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# Economic Analysis of the Norris Cotton Federal Office Building

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National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

Sponsored by:
The Department of Energy
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# ECONOMIC ANALYSIS OF THE NORRIS COTTON FEDERAL OFFICE BUILDING

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## PREFACE

This study was conducted by the Applied Economics Program of the National Bureau of Standards for the Department of Energy to demonstrate how economic analysis can be applied to the post-occupancy evaluation of the Norris Cotton Federal Office Building, owned and operated by the General Services Administration as an energy conserving building.

Drs. Harold E. Marshall and Stephen F. Weber and Mr. Robert E. Chapman provided reviews of the economic aspects of this paper. Drs. James E. Hill and Stanley T. Liu and Mr. Thomas E. Richtmyer furnished thermal engineering data. Mr. G. G. Wells reviewed the architectural and cost aspects of this study. Mr. Gerald K. Farrington provided building operation and energy consumption data. Ms. Kimberly A. Hockenbery made cost calculations. The author wishes to express his appreciation to the above persons without whose help this study could not have been completed.

ABSTRACT

The Norris Cotton Federal Office Building in Manchester, New Hampshire, has been constructed and occupied by the General Services Administration to demonstrate energy conservation techniques in the design and operation of a contemporary office building. This post occupancy economic evaluation conducted by the National Bureau of Standards shows that additional construction costs incurred in order to reduce the energy consumption of the building are adequately offset by the present value of the resulting annual energy savings. In the economic model, the actual construction cost and energy consumption of the constructed building are compared with the estimated construction cost and energy consumption of a hypothetical equivalent conventional building. The present value costs of the two buildings are calculated for each year during a 40-year study period.



Keywords: Building design; construction cost estimation; discounted payback period; economic analysis; economic evaluation; energy conservation; life-cyle costing; present value analysis.

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## SI Conversion Units

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this publication. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, appropriate conversion factors have been provided in the table below. The reader interested in making further use of the coherent system of SI units is referred to:

NBS SP330, 1972 Edition, "The International System of Units"
E380-72 ASTM Metric Practice Guide (American National Standard Z210.1)

Table of Conversion Factors in Metric (S.I.) Units

| Physical Quantity (and symbol used in paper) | | To convert from | to | multiply by |
|---|---|---|---|---|
| Length | x | inch | meter | 2.54* x $10^{-2}$ |
| | | foot | m | 3.048* x $10^{-1}$ |
| Area | | $inch^2$ | $m^2$ | 6.4516 x $10^{-4}$ |
| | | $foot^2$ | $m^2$ | 9.290 x $10^{-2}$ |
| Volume | | $inch^3$ | $m^3$ | 1.639 x $10^{-5}$ |
| | | $foot^3$ | $m^3$ | 2.832 x $10^{-2}$ |
| Temperature | | Fahrenheit | Celsius | $t_C = (t_F-32)/1.8)$ |
| Temperature difference | | Fahrenheit | Kelvin | $K = (\Delta t_F)/1.8$ |
| Pressure | | inch Hg (60°F) | newton/$m^2$ | 3.377 x $10^2$ |
| Mass | | lbm | kg | 4.536 x $10^{-1}$ |
| Mass/unit area | M | lbm/$ft^2$ | kg/$m^2$ | 4.882 |
| Moisture content rate | | lbm/$ft^2$week | kg/$m^2$s | 8.073 x $10^{-6}$ |
| Density | ' | lbm/$ft^2$ | kg/$m^2$ | 1.602 x $10^1$ |
| Thermal conductivity | k | Btu/hr $ft^2$(F/inch) | $\frac{W}{mk}$ | 1.442 x $10^{-1}$ |
| U-value | | Btu/hr$ft^2$°F | $\frac{W}{m^2K}$ | 5.678 |
| Thermal resistance | R | F/(Btu/hr $ft^2$) | K/(W/$m^2$) | 1.761 x $10^{-1}$ |
| Heat flow | | Btu/hr $ft^2$ | W/$m^2$ | 3.155 |
| Water vapor: | | | | |
| permeability | p | $\frac{\text{grain}}{\text{hr ft}^2\text{(in.Hg/in.)}}$ | kgm/Na | 1.457 x $10^{-12}$ |
| permeance | p,P | $\frac{\text{grain}}{\text{hr ft}^2\text{(in.Hg)}}$ (perm) | kg/Na | 5.738 x $10^{-11}$ |

* Exact value; others are rounded to fourth place.

## 1.0 INTRODUCTION

As part of its response to the energy crisis, the General Services Administration (GSA), in 1972, designated the proposed Federal Office Building in Manchester, New Hampshire, as an energy conservation demonstration project to evaluate energy conservation techniques in the design and operation of a contemporary office building.

The GSA subsequently appointed a design team to incorporate energy conservation techniques in the building. This team consisted of the GSA project administrator and staff from the Central and Region I Offices; Dubin Bloome Associates, Energy Conservation Consultants; Isaak and Isaak, Architects; Rose, Goldberg and Associates, Structural Consultants; Richard D. Kimball Co., Mechanical Consultants; and the National Bureau of Standards (NBS), design and evaluation consultants.

With the aid of the computerized National Bureau of Standards Load Determination Programs (NBSLD)[1], the effects of various building design alternatives on the annual energy consumption of the proposed building were evaluated by NBS. The NBS also assisted the Mechanical Consultant in sizing various components of the heating ventilation and air conditioning HVAC systems. Furthermore, the NBS drafted specifications to purchase a computerized energy monitoring and control system to measure the energy consumption and performance data.

In brief, the design team selected for the proposed Federal building the following opportunities for energy conservation: building envelope design including doors, windows, mass and insulation; various designs; solar energy for space heating and cooling; and various lighting systems.[2] Construction of the building began in December 1974 and was completed in August 1976. Fifteen Federal agencies serving the region now occupy the building, which has subsequently been designated as the Norris Cotton Federal Office Building.

In addition to its role in the building design and energy monitoring, NBS was also requested by the then Energy Research and Development

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[1] Tamami Kusuda, James E. Hill, Stanley T. Liu, James P. Barnett and John W. Bean, Pre-Design Analysis of Energy Conservation Options for a Multi-Story Demonstration Office Building, U.S. Department of Commerce, National Bureau of Standards, Building Science Series 78,

[2] For a detailed description of the specific energy conservation features selected for the building, see Nicholas Isaak and Andrew Isaak, Designing an Energy-Efficient Building: A Case Study, General Services Administration, September 1975.
November 1975.

