in the month of the highest peak demand. For all other months the spreads are relatively constant.

Figures 4.5 and 4.6 show the hourly load impacts of the policies for TUEC on the peak summer and peak winter days. Figures 4.7 and 4.8 show the corresponding hourly load impacts for NPC. The same general trends noted in examining the monthly plots are also observed in these hourly load profiles for the peak summer and winter day.

Table 4.1 Load Shape Impacts - Texas Utilities Electric Company

Policy Case	Energy Total (GWh)	Energy Savings (GWh)	Peak Demand Total (MW)	Peak Demand Savings (MW)	Class Load Factor (%)
Base	9522.9		2636.0		41.2
New Construction	9103.0	(419.9)	2539.7	(96.3)	40.9
Weatherization	8608.4	(914.5)	2261.4	(374.6)	43.5
Floor Insulation	9035.7	(487.2)	2608.4	(27.6)	39.5
Triple Glazing	8945.7	(577.2)	2398.2	(237.8)	42.6
Passive Solar	7006.3	(2516.6)	1755.3	(880.7)	45.6

Table 4.2 Load Shape Impacts - Nevada Power Company

Policy Case	Energy Total (GWh)	Energy Savings (GWh)	Demand Total (MW)	Demand Savings (MW)	Class Load Factor (%)
Base	2918.2		821.3		40.6
New Construction	2626.2	(292.0)	757.0	(64.3)	39.6
Weatherization	2805.9	(112.3)	792.6	(28.7)	40.4
Floor Insulation	2709.0	(209.2)	796.1	(25.2)	38.8
Triple Glazing	2846.0	(72.2)	801.7	(19.6)	40.5
Passive Solar	2511.4	(406.8)	671.1	(150.2)	42.7

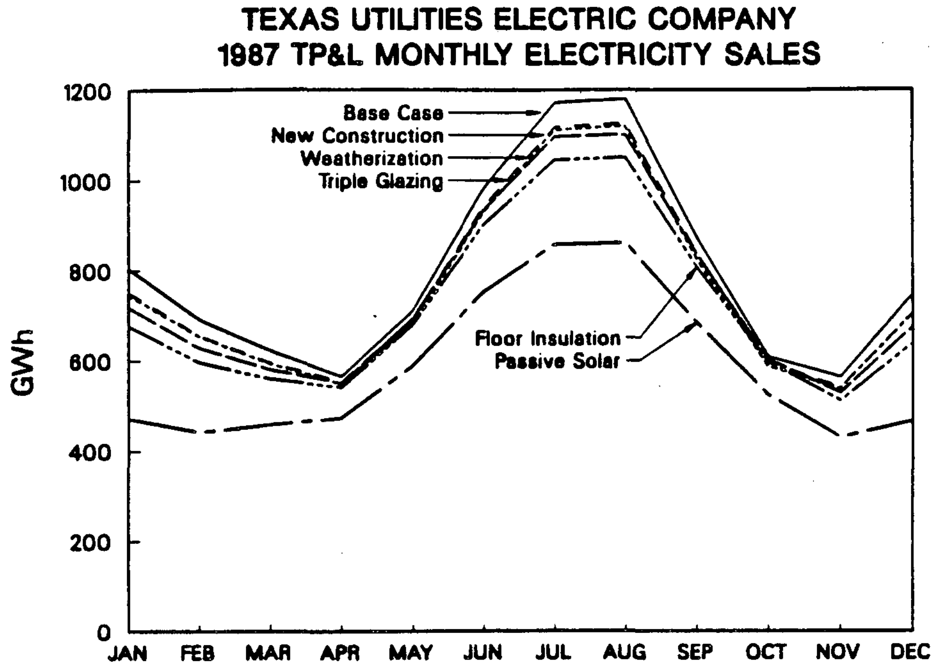

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Figure 4.1 Monthly residential sales for the TP&L service territory of TUEC for the base and each policy case in 1987.

