GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

# PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3198 — DATE 6/25/82

Project Director: ~~Jerry Jackson~~ R. Lann — ~~School~~/Lab EDL/BDD

Sponsor: Synergic Resources Corporation

Type Agreement: Subcontract Agreement No. 7105 -1 (under DOE Prime #DE-AC79-82BP30593)

Award Period: From 2/1/82 To ~~12/31/82~~ 3/1/83 (Performance) ______ (Reports)

Sponsor Amount: $36,763 — Contracted through:

Cost Sharing: ______ GTRI/GIT

Title: Development of Fuel Choice and Floor Space Models for BPA's Commercial Model

## ADMINISTRATIVE DATA

OCA Contact Faith G. Costello x4820

1) Sponsor Technical Contact:

Craig McDonald
Synergic Resources Corp.
One Bala Cywyd Plaza (Suite 630)
Bala - Cynwyd, PA 19004

See Attachment

2) Sponsor Admin/Contractual Matters:

Sharon H. Limaye
Director, Finance and Administration
Synergic Resources Corp.
One Bala Cynwyd Plaza (Suite 630)
Bala - Cynwyd, PA 19004

(215) 667-2160

Defense Priority Rating: n/a — Security Classification: n/a

## RESTRICTIONS

See Attached (DOE) Gov't Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Government, except that items costing less than $1,000 vest with GIT upon acquisition if prior approval obtained from Sponsor.

## COMMENTS:

Prime Contract Number from DOE: DE-AC79-82BP30593

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FORM OCA 4:781

8R39/97

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

## SPONSORED PROJECT TERMINATION SHEET

Date 4/13/83

**Project Title:** Development of Fuel Choice and Floor Space Models for BPA's Commercial Model

**Project No:** A-3198

**Project Director:** Robert B. Lann

**Sponsor:** Synergic Resources Corporation

**Effective Termination Date:** 3/1/83

**Clearance of Accounting Charges:** 3/1/83

**Grant/Contract Closeout Actions Remaining:**

- [x] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [x] Final Report of Inventions
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FORM OCA 10:781

A-3198

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

PROGRESS REPORT

Development of Fuel Choice and Floor Space Models
for BRA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
to
June 30, 1982

(Covers period from start date to formal award date)

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours* | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Jerry Jackson | 182 | $30.95 | $5,633.55 |
| Robert Lann | 342 | 19.65 | 6,730.01 |
| Research Assistant | 24 | 6.00 | 142.80 |
| Secretarial | 4 | 6.68 | 28.95 |
| Subtotal | | | 12,535.31 |
| b. Retirement | | | 1,432.93 |
| c. Travel | | | 0.00 |
| d. Computer | | | 1,280.90 |
| e. Other Expenses | | | 32.92 |
| f. Overhead | | | 8,405.14 |
| Total | | | $23,687.20 |

III. Summary of Progress:

Task 2

A copy of the most recent version of the commercial sector energy demand forecasting model has been made available to BPA.

Task 3

The preliminary version of the new fuel choice algorithm has been encoded and is contained in the model made available to BPA along with

* Hours are rounded

parameter estimates for 8 regions and 2 weather zones in the PNW region. Continuing examination of the behavior of the simulation model and its sensitivity to distribution parameters is being conducted.

Task 4

The floor space forecasting model has been completed for the PNW region and is encoded in the model. The parameter estimates of the model have been included in the data sets mentioned in Task 3. The examination of the three approaches to floorspace forecasting is completed. Due mostly to the severe data problems encountered for developing approaches a. and b., approach c. was decided on and incorporated in the model. It should be noted that the coding necessary to implement approaches a. or b. has been incorporated in the model so that in future when and if the data issues are resolved either of the other two approaches can easily be incorporated in the simulation model.

A-3138

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

PROGRESS REPORT

Development of Fuel Choice and Floor Space Models
for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period

July 1982

I This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | | Hours* | Rate | Cost |
|---|---|---|---|---|
| a. | Labor | | | |
| | Research Assistant | 12 | 6.00 | 72.00 |
| b. | Retirement | | | 0.00 |
| c. | Travel | | | 0.00 |
| d. | Computer | | | 409.06 |
| e. | Other Expenses | | | 1.56 |
| f. | Overhead | | | 227.80 |
| | Total | | | 710.42 |

No labor was expended by key personnel in July. The hours for the research assistant involved tabulation of results from simulation runs.

*Hours are rounded

A-3198


Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332


# PROGRESS REPORT

Development of Fuel Choice and Floor Space Models
for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
August 1982

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. <u>Itemized Expenditures</u>:

| | Hours* | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Robert Lann | 33 | 19.65 | 642.00 |
| Secetarial | | 6.68 | 2.68 |
| b. Fringe Benefits | | | 133.03 |
| c. Travel | | | 977.59 |
| d. Computer | | | 307.50 |
| e. Other Expenses | | | 87.78 |
| f. Overhead | | | 1,015.07 |
| Total | | | 3,165.65 |

III. <u>Summary of Progress</u>:

<u>Task 3</u>

Additional simulation analysis was performed to examine the behavior of the fuel share/efficiency choice algorithms.

*Hours are rounded

A-3198

ENGINEERING EXPERIMENT STATION

Georgia Institute of Technology

A Unit of the University System of Georgia

Atlanta, Georgia 30332

PROGRESS REPORT

Development of Fuel Choice and Floor Space Models for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
September 1982

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Research Assistant | 4.5 | 6.00 | 27.00 |
| Secetarial | 1.2 | 6.68 | 8.02 |
| b. Fringe Benefits | | | .54 |
| c. Travel | | | 0.00 |
| d. Computer | | | 83.11 |
| e. Other Expenses | | | 218.94 |
| f. Overhead | | | 159.35 |
| Total | | | 496.96 |

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ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

# PROGRESS REPORT

Development of Fuel Choice and Floor Space Models
for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
October 1982

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Robert Lann | 40.8 | 19.65 | 802.50 |
| Secetarial | 0.9 | 6.68 | 6.01 |
| b. Fringe Benefits | | | 166.76 |
| c. Travel | | | 0.00 |
| d. Computer | | | 89.93 |
| e. Other Expenses | | | 57.24 |
| f. Overhead | | | 529.79 |
| Total | | | 1,652.23 |

III. Summary of Progress:

Task 4

In response to your letter of October 20, 1982 and phone conversation previous to the letter, I spent one week in October on additional work for Task 4 as outlined in your letter. The results of this effort were mailed to SRC on November 3, 1982.

A-3198

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

# PROGRESS REPORT

Development of Fuel Choice and Floor Space Models
for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
December 1982

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours | Rate | Cost |
|---|---|---|---|
| d. Computer | | | 12.48 |
| e. Other Expenses | | | .54 |
| f. Overhead | | | 6.15 |
| Total | | | 19.17 |

III. Summary of Progress:

Task 6: Documentation

A draft of the final report will be completed and sent to SRC for review by the end of January 1983.

A - 3198

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

# PROGRESS REPORT

## Development of Fuel Choice and Floor Space Models for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
January 1983

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Robert Lann | 123 | 19.65 | 2,407.50 |
| Secretarial | 10 | 6.68 | 66.81 |
| b. Fringe Benefits | | | 547.92 |
| c. Travel | | | 0.0 |
| d. Computer | | | 21.63 |
| e. Other Expenses | | | 2.46 |
| f. Overhead | | | 1,437.86 |
| Total | | | 4,484.18 |

III. Summary of Progress:

Task 6: Documentation

A draft of the final report has been completed and sent to SRC for review.

A-3198

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

# PROGRESS REPORT

## Development of Fuel Choice and Floor Space Models for BPA's Commercial Model

Sub-Contract to Synergic Resources Corporation

Report Period
February 1983

I. This progress report covers work expended on subcontract agreement no. 7105-1 (under DOE prime #DE-AC79-82BP30593) with Synergic Resources Corporation.

II. Itemized Expenditures:

| | Hours | Rate | Cost |
|---|---|---|---|
| a. Labor | | | |
| Robert Lann | 58 | 19.65 | 1,140.76 |
| Secretarial | 5 | 6.68 | 32.73 |
| b. Fringe Benefits | | | 258.17 |
| c. Travel | | | 0.0 |
| d. Computer | | | 177.84 |
| e. Other Expenses | | | 43.84 |
| f. Overhead | | | 780.38 |
| Total | | | 2,433.72 |

III. Summary of Progress:

Task 6: Documentation

The final report has been completed and sent to SRC.

# DEVELOPMENT OF FUEL CHOICE AND FLOOR SPACE MODELS FOR BPA'S COMMERCIAL MODEL

FINAL REPORT

Prepared for

Synergic Resources Corporation
4th & Pike Building, Suite 820
Seattle, WA 98101
February 1, 1983

Prepared by

Jerry R. Jackson
Robert B. Lann

Economic Development Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332

**Table of Contents**

Chapter 1

# INTRODUCTION

In February 1982, the Synergic Resources Corporation contracted with Georgia Institute of Technology to improve on two components of a commercial sector end use energy forecasting model, to provide the most recent version of this model and outline model sensititivy and validation exercises for testing the end use model. Georgia Tech's effort was, in fact, a subcontract to a larger effort being performed by Synergic Resources Corporation for the Bonneville Power Administration. The two components of the model Georgia Tech developed were the floor space forecasting module and the space heat fuel share/efficiency choice module.

These new components, most importantly the fuel share module, were incorporated into the latest version of a commercial end use model developed at Oak Ridge National Laboratory in 1976. The model has gone through phases of development at different locations so that no one version incorporated all of the enhancements. The version delivered to Synergic Resources Corporation does incorporate the improvements from past efforts as well as new coding that enhances the analysts ability to operate the model in a variety of settings with a minimum of effort.

The report is organized into four chapters with three appendices that exhibit the FORTRAN code of the two modules to be discussed, and heat load simulation results used to develop parameters for the fuel share/efficiency choice module. Chapter 2 will discuss the floor space methodologies we examined, the chosen approach and the data development performed to operate the module. Chapter 3 will discuss the fuel share component methodology, the data development and requirements, the heat load model simulations, parameter estimation, and the submodule structure of the code.

# Chapter 2

# FLOOR SPACE SUBMODULE

## Introduction

The stock of floor space is a major determinate of future commercial sector energy use. Despite its importance, our knowledge of commercial floor space characteristics and our improvement in forecasting these characteristics has increased at a much slower rate than many other less important variables. The reason for this situation relates to data collected and made available by the F. W. Dodge Company. In 1977, the Energy Information Administration obtained copies of the detailed Dodge data base. It was believed at that time that these data were acceptably complete and would provide a data source for econometric models far superior to any other available data.

Because of unusually long delays in providing these data for further analysis and the more recent budget problems at DOE, these data have not as yet been fully analyzed or used in their detailed form to support a floor space modeling effort (less intensive studies based on aggregate data have been conducted at ORNL and more recently at Battelle Northwest for the Bonneville Power Administration). In spite of the lack of detailed analysis of the Dodge Data, recent evidence indicates a severe underreporting problem in the Dodge data, at least for certain building types and geographic areas. This issue is discussed more fully later in this section.

Consequently, we find ourselves in a situation where the long anticipated use of the "ultimate" data source has inhibited additional research in this area. Fortunately, the recently available data sources that led us to question Dodge data integrity can be used to develop more accurate floor space stock estimates and models than existed previously.

The objectives of our floor space modeling effort are: to develop the most accurate estimates possible of floor space stock by building type and state for our base year (1979), and to develop the most accurate floor space forecasting model possible with existing time and budget constraints. The purpose of this chapter is to document these efforts.

The remainder of this chapter includes a discussion of the conceptual issues considered in our modeling approach and in past studies. Data issues and our empirical estimates are also discussed.

## Discussion of Methodologies

The various approaches to modeling future floor space stock (or floor space additions) are related through a general framework that describes the production of commercial services. Floor space is one of the factors used to produce commercial services provided in all of the various commercial sector activities. The amount of floor space used in any building type category depends upon the level of activity in that category. This floor space demand also depends on the prices of the other factors used to produce commercial services (e.g., energy, land, labor). This discussion relates the floor space stock demand to explanatory variables; we may just as easily relate floor space additions to these same variables by focusing on the change in stock demanded from one year to the next.

As is obvious from our discussion above, several estimable floor space relationships can be specified consistent with the commercial services production process. The three most-used relationships include:

1. Stock demand. The stock of floor space (i.e., the services provided by that stock) is typically related to measures of appropriate commercial activity and possibly to other factors such as construction prices.
2. Investment demand. Floor space additions have been empirically related to the prices of inputs in the

commercial services production process and to levels of commercial sector activity.

3. Floor space-per-employee. The relationship between these two factors used in the production of commercial services are used to estimate future floor space stock by utilizing available forecasts of employment.

Each of these approaches has been used successfully in previous studies to forecast floor space stock. Early studies (Jackson (1978), Westinghouse (1975), Arthur D. Little (1974)) used the stock demand approach exclusively. Dodge floor space additions data published in the Statistical Abstract of the United States are sufficient to develop national historical series of aggregate floor space stock. This data development requires assumptions on floor space removals and on an initial floor space stock estimate for some early year as well as an adjustment for limited geographic coverage of several western states prior to the early 1950s. Despite these adjustments and assumptions this approach is generally judged to provide a reasonably accurate time series for limited time spans if the Dodge data coverage is relatively accurate (coverage relates to floor space not number of buildings; thus Dodge's recognition of undercoverage of small buildings is not, by itself, cause for concern). A detailed discussion of this approach is provided in Jackson and Johnson (1978).