Administration (ERDA) and now the Department of Energy (DOE) to make post-occupancy evaluations on the economic, engineering and user acceptance aspects of the energy conservation technqiues. This report is written to fulfill the requirement of an economic evaluation after the building is occupied.

## 1.1 PURPOSE

The purpose of this report is to present the results of an analysis of the cost effectiveness of the investments made in the energy conserving techniques for the Norris Cotton Federal Office Building in Manchester, N.H. This analysis addressed the question of whether the additional construction costs incurred in order to reduce the energy consumption of the building are adequately offset by the value of the resulting annual energy savings.

## 1.2 SCOPE AND APPROACH

In this report, the construction costs of the Norris Cotton Federal Office Building (NCFOB) and an Equivalent Conventional Building (ECB) are combined with the corresponding annual energy consumption in a present value format of a maximum lifespan of 40 years. The ECB was designed in such a way that its size and shape, quality of material and construction, and occupancy requirements would be approximately equal to those of the NCFOB. The life-cycle costs resulting from initial construction and annual energy use are calculated for both buildings and serve as the basis of the economic evaluation.

Since the computerized energy monitoring and control system did not become operational until December 1977, detailed energy consumption and corresponding operating efficiencies of the individual energy conserving features could not be measured at this time. Therefore, only the monthly energy consumption data as reported by the utility companies for the past year are used in conjunction with the actual construction cost of NCFOB to present the life-cycle cost of the building as a whole. In accordance with the GSA Design Handbook of 1969, the building costs and yearly energy consumption for the ECB are estimated. These estimates are compared and validated with data compiled by GSA.

For the past year, the NCFOB has been operated and maintained by GSA personnel as well as the construction contractors who have been, from time to time, correcting the defects and furnishing the omissions in the building. Therefore, no meaningful data on the non-energy operation and maintenance are accurate enough to be included in the economic analysis at this time. This report includes only the total building construction costs and yearly energy costs of the NCFOB and ECB in the economic evaluation. Economic evaluations involving other variables are suggested in Section 4.0 as future research efforts.

## 1.3 ORGANIZATION

The remainder of this report is divided into the following sections and appendices.

Section 2.0 describes the physical attributes, the costing method and construction costs for both the NCFOB and ECB. The methods of calculating annual energy consumption for both the NCFOB and ECB are also described.

Section 3.0 contains the economic evaluation of both NCFOB and ECB. A life-cycle cost model is developed here using present worth analysis of the building investment cost and energy cost for a lifespan of up to 40 years. This model is used to obtain the present values of both NCFOB and ECB costs, based on (reasonable) upper and lower limits of energy use, energy price increases and lifespans.

Section 4.0 summarizes the findings of the economic analysis for the NCFOB. Recommendations are made for conducting further research such as the inclusion of operation and maintenance costs in the life-cycle model and performing economic analyses of those individual energy-conserving features which permit independent evaluation.

The appendices include the detailed listings of all construction cost, energy usage and price data and the year-to-year present value costs for both the NCFOB and ECB.

## 2.0 CONSTRUCTION COST AND ENERGY CONSUMPTION

Two kinds of data, namely construction cost and energy consumption, are developed in this section. Preceding the development of construction cost and energy consumption data, the selection of the ECB suitable for the economic comparison is required. The procedure for choosing a design for the ECB is as follows.

### 2.1 ECB SELECTION

A brief description of the NCFOB is needed in order to understand how the ECB is selected.

#### 2.1.1 NCFOB Description

The NCFOB was designed and constructed with two levels for underground parking, seven office floors, and a mechanical house. The typical office floor is 130 feet x 110 feet in size. The entire building has an area of approximately 176,000 gross square feet.

In order to reduce heat loss through the exterior surfaces, the building is shaped like a cube from the second through the seventh floors. First floor area is extended beyond the general cube to provide for additional ground floor space. The exterior surfaces are more massive than that of conventional buildings. There is also less window area and thicker insulation provided for the exterior surfaces in this building. Energy conserving mechanical and electrical systems are provided in the building. Part of Appendix A is devoted to presenting more specific details of the design requirements for the NCFOB.

#### 2.1.2 ECB Design Requirements

In 1976, the architectural consulting firm of Isaak and Isaak in Manchester, New Hampshire, was contracted by the NBS to develop a comparable design and corresponding construction cost for the ECB. Issak and Isaak had done an early version of the NCFOB. Following is a list of general criteria used for the selection of the ECB design.

1. That the total assignable area be identical to that in the NCFOB.
2. That the auxiliary spaces such as parking and maintenance work spaces be of the same size as the NCFOB.
3. That the construction site be the same as the NCFOB.
4. That the conventional design be in compliance with GSA Design Handbooks and acceptable local practices.
5. That the architectural and engineering quality be the same as the NCFOB.
6. That the period of construction be the same as the NCFOB, from May 1, 1974 to August 24, 1976.

A design for the ECB was selected by Isaak and Isaak and accepted by the NBS. The specific design requirements are described in Appendix A.

## 2.2 BUILDING CONSTRUCTION COSTS

The construction costs developed here for the NCFOB and ECB do not include the following cost items: Site acquisition cost; architecture and engineering design fees[1]; furniture and furnishing cost; and relocation cost. These cost items are excluded from the economic comparison because they are generally considered to be equal for both buildings and therefore will not affect the outcome of the cost comparison of both buildings. The construction costs are described as follows.

The NCFOB construction cost represents the original contract price in the Spring of 1974 to be fully paid for in the Fall of 1976. All contract change orders made during the construction period were adjusted so that the resulting figures represent the dollar values as of the start of construction. The sum of the original contract price and the adjusted change order prices is used here as the total NCFOB construction cost incurred at the end of 1976.

The ECB construction cost developed here was originally estimated by Isaak and Isaak and subsequently modified by the NBS and reviewed by the GSA. A major modification is the change from a six story building to a seven story building to provide the same height for both buildings.

Based on the cost data contained in Appendix A, the resulting information suitable for the economic evaluation is shown in Table 2.1.