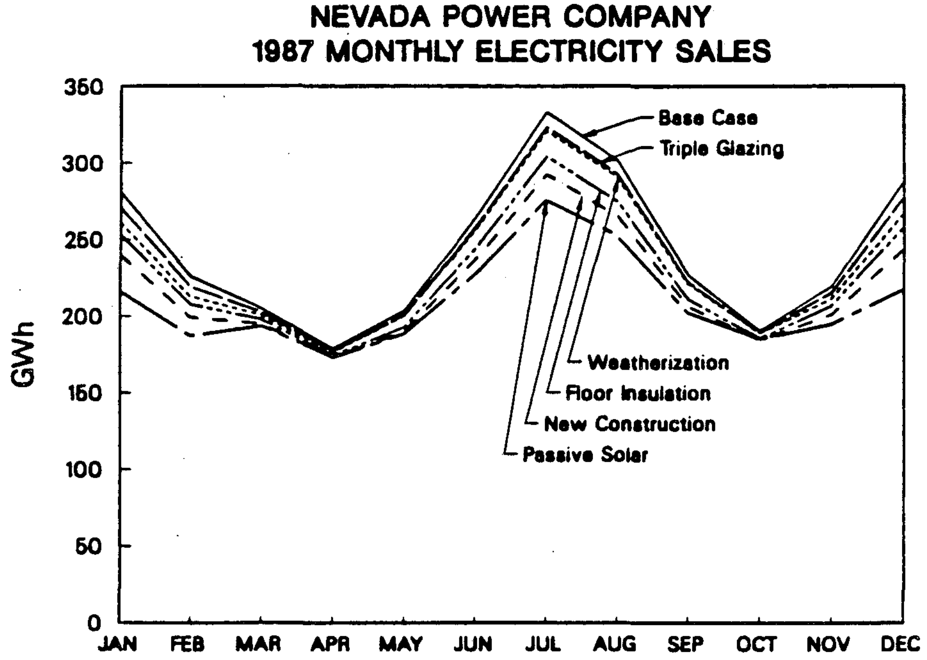

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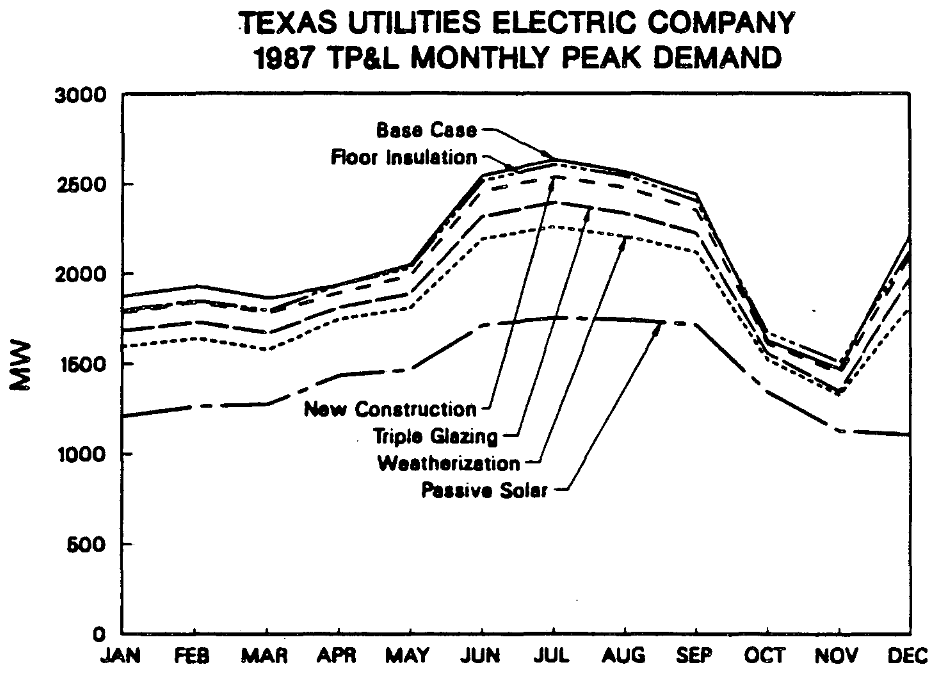
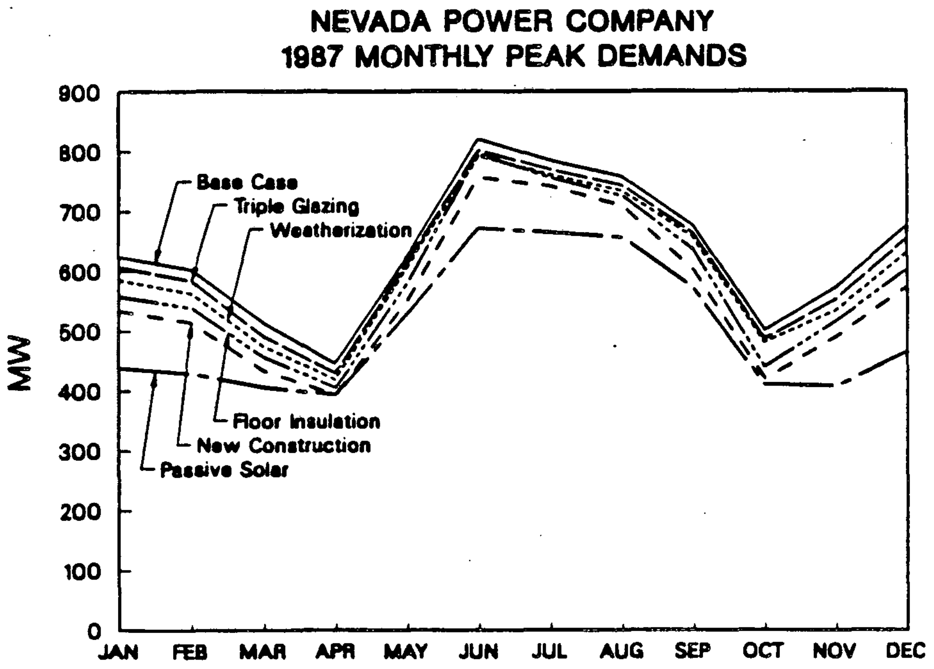
Figure 4.2 Monthly residential sales for NPC for the base and each policy case in 1987.



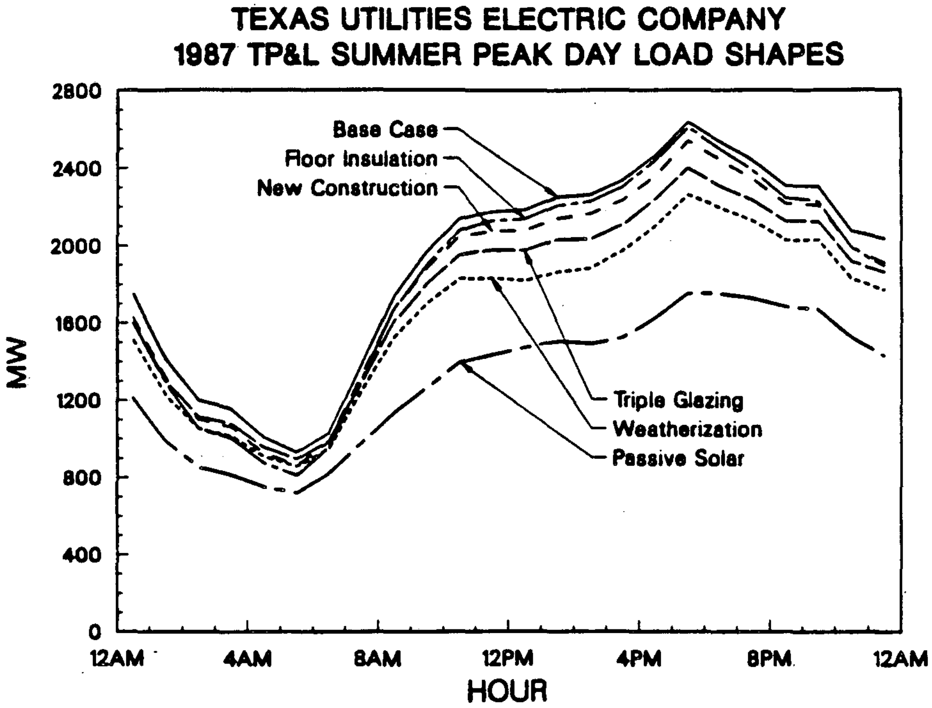
XCG 867-7324

Figure 4.3 Monthly residential class peak demands for the TP&L service territory of TUEC for the base and each policy case in 1987.



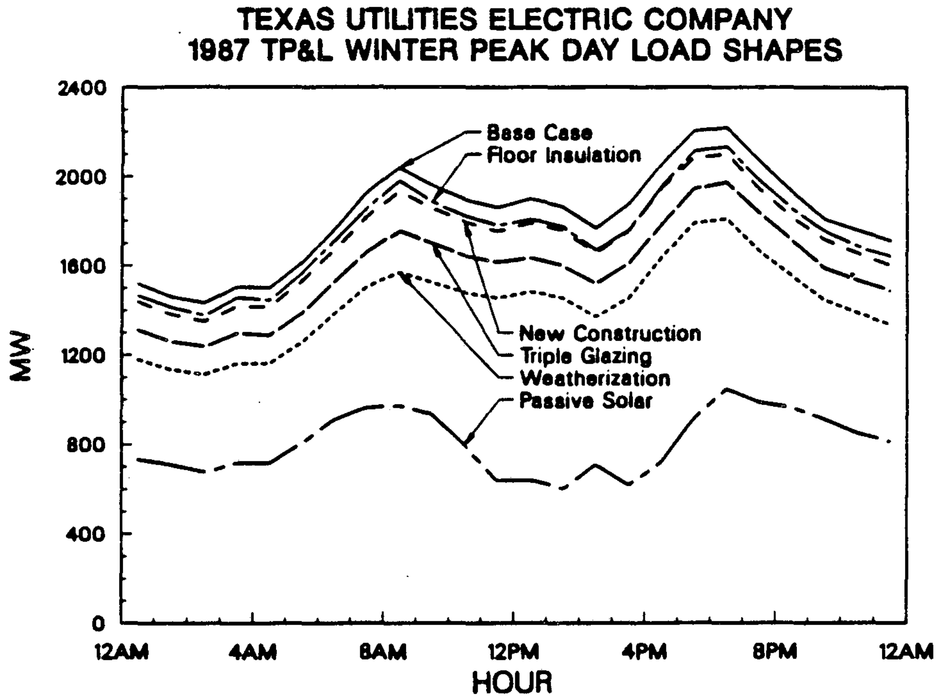
XCG 867-7322

Figure 4.4 Monthly residential class peak demands for NPC for the base and each policy case in 1987.



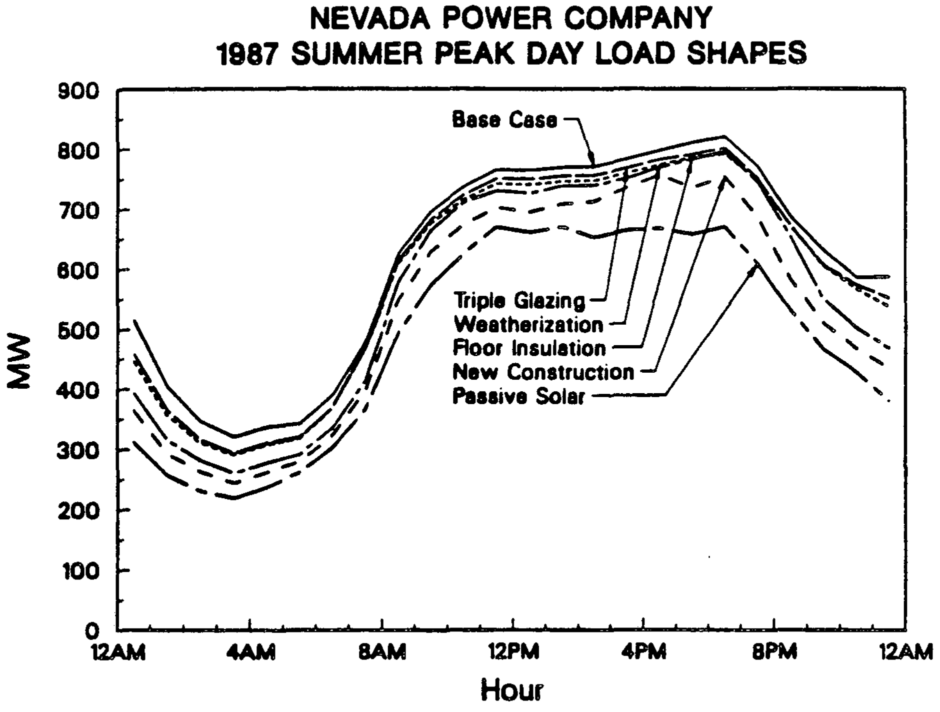
XCG 867-7320

Figure 4.5 Summer peak day for the TP&L service territory of TUEC for the base and each policy case in 1987.