More recently Corum developed a much improved floor space stock model at Oak Ridge National Laboratory (Cohn, et al. (1979). The Corum model, which is currently the most widely used floor space model, makes use of variations in floor space stock across geographic areas at one point in time to relate floor space stock by building type to aggregate variables such as income and population.

Stock demand models reflect stable long-term trends and consequently are less likely to be affected by several years of atypical cyclical influences than the other approaches. Unfortunately, the aggregate nature of data generally available for such studies precludes the successful determination of the influence of factors such as construction costs, land prices and energy prices. The primary drawback of the stock demand approach is it susceptibility to biases resulting from Dodge coverage problems and the inability to distinguish the impacts of collinear influences (e.g., land prices, capital cost) over time. Since Dodge is the only comprehensive source of time series data, the fortunes of stock demand models are tied to the integrity of the Dodge data.

Investment demand models relate floor space additions to explanatory variables such as construction costs and commercial activity. Despite several attempts, Lann's (1979) study is the only successful investment demand analysis relating to commercial floor space. The advantage of this approach is the potential for determining the impacts of a wider variety of explanatory variables. The disadvantages relate to estimation difficulties arising from the cyclical nature of both floor space additions and explanatory variables. Investment demand models must also rely on Dodge data making them susceptible to the many problems caused by potential systematic biases in the dependent variable, floor space additions. In most cases the time and other resources required to develop a reliable investment demand model represents the greatest drawback in using this approach.

The floor space-per-employee approach is the third major modeling approach. One of the earliest applications of this approach (Jackson (1980)) was prompted because of dissatisfaction with the original ORNL stock demand model. The advantages of this approach include representation of a presumably stable relationship, reliance on non-Dodge data, and the availability of employment forecasts which drive floor space estimates. Disadvantages include the sparsity of non-Dodge floor space stock data and the cyclical nature of the employment series which is one of the two data series required for the ratio estimates. A potentially serious problem is the estimation difficulties faced in estimating temporal changes in the ratio resulting from changing relative prices of the inputs used in producing the commercial services, changes in marketing and business environments and other factors.

As this brief review makes clear all approaches suffer from several potential deficiencies. In choosing our modeling approach we first ruled out the investment demand model. The immediate reason was our lack of access to the detailed Dodge data required for such analysis; however, even if access were obtained, the time frame for our project was clearly too short to feel positive about the possibility of deriving usable results.

Beyond these immediate considerations, however, we feel that the investment demand approach is unlikely to yield a forecasting model that is as robust as a model derived from one of the other two methods. The out-of-phase cyclical nature of all of the data series involved in such analysis, the role of expectations in the commercial structure investment market, the role of other constraints in determining construction (e.g., failure of local bond initiatives for public buildings), the difficulty encountered in modeling the dynamic character of the market, and the high correlation (both positive and negative) reflected in the explanatory data series often yield models which generate unstable and/or inaccurate forecasts. This problem is inherent in all investment demand models. Poor forecasts of investment in durable goods is a well-recognized culprit in problems exhibited by macro-econometric models of the economy.

One difficulty which must be overcome before a large-scale investment demand modeling approach is undertaken relates to the underreporting problem of the Dodge data. A systematic bias in this data series will result in model parameters that are also biased. As indicated below, this problem is also a major consideration in evaluation of the stock demand approach.

Developing a stock demand model requires data series reflecting the stock of commercial structures by building type. The only feasible data source for developing such a series is the Dodge data. To develop such a series, one must estimate the stock at some point in time and use Dodge floor space additions data and an assumptionon stock removals to work backward (or forward) from the stock estimate. An obvious requirement in developing a data series that differs from the actual only by a random component (as permitted in our estimation technique) is that the Dodge data coverage is complete, or that the undercoverage can be estimated. If one of these two conditions cannot be reasonably satisfied then the potential for biased forecasts is uncertain.

Thus, the choice between the stock demand and floor space-per-employee approach hinges in part on the Dodge coverage problems. One way of assessing this problem is to use publicly available Dodge data to develop national floor space stock estimates and to compare these stock estimates to other sources.

We used our earlier work in Jackson and Johnson (1978) and Jackson (1980) for the Dodge-based floor space stock estimates. The approach used in these studies to develop floor space stock estimates consists of three primary steps including:

1. estimation of the stock of floor space in 1924;
2. summation of annual data on floor space additions (available in published sources for years following 1925);
3. subtraction of a fraction of floor space to account for building removals.

Adjustments were made to the publicly available Dodge data series to compensate for incomplete geographical coverage. Since the pre-1950 construction represents only about one-third of current Dodge-based stock estimates, the impact of uncertainty in the building removal rate and the 1924 stock is diminished. The resulting national Dodge-based floor space stock estimates are given in the third column of Table 2-1 for selected building types for 1979.

We also developed estimates of national floor space stock estimates from two other sources. The first is derived from the DOE Interim survey developed by the Energy Information Administration (1981). Unfortunately, the detailed data tapes are not currently

Table 2-1

Estimates of National Floor Space by Building Types, 1979, $10^6$ $ft^2$

Basic Data Source

| Building Type | California Energy Commission | DOE Interim Survey | F.W. Dodge |
|---|---|---|---|
| Office | 8,376 | 7,263 | 5,809 |
| Retail | 7,885 | 8,891 | 5,329 |
| Warehouse | 5,006 | 6,327 | 2,432 |
| Education | 6,715 | 6,142 | 6,970 |
| Health | 1,973 | 1,387 | 2,027 |
| Hotel/Motel | 1,566 | 1,856 | 1,647* |
| Miscellaneous | 6432 | 10,171 | 5852 |
| Total | 37,953 | 42,038 | 30,066 |
| Warehouse Adjustment | | -1,321 | |
| Adjusted Total | 37,953 | 40,717 | 30,066 |
| Total Relative to DOE | .93 | 1.0 | .73** |

*Not estimable from national Data; estimate taken from Jackson (1978) as developed at ORNL.

**Calculated without Hotel/Motel category in DOE and Dodge total.

available so some processing of the publicly available data were required to make the data conform to our use. Data are provided by DOE on total nonresidential floor space stock, and size distribution by building type. We assumed that the number of buildings in each of the seven size categories multiplied by the midpoint of the size category would provide estimates reasonably close to those derivable from the detailed tape. The midpoint of the largest open-ended size category was determined in such a way that total nonresidential floor space equalled the DOE estimated total of 54.6 billion square feet. We then converted this nonresidential floor space to conform with our commercial sector definition by subtracting the estimates of residential buildings (included in the survey because of some commercial activity in the building), industrial buildings, and vacant buildings.

A second estimate of national floor space stock was derived from results of a utility survey conducted by California utilities for the California Energy Commission (CEC) in 1978. A total of more than 14,000 usable responses were received representing a response rate of 26%. Floor space stock for our 1979 comparison year was developed by using the CEC estimated 1977 stock and estimated additions and removals for 1978 and 1979.

The 1979 California stock estimates by building type were related to <u>County Business Patterns</u> (CBP) employment SIC categories as indicated in Table 2-2. In some cases it was felt that activity measures other than employment were more appropriately related to floor space stock (see Table 2-3). The resulting floor space-per-employee activity estimates were used with national CBP employment data and other measures of subsector activity to develop national estimates of floor space stock. The DOE and CEC-based national estimates are also presented in Table 2-1. Definitions differ among the three basic sources so that building-specific estimates are not strictly comparable. The DOE Interim results undoubtedly reflect the most accurate estimate of total national floor space because of the sampling and survey approach used. One can argue that the California results may reflect some nonresponse bias because of the incomplete response. The nature of relationships between floor space and employment is not likely to differ significantly from a California application to a National application.

The following conclusions can be drawn from the data in Table 2-1:

- When dormatories are accounted for in the CEC data, the CEC and DOE Interim education results are very similar. Dodge estimates are greater, probably representing an underestimate of removals in the 1970s.
- When nursing home floor space estimates are added to the DOE Interim Health estimates (which exclude nursing homes), the CEC, DOE and Dodge estimates are not significantly different.
- The CEC and ORNL hotel/motel estimate are very close. The DOE hotel/motel category contains dormatories and nursing homes; when appropriate adjustments are made, the DOE figure appears to be about 60% of the other two.
- The DOE estimate of warehouse floor space is considerably higher than the CEC or Dodge. This is likely the result of the DOE inclusion of industrial warehouses which was not part of the CEC effort. We have subtracted the difference and adjusted our estimate of the DOE commercial warehouses downward by this amount. The Dodge warehouse estimate is only about one-half of the CEC estimate.
- A close correspondence exists between food sales floor space in the DOE and CEC surveys. (Not shown in Table 2-1).
- While the definitions of office buildings are similar for Dodge and CEC figures, the DOE definition classifies many office related activities of federal and state governments to the miscellaneous category.
- The definitional discrepancies in the retail sector are difficult to determine.
- Except for the miscellaneous category, the CEC and DOE interim estimates are extremely consistent. This difference

is probably explained by the fact that the Interim sample picks up some utility customers not classified as commercial.

As the last row of Table 2-1 indicates, the Dodge data represent 73% of the DOE interim estimate. The CEC estimates, on the other hand, reflect 93% of the DOE estimate. Consideration of these items led us to the conclusion that the best national estimate of floor space stock by building types is derived by using the CEC based estimates for all building types except miscellaneous which should be adjusted upward by 43% to reflect the more appropriate commercial sector coverage in the DOE survey. The CEC estimates are chosen over the Interim estimates because they are more detailed on a building type basis and because the two sources appear to be very close. Thus the CEC column with a new miscellaneous total of 9,196 and a total floor space stock of 40,717 million square feet reflects our best estimate of the national stock of floor space.

Turning back to our consideration of the floor space stock approach, it appears that the Dodge undercoverage problem is severe enough to significantly impact estimated stock demand model coefficients. Thus, we consider the floor space-per-employee the only feasible approach that can be pursued in this study.

## Methodology Selected

Having settled on the floor space-per-employee modeling approach, we can now specify our empirical model. A general form of this relationship can be represented as:

$$S_t = F \cdot e^{r(t - t_0)} \cdot E_t \qquad (2\text{-}1)$$

where

$S$ = floor space stock

$t$ = forecast period

$F$ = floor space-per-employee in base year period $t_0$

$r$ = annual rate of growth of $F$

$E$ = Employment

With sufficient time series data this relationship can be estimated. Our reason for rejecting the stock demand approach was, however, because of the lack of such data. Data requirements are less severe here since we can estimate F for a base year, and E for the forecast period. Thus an estimate of r from some other source can be used, or values of r can be chosen judgmentally and perhaps examined in sensitivity analysis.

It is interesting to note that if we multiply F by the term $E_{t_o}$ and divide $E_t$ by that same term we transform the equation above into

$$S_t = S_{t_o} \cdot e^{r(t-t_o)} \cdot E_t/E_{t_o} \qquad (2\text{-}2)$$

Thus we may focus our efforts on estimation of floor space stock by building type for the base year and the relative increase in employment in the future. Operationally this form is preferred because it allows development of the floor space stock estimates with measures of activity that are currently available and most accurate but may not be available in a forecasting situation, it simplifies updating the model equation with new data and it is less sensitive to definitional variations between the CBP employment data used to develop $S_t$ from the CEC data and employment forecasts that may be generated based on different data.

As indicated above, development of the empirical model requires estimation of the stock of floor space in the base year ($S_{t_o}$) and the rate of increase in the relationship between floor space stock and employment (r). The employment variables $E_t$ and $E_{t_o}$ are used in the forecasting mode but are not required in development of the empirical model.

## Development of Model Parameters

We develop four models, one for each of the four states in the Pacific Northwest region. We assume that each of the state models applies equally well to public and private rate pools within the state. We focus on the two primary parameters separately.

Base Year (1979) Floor Space Stock. As indicated in our discussion of the stock demand approach we have adopted the CEC survey data with an adjusted miscellaneous category floor space estimate. A floor space-per-activity relationship developed for the state of California using the estimated stock figures and measures of subsector activity such as county business patterns employment and school enrollment data were used along with the appropriate state level values for the activity measures in the four states to develop state level floor space stock estimates by building type. The activity measures used for the various building types are given in Tables 2-2 and 2-3.

Before presenting the state level estimates we briefly discuss our considerations of one alternative data sources used in developing these parameters. As indicated in the preceding section we reviewed alternative data sources available for parameter development. We reviewed a number of sources such as those developed by General Electric (1978) and Data Resources, Incorporated (1979) which are not discussed here because they either reflected seriously flawed approaches in our estimation or they reflect results very similar to the Dodge-based data presented in the last section.