## 2.3 ANNUAL ENERGY CONSUMPTION

Two distinct estimates of the annual energy consumption for each of the two buildings were made. The detailed data on which these estimates were made can be found in Appendix B.

### 2.3.1 Energy Consumption for NCFOB

For the NCFOB the predicted level of energy consumption shown in Table 2.2 was computed by the NBSLD program using 1962 weather data.[2]

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[1] The design fees for the NCFOB are considerably larger than those for the ECB at this time. It is expected, however, that by sharing design methods in professional publications, the design fees for energy conservation buildings eventually will be equal to those for the conventional buildings.

[2] The monthly average temperatures for 1962 were very close to the thirty year norm values for Manchester, N.H. See Tamami Kusuda, James E. Hill, Stanley T. Liu, James P. Barnett and John W. Bean, <u>Pre-Design Analysis of Energy Conservation Options for a Multi-story Demonstration Office Building,</u> U.S. Department of Commerce, National Bureau of Standards, Building Science Series 78, November 1975.

Table 2.1

Building Construction Costs in 1976 Dollars

| Building Elements | Buildings | |
|---|---|---|
| | NCFOB | ECB |
| Architectural/Structural | $6,147,122 | $5,706,361 |
| Mechanical | 1,195,731 | 944,028 |
| Electrical | 576,181 | 698,698 |
| Subtotal | 7,919,034 | 7,349,087 |
| GC Overhead/Profit | 601,847 | 558,531 |
| TOTAL | 8,520,881 | 7,907,620 |
| Less Extras For Non-building Items[a] | -285,765 | None |
| Comparable Cost | $8,235,116 | $7,907,620 |

[a] This figure represents the "Demonstration" items as explained in Appendix A.

Table 2.2

Annual Energy Consumption for NCFOB in $10^9$ BTU and 1977 Dollars

| Energy Type | Predicted Level for 1962 Weather Data | | Actual Level for 1977 | |
|---|---|---|---|---|
| | $10^9$ BTU | 1977 Dollars[a] | $10^9$ BTU | 1977 Dollars[a] |
| Natural gas | 2.290 | $13,900 | 2.421 | $14,695 |
| Fuel oil | 0 | 0 | 0.801 | 2,339 |
| Electricity | 3.886 | 40,298 | 5.465 | 56,672 |
| TOTAL | 6.176 | $54,198 | 8.687 | $73,706 |

[a] See Appendix B for detailed energy consumption data and prices for various energy types.

The actual level of energy consumption was calculated from the monthly utility bills actually paid in 1977.

The actual energy usage in 1977 is 40.7 percent higher than the predicted level for 1962. This 40.7 percent increase may be traced to the difference in weather conditions between 1962 and 1977, the requirement for equipment shake-down operations during the first year of occupancy and other non-weather factors which might include the effective insulation value and infiltration value of the building envelop and the operating efficiency of this building equipment.

While the actual energy usage in 1977 is 40.7 percent higher than the predicted level in 1962, the dollar value of the actual energy use in 1977 is 36 percent more than the predicted level in 1962. This apparent discrepancy between 36 and 40.7 percent is caused by the fact that in 1977, about 9 percent of the total energy used was supplied by fuel oil, the unit price of which (cost per million BTU) is less than one half of that for the natural gas. Consequently this unit price differential between fuel oil and natural gas reduces the effective increase from 40.7 to 36 percent.

### 2.3.2 Energy Consumption for ECB

For the ECB the predicted level of energy consumption shown in Table 2.3 was computed by the NBSLD program using 1962 weather data. To correct for the difference in weather conditions between 1977 and 1962, the adjusted level of energy consumption is shown in Table 2.3 to reflect a 10 percent increase[1] of energy consumption from the predicted level.

The annual energy costs are assumed to accrue at the end of the year. The construction cost and building energy consumption data in this section will be used for the economic evaluation presented in Section 3.0.

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[1] A 10 percent increase of energy consumption was selected because of the effect of the 8209 degree-days recorded for 1977 over the 7586 degree-days recorded for 1962. This increase of degree-days is equivalent to a 10% increase in energy use based on the average response of similar buildings studied by the Building Owners and Managers Association (BOMA) for 91 conventional office buildings.

Table 2.3

Annual Energy Consumption for ECB in $10^9$ BTU and Dollars

| Energy Type | Predicted Level for 1962 Weather Data | | Adjusted Level for 1977 | |
|---|---|---|---|---|
| | $10^9$ BTU | 1977 Dollars[a] | $10^9$ BTU | 1977 Dollars[a] |
| Natural Gas | 4.983 | $ 30,247 | 5.481 | $ 33,270 |
| Fuel Oil | 0 | 0 | 0[b] | 0[b] |
| Electricity | 7.277 | 75,462 | 8.005 | 83,012 |
| TOTAL | 12.260 | $105,709 | 13.486 | $116,281 |

[a] See Appendix B for detailed energy consumption data and prices for various energy types.

[b] Since fuel oil is the standby energy type for heating and is intended to be used intermittently and without any planned frequency, the annual fuel oil consumption for the adjusted level in 1977 is assumed to be zero. This assumption tends to increase the total dollar value of the energy consumption for ECB when comparing with the actual level for NCFOB in 1977 listed in Table 2.2.

## 3.0 ECONOMIC EVALUATION

The comparable building cost and energy consumption data presented in the preceding section will be combined here to form the building life-cycle costs for owning and operating the NCFOB and ECB. These building life-cycle costs will be used for the economic evaluation.

### 3.1 LIFE-CYCLE COST MODEL

There are several methods to express the combined cost of an initial investment and associated recurring costs of energy consumption, operation, and maintenance of a building. One method is to transform the initial investment cost into an equivalent yearly uniform capital recovery payment over the life and then combine this yearly payment with the corresponding recurring costs associated with operation, maintenance and energy consumption over the life of the building. Another method is to transform both the initial building investment cost and the recurring costs to a single capital recovery amount occurring at the end of the lifespan. The third method is to bring the stream of recurring costs back to the same period in which the initial building investment was made and then combine these transformed recurring costs with the initial investment to arrive at the present value cost of owning and operating a building throughout its life. This present value cost method will be used for the economic evaluation of both buildings. Formula 3.1 is the general expression used to obtain present value costs over a building lifetime.

$$PVC = C + \sum_{i=i}^{L} (1+D)^{-i}(E_i+M_i) - (1+D)^{-L}\cdot S \quad , \tag{3.1}$$

where

PVC = Present value cost
C = Construction cost
D = Discount rate
$E_i$ = Annual energy cost in period i
$M_i$ = Annual operation and maintenance cost (excluding energy cost)
L = Lifespan of the building in years
S = Salvage value at the end of lifespan

For the first 12 months since the completion of the building, both the building contractors and the GSA personnel have been jointly responsible for the building operation including the start-up and the adjustment of building equipment. With the exception of energy cost, no meaningful physical and cost data for building operation and maintenance have yet been collected.[1] Until such meaningful operation and maintenance data

[1] Generally, the building contractors will correct the defects in construction and adjust the building equipment to comply with the original design during the warranty period.

become available, it is not unreasonable to assume that these costs would be approximately equal for both buildings.