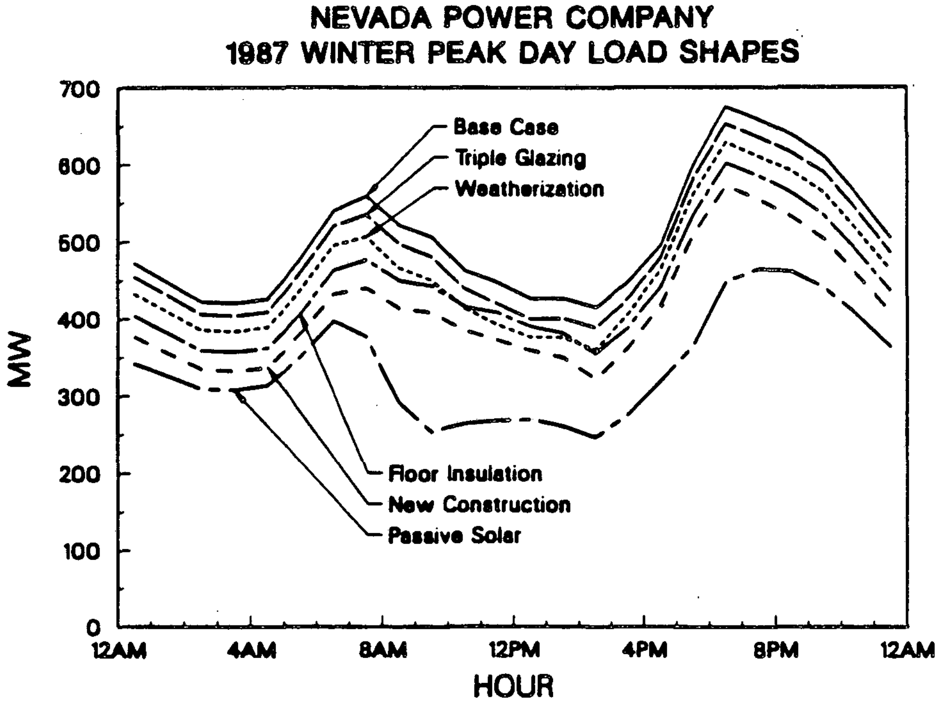
XCG 867-7321

Figure 4.6 Winter peak day for the TP&L service territory of TUEC for the base and each policy case in 1987.



XCG 867-7318

Figure 4.7 Summer peak day for NPC for the base and each policy case in 1987.



XCG 867-7319

Figure 4.8 Winter peak day calibration for NPC for the base and each policy case in 1987.

2. Financial Impacts

We consider financial impacts on both the utility and society. The basis for both impacts is the avoided production cost benefits resulting from reduced electricity demands. Tables 4.3 and 4.4 summarize these benefits for TUEC and NPC, respectively. The quantities in these and all other tables represent 1985 present values for the 20-year stream of benefits or costs that results from load shape changes in 1987. For brevity, these tables only report on the values used in the utility impact analyses. The equivalent tables for the societal impact analyses would reflect the lower discount rate being used to express the NPC results.

Examining the per unit values quantifies the influence of class load factors on the valuation; higher load factors tend to be associated with greater production cost savings. The triple glazing and weatherization policies for TUEC, and the new construction and passive solar policies for NPC have both the highest per unit values and the highest load factor. Although total avoided production costs scale with the amount of energy saved, the per unit values associated with each policy are a better indicator of the relative worth of avoided production expenses. Further examination of the components of avoided production expenses shows that the differences in capacity value ultimately determine which policy has the highest per unit value. The per unit values for the energy component of each policy are nearly identical because the policies have consistent monthly load shape impacts (see Figures 4.1 and 4.2). That is, the variations in marginal energy cost by month do not serve to differentiate among policies since the amount of energy saved by policies across seasons is relatively constant.

Utility Impact

The utility impact is measured by comparing avoided production cost benefits with the rate impact costs (see Tables 4.5 and 4.6). For the rate impact cost, the most revealing term is again the per unit value of the rate impact and its components. For TUEC, the lost revenue term fluctuates with the level of winter sales relative to summer sales due to application of the block-adjustment procedure to the tiered winter tariff. Since these rate impacts are costs, the policies with lower per unit rate impacts (triple glazing and new construction for TUEC) will be relatively more valuable in the final calculation of ratepayer impact. For NPC, the rate impact cost is actually a benefit since lost revenues are offset by higher valued avoided variable costs. The greatest benefit for NPC results from the triple glazing policy, which is followed by passive solar, floor insulation, new construction, and weatherization.

The net impact on the utility is positive for all policies in both utility service territories (see Tables 4.7 and 4.8). Although the policy that yields the greatest reduction in sales has the highest absolute value (passive solar), the ordering changes dramatically for the other policies.

Examining per unit values reveals that for both TUEC and NPC the triple glazing policy yields the greatest relative benefit. For TUEC, this result stems from the high avoided production cost benefit and the low rate impact cost for this policy. For NPC, the result is due primarily to the rate impact cost (which is a positive benefit).

Unlike the avoided production cost results, the ordering of per unit utility impacts is not obvious from examination of the load shape impacts, alone. The triple glazing policy has the lowest of the positive impacts on the TUEC residential class load factors and a negative impact on NPC residential class load factor (see Tables 4.1 and 4.2). These same load shape impacts, however, contribute to lower per unit rate impact costs that, combined with avoided production costs, result in the greatest relative benefits to the utility.

Table 4.3 Avoided Production Costs - Texas Utilities Electric Company

	Energy Savings			Capacity Savings			Total	
Policy Case	(GWh)	(M$)	($/kWh)	(MW)	(M$)	($/kWh)	(M$)	($/kWh)
New Construction	419.9	170.4	0.406	87.6	43.4	0.103	213.7	0.509
Weatherization	914.5	370.9	0.406	314.9	155.9	0.171	526.8	0.576
Floor Insulation	487.2	197.9	0.406	38.2	18.9	0.039	216.8	0.445
Triple Glazing	577.2	233.5	0.405	196.9	97.5	0.169	331.0	0.573
Passive Solar	2516.6	1018.5	0.405	684.0	338.7	0.135	1357.2	0.539

Table 4.4 Avoided Production Costs - Nevada Power Company

	Energy Savings			Capacity Savings			Total	
Policy Case	(GWh)	(M$)	($/kWh)	(MW)	(M$)	($/kWh)	(M$)	($/kWh)
New Construction	292.0	105.4	0.361	74.6	23.4	0.080	128.8	0.441
Weatherization	112.3	40.2	0.358	20.6	6.5	0.058	46.7	0.416
Floor Insulation	209.2	75.6	0.361	45.0	14.1	0.068	89.7	0.429
Triple Glazing	72.2	26.1	0.361	13.8	4.3	0.060	30.4	0.421
Passive Solar	406.8	146.9	0.361	116.9	36.7	0.090	183.6	0.451