One alternative data source relating specifically to the Pacific Northwest was provided by Bonneville Power Administration (BPA) from the results of three survey feasibility studies conducted in the Pacific Northwest. Three areas were surveyed including roughly the central city portion of Seattle, the Portland metropolitan area and the tri-cities of Richland, Kennewick and Pasco in southeastern Washington. Data from these surveys on floor space and employment were related to BPA employment series and used to develop estimates of floor space stock by three general building categories. These survey data were also provided by BPA on more detailed building type basis. Approximately 1,300 responses were obtained. After comparing this data source to the others described in the preceding section we decided that the feasibility results presented one potential problem

Table 2-2

Building Type - TWO DIGIT SIC CODE CORRESPONDENCE

| Building Type | Corresponding SIC Codes | SIC Code Description |
|---|---|---|
| Office | 40 - 49 | Transportation, Communications, Electric, Gas and Sanitary Services |
| | 60 - 67 | Finance, Insurance and Real Estate |
| | 73 | Business Services |
| | 81 | Legal Services |
| | 83 | Social Services |
| | 89 | Miscellaneous Services |
| | 90 - 96 | Public Administration (except National Security and International Affairs) |
| Retail | 52 - 53 | |
| | 55 - 57 | Division G (Retail trade) - Except for 54 (Food stores) and 58 (eating and drinking places) |
| | 59 | Miscellaneous Retail |
| | 72 | Personal Services |
| | 76 | Miscellaneous Repair Services |
| Elementary/Secondary | 82 | Educational Services |
| Colleges | 82 | Educational Services |
| Hospital | 80 | Health Services |
| Grocery | 54 | Food stores |
| Restaurant | 58 | Eating and drinking places |
| Hotel/Motel | 70 | Hotels, Rooming Houses, Camps and other Lodging places |
| Warehouse | 50 - 51 | Wholesale Trade |
| Miscellaneous | 75 | Automotive Repair, Services and Garages |
| | 78 | Motion Pictures |
| | 79 | Amusement and Recreation Services (except 78) |
| | 84 | Museums, Art Galleries, Botanical and Zoological Gardens |
| | 86 | Membership Organizations |
| | 97 | National Security and International Affairs |
| | 99 | Nonclassifiable Establishments |

Table 2-3

Activity Measures Used To Develop
State Level Pacific Northwest
Floor Space Stock Estimates

| Building Type | Activity Measure |
| --- | --- |
| Office | CBP employment; federal and state government employment |
| Restaurant | CBP employment |
| Retail | CBP employment |
| Grocery | CBP employment |
| Warehouse | CBP employment |
| Elementary/Secondary | School enrollment |
| College | Full time college enrollment |
| Health | Hospital and nursing home bed space |
| Hotel/Motel | CBP employment |
| Miscellaneous | Population |

that was more difficult to resolve than the problems of the CEC-adjusted data. Since these feasibility surveys were not intended to represent the population of commercial buildings in the Pacific Northwest, several issues must be resolved to develop such population estimates. For instance, to what extent is the Seattle City Light area (the area sampled in the Seattle study) representative of metropolitan Seattle? How representative is the tri-cities areas of nonmetropolitan areas? A detailed resolution of these issues was clearly not feasible in this project. Another important consideration in this evaluation process relates to the likely reduction in sampling error accompanying use of the DOE survey based on over 6,000 responses and the CEC survey of 14,000 commercial establishments.

The 1979 state level floor space stock estimates developed from CEC-adjusted floor space stock estimates and building-specific activity measures are given in Table 2-4. These estimates represent $S_{t_o}$ in the forecasting equation 2-2.

<u>Rate of Growth of Floor Space-per-Employee Ratio (r)</u>. The change in the relative use of floor space and employment factors over time is reflected in the variable r of equation 2-2. With sufficient data one could specify r as a function of relative factor prices and transform the extended form of 2-2 into an estimable relationship. As our discussion earlier makes clear, data required to support the econometric estimation of this relationship are not available.

A next best alternative is to develop an estimate of floor space stock ($S_t$) for an earlier year along with employment series (consistent with series to be used in the forecasting situation) and to estimate the rate of change of the floor space-per-employee estimate over time. Several problems must be considered in pursuing this approach. First one must choose comparison points in time that reflect a period of relative equilibrium. That is a period where employment and floor space stock are likely to reflect the kind of stable growth pattern implicit in forecasting situations. Our base year (1979) and 1965 were chosen as reasonably close to fulfilling this requirement. Both years are periods of relatively low unemployment and are at the end of periods of stable GNP growth of three years. (Employment figures relate to mid-March of the year, floor space stock relates to end of year estimates.)

Table 2-4

1979 Floor Space Stock Estimates
By State and the Pacific Northwest, $10^6$ $ft^2$

| | Washington | Oregon | Idaho | Montana | Pacific Northwest |
|---|---|---|---|---|---|
| Office | 149.49 | 95.59 | 29.40 | 10.46 | 284.94 |
| Restaurant | 15.64 | 10,98 | 3.17 | 1.22 | 31.01 |
| Retail | 99.64 | 68.91 | 20.33 | 7.17 | 196.05 |
| Grocery | 23.51 | 15.40 | 5.48 | 1.86 | 46.25 |
| Warehouse | 88.24 | 62.91 | 22.28 | 6.09 | 179.52 |
| Elementary/Secondary | 83.91 | 51.26 | 21.66 | 6.47 | 163.30 |
| College | 40.62 | 23.90 | 7.75 | 2.50 | 74.77 |
| Health | 30.18 | 16.71 | 5.86 | 2.80 | 55.55 |
| Hotel/Motel | 24.33 | 20.87 | 8.41 | 3.89 | 57.50 |
| Miscellaneous | 165.21 | 106.34 | 37.64 | 12.08 | 321.27 |
| Total | 720.77 | 472.87 | 161.98 | 54.54 | 1,410.16 |

Aggregate building type summaries of national F.W. Dodge reported additions were available from ORNL. The 1979 national floor space stock estimates, the national floor space additions and national employment in the related categories for 1979 and 1965 were used to determine the likely range of rates of change in r. A range was developed because of the uncertainty surrounding the undercoverage of the Dodge data. We assumed two situations: the first represents a best case where Dodge additions are accurately reported from 1966 to 1979, the worst case is where the additions undercoverage equals the estimated stock undercoverage indicated in Table 2-1. 1965 stock was then developed by subtracting the sum of 1966-1979 additions from the 1979 stock. This was performed using reported additions for the best case, while an adjusted figure based on undercoverage estimates from Table 2-1 was used to inflate additions for the worst case. In both situations the rate of change in the ratio reflects the fact that gross additions (i.e., both new and replacement floor space additions) were used. To convert this gross ratio to the ratio appropriate in the model the impact of replacements must be subtracted. Replacement demand is about .8% on average for most building types in this period.

This distinction is more clearly illustrated with an example. If the ratio of floor space per employee in offices does not increase over this period, we can take the 1965 floor space, add the gross additions and subtract the portion of these additions required to offset removals from the building stock to derive 1979 floor space. Dividing by 1979 employment would yield the same ratio as existed in 1965. If the replacement additions were unknown and in fact reflected 1% of the stock, summing the gross additions, adding to the 1965 stock and dividing by employment would yield a ratio that is about 15% greater than the 1965 ratio with an average annual increase in the ratio of 1%. Thus, rates of increase in the ratio determined from gross additions must be decremented by the rate of replacement: about .8%. The results of such calculations are given in Table 2-5. In most cases the range, especially when adjusted for replacements appears to bracket zero. Assuming a replacement demand of .8% the total floor space range is -1.51 to 1.13 with an average rate of increase of -.19%. Only the warehouse building type exhibits a range entirely in positive numbers.

Some care must be applied when comparing the estimates of Table 2-5 with casual empiricism. First, building categories are somewhat broader than what may come to mind when one reviews the table. Office buildings, for instance, include all office related activities including public administration activities such as courthouses, jails, etc. Even in a narrowly defined sense office buildings appear to have increased their use of floor space per employee at a more moderate rate than anecdotal experience suggests. For instance information in

Armstrong (in Daniels, 1979) yields estimates of an average annual increase of only .8% per year over the 1964 to 1975 period.

Table 2-5

Average Annual Rates of Change in
Gross Floor Space-Per-Employee Ratios
Implied by F.W. Dodge Data

| Building Type | Average Annual Rate of Change Minimum | Average Annual Rate of Change Maximum |
|---|---|---|
| Office | -1.11 | 0.60 |
| Retail | -0.08 | 2.58 |
| Warehouse | 0.85 | 11.03 |
| Education | -0.05 | 0.51 |
| Health | -1.52 | -1.33 |
| Hotel/Motel - Miscellaneous | -0.75 | 1.35 |
| Total | -0.71 | 1.93 |

It was our conclusion after considering the results of Table 2-5 that rates of change in the building specific ratios are likely to be close to zero and that in the absence of better information to the contrary, it is best to use zero as our best estimate at this point.

## Subroutine Structure

In designing the subroutine that would incorporate the methodology for forecasting floor space stock and additions we wanted to allow maximum flexibility for the user. Rather than confining the coding to the chosen floor space-per-employee model discussed above, we wanted to encode enough flexibility to have the model handle any of the three approach's discussed in the methodology section; stock demand, investment demand, and the floor space-per-employee models.

We have encoded subroutine STOK in two sections; one section for dealing with models that forecast floor space <u>stock</u> directly and one section for models that use floor space <u>additions</u> as the dependent variable. We have included a copy of the subroutine as Appendix A. Definitions for variables that appear in the subroutine are listed below in alphabetical order.

| Variable | Definition |
|---|---|
| ADD | Contains the floor space additions |
| ALAG | Stores lagged stock or additions |
| ASTK | Stores first historical year's floor space |
| CADD | Comparison variable for ALAG selection |
| CF | Contains the model coefficients |
| CNO | Comparison variable for ALAG selection |
| CSTK | Comparison variable for ALAG selection |
| EP985 | Stores survival fractions for ASTK |
| EXOG | Contains explanatory variable data |
| F | Stores survival fractions for ADD |
| FAC | Temporary variable for FSG |
| FSCH | Logical variable for section selection |
| FSG | Temporary variable for FSGRTH |
| FSGRTH | Contains FT2/emp growth rates |
| LAG | Stores information for ALAG selection |
| S | Stores forecasted floor space stock |

Variable FSCH is used to direct execution to either of the two sections by a logical yes/no test. If the stock section is to be selected for a particular building subsector, L, then FSCH(L) should contain YES, and if the additions section is selected FSCH(L) should contain a NO. Since FSCH contains a value for each building subsector the user can use different sections and therefore different models for each subsector.

Once a section has been selected the LAG variable is used to select a lagged variable option. The choices are 1) a stock lag, 2) an additions lag, and 3) no lagged variable. This feature was included to accommodate the stock demand and investment demand models which often specify a lagged dependent variable in the estimating equation.

Since we have chosen the floor space-per-employee model for all building subsectors, the FSCH variable will contain all YES's. This directs execution of the stock section for each L. The LAG variable will contain all NO's since no lagged variable is used in this model.

Since the stock section is used for this type of model a variable is included in this code section to store the value of r from equation 2-2 above. The growth rate variable FSGRTH stores individual values for each building subsector, allowing the user to specify a declining, constant or growing value for floor space-per-employee for each building subsector individually.

## Chapter 3

## HVAC FUEL CHOICE/EFFICIENCY CHOICE SUBMODULE

### Methodology

Heating, ventilation and air conditioning systems (HVAC) fuel choice and efficiency choice are jointly determined in a process that is structured to provide the average values for these end uses as required in the overall model based on the results of the simulated choices of many firms.

In describing this process, it is easiest to first focus on the choices modeled for an individual firm. Therefore, we first consider the decision process for a firm assuming that the energy use requirements, price expectations and discount rate have already been ascertained for that firm.

Decision Process For a Single Firm. When an HVAC equipment purchase is imminent (when old equipment is "worn out" or when a new building is designed), the decision maker must choose both a fuel type and HVAC characteristics. As demonstrated below, this is properly modeled as a joint decision.

The decision maker must select a system with the efficiency-cost combination that most closely fits the investment criterion used in that firm. The feasible combinations are described by an HVAC production relationship (i.e., the technology based relationship between equipment cost and efficiency) and represented as

$$S = A K^a E^b X^c \qquad (3\text{-}1)$$

where K = stock of HVAC equipment

E = energy use

X = other factors

A,a,b,c, = parameters of the production relationship.

K and E can be related to the other variables as

$$K = A^{-1/a} S^{1/a} E^{-b/a} X^{-c/a} \qquad (3\text{-}2)$$

and $$E = A^{-1/b} S^{1/b} K^{-a/b} X^{-c/b} \qquad (3\text{-}3)$$

Relationships 3-2 and 3-3 indicate the level of capital and energy used for various levels of the other input factors and the level of output, assuming that the most efficient production process is used.

In an attempt to minimize life-cycle-cost of the end use system, decision makers will choose a system whose energy use-capital cost characteristics minimize the following relationship

$$LCC_T = P_{K,T} K + \sum_{t=T}^{T+n} \left[ \frac{E P_{E,t} + M_t}{(1+r)^t} \right] \qquad (3\text{-}4)$$

where $LCC_T$ = life-cycle-cost of the system in current year, T

$P_k$ = price of capital

K = quantity of capital

E = energy use of the system

$P_E$ = price of energy

M = maintenance cost of the system

r = discount rate applied in this investment decision

n = life of the system

Substituting 3-2 for K in equation 3-4 constrains the life-cycle-cost equation to reflect the production technology. Minimizing this new equation with respect to E gives the life-cycle-cost minimum choice of E. The corresponding K is provided by substituting the resulting value for E in equation 3-2.