Similarly, for practical purposes the salvage values for the NCFOB and ECB are considered equal and negligible, given the relatively long expected life of a building. Therefore, Formula 3.1 can be simplified to

$$PVC = C + \sum_{i=1}^{L} (1+D)^{-i} \cdot E_i \qquad (3.2)$$

Formula 3.2 will be used for the economic evaluation in this report.

## 3.2 DATA ASSUMPTIONS

Derived in the previous section, the specific data used here for calculations are the building construction costs shown in Table 2.1 and the annual energy consumption listed in Tables 2.2 and 2.3.

In order to obtain estimates of the annual energy price increases for Manchester, New Hampshire, the Environment and Energy Branch in the Central Office of GSA was consulted.[1] The GSA energy price increases for the next 40 years depicted in Table 3.1 are the product of this consultation. Also, the energy price increases in the New England Region as forecasted by the Federal Energy Administration[2] are shown as the FEA price increases in Table 3.1.

The discount rate, D, required for the calculation in Formula 3.2, is 10 percent throughout the economic evaluation in compliance with OMB Circu;ar No. A-94, Revised, March 27, 1972.

## 3.3 ECONOMIC COMPARISON

Based on the construction costs listed in Table 2.1, energy consumption data listed in Tables 2.2 and 2.3, annual energy price increases listed in Table 3.1 and the discount rate of 10 percent, present value costs are calculated with Formula 3.2. The results for the NCFOB and the ECB are shown in Table 3.2.

The present value of savings listed in Table 3.2 are the differences between the present value cost of the ECB and the NCFOB. The range of present value savings represents the cost effectiveness of the energy conservation investment made in the NCFOB, when measured with the actual (or adjusted) and predicted energy consumption levels and the GSA and FEA energy price increases.

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[1] G. Wells, Chief of the Environment & Energy Branch, Public Building Series, GSA, was particularly helpful in this regard.

[2] "Energy Audit Procedure: Proposed Rules and Hearing," Federal Register, Vol. 42, No. 73, April 15, 1977.

Table 3.1

Estimated Annual Percentage Increases in Real Energy Prices

| Period | Type of Energy | Annual Energy Price Increase (%) Probable[a] | Low[b] |
|---|---|---|---|
| 1978 through 1980 | Natural gas | 16 | 3.62 |
| | Fuel oil | 8 | 1.20 |
| | Electricity | 16 | 0.38 |
| 1981 through 1990 | Natural gas | 6 | 3.62 |
| | Fuel oil | 4 | 1.20 |
| | Electricity | 6 | 0.38 |
| 1991 through 2016 | Natural gas | 6 | 0 |
| | Fuel oil | 4 | 0 |
| | Electricity | 6 | 0 |

[a] Estimates of the GSA Environmental and Energy Branch for the Manchester, N.H. area.

[b] Estimates for the New England Region, published by FEA, "Energy Audit Procedure, Proposed Rules and Hearing," Federal Register Vol. 42, No. 73, April 15, 1977.

Table 3.2

Present Value Costs and Calculation of Present Value Savings ($1000)

| | | Lifespan and energy price increase | | | |
|---|---|---|---|---|---|
| | | 40 year | | 20 year | |
| | | GSA Energy Price Increase | FEA Energy Price Increase | GSA Energy Price Increase | FGA Energy Price Increase |
| Adjusted or actual Energy Consumption 1977 | ECB | $10,787 | $9,165 | $9,836 | $8,988 |
| | NCFOB | 10,059 | 9,021 | 9,457 | 8,911 |
| | Saving[a] | 728 | 144 | 379 | 77 |
| Predicted Energy Consumption 1962 | ECB | 10,524 | 9,050 | 9,660 | 8,889 |
| | NCFOB | 9,577 | 8,816 | 9,134 | 8,735 |
| | Saving[a] | 947 | 234 | 526 | 154 |

[a] Present value savings of the NCFOB over the ECB for the given lifetime.

Several noteworthy conclusions can be drawn from an examination of Table 3.2. Most importantly, the present value savings under all sets of assumptions are positive. These positive present value savings indicate that the additional investment in energy conservation in the NCFOB is more than compensated by the value of the energy savings over the 40 year and 20 year lifespans assumed. In other words, the NCFOB is economically more attractive than the ECB for all cases studied.

Another result is that the present value savings under all four cases assuming adjusted and actual (1977) energy consumptions are lower in value than the corresponding savings calculated for the predicted (1962) in energy consumptions. This anomaly has arisen because the values of the 1977 energy consumption for the ECB and NCFOB do not represent an equal percentage increase over the corresponding 1962 consumption values. As stated in Section 2.0, the dollar value of the actual energy used in the NCFOB was 36 percent greater than that of the consumption calculated for the 1962 base year while the 1977 energy consumption estimated for the ECB is only 10 percent more than that of the 1962 base year when weather differences only are taken into account. One way to eliminate this anomaly is to increase the estimated 1977 energy expenditures for the ECB to 36 percent above that which was calculated by the NBSLD for the 1962 base year. The results of this modification are presented in Table 3.3.

A comparison of Table 3.3 with Table 3.2 reveals that the modification of the energy consumption for ECB makes the present value savings greater for the actual energy consumption case than for the low consumption case, as one would expect.