Table 4.5 Rate Impact - Texas Utilities Electric Company

		A Lost Revenues		B Avoided Variable Cost		A - B Rate Impact	
Policy Case	Savings (GWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)
New Construction	419.9	265.8	0.633	183.2	0.436	82.5	0.197
Weatherization	914.5	732.9	0.801	399.1	0.436	333.8	0.365
Floor Insulation	487.2	332.3	0.682	212.6	0.436	119.7	0.246
Triple Glazing	577.2	344.9	0.598	251.9	0.436	93.0	0.161
Passive Solar	2516.6	1858.2	0.738	1098.2	0.436	760.0	0.302

Table 4.6 Rate Impact - Nevada Power Company

		A Lost Revenues		B Avoided Variable Cost		A - B Rate Impact	
Policy Case	Savings (GWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)
New Construction	292.0	140.1	0.480	170.1	0.582	-30.0	-0.103
Weatherization	112.3	53.9	0.480	57.9	0.516	-4.1	-0.036
Floor Insulation	209.2	100.3	0.480	123.9	0.592	-23.5	-0.112
Triple Glazing	72.2	34.6	0.480	47.6	0.659	-12.9	-0.179
Passive Solar	406.8	195.1	0.480	247.1	0.607	-52.0	-0.128

Table 4.7 Utility Impact - Texas Utilities Electric Company

	Load Shape Change		A Avoided Cost Benefit		B Rate Impact Cost		A - B Net Benefit	
Policy Case	Energy (GWh)	Capacity (MW)	Total (M$)	($/kWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)
New Construction	419.9	87.6	213.7	0.509	82.5	0.197	131.2	0.313
Weatherization	914.5	314.9	526.8	0.576	333.8	0.365	193.0	0.211
Floor Insulation	487.2	38.2	216.8	0.445	119.7	0.246	97.2	0.199
Triple Glazing	577.2	196.9	331.0	0.573	93.0	0.161	238.0	0.412
Passive Solar	2516.6	684.0	1357.2	0.539	760.0	0.302	597.2	0.237

Table 4.8 Utility Impact - Nevada Power Company

	Load Shape Change		A Avoided Cost Benefit		B Rate Impact Cost		A - B Net Benefit	
Policy Case	Energy (GWh)	Capacity (MW)	Total (M$)	($/kWh)	Total (M$)	($/kWh)	Total (M$)	($/kWh)
New Construction	292.0	74.6	128.8	0.441	-30.0	-0.103	158.8	0.544
Weatherization	112.3	20.6	46.7	0.416	-4.1	-0.036	50.7	0.452
Floor Insulation	209.2	45.0	89.7	0.429	-23.5	-0.112	113.2	0.541
Triple Glazing	72.2	13.8	30.4	0.421	-12.9	-0.179	43.3	0.600
Passive Solar	406.8	116.9	183.6	0.451	-52.0	-0.128	235.6	0.579

For TUEC, the new construction policy yields the next largest per unit benefit. This policy again has a negative impact on the residential class load factor, a relatively low per unit avoided production cost benefit, but a low per unit rate impact cost. For NPC, the next largest per unit benefit results from the passive solar policy. In this case, the result is consistent with the improvement in residential class load factor.

The policies with the lowest ratepayer benefit are floor insulation for TUEC and weatherization for NPC. For each policy, per unit avoided production cost benefits are lowest and the per unit rate impact cost are highest. While this result correlates with the reduction in load factor of the policy for TUEC, several policies reduce load factors further in NPC.

Societal Impacts

The calculation of societal impacts starts with the avoided production cost benefits described earlier. These benefits are increased by direct fuel savings resulting from decreased fuel consumption. The costs of the thermal integrity conservation policies to society are the material and labor cost of the retrofits and, in the case of new buildings, the incremental levels of insulation or glazings required. The appendix contains details of this component of the calculation. Societal costs are not calculated for the passive solar case due to the extreme thermal integrity measures called for by the policy. These measures, especially those calling for increases in building thermal mass and reorientation of glazing surfaces, would be prohibitively expensive as retrofit measures. In keeping with our previous case studies of these two utilities, we use the utility's rate of disadvantage to express our results in 1985 present values. Tables 4.9 and 4.10 summarize the societal impact calculations for each policy for TUEC and NPC, respectively.

We find that the preferences of ratepayers and society for the thermal integrity conservation policies differ markedly. With one exception, the societal impact of our policies is negative. Only the floor insulation policy in NPC houses shows a net benefit from the societal perspective. It is worth noting that this policy also has the worst impact on load factor for NPC.

For TUEC, the floor insulation and triple glazing policies have the least negative societal impact. The societal impacts of the new construction and weatherization policies are large. After floor insulation the ranking for NPC is triple glazing, new construction, and weatherization.

The appendix suggests that the costs developed for these societal impact calculations may be high. Nevertheless, it is unlikely that even substantially lower retrofit costs would alter our conclusions.

Table 4.9 Societal Impact - Texas Utilities Electric Company

	Load Shape Change		A Avoided Production Cost Benefit		B Direct Fuel Savings Benefit		(A + B) Total Benefit	C Mat'l & Labor Costs	(A + B) - C Net Benefit
Policy Case	Energy (GWh)	Capacity (MW)	Total (M$)	($/kWh)	Total (M$)	($/MBtu)	(M$)	(M$)	(M$)
New Construction	419.9	87.6	213.7	0.509	152.4	62.96	366.1	1830.0	-1463.9
Weatherization	914.5	314.9	526.8	0.576	316.1	62.96	842.9	3441.0	-2598.1
Floor Insulation	487.2	38.2	216.8	0.445	158.0	62.96	374.8	871.0	-496.2
Triple Glazing	577.2	196.9	331.0	0.573	222.3	62.96	553.3	1150.0	-596.7

Table 4.10 Societal Impact - Nevada Power Company

	Load Shape Change		A Avoided Production Cost Benefit		B Direct Fuel Savings Benefit		(A + B) Total Benefit	C Mat'l & Labor Costs	(A + B) - C Net Benefit
Policy Case	Energy (GWh)	Capacity (MW)	Total (M$)	($/kWh)	Total (M$)	($/MBtu)	(M$)	(M$)	(M$)
New Construction	292.0	74.6	133.7	0.458	211.7	69.423	345.4	646.0	-300.6
Weatherization	112.3	20.6	49.3	0.439	112.5	69.423	161.8	791.0	-629.2
Floor Insulation	209.2	45.0	94.1	0.450	152.7	69.423	246.8	109.0	+137.0
Triple Glazing	72.2	13.8	32.1	0.444	71.5	69.423	103.6	262.0	-158.4

V. SUMMARY

We have performed an integrated analysis of the load shape and financial impacts of increased thermal integrities for residential buildings in the Texas Utilities Electric and Nevada Power Company service territories. The analysis incorporated results from four LBL models, including the DOE-2 Building Energy Analysis Model, the LBL Residential Energy Model, the LBL Residential Hourly and Peak Demand Model, and the LBL Financial Impacts on Utilities of Load Shape Changes Model. Financial impacts on both ratepayers and society were calculated.

The analysis began with DOE-2 computer simulations of the effect of five sets of thermal integrity improvements on annual heating and cooling loads. These estimates were generated by repeated simulations for prototypical buildings developed from reported characteristics of the existing stock and new construction practice in each service territory.

The five sets of thermal integrity improvements were:

1. Increasing levels of insulation and numbers of glazings in existing homes to those of new construction;
2. Implementing a weatherization package that includes high insulation levels, low infiltration, and multiple glazings;
3. Installing floor insulation, alone;
4. Installing triple glazing, alone;
5. Implementing a passive solar package, which includes the measures from the weatherization package, additional thermal mass, and re-orientation of glazing surfaces.

The relative improvements in heating and cooling loads from DOE-2 were then input to the LBL Residential Energy and LBL Residential Hourly and Peak Demand Models to produce detailed forecasts of energy and hourly demands by end-use. Together, these models are capable of producing a twenty year forecast of hourly end-use electricity demands. Though not analyzed in the current study, the LBL Residential Energy Model also accounts for non-electrical energy use and fuel-switching. Extensive calibration to historic sales and peak demands preceded these forecasts.