This life-cycle-cost minimizing value of E is:

$$\ln E = -\frac{a}{b+a} \ln \sum_{t=T}^{T+n} \frac{P_{E,t}}{(1+r)^t} - \frac{a}{b+a} \ln \frac{a}{b} - \frac{c}{b+a} \ln X + \frac{1}{b+a} \ln S + \frac{a}{b+a} \ln P_k - \frac{1}{b+a} \ln A \qquad (3\text{-}5)$$

The relationships between the energy use of the system chosen and other variables can be summarized as

$$\frac{\partial E}{\partial P_E} < 0 \ , \ \frac{\partial E}{\partial r} > 0 \ , \ \frac{\partial E}{\partial x} < 0 \ , \ \frac{\partial E}{\partial S} > 0 \ , \ \frac{\partial E}{\partial P_K} > 0 \ ,$$

That is, increases in the discount rate, level of end use services and the price of equipment tends to increase energy use (decrease efficiency). Increases in fuel price or the level of other factors (e.g., structural efficiency) tends to reduce energy use (increase efficiency). The inverse relationship between E and K (equation (3-2)) indicates that increases in each of these variables has just the opposite effect on the level of capital used in producing the end use service.

Thus, given the discount rate (r) used by the firm in making its energy-related investments and the prices expected over the next n years ($P_{E,t}$), we may use equation 3-5 to determine the preferred energy use characteristics (i.e., efficiency) of each system under consideration. Since price expectations vary across fuels and the parameters of equation 3-1 vary to reflect fuel specific system characteristics, the efficiency choice that a firm exhibits will vary by fuel type chosen. Equation 3-5 allows us to estimate that efficiency choice for each fuel specific system as if that system were actually chosen.

The resulting energy use requirement, (E), and corresponding, (K) of each system is used in equation 3-4 to determine which fuel-specific system reflects the least life cycle cost. This minimum life cycle cost option is then chosen by the firm under consideration.

The "other" factors represented by the variable X in equation 3-2 can include lighting levels, the thermal integrity of the structure, occupancy characteristics, equipment loads, etc.

Monte Carlo Approach. The process described above is actually repeated a large number of times in each forecast year, for each building type and building vintage in order to develop an average fuel choice and efficiency choice. Certain characteristics are allowed to vary from firm to firm to represent the actual variation in certain decision factors that influence the values of equation 3-4 and 3-5.

Within each building type, the particular values of fuel price expectations and a discount rate occur with a frequency in our sample of establishments that corresponds to the population frequency. The use of discount rates and price expectations give the simulation its "behavioral" component since the values of these variables are determined in large part by the cost of information, access to capital markets, judgmentally based forecasts of energy market factors and other items that result in actions by commercial establishments that differ from actions expected under a perfectly competitive market scenario.

This Monte Carlo process utilizes prespecified population distributions. Currently, the lower, median, and upper bound distribution parameters are supplied such that 80% of the population values are between the upper and lower bounds and the median value is identical to the median parameter. A Weibull distribution was chosen because, depending on the distribution parameter values, the Weibull distribution can represent a variety of density function shapes. The Weibull cumulative distribution inverse (equation 3-6) is used to calculate each firms discount rate and price growth rate expectation. The parameters of equation 3-6 are solved using the upper and lower bounds and median.

$$X = a \left[ -\ln \left( 1-F(X) \right) \right]^{\frac{1}{c}} + b \qquad (3\text{-}6)$$

Using F(X)=.1 for the lower bound, F(X)=.5 for the median and F(X)=.9 for the upper bound a, b and c are solved. The b parameter is not straight forwardly solved and must be estimated using numerical methods. The method of successive approximations is used to iterate to a value for b given lower, upper, and median values for X.

Equations 3-7 and 3-8 represent the solutions for c and a, respectively. Equation 3-9 is the relationship used to estimate b.

$$c = \frac{1.2005}{\ln \left( \frac{(X_u - b)}{(X_m - b)} \right)} \qquad (3\text{-}7)$$

$$a = \exp\left[\frac{.3665}{c} + \ln(X_m - b)\right] \quad (3\text{-}8)$$

$$b_{n+1} = X_L - \frac{(X_m - b_n)^{2.5692}}{(X_u - b_n)^{1.5692}} \quad (3\text{-}9)$$

where $X_m$ = median value

$X_L$ = lower bound value

$X_u$ = upper bound value

$F(X)$ = value of the cummulative distribution given X

n = iteration step number

This Monte Carlo approach is a very attractive way of representing fuel and efficiency choice because it incorporates the same decision variables actually used by firms in making these decisions and it permits a representation of the variation in the factors which do, in fact, vary from firm to firm. This approach offers considerable advantage over the econometric fuel-split approach used previously. The econometric representation was determined to be faulty when the model failed to forecast significant choice of electric space heating when that fuel offered significant cost advantages. Since 3-5 is a cost-based equation, that difficulty should not occur. The observed reluctance of commercial decision makers to invest in energy saving options is captured in the use of discount rate values that reflect such patterns. The interaction of end use systems such as lighting is reflected by the "other" factors in determining the energy use requirements of an HVAC system. While not pursued in our present research, this approach allows a straightforward incorporation of new technologies if one provides the energy-capital cost technology curve and the cost-equivalent disincentive generated by uncertainty of the new technology. The obvious new issues raised with this approach relates to the estimation of the population distributions of fuel price expectations and discount rates. This topic is the focus of the next section.

## Data Development

To calculate the distribution of discount rates and price expectations as discussed in the previous section the Monte Carlo approach is employed. To generate the numbers usng equation 3-6 a set of uniform probabilities, one set of five (three fuels and two discount rates (Public vs. Private sector), for each observation are chosen using a computerized random number generator in the interval 0,1. The population distribution parameters, $X_L$, $X_m$, $X_u$ are derived as follows.

On the basis of a review of approximately two hundred case studies compiled from past issues of Energy Users News, we have concluded that commercial firms are reluctant to invest in energy saving investments. That is, unexpectedly strict investment criterion are used to evaluate energy-related investments. This finding is consistent with the conventional wisdom and "rules-of-thumb" often reported in this area. We believe that such behavior is, in fact, economically rational and can be explained by several factors including, uncertainty related to cost savings (in part from uncertainty over the technology, in part from other factors such as uncertainty of future weather trends which help determine cost savings), fuel price, and resource competition with other goals of the organization such as enhancement of market shares through advertising expenditures or product upgrading.

In any case, high discount rates (i.e., short payback periods) are without question applied in energy related investment decisions. We have specified the upper, median, and lower bound parameters of 25%, 50%, and 75% for the discount rate parameters. That is, we assume that 80% of all commercial establishments use discount rates between 25% and 75% with a corresponding required payback period of from 5 and 2.3 years.

To estimate the distribution of expected prices we used price expectations published by Energy Users News from their survey of energy users. The number of panelists ranged from 64 to 70 in January, February, March, and April 1982 issues which were used to determine the appropriate parameters for this application. Energy Users News publishes the median estimate and the highest and lowest estimate. Oftentimes the two highest (or two lowest) estimates are published if the highest (or lowest) estimate appears to be an outlier. We used these data to develop an estimate of the variance of the price expectations around the median. The resulting upper and lower bound parameters showed an approximately 80% coverage for rates of electricity price increase that varied from -10.33 to 6.33% around the median; from -11.07% to 6.33% for gas; and from -8.33% to +8.33% around the reported oil prices median expectation. Thus, on the basis of these data, if the median electricity price expectations were 12%, we can assume that 80% of the population expects rates of increase that range from 1.67% to 18.33%. In our forecasts, we assume that commercial decision makers are accurate forecasters of price increases on average, but that individual forecasts vary according to the information developed from Energy Users News. This assumption allows us to use exogenously supplied price forecasts to represent the average price in any forecast year.

Incorporating these values into the model where the median expectation is equal to the exogenously supplied price forecast, the bounds are input as:

| | Lower | Median | Upper |
|---|---|---|---|
| Electricity | .8967 | 1.00 | 1.0633 |
| Natural Gas | .8833 | 1.00 | 1.0633 |
| Fuel Oil | .9167 | 1.00 | 1.0833 |

Additional Data Requirements. The DOE 2.1 heat load model is used to develop the annual HVAC energy use requirements (E) used in estimation of equation 3-3. DOE 2.1 inputs require a vast array of information on building shell characteristics, equipment characteristics, internal loads and schedules, and weather. Based on the HVAC system modeled and the shell characteristics, cost estimates in dollars per square foot can be calculated for each run. Lighting level is input to DOE 2.1 and, therefore, predetermined. These data are generated in a controlled experiment by running DOE 2.1 using all of the sixteen possible combinations of the four input factors (see equation 3-10 below) with two specifications; one for high energy use and one for low energy use.

Three prototype building specifications were modeled for DOE 2.1 consisting of a 40,500 sq. ft. office, a 40,000 sq. ft. school and a 180,000 sq. ft. hospital. Tables 3-1 through 3-3 contain the specifications for each, respectively.

Each building prototype was run with weather for two locations; Portland, Oregon and Yakima, Washington. Weather tapes from the National Oceanic and Atmospheric Administration (NOAA) were used for weather information corresponding to a typical meteorlogical year (TMY). These TMY tapes use actual months selected from various years in which the month selected is representative of 'typical' weather. That is, weather data for say January could be from 1960 and February weather could be from an entirely different year.

## Parameter Estimation

As stated above, there are sixteen combinations to consider for running a regression to estimate the parameters in equation 3-3. Our empirical specification identifies two components of "other" factors; structure capital (thermal integrity) and lighting level. Equation 3-10 illustrates this estimating equation.

$$\ln E = a_0 + a_1 \ln KE + a_2 \ln KS + a_3 \ln S + a_4 \ln L \qquad (3\text{-}10)$$

where E = HVAC Energy use per sq. ft.

KE = HVAC equipment cost per sq. ft.

KS = Cost per sq. ft. of the components of structure that change from high to low energy use settings; windows, walls, and roof

Table 3-1

OFFICE BUILDING DOE 2.1 SPECIFICATIONS

eneral:
Area = 40,500 square feet
Number of stories = 3
Yearly Schedule = 12 months

| | High Energy Use | Low Energy Use |
|---|---|---|
| ights: | | |
| Recessed Flourescent in ceiling | 3.5 watts/sq. ft. | 2.5 watts/sq. ft. |
| /AC Equipment: | | |
| Air Delivery | Multizone with constant air-flow to 5 zones | Same with addition of rotary heat exchanges |
| Plant | Electric hot water boiler<br>Hermetic reciprocating chiller and cooling tower | Electric hot water boiler<br>Double bundle chiller |
| ructure: | | |
| Walls | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" gypsum board | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" insulation, R-2<br>1/2" gypsum board |
| Roof | 1/2" stone<br>3/8" felt<br>1" insulation, R-3<br>Metal deck<br>Air space<br>Suspended Acoustic Tile | 1/2" stone<br>3/8" felt<br>2 1/2" insulation, R-7<br>Metal deck<br>Air space<br>Suspended Acoustic tile |
| Windows | 30% of wall area<br>Single pane | 30% of wall area<br>Triple glazing |
| erating: | | |
| Thermostat settings | 7:00 am. - 6:00 pm. on workdays<br>Cooling-70° Heating-75°<br>Set back 6° at all other times | 7:00 am. - 6:00 pm. on workday<br>Cooling-76° Heating-68°<br>Set back 6° at all other times |
| Outside air | 20 CFM/person | 10 CFM/person |

Table 3-2

HOSPITAL BUILDING DOE 2.1 SPECIFICATIONS

eneral:
Area = 180,000 square feet
Number of stories = 4
Yearly Schedule = 12 months

| | High Energy Use | Low Energy Use |
|---|---|---|
| ights: | | |
| Recessed Flourescent in ceiling | 3.5 watts/sq. ft. in core<br>2.25 watts/sq. ft. in perimeter | 2.5 watts/sq. ft. in core<br>1.75 watts/sq. ft. in perimeter |
| /AC Equipment: | | |
| Air Delivery | Four pipe fan coil in each patient room<br>Constant air volume in treatment rooms | Same with addition of a noncontact heat exchanger |
| Plant | Electric hot water boiler<br>Centrifugal chiller and cooling tower | Electric hot water boiler<br>Double bundle chiller |
| ructure: | | |
| Walls | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" gypsum board | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" insulation, R-2<br>1/2" gypsum board |
| Roof | 1/2" stone<br>3/8" felt<br>1" insulation, R-3<br>Metal deck<br>Air space<br>Suspended Acoustic Tile | 1/2" stone<br>3/8" felt<br>2 1/2" insulation, R-7<br>Metal deck<br>Air space<br>Suspended Acoustic tile |
| Windows | 20% of wall area<br>Single pane | 20% of wall area<br>Triple glazing |
| erating: | | |
| Thermostat settings | 7:00 am. - 6:00 pm. on workdays<br>Cooling-70° Heating-75°<br>Set back 6° at all other times | 7:00 am. - 6:00 pm. on workday<br>Cooling-76° Heating-68°<br>Set back 6° at all other times |
| Outside air | 3.5 Airchanges/hour in core<br>2.0 Airchanges/hour in perimeter | 3.0 Airchanges/hour in core<br>1.8 Airchanges/hour in perimeter |

Table 3-3

SCHOOL BUILDING DOE 2.1 SPECIFICATIONS

eral:
Area = 40,000 square feet
Number of stories = 1
Yearly Schedule = 9 months

| | High Energy Use | Low Energy Use |
|---|---|---|
| hts: | | |
| ecessed Flourescent in ceiling | 3.0 watts/sq. ft. | 2.0 watts/sq. ft. |
| C Equipment: | | |
| Air Delivery | Four pipe fan coil in classrooms, office, cafeteria | Same |
| Plant | Electric hot water boiler<br>Hermetic reciprocating chiller and cooling tower | Electric hot water boiler<br>Double bundle chiller |
| ıcture: | | |
| Walls | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" gypsum board | 4" face brick<br>1" air space<br>8" concrete block<br>1/2" insulation, R-2<br>1/2" gypsum board |
| Roof | 1/2" stone<br>3/8" felt<br>1" insulation, R-3<br>Metal deck<br>Air space<br>Suspended Acoustic Tile | 1/2" stone<br>3/8" felt<br>2 1/2" insulation, R-7<br>Metal deck<br>Air space<br>Suspended Acoustic tile |
| indows | 15% of wall area<br>Single pane | 15% of wall area<br>Triple glazing |
| ating: | | |
| hermostat settings | 7:00 am. - 6:00 pm. on workdays<br>Cooling-70° Heating-75°<br>Set back 6° at all other times | 7:00 am. - 6:00 pm. on workdays<br>Cooling-76° Heating-68°<br>Set back 6° at all other times |
| utside air | 15 CFM/person | 12 CFM/person |

Table 3-4

HEAT PUMP SPECIFICATIONS

Office:

Individual heat pumps serving each zone with the outside coil a water-to-refrigerant heat exchanger connected to a common water loop which is normally at a temperature between the conditioned space and outside, thus increasing efficiency. Electric hot water boiler and cooling tower backup.