Another important result in Table 3.2 is that the present value savings rendered by the NCFOB are \$947,000 in 40 years and \$526,000 in 20 years under the most probable set of assumptions. These assumptions seem to be the most reasonable because the 1962 weather data year is a more representative one to base the life-cycle cost analysis on than that of 1977.[1] Furthermore, the computer analysis performed for both the NCFOB and ECB with 1962 weather data are based on the same assumptions included in the NBSLD calculations. In contrast, the 1977 analysis is based on the actual energy consumption for the NCFOB but is forced to depend on the computer calculations of energy consumption for the ECB.

Table 3.2 also indicates that for a 40 year lifespan, there is a low present value saving of \$234,000 for the FEA energy price increases and a high present value saving of \$947,000 for the GSA energy price increases. This result fulfills the expectation that for this NCFOB, the present value saving becomes larger, the faster energy prices rise. Also as expected, Table 3.2 indicates that for the NCFOB, the longer the lifespan chosen for evaluation, the bigger the present value saving accumulated over that life.

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[1] As noted above the monthly average temperatures in 1962 were very close to thirty year norm values for Manchester, N.H.

Table 3.3

Present Value Costs and Savings with Modified

Energy Consumption for ECB ($1000)

| | Lifespan and energy price increase | | | |
|---|---|---|---|---|
| | 40 year | | 20 year | |
| | GSA Energy Price Increase | FEA Energy Price Increase | GSA Energy Price Increase | FEA Energy Price Increase |
| ECB[a] | $11,466 | $9,462 | $10,291 | $9,243 |
| NCFOB | 10,059 | 9,021 | 9,457 | 8,911 |
| Saving[b] | 1,407 | 441 | 834 | 332 |

[a] Present value costs for ECB assuming energy consumption 36 percent greater than estimated for the 1962 base year.

[b] Present value savings of the NCFOB over the ECB for the given lifetime.

In addition to the present value saving, it is possible to calculate the discounted payback period for the additional investment made on the energy conserving features of the NCFOB. The discounted payback period is defined as the number of years required for the additional investment in a building to be fully paid for with the present value savings produced by the energy conservation features, taking into account the time value of money.[1] The discounted payback periods, 6.4 years, 9.7 years, 7.8 years and 12.8 years, are shown in Figures 3.1 through 3.4 for the energy conservation investment made in the NCFOB compared with the ECB under the four sets of assumptions conserning the level of energy consumption and energy price increases. The present value savings of the NCFOB over the ECB for all given liftimes of up to 40 years can also be determined by measuring the distance between the two curves shown on each of the four figures.

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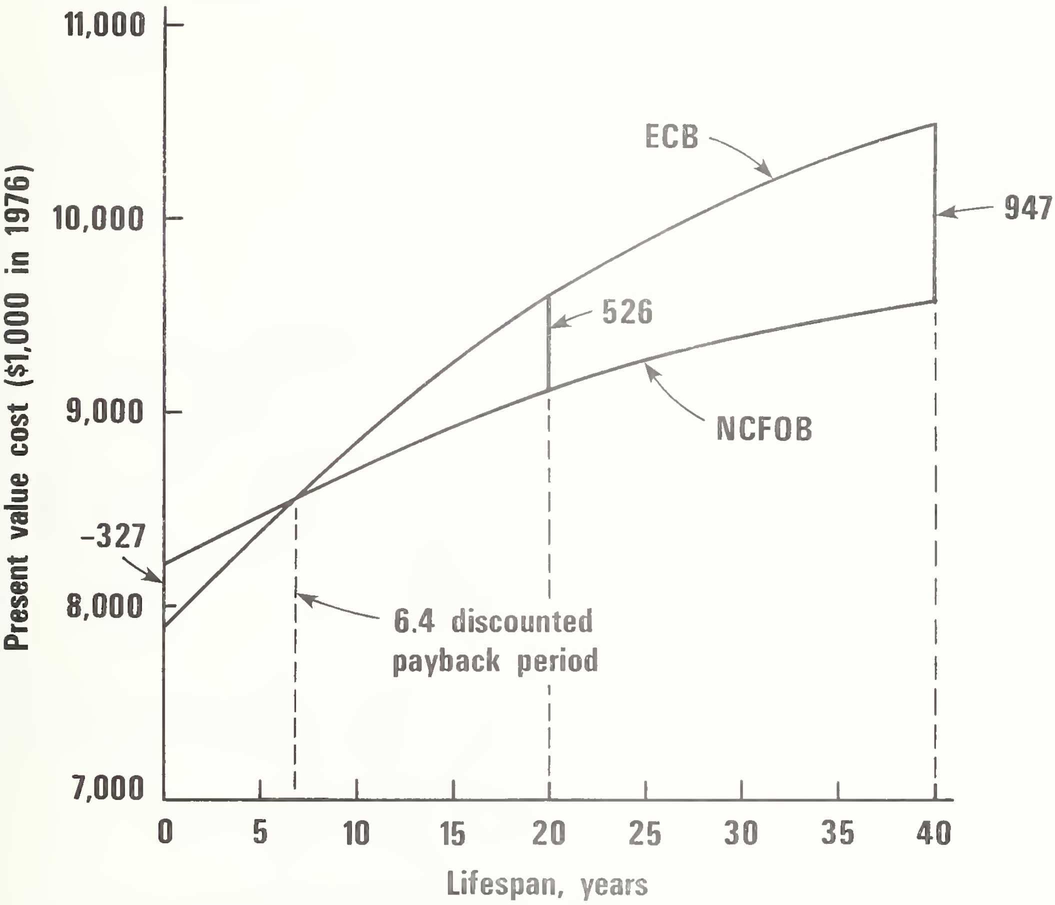
[1] The discounted payback for this type of economic analysis is calculated by finding that lifespan for which the present value costs of the NCFOB and the ECB are equal. See Appendix C for the listing of present value costs for each building for all lifespans from 1 through 40 years.