The LBL Financial Impacts on Utilities of Load Shape Changes model was used to calculate results from both a utility perspective and a societal perspective. Avoided costs for both energy and capacity in both the long- and short-run were calculated, primarily from utility-supplied data. In the short-run, avoided production costs are determined by the variable operating costs of existing plants. In the long-run, capital costs of as yet unbuilt plants figure into the calculation of avoided production costs. Both a reliability or capacity-related component and an energy-related component of the long-run capital investment decision were isolated. For the Nevada Power case study, we were able to make independent estimates of avoided production costs with the aid of an EPRI production-cost model. For the Texas Utilities case study, we relied on published offers to purchase power from cogenerators.

The utility impact of load shape changes was measured by comparing the avoided production cost benefits to the rate impact costs. The rate impact cost is the under-recovery of fixed costs resulting from decreased sales of electricity, which must be recovered from existing customers. The rate impact cost was calculated by reducing lost revenues, as determined by the utility's forecast of future retail rates, by avoided marginal variable operating costs. For NPC, this cost was, in fact, a benefit since avoided marginal variable operating costs exceed projected retail rates. The societal impact of load shape changes considered both the ratepayer impact and the additional cost of higher levels of thermal integrity. In addition, a lower discount rate was used to compute the present value of savings for NPC.

Tables 5.1 and 5.2 summarize the load shape and financial impacts of the five policy cases for TUEC and NPC, respectively.

We find that ratepayers and society will differ in their preferences for the conservation policies that raise the thermal integrity of residential buildings. In particular, we observe that while all conservation policies examined have positive net benefits for ratepayers, the costs exceed benefits from the societal perspective. The driving force for this conclusion is the large material and labor costs associated with the implementation of the policies.

An analysis of our results and its components with per unit values revealed that simple aggregate statistics such as the effect of policies on class load factors did not correlate well with the financial impacts on ratepayers and society.

Future Work

The analyses to date have pointed to two directions for enhancements to our policy analysis methods:

1. We would like be able to relate the effects of load shape changes more directly to retail rates in our rate impact cost calculation. To date, we have relied on utility-supplied estimates of future retail rates.
2. The data base for the material and labor cost and improvements to appliance equipment efficiency is known to be out-dated. We are now in the process of up-dating these data.

Table 5.1 Summary of Results - Texas Utilities Electric Company

	Load Shape Impacts			Financial Impacts			
				Utility		Societal	
Policy Case	Energy	Demand	Load Factor	Total	Per Unit	Total	Per Unit
New Construction	5	4	4 (-)	4	(2)	3	(-)
Weatherization	2	2	2 (+)	3	(4)	4	(-)
Floor Insulation	4	5	5 (-)	5	(5)	1	(-)
Triple Glazing	3	3	3 (+)	2	(1)	2	(-)
Passive Solar	1	1	1 (+)	1	(3)	n/a	

Table 5.2 Summary of Results - Nevada Power Company

	Load Shape Impacts			Financial Impacts			
				Utility		Societal	
Policy Case	Energy	Demand	Load Factor	Total	Per Unit	Total	Per Unit
New Construction	2	2	4 (-)	2	(3)	3	(-)
Weatherization	4	3	3 (-)	4	(5)	4	(-)
Floor Insulation	3	4	5 (-)	3	(4)	1	(+)
Triple Glazing	5	5	2 (-)	5	(1)	2	(-)
Passive Solar	1	1	1 (+)	1	(2)	n/a	

For all columns, 1 corresponds to the greatest savings or value, 5 to the lowest. For load factor, + in parentheses means an increase in residential class load factor relative to the base case, - means a decrease. For ratepayer impact, 1 in parentheses corresponds to the largest per unit value, 5 to the lowest. For the societal impact, + in parentheses means that the impact is positive, - means that it is negative.

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APPENDIX: METHODOLOGY AND DATA SOURCES USED TO CALCULATE THE COST OF THERMAL INTEGRITY IMPROVEMENTS

This appendix illustrates how we calculated the cost of installing selected thermal integrity improvements in new and existing houses in 1987. To facilitate the analysis, we divided the housing stock of each utility into three separate populations: homes built before the first year of the forecast that are still standing in 1987 (group A), homes built between the first year of the forecast and 1987 (group B), and new homes built in 1987 (group C). This division is helpful because the thermal integrity characteristics of homes within these groups are either well known (group A) or can be easily estimated (groups B and C). We defined an average house for each of these three groups, and calculated the expenditures needed to improve the thermal integrity of these average houses.

The cost of efficiency improvements for some average new house under building efficiency standards should be calculated with reference to the thermal integrity of the new house that would have been built if the standards did not exist. The LBL Residential Energy model calculates changes in the thermal integrity of new and existing homes over the analysis period, based on changes in personal income, fuel prices, and appliance efficiency. The model expresses these changes in thermal integrity as changes in a Thermal Integrity (TI) ratio. The TI ratio for heating is the heating-load of the average new house or average existing house in some year divided by the heating load of the base-year average existing house. An analogous ratio exists for cooling that is not necessarily equal to the heating TI ratio. The thermal integrity ratio for average existing homes in the base year is equal to one, by definition. This appendix focuses exclusively on changes in the heating TI ratio, but the analysis could have been done using cooling TI ratios; the choice is arbitrary.

Forecasted improvements in the thermal integrity ratio are not related directly to specific thermal integrity measures by the LBL Residential Energy Model. Instead, a forecasted change in TI must be converted to a series of specific measures based on supply curves of conserved energy; this conversion introduces uncertainty. This supply curve approach is developed more fully in the second part of this appendix and is used to calculate adjustment factors for the costs of improving the TI of homes in groups B and C.

For retrofit costs, we used the Solar Energy Research Institute's (SERI's) Residential Retrofit Specification/Cost Data Base [**SERI, 1982**]. For the cost of thermal integrity measures in new homes, we used a report prepared by the National Association of Homebuilders' (NAHB) Research Foundation for the American Society of Heating, Refrigeration, and Air-Conditioning Engineers [**NAHB, 1986**]. These sources of cost data are themselves uncertain. See the last part of this appendix for a discussion of the relevant uncertainties.

The first section of this appendix presents the base-year TI characteristics of new and existing homes in the TP&L and NPC service territories. The second section uses supply curves of conserved energy to estimate how much the reduction in heating-load TI ratios in the base case (caused by market forces) reduces the cost of improving the TI in the policy cases for homes in groups B and C. The third section illustrates the method we used to calculate the costs of retrofitting TI improvements, and the fourth section illustrates the method for deriving the costs of these improvements for new homes and presents a summary table of the results. The final section discusses the causes of uncertainties in the calculations, and provides a rough estimate of their magnitude.

Base Year Thermal Characteristics of New and Existing Homes

Table A-1 shows the characteristics of the prototypical homes used in the analysis that are not specifically related to thermal integrity. Because these are "average" houses, they may have seemingly anomolous characteristics, like fractional numbers of windows. We do not claim that our prototypes correspond to any homes currently in existence, only that they represent a plausible synthesis of the relevant statistics about all dwellings in the TP&L and NPC service territories.

The prototypical house was derived by combining utility survey data (average floor area, insulation levels, etc.) with the characteristics of the prototypical houses used by LBL's DOE-2 building-energy simulation program [**Huang, 1986**]. Some characteristics of the DOE-2 prototypes have been scaled up or down as the square root of the floor area, such as wall area, foundation perimeter, and window perimeter. Other characteristics have been scaled linearly with the floor area, such as window area, number of windows, and rate of air infiltration.

About two-thirds of NPC homes are built with a crawl space underneath the floor, while the rest are built on slabs. We assumed that the prototypical NPC home had a crawl space, because we could find no easy way to combine the characteristics of slab and crawl space homes when using the DOE-2 model. Almost all TP&L homes are built on slabs. We assume that these houses are one story, so that each square foot of floor area corresponds to one square foot of ceiling area, and the wall area shown in Table A-1 is the foundation perimeter times the height of the ceiling (8 ft).