Hospital:

Not modeled.

School:

Individual through-the-wall air-to-air heat pump in each room. Electric hot water boiler and cooling tower backup.

S = level of end use services, arbitrarily set at 2 for high energy use and 1 for low energy use

L = lighting level in watts per sq. ft.

Table 3-5 illustrates the way in which the high/low settings are arranged for running the sixteen alternative specifications with DOE 2.1 and setting up the regression. Alternatively, to reduce the expenditures of running DOE 2.1, and without severely compromising the results, ten runs could be used for estimation. These include all cases where each of the four variables are changed one at a time while holding all others at first their high settings and then at their low settings. In Table 3-5, these would be cases 1, 2, 4, 5, 7, 8, 9, 12, 14, and 16. This reduces the number of runs from 32 (16 x 2 weather zones) to 20 (10 x 2 weather zones) for each building. For three prototypes this reduces the runs from 96 down to 60.

Table 3-5

EXPERIMENTAL DESIGN FOR DOE 2.1 RUNS

Energy Use Characterizations

| Case # | Structure | Lights | Service | Equipment |
|---|---|---|---|---|
| 1 | H | H | H | H |
| 2 | H | L | H | H |
| 3 | L | H | L | H |
| 4 | L | H | L | L |
| 5 | L | H | H | H |
| 6 | L | H | H | L |
| 7 | L | L | L | H |
| 8 | L | L | L | L |
| 9 | L | L | H | L |
| 10 | L | L | H | H |
| 11 | H | L | H | L |
| 12 | H | H | H | L |
| 13 | H | H | L | L |
| 14 | H | L | L | L |
| 15 | H | L | L | H |
| 16 | H | H | L | H |

Four HVAC systems are specified for analysis and use in the fuel share module. These are electric resistance, electric heat pump (see Table 3-4), a natural gas heating system, and an oil heating system. A set of coefficients is required for each of the four systems both with and without air conditioning. Ideally, DOE 2.1 should be run without an air conditioning system to derive the data for estimating this specification. Alternatively, the air conditioning annual load can be subtracted from HVAC annual use and the KE variable adjusted accordingly to set up the data to estimate systems without air conditioning. The efficacy of this alternative must be determined by weighing the costs of additional runs against the importance of non-air conditioned space in commercial buildings. Since it is widely accepted that almost all new floor space in the commercial sector has for years been built with air conditioning, this trade off is probably acceptable.

As Tables 3-1 to 3-3 indicate, an electric heating system was specified for each run. To derive data necessary for the natural gas systems, an efficiency factor is used to adjust the HVAC annual loads and KE is adjusted accordingly. The electric heating load is multiplied by 1.27 to derive the natural gas numbers. Coefficient estimates for the natural gas system are then used for the oil system. In the model, different base year capital cost figures are used for gas and oil but the responsiveness of HVAC efficiency choice to the explanatory variables is assumed to be the same for both.

For this project, we opted to reduce the runs to the minimum five per building per weather zone. The coefficients of equation 3-10 shown in Table 3-6 can be estimated by simply looking at two cases for each coefficient; one with the high setting and one with the low where all other variables stay at their high settings. The resulting change in E is a consequence then of the change in that one variable. Taking the ratio of the percentage change in E to the percentage change in the explanatory variable will produce an estimate of that coefficient.

For example, using data from Appendix C, Office-Portland, the coefficient for kE (-2.24 in Table 3.6) is calculated by taking the ratio of the percentage change in HVAC going from case HHHH to HHHL, to the percentage change in costs:

$$\% \text{ HVAL} = \frac{(4{,}713 - 10{,}698)}{10{,}698} = -.5595$$

$$\% \text{ Costs} = \frac{(\$6.50-\$5.20)}{\$5.20} = .25$$

$$kE = \frac{-.5595}{.25} = -2.24$$

Our decision to estimate the coefficients in this manner was based primarily on budget constraints. The costs associated with running DOE 2.1, producing the data series for estimation and the estimation phase were judged to be beyond the limits of our budget for these tasks. The exploratory nature of this analysis and our recognition of other important issues which are involved but could not be addressed because of data limitations as well as budget constraints led us to this decision. Once better survey information is compiled on a large sample of buildings in each building type, e.g., office, retail, hospital, grocery, restaurants, etc., a better determination of what is a "typical" structure in both a physical and operational sense can be sought. This will greatly improve confidence in the results by virtue of improving the representativeness of the prototype buildings.

The heat load results and cost data are contained in Appendix C.

## Subroutine Structure

This section will describe how the fuel/efficiency choice methodology is implemented into the overall commercial end use model code. Appendix B contains a copy of the FSHAR subroutine to help the reader follow the series of calculations contained in the subroutine.

Table 3-6

Coefficient Estimates for Equation 3-5

| | Office | | | Hospital | | | School | | |
|---|---|---|---|---|---|---|---|---|---|
| | ER | HP | FF | ER | HP | FF | ER | HP | FF |
| **Portland** | | | | | | | | | |
| With AC | | | | | | | | | |
| KE | -2.24 | -2.24 | -1.40 | -2.58 | -2.58 | -1.65 | -2.00 | -2.00 | -1.50 |
| KS | -.170 | -.170 | -.150 | -.210 | -.210 | -.150 | -.040 | -.040 | -.040 |
| L | .300 | .300 | .350 | -.100 | -.100 | .100 | -.040 | -.040 | .010 |
| S | .88 | .88 | .33 | .02 | .02 | .09 | .11 | .11 | .12 |
| Without AC | | | | | | | | | |
| KE | -2.77 | -2.77 | -2.09 | -2.77 | -2.77 | -2.09 | -2.00 | -2.00 | -1.50 |
| KS | -.220 | -.220 | -.190 | -.220 | -.220 | -.190 | -.040 | -.040 | -.040 |
| L | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -.05 | -.05 | 0.0 |
| S | .40 | .40 | .37 | .40 | .40 | .37 | .11 | .11 | .12 |
| **Yakima** | | | | | | | | | |
| With AC | | | | | | | | | |
| KE | -2.41 | -2.41 | -1.56 | -3.32 | -3.32 | -2.35 | -2.00 | -2.00 | -2.00 |
| KS | -.180 | -.180 | -.180 | -.110 | -.110 | -.090 | -.050 | -.050 | -.040 |
| L | 0.0 | 0.0 | .35 | -.05 | -.05 | .09 | -.04 | -.04 | 0.0 |
| S | .39 | .39 | .35 | .05 | .05 | .10 | .10 | .10 | .11 |
| Without AC | | | | | | | | | |
| KE | -2.91 | -2.91 | -2.23 | -2.91 | -2.91 | -2.23 | -2.00 | -2.00 | -2.00 |
| KS | -.190 | -.190 | -.180 | -.190 | -.190 | -.190 | -.050 | -.050 | -.050 |
| L | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -.04 | -.04 | 0.0 |
| S | .41 | .41 | .38 | .41 | .41 | .38 | .10 | .10 | .11 |

ER = Electric Resistance, HP = Heat Pump, FF = Fossil Fuel (Gas & Oil)

---

FSHAR has been divided into two sections using an ENTRY statement to call the second section. The subroutine is called by MAIN at the beginning of execution and a series of calculations are performed to set up values for arrays which are either constant over time or not dependent on other variables which are redefined as execution proceeds. The main function of this portion is to set up the price expectation and discount rate distributions for the sample of firms whose fuel and efficiency choices will be simulated over the forecast period in the second section. Additionally, this first section will calibrate the encoded form of equation 3-5 by calculating a constant that ensures an initial value of E equal to the base year value input.

Before beginning the discussion of Section 1, we need to provide a list of the variables and their definitions from FSHAR. Because of the large number of variables in FSHAR, both those exclusive to FSHAR and those in common, we present the variable list in two sections.

Variables Exclusive to FSHAR

| Variable | Definition |
|---|---|
| ACFLAG | Controls presence of AC in calculations |
| ACSUM | Sum of system AC EUI's for weighted average calculation |
| BD | Temp. var., used in coefficient transformation |
| B1 | Temp. var., used in coefficient transformation |
| B2 | Temp. var., used in coefficient transformation |
| B3 | Temp. var., used in coefficient transformation |
| B4 | Temp. var., used in coefficient transformation |
| CCOST | Stores captial cost of heating system |
| CD | Stores intermediate results in discount rate distribution calculation |
| CDEN | Temp. var., used in CCOST calculation |
| COVCOST | Stores conversion cost factor for water to air distribution system |
| CP | Stores intermediate results in fuel price distribution calculation |
| CSFF | Stores capital cost value |
| CYS | Stores number of choices by system |
| CYSAC | Stores number of choices, with air conditioning as part of HVAC |
| C1 | Temp. var., used in CCOST calculation |
| C2 | Temp. var., used in CCOST calculation |
| C3 | Temp. var., used in CCOST calculation |
| DAL | Temp. var., used in discount rate distribution calculation |
| DD2 | Temp. variable 4, air cond. utilization weight |
| DD3 | Temp. variable 4, ventilation utilization weight |
| DIFE | Stores result for iterative check |
| D4 | Utilization weights denominator |
| EAC | Air conditioning EUI by system & observation |
| EBS21L | Stores AC base year EUI |
| EBS31L | Stores ventilation base year EUI |
| ED | Temp. variable used in discount rate distribution calculation |
| EDR | Stores dicount rates by observation |
| ED1 | Temp. variable used in discount rate distribution calculation |

| Variable | Definition |
|---|---|
| EHT | Space heating EUI by system & observation |
| ELT | Stores previous year new lighting EUI |
| EP | Temp. var., used in price distribution calculation |
| EPR | Stores price percent deviation from median by system and observation |
| EP1 | Temp. var., used in price distribution calculation |
| EVT | Ventilation EUI by system and observation |
| HALF | Stores half of NOBS to control COVCOST application |
| HTMP | Temporary variable for heating EUI |
| HVAC | HVAC EUI |
| LCC | Life cycle cost |
| ONC | Stores LCC in minimization check |
| OPCOST | Operating cost for life cycle cost |
| PAL | Intermediate result in price distribution calculation |
| PP2 | Utilization part of CCOST calculation |
| PP3 | Lighting part of CCOST calculation |
| PP4 | Thermal integrity part of CCOST calculation |
| PRI | Stores base year electricity price |
| PRICE | Stores base year prices |
| PVAC | Present value of air conditioning operating cost |
| PVHT | Present value of space heating operating cost |
| PVVT | Present value of ventilation operating cost |
| PO | Constant coefficient in HVAC equation |
| P1 | Stores operating cost for HVAC equation |
| P2 | Stores HVAC utilization for HVAC equation |
| P3 | Stores lighting EUI for HVAC equation |
| P4 | Stores thermal integrity value for HVAC equation |
| RHT | Stores HVAC lifetime |
| SPLIT1 | Stores the ventilation coefficient to split HVAC changes into its components |
| SPLIT2 | Stores the air conditioning coefficient to split HVAC changes into its components |
| SUM | Temp. var. for operating cost summation |
| SUMAC | Stores sum of EAC values for chosen systems |
| SUMHT | Stores sum of EHT values for chosen systems |
| SUMPV | Present value of indexed prices |
| SUMVT | Stores sum of EVT values for chosen systems |
| TD | Temp. var. in distribution calculation |
| TIN | Stores thermal integrity value |
| TOTSYS | Denominator for fuel share calculation |
| UWT | Stores weighted utilization value |
| U1I | Stores space heat utilization |
| U21 | Stores AC utilization |
| U31 | Stores ventilation utilization |
| VTFLAG | Controls presence of ventilation in calculation |
| VTMP | Temporary var. for ventilation EUI |
| VTSUM | Sum of system ventilation EUI's for weighted average calculation |
| WTU1 | Stores space heating utilization weight |
| WTU2 | Stores air cond. utilization weight |