Figure 3.1

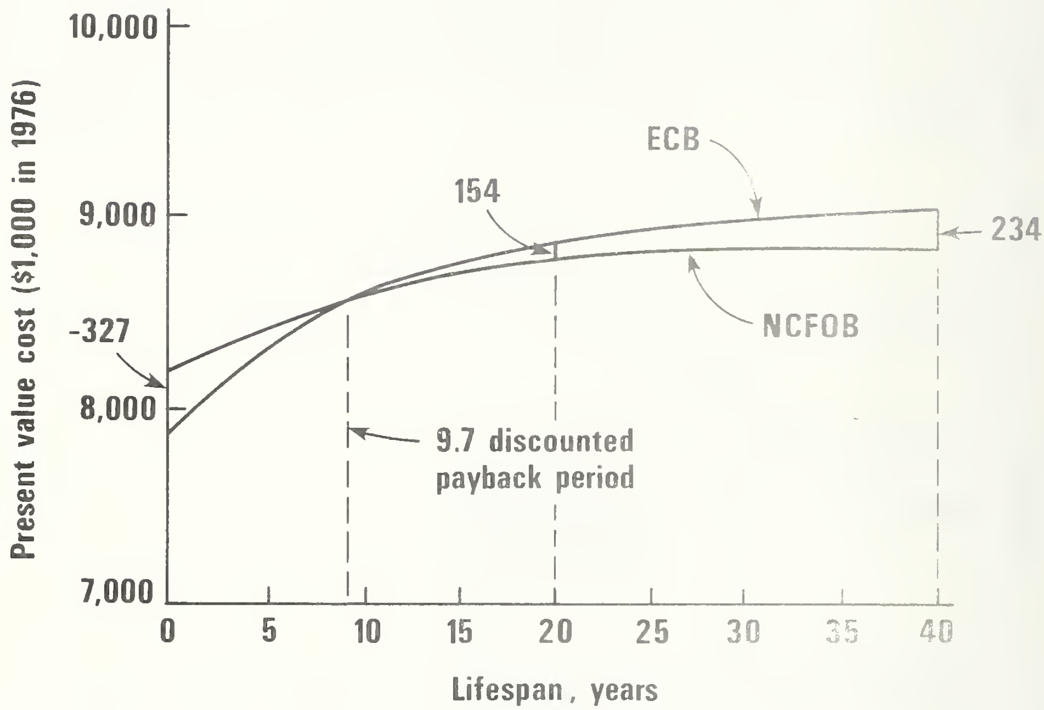
**Case I - Present Value Cost[a] vs Lifespan for NCFOB and ECB**




[a] Case I - Present value cost is assumed to include the building construction cost, energy cost as computed for 1962 consumption and GSA estimates for annual energy price increase.

Figure 3.2

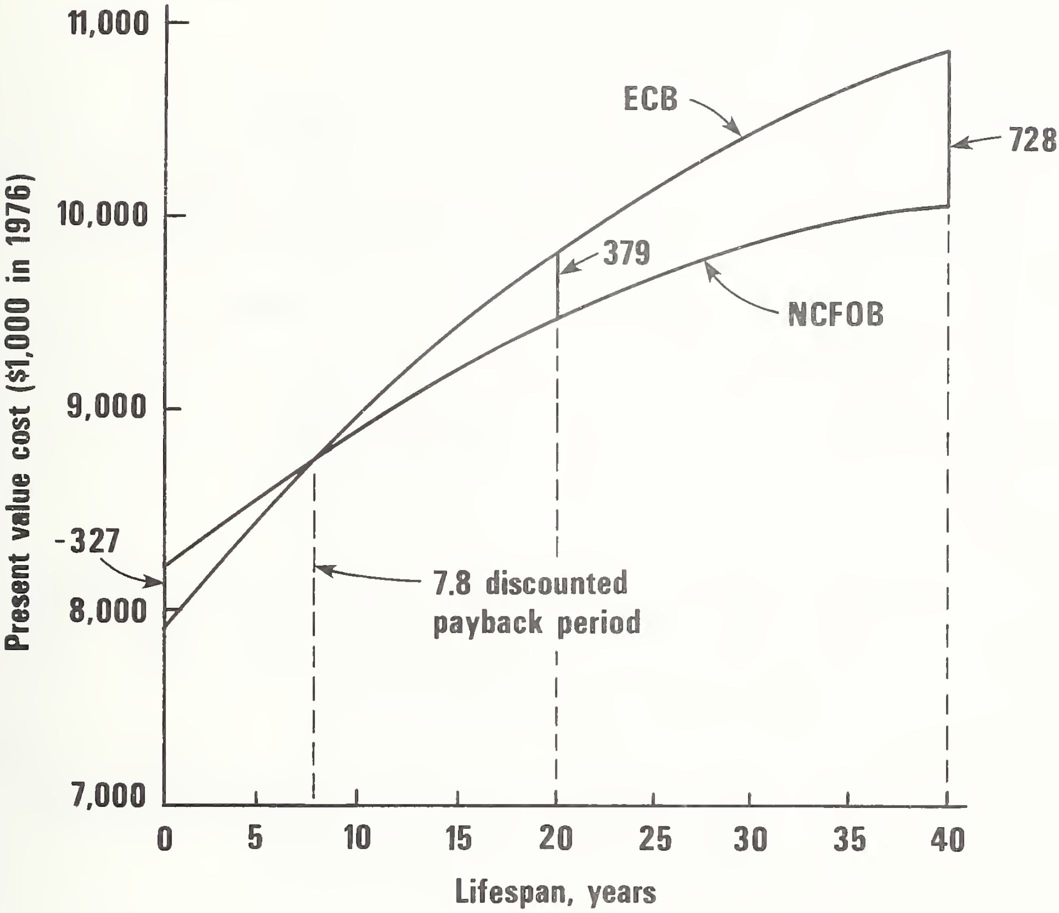
Case II - Present Value Cost[a] vs Lifespan for NCFOB and ECB




a Case II - Present value cost is assumed to include the building construction cost, energy cost as computed for 1977 consumption and GSA estimates for annual energy price increase.