Table A-1: Characteristics of Prototypical Houses

Characteristic	DOE-2	NPC	TP&L
Floor Area (ft^2)	1540	1510	1660
Wall Area (ft^2)	1328	1315	1379
Window Area (ft^2)	154	151	166
Wall Area (w/o windows)(ft^2)	1174	1164	1213
Number of Windows	8	7.84	8.62
Window Perimeter (ft)	140.4	139	146
Foundation Perimeter (ft)	166	164	172
Air Infiltration @ 0.7 ach (cfm)	143.7	140.9	154.9
Air Infiltration @ 0.4 ach (cfm)	82.1	80.5	88.5

Adjusting Costs to Account for Improving TI Ratios In The Base Case

We calculated the costs for retrofitting homes built before the base year still existing in 1987 (group A) with reference to the characteristics of new and existing homes described in the body of this report. For example, when calculating the cost for additional ceiling insulation to reach R-38 for existing houses in the TP&L service territory, the incremental amount of insulation installed is (R-38 minus R-15) or R-23 for this group of TP&L houses .

Calculating changes in thermal integrity characteristics is more complicated for homes built between the base year and 1987 (group B), and for new homes in 1987 (group C), because the thermal integrity of these homes is improving every year, due to increases in fuel prices. The change in some characteristic, say ceiling insulation, must be measured with respect to the improving thermal integrity of homes in the base case. The rest of this section is devoted to explaining how to estimate the changes in each TI characteristic due to changes in the forecasted base-case heating-load TI ratios. This estimation results in the correction factors in Table A-5, which can be used to adjust the cost for thermal integrity improvements as calculated using the difference between the TI characteristics for new homes in the base year and the TI characteristics mandated in the policy cases.

The thermal integrity ratios calculated by the LBL Residential Energy model do not indicate which thermal integrity measures are undertaken to achieve a given TI ratio. We assume that a building owner who minimizes life-cycle costs will implement first those conservation measures with the lowest cost of conserved energy (CCE). We calculated the CCE for thermal integrity improvements affecting all parts of the house, and estimated the size of the TI change that each measure would induce. By ranking each of the measures from lowest CCE to highest, we identified those measures that could account for a given change in the TI ratio, and in what order the measures would be implemented.

Table A-2 shows selected measures ranked by costs of conserved energy for new homes built in the base year, with their associated changes in the TI ratios.** The change in a TI ratio is the change in energy consumption due to the measure, divided by the total energy consumption of an average existing house in the base year. We calculated the energy savings for each of the measures (except for infiltration reduction) using the formula

$$\text{Annual Energy Savings/ft}^2 = (U_1\text{-}U_2)(\text{HDD/yr})(24\text{hrs/day})/\text{Furnace Efficiency}$$

where

U_1 = conductance before installation (Btu/ft^2-hr-°F),

U_2 = conductance after installation (Btu/ft^2-hr-°F),

Furnace Efficiency = 0.7

and

HDD = heating degree days (65 °F base).*

For infiltration savings, we used the following formula from the ASHRAE fundamentals [ASHRAE, 1985, p. F-25.7]:

$$\text{Annual Energy Savings} = 1.08(\text{Chg in infiltration in cfm})(\text{HDD/yr})(24)/\text{Furnace Efficiency}$$

We compared the cost of conserved energy for many measures, and those with the lowest CCE are shown in Table A-2. For NPC, the cheapest measures analyzed are increasing wall insulation from R-12.5 to R-19, reducing infiltration from 0.7 ach to 0.4 ach, upgrading to triple pane glazing from double pane, and adding R-5 ceiling insulation to the R-31.7 already in the ceiling. For TP&L, the cheapest measures analyzed are improving slab insulation from R-5 to R-7.5 (2 ft.), reducing infiltration from 0.7 ach to 0.4 ach, adding double pane instead of single pane glazing, and improving wall insulation from R11.8 to R-19.

Table A-2: Ranking of Selected Measures By Cost of Conserved Energy

Measure	CCE 1985$/MMBtu	Ratio	Change in TI
NPC			
Wall R12.5-19	5.86	1.0	-5.4%
Infiltration	7.78	1.3	-9.8%
Window-2-3panes	14.06	2.4	-4.1%
Ceiling-R31.7-36.7	26.66	4.5	-0.7%
TP&L			
Slab-R-5-7.5, 2 ft.	3.17	1.0	-1.5%
Infiltration	7.71	2.4	-12.9%
Window 1-2panes	10.04	3.2	-16.4%
WallR11.8-19	11.86	3.7	-7.9%

The difference between the CCEs for wall insulation for NPC and TP&L is caused to a large degree by regional differences in installation costs, and to a lesser degree by the difference in Heating Degree Days.

Because we only need to know the order that the measures are implemented, the absolute values for the costs of conserved energy are not as important as the ratios between each measure's CCE and that of the least expensive measure. We calculated the dollar values of the CCEs using

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**The costs in the CCE calculation are taken from NAHB, 1986

*Note also that conductance =1/R-value

the formula

$$CCE = (CRF)(Cost/ft^2)/(Annual\ Energy\ Savings/ft^2)$$

where CRF is the capital recovery factor, calculated using each utility's rate of disadvantage and an amortization lifetime of twenty years, and the $Cost/ft^2$ is derived from the NAHB database for new homes (because the thermal integrity improvements between the base year and 1987 are occurring in new homes built in those years).

For consistency, the costs of conserved energy were calculated assuming that all homes are heated by natural gas, with a furnace efficiency of 0.7. Since we were only interested in the ratios of the CCEs, this convention will not introduce significant error.

Using the output from the LBL Residential Energy model, we calculated the weighted average percentage improvement in TI for homes in group B, as well as the percentage improvement in TI for homes in group C. Table A-3 shows these percentage changes, measured with respect to the base-year TI.

Table A-3: Forecasted Percentage Changes in TI Ratios

Utility	Housing Group	Change in TI Ratio
NPC	A	0%
NPC	B	-4.1%
NPC	C	-8.6%
TP&L	A	0%
TP&L	B	-3.6%
TP&L	C	-8.0%

Combining Table A-2 and Table A-3, we see that additional slab insulation plus infiltration reduction (for the TP&L case) and wall insulation plus infiltration reduction (for the NPC case) can more than account for the changes in the TI ratios calculated by the LBL Residential Energy model. For both cases, we used the following formulas to adjust the slab (or wall) insulation and infiltration costs. Factor 1 is the adjustment factor for the cost of the first measure in the supply curve (slab or wall insulation) and Factor 2 is the adjustment factor for the cost of the next measure (infiltration reduction) for a given change in the forecasted TI ratio.

Factor1 = 100% - Chg in TI for (Slab or Wall) Insulation

Factor2 = 100%-(Forecasted Chg in TI - Chg in TI for Slab or
Wall Insulation)/ (Chg in TI for full infiltration reduction)

Table A-4 shows cost-adjustment factors calculated using the above formulas. These factors are multiplied by the cost of improving the new house in the base year to the standard level for each measure. These factors represent the adjustment to account for the improving thermal integrity of new homes built between the base year and the year that the standard is implemented, and those built after the year that the standard is implemented.

Table A-4: Cost-Adjustment Factors

Measure	Housing Group	NPC	TP&L
Slab Edge Insulation	B and C	—	0.959
Wall Insulation	B	0.241	—
Wall Insulation	C	0	—
Infiltration	B	—	0.849
Infiltration	C	0.673	0.622

For example, the adjustment factor for the cost of wall insulation for homes in group B of the NPC service territory is 0.241. This number implies that the cost of retrofitting wall insulation to R-19 for homes built during the period 1981 to 1986 is only one-fourth of the cost that we would expect by calculating the difference in cost between new homes with the amount of wall insulation in the base year (R-12.5) and new homes with R-19 insulation. An equivalent interpretation is that roughly three quarters of the homes built during the period 1981 to 1986 will already have installed R-19 insulation in the walls. New homes built in 1987, will, according to the same analysis, all have R-19 wall insulation, and the additional costs for group C due to a standard requiring this level of insulation will be zero (hence the entry of zero in the table of adjustment factors for wall insulation for group C).