## Variable List - COMMON BLOCKS

COMMON/SETVAR/

| Variable | Definition |
|---|---|
| NNI | Number of fuel types |
| NNIHT | Number of fuels to use in FSHAR |
| NNK | Number of end uses |
| NNL | Number of building types |
| NOBS | # of cases in FSHAR simulation |
| NSP | Number of simulation periods |
| NVNT | Ventilation end use indicator |

COMMON/SIMVAR/

| Variable | Definition |
|---|---|
| A | Stores fuel shares by vintage |
| E | Stores EUI's by vintage |
| EBS | Stores base year EUI's |
| FPBS | Base year fuel prices |
| NREP1 | Lifetimes for end uses |
| PR | Fuel price vectors, relative to base year |
| U | Stores utilization factors by vintage |

COMMON/SHRVAR/

| Variable | Type | Definition |
|---|---|---|
| AIRC | | New construction air cond. electricity, fuel share |
| B | | Weibal function parameter |
| CS | | Coefficients for the technology curves |
| CSF | | Cost/SQ.Ft. of HVAC systems |
| CZF | | Fraction of population in climate zone 1 |
| CZWT | | Weights for partitions: CLZ1 with/without AC and CLZ2 with/without AC |
| D1 | | Space heating utilization weighting factor |
| D2 | | AC utilization weighting factor |
| D3 | | Ventilation utilization weighting factor |
| EBSHP | | Ratio of Heat Pump EUI to Resistance EUI |
| EUICZ | | Weights for climate zone EUI weighting |
| FREQ | | Array containing random sets of probabilities for fuels and discount rates |
| G | | Weibal function parameter |
| HTEBS | | Space heating base year EUI array |
| IRB | | Index for discount rate choice |
| SPLIT | | Coefficients for HVAC EUI split |
| TI | | Thermal integrity index |

| | |
|---|---|
| XD | Array containing lower, median, upper bounds of discount rate distribution |
| XP | Array containing lower, median, upper bounds of price distribution |

Section 1

Price and Discount Rate Distribution: The discount rate distributions (EDR) are calculated first followed by the price expectation distributions (EPR) for each fuel. The series of calculations used to calculate the values for each array are identical in logic. In the section on methodology, equations 3-6 thru 3-9 were presented. These equations are encoded into a series of calculations beginning with the iterative solution for, b (ED), using equation 3-9. Once, b, is determined, the code calculates a value for, c (CD), using equation 3-7. The value for, c, is then used to calculate, a (DAL), using equation 3-8.

Equation 3-6 is encoded in a loop which calculates a discount rate for each firm using the previously calculated values for a, b and c. The index, ID, in the code takes on values of 1 and 2 and is used to index EDR for storage of two discount rates per firm. The two discount rates can represent private and public sector values, respectively. Public institutions such as schools may use a different discount rate than private sector firms given their different pay back period criteria and availability to financing. The values of $X_L$, $X_m$, and $X_u$ are used to differentiate between the two and the variable IRB is used to select one or the other for each building type.

The price expectation distribution array EPR follows the same series of calculations with variable names changed to distinguish them from the previous discount rate calculations. ED becomes EP, CD becomes CP, and DAL becomes PAL.

Present Value Calculation: Once EDP and EPR are calculated the code performs the present value calculation of fuel costs for each fuel type and firm in the sample for all simulation years. The variable SUMPV stores these values for later use in the second section. RHT contains the number of years input from variable NREPL corresponding to the lifetime of HVAC systems.

Calibration of Equation 3-5: Using the base year value of SUMPV, the base year space heating EUI's (electric is split into electric resistance and heat pump and stored in HTEBS as well as the gas and oil EUI's) and fuel prices in the base year, the dollar value of the present discounted value of operating costs is calculated. PVHT, PVAC and PVVT store the present value calculations for heating, cooling, and ventilation, respectively.

Going back to equation 3-5, and noting that E is normalized to 1.0 in the base year for use in the model coding, it is clear that for E to average out to 1.0 in the base year the constant needs to be equal to the reciprical of the base year present value calculation. The other terms in the equation; lighting EUI, thermal integrity and utilization are also all normalized to 1.0 in the base year for use in the model code. Therefore, the product of the constant and the present value term in the equation must average to 1.0 over all firms. The constant is then stored in CS (I, 1, L).

Section 2

The second section in FSHAR is called SHRCAL. This block of code is called from SUBROUTINE UPDAT twice each year of the simulation; once for replacement systems and once for new construction. The other floor space stock vintages replacing HVAC systems acquire the same results calculated by SHRCAL for the replacement system on the first pass through.

The comment statement that reads as PARTITION LOOP - CLIMATE ZONES, WITH/WITHOUT AIR COND begins the loop that calculates the efficiency choice, the capital cost corresponding to the efficiency choice and the resulting life cycle cost (LCC). These calculations are run for the sample of firms for each of the four systems with and without air conditioning and for each climate zone. In effect, there are four segments of the population which are run through the calculations. First, split the population by climate zone giving two segments and then divide each segment into 2 more segments using the air conditioning penetration to differentiate between firms in buildings with air conditioning and firms in buildings without air conditioning.

The estimated parameters of equation 3-10, are transformed to calculate the parameters of equation 3-5, which is the life cycle cost minimizing relationship for efficiency choice, E. In the code these transformed parameters are B1, B2, B3, and B4. The capital cost equation (3-2) parameters are also calculated from the estimated parameters of equation 3-10. In the code these transformed parameters are C1, C2, C3, and CDEN.

Since the model requires separate heating, cooling, and ventilation EUI's the HVAC EUI is split into its components after efficiency is calculated. Estimates of how much of an efficiency gain could be attributed to each end use on average were calculated from the heat load runs. The variable SPLIT1 and SPLIT2 contain these estimates.

Once LCC is calculated for each system for a particular firm, the minimum is found and the system index and HVAC EUIS are stored away until all firms have been run through. Each choice is weighted by a climate zone/air conditioning factor corresponding to the segment being simulated. The fuel shares are then calculated from the accumulated number of weighted choices for each fuel type (electric resistance and heat pump are combined into electric) after all four segments have been run through. The average heating, cooling, and ventilation EUIs are calculated from the chosen systems of each fuel type.

# References

AIA Research Corporation, Phase One/Base Data for the Development of Energy Performance Standards for New BUildings. Prepared for the Department of Housing and Urban Development and the Department of Energy, January 30, 1978.*

Bonneville Power Administration, Bonneville Power Administration Forecasts of Electricity Consumption in the Pacific Northwest, 1980-2000, Draft Report, DOE/BP-98, April 1982.

California Energy Commission, data provided on current energy use requirements of commercial building end uses, April 1982.*

S. Cohn, Fuel Choice and Aggregate Energy Demand in the Commercial Sector, ORNL/COn-27**, December 1978.

S. Cohn, K. Corum, J. Kurish and C. Emerson, A Commercial Energy Use Model for the Ten U.S. Federal Regions, ORNL/CON-40, April 1979 (Draft).

H.G. Huntington and Evan Soffer, The Demand for Energy in the Commercial Sector, Data Resources, Inc. (Preliminary Report to the Electric Power Research Institute), May 1979.

J.R. Jackson, An Econometric-Engineering Analysis of Federal Energy Conservation Programs in the Commercial Sector, ORNL/CON-30, January 1979.

J.R. Jackson, Energy Use in the Commercial Buildings Sector: Historical Patterns and Future Scenarios, Report Submitted to Solar Energy Research Institute and Consultant Agreement C-0-0179-1, October 1980.

J.R. Jackson, S. Cohn, J. Cape and W.S. Johnson, The Commercial Demand for Energy: A Disaggregated Approach, ORNL/CON-15, April 1978.

J.R. Jackson and P. DeGenring, (Charles River Associates), Development and Application of a Commercial Sector Energy Use Model for New York State, CRA Report #438, April 1980.

J.R. Jackson and W.S. Johnson, Commercial Energy Use: A Disaggregation by Fuel, Building Type and End Use, ORNL/CON-14, February 1978.

J.R. Jackson and R. Lann, Refinement and Extension of the NYSEO Commercial Sector Energy Demand Model, November 1981.

W.S. Johnson and F.E. Pierce, Energy and Cost Analysis of Commercial Building Shell Characteristics and Operating Schedules, ORNL/CON-39*, April 1980.

R. Lann, et al., Technical Documentation of the Commercial Sector Forecasting Model, California Energy Commission, October 1979.

A.D. Little, Project Independence Blueprint, Final Task Force Report, Residential and Commercial Energy Use Patterns, 1970-1990, report prepared for the Federal Energy Administration, November 1974.

R.E. Lyman, Jr., Energy and Cost Analysis of Commercial HVAC Equipment: Offices and Hospitals, Masters Thesis, University of Tennessee, December 1978.

Synergic Resources Corporation, data provided by Joan Gamble on schools and hospitals in the Pacific Northwest, April and May 1982.*

U.S. Department of Commerce, Bureau of the Census, County Business Patterns, 1977.

U.S. Department of Energy, Nonresidential Buildings Energy Consumption Survey: Buildings Characteristics, DOE/EIA-0246, March 1981.*

U.S. Department of Energy, Bonneville Power Administration, selected data from the Department of Energy Nonresidential Buildings Feasibility Survey, provided by Phillip Windell and John McConnoughey, May 1982.*

Westinghouse Research Laboratories, Assessing the Potential for Optimal Utilization of Off-Peak Power, prepared for the Federal energy Administration, December 1975.

*References used in data development are designated with an asterisk following the date of publication.

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# APPENDIX A

## Listing of the STOK Subroutine

```
C
C
C
C      SUBROUTINE STOK
C
C      THIS SUBROUTINE DETERMINES ADDITIONS AND FLOOR SPACE
C      STOCK FOR THE SIMULATION PERIOD USING ONE OF TWO
C      METHODS.
C
C
       SUBROUTINE STOK(L)
C
C
C
       REAL LAG(13)
       LOGICAL LOPT1(7),LOPT2(13),LOPT3(4),FSCH(13)
C
       COMMON /STKVAR/ ADD(13,79),S(13,31),EXOG(13,4,31),CF(6,13),
      2                ASTK(13),F(79),EP985(79),FSGRTH(13)
       COMMON /SETVAR/ TITLE(20,2),NILOOP(8),NISTD(8),IRGN,NRGN,NNI,NNK,
      2                NNL,NNE,NDD,NSP,NYRBS,NYRFS,NYRRT,NST,NST1,NSTM1,
      3                NEND,NRTST,N70,N71,N73,N80,NVNT,NWH,NCK,NRF,NOBS,
      4                NSPRI,NNIHT,LOPT1,LOPT2,LOPT3,FSCH,LAG
       DATA CSTK/"STK "/,CADD/"ADD "/,CNO/"NO  "/
C
C      FOR VARIABLE S, N=1 CORRESPONDS TO NYRBS
C      FSCH IS .TRUE. FOR STOCK APPROACH AND .FALSE. FOR
C      THE INVESTMENT DEMAND APPROACH.
C
C      F IS FRACTION OF FLOOR SPACE ADDS FROM VINTAGE NN STILL IN N
C
       IF(L.NE.1)GO TO 10
       DO 20 N=1,NEND
    20 F(N)=1.0-1.0/(1.0+EXP(6.91-0.15356*N))
    10 IF(FSCH(L)) GO TO 500
C
C      ADDITIONS APPROACH SECTION
C
       DO 30 N=NST,NEND
       NIND=N-NSTM1
       SUM=0.0
       N2=N-2
       ADD(L,1)=0.0
       DO 40 NN=1,N2
    40 SUM=SUM+F(NN)*ADD(L,N-NN)
       SUM=SUM+ASTK(L)*EP985(N-1)
       IF(N.EQ.NST) GO TO 50
       IF(LAG(L).EQ.CSTK) ALAG=SUM
       IF(LAG(L).EQ.CADD) ALAG=ADD(L,N-1)
       IF(LAG(L).EQ.CNO) ALAG=0.0
       ADD(L,N)=CF(1,L)+CF(2,L)*EXOG(L,1,NIND)+CF(3,L)*EXOG(L,2,NIND)+
      1         CF(4,L)*EXOG(L,3,NIND)+CF(5,L)*EXOG(L,4,NIND)+
      2         CF(6,L)*ALAG
       IF(ADD(L,N).LT.0.0) ADD(L,N)=0.00
    50 S(L,NIND)=SUM+ADD(L,N)
    30 CONTINUE
       GO TO 600
```

```
C
C     STOCK APPROACH SECTION
C
  500 FSG=FSGRTH(L)
      DO 60 N=NST,NEND
      NIND=N-NSTM1
      FAC=EXP(FSG*NIND)
      SUM=0.0
      N2=N-2
      ADD(L,1)=0.0
      DO 70 NN=1,N2
   70 SUM=SUM+F(NN)*ADD(L,N-NN)
      SUM=SUM+ASTK(L)*EP985(N-1)
      IF(N.EQ.NST) GO TO 80
      IF(LAG(L).EQ.CSTK) ALAG=SUM
      IF(LAG(L).EQ.CADD) ALAG=ADD(L,N-1)
      IF(LAG(L).EQ.CNO) ALAG=0.0
      SQFEMP=CF(2,L)*FAC
      S(L,NIND)=CF(1,L)+SQFEMP*EXOG(L,1,NIND)+CF(3,L)*EXOG(L,2,NIND)+
     1          CF(4,L)*EXOG(L,3,NIND)+CF(5,L)*EXOG(L,4,NIND)+
     2          CF(6,L)*ALAG
      ADD(L,N)=S(L,NIND)-SUM
      IF(ADD(L,N).LT.0.0) ADD(L,N)=0.00
      GO TO 60
   80 S(L,1)=SUM+ADD(L,NST)
   60 CONTINUE
C
  600 CONTINUE
C
      RETURN
      END
```