## Figure 3.3

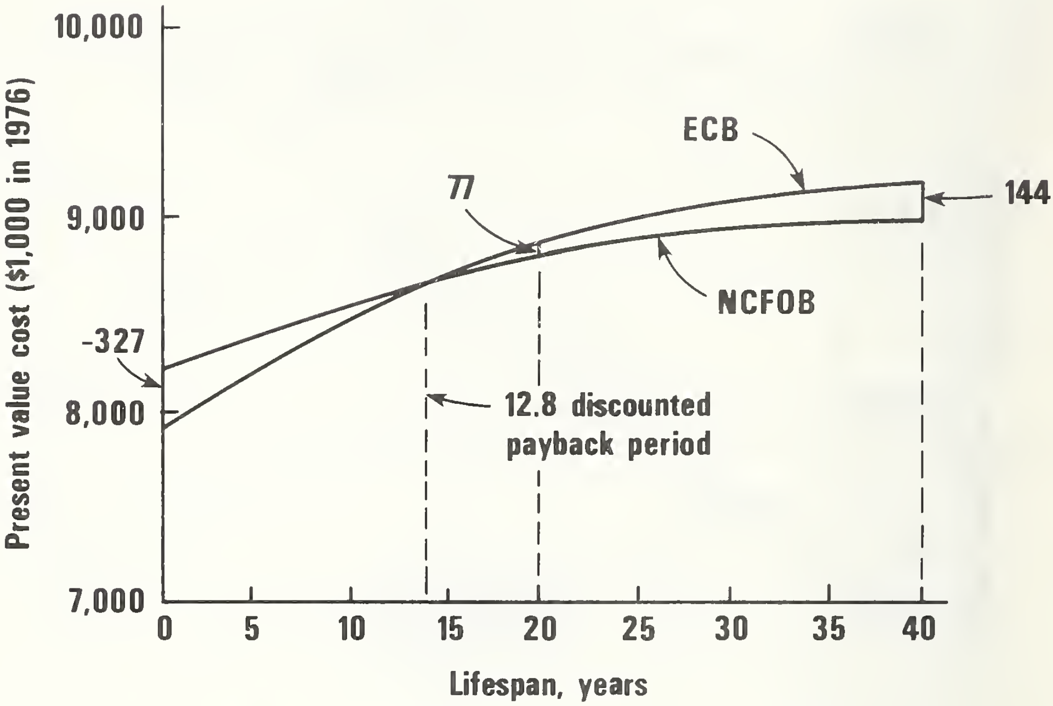
## Case III - Present Value Cost[a] vs Lifespan for NCFOB and ECB




[a] Case III - Present value cost is assumed to include the building construction cost, energy cost as computed for 1962 consumption and FEA estimates for annual energy price increase.

Figure 3.4

Case IV - Present Value Cost[a] vs Lifespan for NCFOB and ECB




[a] Case IV - Present value cost is assumed to include the building construction cost, energy cost as computed for 1977 consumption and FEA estimates for annual energy price increase.

## 4.0 SUMMARY AND RECOMMENDATIONS FOR FURTHER RESEARCH

As a result of this economic evaluation, a brief summary and several recommendations for further research can be offered.

### 4.1 SUMMARY

1. It cost $327,000 more to build the NCFOB than the ECB. This additional cost amounts to 4.1 percent of the ECB construction cost estimated to be $7,908,000. Once the design and construction methods suitable for energy conservation become more widely known and practiced, the additional cost of constructing such an energy conserving building as compared to a conventional building might be even less.

2. Depending on the assumptions made concerning the levels of energy consumption, the rates of energy price increase, and the useful lifespans, the present value savings of investing in the energy conserving features in the NCFOB are all positive and range from a low of $77,000 to a high of $1,407,000. Based on the most probable set of assumptions, the present value savings measured in 1976 dollars are $947,000 for a 40 year lifespan and $526,000 for a 20 year lifespan.

3. Depending on the assumptions made concerning the levels of energy consumption and the rates of energy price increase, the discounted payback periods range from a low of 6.4 years to a high of 12.8 years. Under the most probable set of assumptions, the discounted payback period for the additional investment ($327,000) made in the NCFOB is 6.4 years.

4. The actual energy cost, based on the utility bills paid for the NCFOB in 1977, is 36 percent more than the computed energy cost based on the NBSLD calculation for 1962 weather conditions. Of this increase, only a small percentage can be attributed to the change in weather conditions. The bulk of the increase cannot be properly explained until the detailed thermal engineering analysis, currently underway for the building and equipment, has been completed.

### 4.2 RECOMMENDATIONS FOR FURTHER RESEARCH

1. I recommend that a study be made on the cost-effective use of the four gas-fired and two standby oil-fired boilers provided in the NCFOB. This study should consider the energy cost, operating efficiency and maintenance cost for the cost-effective use of the two types of boilers. Under present operating condition, the oil-fired boilers have been used intermittently and sparingly in January, February, July, August, September and December of 1977. In view of the current cheaper energy price for fuel oil as compared to that for natural gas, it appears to be more cost effective at this time to run the oil-fired boiler more often. However, other factors such as the operating efficiency and maintenance cost should be included in a study involving the cost-effective use of the two types of boiler.

2. I recommend that an economic evaluation be made of various individual energy conserving features such as the alternative lighting systems, the engine generators, and the heat pumps. The results of this economic evaluation would help building designers, owners and operating personnel to select cost-effective investments for energy conservation in buildings. We anticipate that detailed energy consumption data for individual energy conserving features will be measured and monitored by the new computerized energy monitoring and control system (JC-80), and that these data will be available for evaluation by the Fall of 1978.

3. I recommend that a more comprehensive economic evaluation be made on the NCFOB. This economic evaluation should not only incorporate cost data on building operation and maintenance, but also the revised energy consumption data to be derived from the on-going thermal engineering analysis.

Appendix A

# BUILDING DESIGN AND COST DATA

The following design and cost data have had been extracted from an unpublished report, Nicholas Isaak and Andrew Isaak Comparative Cost Study As Built vs. Equivalent Conventional Buildings, October 1975. This report was funded and monitored by the NBS as Contract No. T73183 -- Request No. 463-3269. These data are divided into three major categories: (1) Design Criteria Comparison; (2) Building Cost Comparison; and (3) Demonstration Items.

## A.1 DESIGN CRITERIA COMPARISON

Both NCFOB and ECB are reinforced concrete structures of seven stories. A comparison of the major design requirements or features[1] are presented in the following three tables.

With the exception of the underground garage and mechanical and electric service areas, all spaces are provided with HBAC. The design requirements of the HVAC. The design requirements of the HVAC systems are listed in Table A.2.

Lighting and power design requirements for the buildings are listed in Table A.3.

## A.2 BUILDING CONSTRUCTION COST COMPARISON

Itemized NCFOB construction costs and the corresponding ECB construction estimates are listed in Table A.4 below in the Construction Specification Institute (CSI) format. The costs include the total construction costs but exclude site acquisition costs and building design fees.

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[1] For a full description of the NCFOB, see Nicholas Isaak and Andrew Isaak, Designing an Energy Efficient Building, A Case Study, (General Services Administration, September 1975.)