Calculating Retrofit Costs

Homes Built Before the Base Year Existing in 1987 (Group A)

We calculated the retrofit costs for thermal integrity improvements for homes built before the base year existing in 1987 from information in the SERI Residential Retrofit Specification/Cost Data Base [**SERI, 1982**]. This source gives cost estimates for conservation retrofits in selected major cities around the U.S. We used retrofit data for Las Vegas, Nevada for houses in the Nevada Power Company's service territory, and data for Houston, Texas for those in the Texas Power and Light Company service territory. The SERI database expresses the costs as of October 1982. We arbitrarily called these 1983 dollars, inflated the costs to 1987 dollars using the Consumer Price Index and each utility's projected inflation rates, and then discounted these costs from 1987 to 1985 using each utility's rate of disadvantage. We used contractor costs in all cases, which is a conservative assumption because some homeowners would surely install some of the retrofit measures by themselves were a building standard to be imposed.

Table A-6 shows the costs for each retrofit measure for each policy case for each utility, broken down by measure and by policy cases. Note that 162,500 NPC homes built before 1980 will be standing in 1987, and 625,500 TP&L homes built before 1981 will be standing in 1987.

Table A-6: Retrofit Costs for Homes in Group A (1985 $)

NPC							
Policy Case	Ceiling	Wall	Floor	Infiltration	Glazing	Totals	All Homes-Total
Current Practice	1526.0	1351.4	669.9	0.0	426.0	3973.4	6.46e8
Weatherization	1883.9	1814.8	0.0	453.4	0.0	4152.0	6.75e8
Floor Insulation	0.0	0.0	669.9	0.0	0.0	669.9	1.09e8
Triple Glazing	0.0	0.0	0.0	0.0	1307.1	1307.1	2.12e8
TP&L							
Current Practice	1334.7	1213.4	372.2	0.0	0.0	2920.3	1.83e9
Weatherization	2159.5	1771.0	0.0	460.5	0.0	4391.0	2.75e9
Floor Insulation	0.0	0.0	1159.2	0.0	0.0	1159.2	7.25e8
Triple Glazing	0.0	0.0	0.0	0.0	1410.1	1410.1	8.82e8

Ceiling Insulation

The SERI retrofit database indicates that its costs for initial R-11 applications of ceiling insulation contain the fixed costs of the contractor traveling to the site and setting up equipment. Because we had no information on the proportions of different types of insulation installed, or on the breakdown of different roof types, we averaged the cost of loose-fill and blanket insulation, and averaged the costs for homes with unfloored/unfinished attics, homes with flat roofs that have crawl spaces, and homes with flat roofs that do not have crawl spaces.

For the TP&L case, the amount of retrofit insulation installed is less than R-11 in one of the policy cases. We extracted the fixed costs implicit in the SERI database's number for R-11 insulation by multiplying the cost for an additional square foot of R-1 insulation times 11, and subtracting this number from the cost per square foot for the initial R-11 application. The cost for retrofitting ceiling insulation to a level less than R-11 is the fixed cost per square foot plus the cost for an additional square foot of R-1 insulation times the R-value of the desired insulation level.

Wall Insulation

Some of the policy cases require that homes be retrofit with R-19 wall insulation. The only possible way to accomplish this task in homes with 2" by 4" studs is to install rigid exterior wall insulation. The SERI database only included the cost of rigid exterior insulation for masonry walls, and conversations with independent experts confirm that exterior insulation is almost never installed on homes with stud walls. Such installation requires removing any exterior siding, attaching the insulation, and replacing the siding. Estimating the costs for such an endeavor without adequate experience is necessarily speculative.

The SERI database did not indicate how much of the cost to retrofit exterior wall insulation was for fixed costs and how much for insulation costs. To estimate this breakdown, we used information about the cost to install rigid slab edge insulation given in the NAHB database for new homes (properly inflated and discounted to comparable dollars). While imperfect, this approach is more accurate than ignoring the breakdown of fixed and insulation costs. The cost of slab edge insulation includes the cost of the insulation, the cost of travelling to the site and setting up equipment, the cost of plastering over the insulation, and the cost of covering the insulation with dirt. The NAHB data includes information about insulation costs and the costs of covering the insulation with dirt. Using this information, deriving the fixed costs is trivial. Once the cost per square foot of the insulation is derived, it is multiplied by the wall area.

Floors

For all of the NPC policy cases, the cost of floor insulation is the cost of installing R-11 insulation between the open joists underneath the floor. Since the DOE-2 prototype crawl space house assumes that the crawl space is vented to the outside air, an uninsulated floor is equivalent to an uninsulated wall, and the insulation has a dramatic effect on building energy use. We assume that the relevant insulated area is the same as the floor area.

Calculating the costs of slab edge insulation for TP&L's houses is more complicated, and certainly more speculative. It is unclear that anyone would choose to retrofit slab insulation, which involves digging a trench around the building foundation two to four feet deep. The SERI database of retrofit costs did not even include costs for slab insulation retrofits.

To estimate the costs for retrofits, we used the costs for insulating slabs of new homes from the NAHB data. The NAHB data include the cost per square foot for eight person-hours of labor to install the insulation, cover it with plaster finish, and fill up the trench with dirt. We estimated that digging around the foundation perimeter would take fifteen person-hours of labor for insulation installed two feet down, and twice that time for insulation installed four feet down. We then multiplied the hourly labor cost by these additional hours, and added these costs to the standard cost for installing slab insulation in new homes. The costs are expressed in dollars/square foot of insulation in the NAHB data. The relevant area of insulation is the foundation perimeter multiplied by the depth of insulation (two or four feet).

Infiltration Reduction

Calculating the cost of reducing infiltration a given amount is a speculative endeavor. The costs in the SERI data are expressed in terms of the cost per linear foot of caulk, and the cost of weatherstripping individual doors and windows. There is no information on whether these measures will reduce infiltration from 0.7 ach to 0.4 ach when implemented for all the windows and the single door of the DOE-2 prototype houses, as we assume in this analysis. There will also be substantial variation between the effectiveness of these measures in actual houses, so the uncertainty in the infiltration cost numbers is large. We derived the costs of infiltration reduction by multiplying the perimeter of the doors and windows by the price per linear foot of caulking, and by multiplying the cost per each window and door by the appropriate cost of weatherstripping.

Glazing

The SERI data contained costs for triple-track and fixed-pane storm windows, as well as costs for interior storm windows. We assumed that retrofits from one pane to two panes would use either triple-track or fixed-pane storm windows, because they are cheaper than interior storm windows. We averaged the costs for these two types of storm windows, for lack of better information. We assumed that households that installed a third pane of glazing would do so using interior storm windows. We multiplied the cost per square foot of each of these window types by the window area for each prototypical house. This approach implicitly assumes that the ratio of glazing to sash area is the same for the costs reported in the SERI database as for the prototypical houses used in the analysis.

Retrofitting Houses Built Between the Base Year and 1987 (Group B)

We calculated the costs for retrofitting group B houses using the same assumptions we used when calculating the costs of retrofitting group A houses. We calculated the difference in insulation levels between the base and the policy case houses, multiplied the changes in insulation by the cost for each incremental improvement in thermal integrity, and then multiplied the appropriate costs by the cost-adjustment factors shown in Table A-5. We then multiplied the costs per household by the number of households in group B to yield the total cost for thermal integrity improvements for group B. Table A-7 shows the costs per group B household for the two utilities. Note that 54,420 NPC homes will be built between 1980 and 1987, and 170,290 TP&L homes will be built between 1980 and 1987.