# APPENDIX B

## Listing of the FSHAR Subroutine

```
C
C
C
C     SUBROUTINE FSHAR - CALCULATES SPACE HEATING FUEL SHARES
C     AND SPACE HEATING, AIR CONDITIONING AND VENTILATION EUI'S
C
C
      SUBROUTINE FSHAR(LL,NS,NNS),RETURNS(A1)
C
      LOGICAL LOPT1(7),LOPT2(13),LOPT3(4),FSCH(13)
C
      INTEGER RHT,HALF
      REAL EPR(50,5),EDR(50,2),LCC(50,6),SUMPV(50,10,31),
     2     EHT(50,6),EAC(50,6),EVT(50,6),EP(5),CP(5),PAL(5),
     3     CYS(6),CYSAC(6),ED(2),CD(2),DAL(2),SUMHT(6),
     4     SUMAC(6),SUMVT(6),LAG(13)
      DIMENSION IND(16)
C
      COMMON /SIMVAR/ Q(8,5,31),U(8,5,79),E(8,5,79),A(8,5,79),
     2                EBS(8,5,13),ABS(8,5,13),PR(5,48),DD(13,2),
     3                DDFAC(13,2),EP928(31),UEL(5),EEL(5),EMAX(8),
     4                NREPL(8),NWT(8),CLG(5),FPBS(5),ACS(13)
      COMMON /OUTVAR/ Q1(31,13,5),Q2(31,8,5),Q3(31,13,8),AST(8,5,31),
     2                EST(8,5,31),UC(8,5,31),US(8,5,31),EC(8,5,31),
     3                ES(8,5,31),AC(8,5,31),AS(8,5,31),QC(8,5,31),
     4                Q1T(31,13),STOT(31),ATOT(31)
      COMMON /STKVAR/ ADD(13,79),S(13,31),EXOG(13,4,31),CF(6,13),
     2                ASTK(13),F(79),EP985(79),FSGRTH(13)
      COMMON /SHRVAR/ CS(16,5,13),XP(3,5),XD(3,2),FREQ(7,50),TI(79),
     2                CSF(13,16),IRB(13),AIRC(13),HTEBS(5),CZWT(4),
     3                SPLIT(13,3),HPPEN(13),EUICZ(2),D1(4),D2,D3,G,B,CZF
      COMMON /SETVAR/ TITLE(20,2),NILOOP(8),NISTD(8),IRGN,NRGN,NNI,NNK,
     2                NNL,NNE,NDD,NSP,NYRBS,NYRFS,NYRRT,NST,NST1,NSTM1,
     3                NEND,NRTST,N70,N71,N73,N80,NVNT,NWH,NCK,NRF,NOBS,
     4                NSPRI,NNIHT,LOPT1,LOPT2,LOPT3,FSCH,LAG
C
      DATA IND/4*0,4*1,4*2,4*3/
C
C
C     CALCULATE THE DISTRIBUTION PARAMETERS AND GENERATE
C      DISCOUNT RATES
C
      RHT=NREPL(1)
      DO 10 ID=1,2
      ED(ID)=0.0
      DO 20 IT=1,50
      ED1=XD(1,ID)-(((XD(2,ID)-ED(ID))**G)/((XD(3,ID)
     2   -ED(ID))**B))
      DIFE=(ED1-ED(ID))/ED1
      ED(ID)=ED1
      IF(DIFE.LE.0.05)GO TO 30
      IF(IT.LT.50) GO TO 20
      WRITE(6,5013)IT,DIFE
      GO TO 999
   20 CONTINUE
   30 CD(ID)=1.2005/(ALOG((XD(3,ID)-ED(ID))/(XD(2,ID)
     2       -ED(ID))))
```

```
      DAL(ID)=0.3665/CD(ID)+ALOG(XD(2,ID)-ED(ID))
      DAL(ID)=EXP(DAL(ID))
      CD(ID)=1./CD(ID)
      IN=ID+NNIHT
      DO 40 IO=1,NOBS
      TD=1.0-FREQ(IN,IO)
      TD=ALOG(TD)
      EDR(IO,ID)=DAL(ID)*((-TD)**CD(ID))+ED(ID)
   40 CONTINUE
   10 CONTINUE
C
C     CALCULATE THE DISTRIBUTION PARAMETERS AND GENERATE
C     PRICE EXPECTATIONS FOR EACH FUEL.
C
      DO 50 I=1,NNIHT
      EP(I)=0.0
      DO 60 IT=1,50
      EP1=XP(1,I)-(((XP(2,I)-EP(I))**G)/((XP(3,I)
     2    -EP(I))**B))
      DIFE=(EP1-EP(I))/EP1
      EP(I)=EP1
      IF(DIFE.LE.0.05)GO TO 70
      IF(IT.LT.50) GO TO 60
      WRITE(6,5014)IT,DIFE
      GO TO 999
   60 CONTINUE
   70 CP(I)=1.2005/(ALOG((XP(3,I)-EP(I))/(XP(2,I)
     2       -EP(I))))
      PAL(I)=0.3665/CP(I)+ALOG(XP(2,I)-EP(I))
      PAL(I)=EXP(PAL(I))
      CP(I)=1./CP(I)
      DO 80 IO=1,NOBS
      TD=ALOG(1.0-FREQ(I,IO))
      EPR(IO,I)=PAL(I)*((-TD)**CP(I))+EP(I)
   80 CONTINUE
   50 CONTINUE
C
C     CALCULATE THE PRESENT VALUE OF FUEL COSTS FROM EPR AND EDR
C
      IDD=NNIHT*2
      VTFLAG=1.0
      IF(NVNT.EQ.0)VTFLAG=0.0
      PRI=FPBS(1)*.001
      DO 100 NP=1,NSP
      DO 110 I=1,IDD
      IJ=I
      IF(I.GT.NNIHT) IJ=I-NNIHT
      IF(I.LE.NNIHT) IA=1
      IF(I.GT.NNIHT) IA=2
      DO 120 IO=1,NOBS
      IF(NP.EQ.2.AND.I.EQ.1) EDR(IO,IA)=EDR(IO,IA)*1.1
      SUM=0.0
      DO 130 NT=1,RHT
      NTT=NT+(NP-1)
  130 SUM=SUM+PR(IJ,NTT)*((EPR(IO,IJ)/EDR(IO,IA))**NT)
      SUMPV(IO,I,NP)=SUM
  120 CONTINUE
```

```
  110 CONTINUE
  100 CONTINUE
      DO 140 L=1,NNL
      HTEBS(1)=EBS(1,1,L)*(1./(.5*HPPEN(L)+(1.-HPPEN(L))))
      HTEBS(2)=EBS(1,1,L)*(1./(HPPEN(L)+2.*(1.-HPPEN(L))))
      HTEBS(3)=EBS(1,2,L)
      HTEBS(4)=EBS(1,3,L)
      EBS21L=EBS(2,1,L)
      EBS31L=EBS(3,1,L)
      NCOF=16
      IF(CZF.EQ.1.0) NCOF=8
      DO 150 I=1,NCOF
      SUM=0.0
      CS(I,1,L)=0.0
      ACFLAG=1.0
      IF((I.GE.5.AND.I.LE.8).OR.I.GT.12) ACFLAG=0.0
      IJ=I-4*IND(I)
      JI=IJ
      IF(IJ.GT.1) JI=IJ-1
      IJJ=JI
      IF(IRB(L).EQ.2) IJJ=NNIHT+JI
      IFU=1
      IF(IRB(L).EQ.2) IFU=4
      B1=-CS(I,3,L)/(CS(I,3,L)-1.)
      PRICE=FPBS(JI)*.001
      DO 160 IO=1,NOBS
      PVHT=SUMPV(IO,IJJ,1)*PRICE*HTEBS(IJ)
      PVAC=SUMPV(IO,IFU,1)*PRI*EBS21L*ACFLAG
      PVVT=SUMPV(IO,IFU,1)*PRI*EBS31L*VTFLAG
      SUM=SUM+(PVHT+PVAC+PVVT)**B1
  160 CONTINUE
      CS(I,1,L)=1./(SUM/NOBS)
  150 CONTINUE
  140 CONTINUE
      RETURN
  999 RETURN A1
C
C     CALCULATE HVAC EUI'S AND LIFE CYCLE COST
C
C ************************************************
      ENTRY SHRCAL
C ************************************************
      L=LL
      N=NS
      NN=NNS
      NIND=N-NSTM1
      NNOLD=NN
      IF(NN.EQ.N) NNOLD=N-1
      II=0
      TOTSYS=0.0
      NNIH=NNIHT+1
      TIN=TI(NNOLD)
      ELT=E(NNK-1,1,NNOLD)
      U21=U(2,1,NNOLD)
      U31=U(3,1,NNOLD)
      EBS21L=EBS(2,1,L)
      EBS31L=EBS(3,1,L)
```

```
      IF(NVNT.EQ.0) VTFLAG=0.0
      IF(NVNT.NE.0) VTFLAG=1.0
      HALF=.5*NOBS
      PRI=FPBS(1)*.001
      DO 170 I=1,NNIH
      CYS(I)=0.0
      CYSAC(I)=0.0
      SUMHT(I)=0.0
      SUMAC(I)=0.0
      SUMVT(I)=0.0
  170 CONTINUE
C
C     PARTITION LOOP -  CLIMATE ZONES, WITH/WITHOUT AIR COND
C
      NCLZ=4
      IF(CZF.EQ.1.0) NCLZ=2
      DO 180 J=1,NCLZ
C
      IF(J.EQ.1.OR.J.EQ.3) ACFLAG=1.
      IF(J.EQ.2.OR.J.EQ.4) ACFLAG=0.0
      DD2=D2*ACFLAG
      DD3=D3*VTFLAG
      COVCOST=0.0
      IF(J.LE.2) JJ=1
      IF(J.GE.3) JJ=2
C
      DO 190 I=1,NNIH
C
      IF(ACFLAG.EQ.1.0) SPLIT1=SPLIT(L,1)
      IF(ACFLAG.EQ.0.0) SPLIT1=SPLIT(L,2)
      SPLIT2=SPLIT(L,3)
      IJ=I
      IF(I.GT.1) IJ=I-1
      IJJ=IJ
      IF(IRB(L).EQ.2) IJJ=NNIHT+IJ
      IFU=1
      IF(IRB(L).EQ.2) IFU=4
      II=II+1
      U1I=U(1,IJ,NNOLD)
      PRICE=FPBS(IJ)*.001
      B1=-CS(II,3,L)/(CS(II,3,L)-1.)
      B2=-CS(II,2,L)/(CS(II,3,L)-1.)
      B3=-CS(II,5,L)/(CS(II,3,L)-1.)
      B4=-CS(II,4,L)/(CS(II,3,L)-1.)
      CDEN=1./CS(II,3,L)
      C1=-CS(II,2,L)*CDEN
      C2=-CS(II,5,L)*CDEN
      C3=-CS(II,4,L)*CDEN
      D4=D1(I)+DD2+DD3
      WTU1=D1(I)/D4
      WTU2=DD2/D4
      UWT=(U1I*WTU1+U2I*WTU2+U3I*(1.-WTU1-WTU2))
      P0=CS(II,1,L)
      P2=UWT**B2
      P3=ELT**B3
      P4=TIN**B4
      PP2=UWT**C1
```

```
      PP3=ELT**C2
      PP4=TIN**C3
      CSFF=CSF(L,II)
C
      DO 200 IO=1,NOBS
C
      PVHT=SUMPV(IO,IJJ,NIND)*HTEBS(I)*PRICE
      PVAC=SUMPV(IO,IFU,NIND)*EBS21L*PRI*ACFLAG
      PVVT=SUMPV(IO,IFU,NIND)*EBS31L*PRI*VTFLAG
      P1=(PVHT+PVAC+PVVT)**B1
      HVAC=P0*P1*P2*P3*P4
      EVT(IO,I)=-SPLIT1*VTFLAG*(1.-HVAC)+1.
      EAC(IO,I)=-SPLIT2*ACFLAG*(1.-HVAC)+1.
      EHT(IO,I)=(HVAC*(HTEBS(I)+EBS21L*ACFLAG+EBS31L*VTFLAG)-
     2          EAC(IO,I)*ACFLAG*EBS21L-EVT(IO,I)*VTFLAG*EBS31L)/
     3          HTEBS(I)
      IF(EHT(IO,I).LT.EMAX(1)) EHT(IO,I)=EMAX(1)
      IF(EAC(IO,I).LT.EMAX(2)) EAC(IO,I)=EMAX(2)
      IF(EVT(IO,I).LT.EMAX(3)) EVT(IO,I)=EMAX(3)
      OPCOST=U1I*EHT(IO,I)*PVHT+U21*EAC(IO,I)*PVAC+U31*EVT(IO,I)*PVVT
      CCOST=CSFF*PP2*PP3*PP4*(HVAC**CDEN)
      IF(NN.LT.N) COVCOST=AIRC(L)
      IF(IO.GT.HALF) COVCOST=0.0
      LCC(IO,I)=OPCOST+CCOST+COVCOST
  200 CONTINUE
  190 CONTINUE
C
C     DETERMINE MINIMUM LCC AND CALC FUEL SHARES AND EUI'S
C
      DO 210 IO=1,NOBS
      MINT=1
      ONC=LCC(IO,1)
      IF(LCC(IO,2).GT.ONC) GO TO 220
      MINT=2
      ONC=LCC(IO,2)
  220 IF(LCC(IO,3).GT.ONC) GO TO 230
      MINT=3
      ONC=LCC(IO,3)
  230 IF(LCC(IO,4).GT.ONC) GO TO 240
      MINT=4
      ONC=LCC(IO,4)
  240 CYS(MINT)=CYS(MINT)+CZWT(J)
      CYSAC(MINT)=CYSAC(MINT)+CZWT(J)*ACFLAG
      TOTSYS=TOTSYS+CZWT(J)
      SUMHT(MINT)=SUMHT(MINT)+EHT(IO,MINT)*CZWT(J)*EUICZ(JJ)
      SUMAC(MINT)=SUMAC(MINT)+EAC(IO,MINT)*CZWT(J)*ACFLAG
      SUMVT(MINT)=SUMVT(MINT)+EVT(IO,MINT)*CZWT(J)*VTFLAG
  210 CONTINUE
  180 CONTINUE
C
C     CALCULATE FUEL SHARES AND AVERAGE EUI'S
C
      NM=NN-1
      IF(NM.LE.0) NM=1
      A(1,1,NN)=((CYS(1)+CYS(2))/TOTSYS)*100.
      A(1,2,NN)=(CYS(3)/TOTSYS)*100.
      A(1,3,NN)=(CYS(4)/TOTSYS)*100.
```

```
      IF(A(1,1,NN).EQ.0.0) GO TO 250
      HTMP=(SUMHT(1)+SUMHT(2))/(CYS(1)+CYS(2))
      IF(HTMP.EQ.0.0) E(1,1,NN)=E(1,1,NM)
      IF(HTMP.NE.0.0) E(1,1,NN)=HTMP
       GO TO 260
  250 E(1,1,NN)=E(1,1,NM)
  260 DO 270 I=3,4
      IF(CYS(I).EQ.0.0) GO TO 280
      HTMP=SUMHT(I)/CYS(I)
      IF(HTMP.EQ.0.0) E(1,I-1,NN)=E(1,I-1,NM)
      IF(HTMP.NE.0.0) E(1,I-1,NN)=HTMP
       GO TO 270
  280 E(1,I-1,NN)=E(1,I-1,NM)
  270 CONTINUE
      ACSUM=0.0
      VTSUM=0.0
      DO 290 I=1,NNIH
      IF(CYSAC(I).EQ.0.0) GO TO 290
      ACSUM=ACSUM+(SUMAC(I)/CYSAC(I))*(CYS(I)/TOTSYS)
      VTSUM=VTSUM+SUMVT(I)
  290 CONTINUE
      VTMP=VTSUM/TOTSYS
      IF(VTMP.GT.1.05) VTMP=1.05
      IF(ACSUM.EQ.0.0) E(2,1,NN)=E(2,1,NM)
      IF(ACSUM.NE.0.0) E(2,1,NN)=ACSUM
      IF(VTMP.EQ.0.0) E(3,1,NN)=E(3,1,NM)
      IF(VTMP.NE.0.0) E(3,1,NN)=VTMP
      RETURN
C
C   FORMATS
C
 5013 FORMAT("1ED DID NOT CONVERGE AFTER ",I2,
     2       "ITERATIONS-DIF IS (",F10.5,")")
 5014 FORMAT("1ER DID NOT CONVERGE AFTER ",I2,
     2       "ITERATIONS-DIF IS (",F10.5,")")
      END
```

# APPENDIX C

## Heat Load Simulation Results

## Office - Portland

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S L O E | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| HHHH | 6,975 | 2,008 | 1,715 | 1,178 | 252 | 12,128 | 0 | 0 | 0 | 0 |
| HHHL | 949 | 2,049 | 1,715 | 1,178 | 252 | 6,143 | 0 | 0 | .55 | .75 |
| HHLH | 3,934 | 1,503 | 1,243 | 1,178 | 252 | 8,110 | 0 | 0 | 0 | -.44 |
| HLHH | 6,514 | 1,718 | 1,510 | 841 | 252 | 10,835 | 0 | -.665 | 0 | -.26 |
| LHHH | * | | | | | | | | | |
| LLLL | 350 | 1,177 | 901 | 841 | 252 | 3,521 | 1.58 | -.665 | .55 | -.25 |
| LLLH | 2,907 | 1,089 | 901 | 841 | 252 | 5,990 | 1.58 | -.665 | 0 | -.80 |
| LLHL | 888 | 1,497 | 1,246 | 891 | 252 | 4,724 | 1.58 | -.665 | .55 | .11 |
| LHLL | 235 | 1,431 | 1,050 | 1,178 | 252 | 4,146 | 1.58 | 0 | .55 | -.07 |
| HLLL | 501 | 1,312 | 1,094 | 841 | 252 | 4,000 | 0 | -.665 | .55 | .04 |
| | | | | | Base Cost: | | 1.63 | 2.20 | 5.20 | |

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing) (KE)
H - High energy use
L - Low energy use

## Hospital - Portland

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHH | 20,375 | 1,520 | 5,365 | 11,444 | 6,016 | 44,720 | 0 | 0 | 0 | 0 |
| HHHL | 12,136 | 2,065 | 5,263 | 11,444 | 6,016 | 36,924 | 0 | 0 | .93 | .28 |
| HHLH | 21,771 | 1,123 | 3,917 | 11,444 | 6,016 | 44,271 | 0 | 0 | 0 | -.26 |
| HLHH | 22,107 | 1,168 | 4,680 | 8,454 | 6,016 | 42,425 | 0 | -.49 | 0 | -.07 |
| LHHH | * | | | | | | | | | |
| LLLL | 10,468 | 1,286 | 3,130 | 8,454 | 6,016 | 29,354 | .64 | -.49 | .93 | -.31 |
| LLLH | 21,393 | 909 | 3,237 | 8,454 | 6,016 | 40,009 | .64 | -.49 | 0 | -.47 |
| LLHL | 10,084 | 1,591 | 4,313 | 8,454 | 6,016 | 30,458 | .64 | -.49 | 93 | 0 |
| LHLL | 10,204 | 1,719 | 3,647 | 11,444 | 6,016 | 33,030 | .64 | 0 | .93 | -.15 |
| HLLL | 14,070 | 1,172 | 3,352 | 8,454 | 6,016 | 33,064 | 0 | -.49 | .93 | .11 |
| | | | | | Base Cost: | | .67 | 1.84 | | 10.9 |

*Case not run

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E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery
EQUIP - Change in HVAC cost (sizing) (KE)
H - High energy use
L - Low energy use

## School - Portland

| | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHH | 7,016 | 71 | 638 | 527 | 43 | 8,295 | 0 | 0 | 0 | 0 |
| HHHL | 6,833 | 96 | 638 | 527 | 43 | 8,137 | 0 | 0 | 0 | .70 |
| HHLH | 6,305 | 45 | 515 | 527 | 43 | 7,435 | 0 | 0 | 0 | -.09 |
| HLHH | 7,185 | 50 | 580 | 351 | 43 | 8,209 | 0 | -.625 | 0 | -.07 |
| LHHH | 6,706 | 79 | 618 | 527 | 43 | 7,973 | .88 | 0 | 0 | -.07 |
| LLLL | * | | | | | | | | | |
| LLLH | * | | | | | | | | | |
| LLHL | * | | | | | | | | | |
| LHLL | * | | | | | | | | | |
| HLLL | * | | | | | | | | | |
| | | | | | Base Cost: | | .84 | 1.20 | 4.60 | |

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

## Office - Yakima

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S L O E | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| HHHH | 7,362 | 1,843 | 1,672 | 1,178 | 253 | 12,308 | 0 | 0 | 0 | 0 |
| HHHL | 1,695 | 1,862 | 1,672 | 1,178 | 253 | 6,660 | 0 | 0 | .55 | .60 |
| HHLH | 4,108 | 1,338 | 1,209 | 1,178 | 253 | 8,086 | 0 | 0 | 0 | -.48 |
| HLHH | 6,919 | 1,551 | 1,460 | 841 | 253 | 11,024 | 0 | -.665 | 0 | -.26 |
| LHHH | 5,944 | 1,560 | 1,388 | 1,178 | 253 | 10,323 | 1.58 | 0 | 0 | -.46 |
| LLLL | * | | | | | | | | | |
| LLLH | * | | | | | | | | | |
| LLHL | * | | | | | | | | | |
| LHLL | * | | | | | | | | | |
| HLLL | * | | | | | | | | | |
| | | | | | Base Cost: | | 1.56 | 2.20 | 5.34 | |

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

## Hospital - Yakima

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHH | 30,089 | 1,585 | 5,191 | 11,444 | 6,016 | 54,325 | 0 | 0 | 0 | 0 |
| HHHL | 17,901 | 2,300 | 5,020 | 11,444 | 6,016 | 42,681 | 0 | 0 | .93 | .13 |
| HHLH | 30,055 | 1,173 | 3,794 | 11,444 | 6,016 | 52,482 | 0 | 0 | 0 | -.32 |
| HLHH | 31,595 | 1,279 | 4,503 | 8,454 | 6,016 | 51,847 | 0 | -.49 | 0 | -.11 |
| LHHH | 26,703 | 1,547 | 4,870 | 11,444 | 6,016 | 50,580 | .64 | 0 | 0 | -.17 |
| LLLL | * | | | | | | | | | |
| LLLH | * | | | | | | | | | |
| LLHL | * | | | | | | | | | |
| LHLL | * | | | | | | | | | |
| HLLL | * | | | | | | | | | |
| | | | | | Base Cost: | | .69 | 1.84 | 11.14 | |

*Case not run

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L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

## School - Yakima

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHH | 8,234 | 71 | 644 | 527 | 43 | 9,519 | 0 | 0 | 0 | 0 |
| HHHL | 8,038 | 91 | 644 | 527 | 43 | 9,343 | 0 | 0 | 0 | .60 |
| HHLH | 7,444 | 49 | 532 | 527 | 43 | 8,595 | 0 | 0 | 0 | -.08 |
| HLHH | 8,415 | 52 | 589 | 351 | 43 | 9,450 | 0 | -.62 | 0 | -.07 |
| LHHH | 7,835 | 77 | 621 | 527 | 43 | 9,103 | .88 | 0 | 0 | -.10 |
| LLLL | * | | | | | | | | | |
| LLLH | * | | | | | | | | | |
| LLHL | * | | | | | | | | | |
| LHLL | * | | | | | | | | | |
| HLLL | * | | | | | | | | | |
| | | | | | | Base Cost: | .84 | 1.90 | | 5.03 |

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

## Office - Heat Pump - Portland

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHHP | 2,277 | 538 | 748 | 1,178 | 252 | 4,493 | 0 | 0 | 0 | 0 |
| HLHHP | 2,490 | 412 | 659 | 840 | 252 | 4,653 | 0 | -.625 | 0 | .11 |
| HHLHP | 1,231 | 222 | 533 | 1,178 | 252 | 3,416 | 0 | 0 | 0 | .78 |
| LHHHP | 1,680 | 520 | 630 | 1,178 | 252 | 4,260 | 1.49 | 0 | 0 | .96 |

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use

## School - Heat Pump - Portland

| | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHHP | 4,673 | 99 | 567 | 527 | 43 | 5,909 | 0 | 0 | 0 | 0 |
| HLHHP | 4,708 | 76 | 512 | 351 | 43 | 5,690 | 0 | -.62 | 0 | -.22 |
| HHLHP | 3,945 | 85 | 448 | 527 | 43 | 5,048 | 0 | 0 | 0 | -.53 |
| LHHHP | 4,559 | 105 | 549 | 527 | 43 | 5,783 | .88 | 0 | 0 | -.07 |

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use

## Office - Heat Pump - Yakima

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHHP | 2,862 | 503 | 733 | 1,177 | 252 | 5,527 | 0 | 0 | 0 | 0 |
| HLHHP | 3,098 | 394 | 642 | 840 | 252 | 5,226 | 0 | -.625 | 0 | -.53 |
| HHLHP | 1,628 | 478 | 522 | 1,177 | 252 | 4,057 | 0 | 0 | 0 | -.69 |
| LHHHP | 2,119 | 445 | 606 | 1,177 | 252 | 4,599 | 1.49 | 0 | 0 | -.51 |

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use

## School - Heat Pump - Yakima

| Case | ENERGY (MMBtu) | | | | | | COSTS (Change $/FT**2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HEAT | COOL | AUX | LIGHTS | EQUIP | TOTAL | STR | LGT | REC | EQUIP |
| S L O E | | | | | | | | | | |
| HHHHP | 4,259 | 113 | 545 | 527 | 43 | 5,487 | 0 | 0 | 0 | 0 |
| HLHHP | 4,297 | 90 | 492 | 351 | 43 | 5,273 | 0 | -.62 | 0 | -.15 |
| HHLHP | 3,719 | 98 | 434 | 527 | 43 | 4,821 | 0 | 0 | 0 | -.55 |
| LHHHP | 4,158 | 117 | 527 | 527 | 43 | 5,373 | .88 | 0 | 0 | 0 |

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use