Table A-7: Retrofit Costs for Group B Houses (1985 $)

Policy Case	Ceiling	Wall	Floor	Infiltration	Glazing	Totals	All Homes-Totals
NPC							
Current Practice	0.0	0.0	0.0	0.0	0.0	0.0	0
Weatherization	1247.7	368.4	0.0	453.4	0.0	2069.4	1.13e8
Floor Insulation	0.0	0.0	0.0	0.0	0.0	0.0	0
Triple Glazing	0.0	0.0	0.0	0.0	881.1	881.1	4.80e7
TP&L							
Current Practice	0.0	0.0	0.0	0.0	0.0	0.0	0
Weatherization	1789.1	1461.2	0.0	404.3	0.0	3654.6	6.22e8
Floor Insulation	0.0	0.0	781.1	0.0	0.0	781.1	1.33e8
Triple Glazing	0.0	0.0	0.0	0.0	1410.1	1410.1	2.40e8

Calculating Costs for New Homes Built in 1987 (Group C)

The costs for new homes are easier to calculate than those for existing homes, and are more reliable, because builder's costs are well known. The definitive source on this subject is a draft report prepared by the NAHB Research Foundation for the American Society of Heating, Refrigeration, and Air-Conditioning Engineers [**NAHB, 1986**]. This source contains the costs for various levels of thermal integrity improvements for eleven regions around the country.

We used assumptions similar to those for existing homes when calculating the costs, which need not be repeated in this section. We averaged the cost of batt and loose-fill ceiling insulation. For wall insulation, we included the additional cost of insulation as well as the additional cost of installing 2" by 6" beams, 24" on center (instead of 2" by 4" studs, 16" on center). For infiltration, we used the conservative assumption that installing all three measures for which costs were included in the data base (a plastic infiltration barrier, caulking, and polyurethane foam sealant) would result in a change in infiltration of from 0.7 ach to 0.4 ach.

The cost adjustment factors in Table A-5 also affect the costs of thermal integrity improvements for group C, eliminating all costs for wall insulation for NPC, reducing the cost of infiltration reduction by a factor of 0.673 for NPC and 0.622 for TP&L, and reducing the cost for slab edge insulation by a factor of 0.959 for TP&L. Tables A-8 shows the costs for individual households and for all households in group C. Note that 10,660 NPC new homes will be built in 1987, and 36,070 TP&L new homes will be built in 1987.

Summary

Table A-9 summarizes the cost calculations illustrated in this appendix.

Estimates of Uncertainty

Table A-8: Costs for New Homes Built in 1987 (GROUP C--1985 $)

NPC							
Policy Cases	Ceiling	Wall	Floor	Infiltration	Glazing	Totals	All Homes-Totals
Current Practice	0.0	0.0	0.0	0.0	0.0	0.0	0
Weatherization	128.2	0.0	0.0	200.8	0.0	329.0	3.51e6
Floor Insulation	0.0	0.0	0.0	0.0	0.0	0.0	0
Triple Glazing	0.0	0.0	0.0	0.0	157.3	157.3	1.68e6
TP&L							
Current Practice	0.0	0.0	0.0	0.0	0.0	0.0	0
Weatherization	528.2	299.6	0.0	192.3	0.0	1020.0	3.68e7
Floor Insulation	0.0	0.0	359.8	0.0	0.0	359.8	1.30e7
Triple Glazing	0.0	0.0	0.0	0.0	675.7	675.7	2.44e7

Table A-9: Costs for All Homes By Group (1985 $)

NPC				
Policy Cases	Group A	Group B	Group C	Totals
Current Practice	6.46e8	0	0	6.46e8
Weatherization	6.75e8	1.13e8	3.51e6	7.91e8
Floor Insulation	1.09e8	0	0	1.09e8
Triple Glazing	2.12e8	4.80e7	1.68e6	2.62e8
TP&L				
Current Practice	1.83e9	0	0	1.83e9
Weatherization	2.75e9	6.22e8	3.68e7	3.41e9
Floor Insulation	7.25e8	1.33e8	1.30e7	8.71e8
Triple Glazing	8.82e8	2.40e8	2.44e7	1.15e9

We believe that the costs given in the SERI database for ceiling and wall insulation are high and probably represent an upper bound to the true costs. In fact, costs for these measures estimated using the SERI database might be as much as a factor of two higher than the actual installed costs of such measures. The uncertainty is therefore high and the results should be used with caution. There are three reasons why we believe that the SERI database's cost estimates are extremely conservative: labor costs, economies of scale, and a rough comparison with the experience at the Bonneville Power Administration's Hood River experiment.

Labor Costs

A major factor in the cost of these retrofits is the cost of labor, which in the SERI database represents approximately two-thirds of the cost of contractor installation of these measures. SERI assumes union labor rates when calculating installed contractor costs, which is a poor assumption for states like Nevada and Texas, where most contractors are non-union. Non-union rates are typically thirty percent lower than union rates;* the costs we derived from the SERI data base are therefore based on conservative labor prices.

Economies of Scale

Massive retrofit programs like those postulated in this analysis would benefit to some degree from economies of scale both when installing many measures in each house and installing the same measures in many houses. The SERI report states that "If a homeowner is planning to hire a contractor to install several retrofit items, the cost per item may be lower than the price quoted." [SERI, p. 2]. The cost per item will also be lower if each is ordered in large quantities and the installers learn the tricks of installing each item early in the program (the installers can use this knowledge to make later installations at lower cost). It therefore seems likely that the

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*Chuck Goldman. LBL. Personal Communication. 15 June 1986

SERI estimates of retrofit costs are too high, but it is difficult to estimate the magnitude of the likely economies of scale.

It is possible that the large scale of retrofit programs might lead to diseconomies. For instance, the heavy demands that such programs would put on local suppliers of insulation might cause the local price of the materials to go up. In our judgement, a well planned program that arranged for appropriate supplies from several national suppliers could avoid such bottlenecks, so the scale economies would probably outweigh the scale diseconomies.

Comparison with the Hood River Experiment

Another reason why we believe SERI's costs may be high is because preliminary ceiling insulation costs from the Bonneville Power Administration's Hood River Retrofit Project are lower than those calculated using the SERI data, for similar levels of ceiling retrofits.**

While not all the Hood River retrofits are comparable to the retrofits analyzed in this report, ceiling insulation, floor insulation, and window retrofits appear to be comparable. The Hood River data were adjusted to 1985 dollars and adjusted for the differences between Portland, Oregon prices and Houston, Texas and Las Vegas, Nevada prices using the ratios of prices between these cities for comparable retrofits in the SERI database.

For both NPC and TP&L, SERI's cost for ceiling insulation for both new and existing homes is more than a factor of two higher than those recorded for the Hood River experiment. For NPC, SERI's costs of floor insulation appear to be about a factor of two too low, while SERI's costs of additional glazing are roughly thirty percent lower than comparable Hood River costs for both utilities.

Chuck Goldman at LBL corroborates the conclusion that SERI's costs for ceiling insulation are substantially higher than actual costs for several other retrofit programs. We have no other source to corroborate the underestimate of floor insulation costs in the SERI database. The cost estimates for improved glazing probably vary widely by the type and number of windows in the retrofit houses. Older houses (like those in the Hood River area) would probably have windows with less uniform shapes than the newer houses in the fast-growing cities of Las Vegas and Dallas. We expect that the Hood River costs for glazing retrofits may be higher than costs for a large program in the areas under study due to economies of scale available because of the uniformity of windows in the housing stock.

The costs of insulation are the dominant costs in these calculations. SERI's ceiling insulation costs are almost certainly overestimates of the true costs, and if, as we suspect, the wall insulation costs are also too high, then the actual costs of retrofits would be substantially reduced. The cost of glazing retrofits is uncertain but could be lower or higher than SERI's estimates.

We have continued to use the SERI database for consistency and because it provides an extremely conservative upper bound to the costs of retrofitting thermal integrity improvements. The large uncertainties in calculating these costs may have lead to overestimates of the retrofit costs of about a factor of two, but it is not possible to specify the uncertainty more precisely in the absence of actual data on implementing large retrofit programs.

**Gil Peach. Hood River Conservation Project. Personal Communication. 17 June 1986; [Phillps, 1986].

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