TABLE A.1

Building Structure and Envelope Design Requirements

| Element | Building: NCFOB | Building: ECB |
|---|---|---|
| Roof | U = 0.06, insulation is placed on the exterior side of a 8" thick concrete roof. | U = 0.15, minimum insulation is placed on a 4" thick concrete roof. |
| Wall | U = 0.06, 3 3/4" insulation is placed on the exterior side of the 12" thick block wall; granite exterior facing. | U = 0.16, 1" insulation is placed on a 6" thick block wall; granite exterior facing. |
| Window | U = 0.55, window area is 5% of wall area. Thermally broken double glazed with built in venetian blinds. | U = 1.13, window area is 40% of wall area, 1/4" plate glass, single glazed. |

Table A.2

HVAC Design Requirements

| Requirements | Building: NCFOB | Building: ECB |
| --- | --- | --- |
| Winter outdoor design temperature | (+) 5°F | (-) 10°F |
| Winter indoor design temperature | (+) 68°F | (+) 75°F |
| Summer outdoor design conditions | 86°F. DB, 73°F. WB | 90°F. DB, 73°F. WB |
| Summer indoor design conditions | 78°F. DB, 60% R.H. | 75°F. DB, 50% R.H. |
| Outside air ventilation | 6 CFM per person (generally .06 CFM per square foot of floor) | 0.25 CFM per square foot of floor |
| "U" Walls | 0.06 BTU/S.F./°F | 0.16 BTU/S.F./°F |
| "U" Roof | 0.06 BTU/S.F./°F | 0.15 BTU/S.F./°F |
| "U" Glass | 0.55 BTU/S.F./°F | 1.13 BTU/S.F./°F |
| Shading | Building structure designed to be 80 to 100% efficient in prohibiting summer solar load and 80 to 90% efficient in permitting winter solar. | No special provisions venetian blinds for summer solar reduction |

TABLE A.3

Electrical Design Requirements

| | Building | |
|---|---|---|
| Spaces | NCFOB | ECB |
| Office Space | Lighting = 2W/sq. ft. avg. | Lighting = 6W/sq. ft. max. |
| Storage (Potential Office) | Lighting = 2W/sq. ft. avg. | Lighting = 6W/sq. ft. max. |
| Lobbies | Lighting = 2.5W/sq. ft. | Lighting = 4W/sq. ft. |
| Toilet Storage & Utilities | Lighting = 1W/sq. ft. | Lighting = 3W/sq. ft. |
| Permanent Corridor | (None) | Lighting = 2W/sq. ft. |
| Parking | 1/2 fc average | Lighting = 5 fc storage, 10 fc traffic |
| Office Receptacles | 1W/sq. ft. | 1W/sq. ft. |

## A.3 DEMONSTRATION ITEMS

Following are specific items installed in the NCFOB strictly for special experiments or measurements which are not normally required for the operation of the ECB. Specific item numbers refer to A.4. The negative value of the cost differential indicates that the specific item for the NCFOB costs more than that for the ECB.

Table A.4

Building Construction Cost Comparison

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST($) | NCFOB TOTAL COST($) | ECB QUANTITY | ECB UNIT COST($) | ECB TOTAL COST(S) |
|---|---|---|---|---|---|---|
| DIV. 1 GENERAL | | | | | | |
| 1.1 Temporary facilities | | | 181280 | | | 274000 |
| 1.2 G.C. equipment | | | 288000 | same | | 288000 |
| 1.3 Clean up | | | 30000 | same | | 30000 |
| 1.4 Field Engineering | | | 15000 | same | | 15000 |
| 1.5 Field Offices & Shed | 3 each | 5000 | 15000 | same | | 15000 |
| 1.6 Field overhead | | | | | | |
| a. Superintendent | 125 wk. | 300 | 37500 | same | | 37500 |
| b. Field engineer | 60 wk. | 250 | 15000 | same | | 15000 |
| c. Clerk | 100 wk. | 200 | 20000 | same | | 20000 |
| DIV. 1 TOTAL | | | 601780 | | | 694500 |
| DIV. 2 SITE WORK | | | | | | |
| 2.1 Earth work | | | | | | |
| a. Building excavation | 39000 c.y. | 2.39 | 93060 | same | | 93060 |
| b. Fill & backfill | 3000 c.y. | 1.62 | 4860 | same | | 4860 |
| 2.2 Pile Foundations | | | | | | |
| a. Shoring & shor removal | 18340 s.f. | 9.87 | 181050 | same | | 181050 |
| b. Steel piles | 8422 l.f. | 14.31 | 120526 | 8000 l.f. | 14.31 | 114480 |
| c. Pile caps | 1600 c.y. | 34.53 | 55250 | same | | 55250 |
| d. Rock bolts | 1600 l.f. | 45.58 | 72930 | same | | 72930 |
| 2.3 Dewatering | 15 mo. | 3111 | 46665 | same | | 46665 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST($) | NCFOB TOTAL COST($) | ECB QUANTITY | ECB UNIT COST($) | ECB TOTAL COST($) |
|---|---|---|---|---|---|---|
| 2.4 Site utilities | | | 11475 | same | | 11475 |
| 2.5 Landscaping | | | 12920 | same | | 12920 |
| DIV. 2 TOTAL | | | 598736 | | | 592690 |
| DIV. 3 CONCRETE | | | | | | |
| 3.1 Cast in place concrete | | | | | | |
| a. Sub grade walls | 682 c.y. | 228 | 155462 | same | | 155462 |
| b. Sub basement slab | 1782 c.y. | 150 | 267444 | same | | 267444 |
| c. Basement slab & beams | 1344 c.y. | 208 | 273700 | same | | 273700 |
| d. Columns below grade | 130 c.y. | 120 | 15640 | 120 c.y. | 120 | 14400 |
| e. Gr. level slab & beams | 1936 c.y. | 166 | 320620 | 1730 c.y. | 166 | 290320 |
| f. Concrete fireproofing | 170 c.y. | 138 | 23460 | 240 c.y. | 138 | 33120 |
| g. Roof slab & penthouse | 635 c.y. | 160 | 101660 | 276 c.y. | 160 | 44160 |
| h. Concrete topping | 351 c.y. | 111 | 39100 | same | | 39100 |
| i. Planters & ret. walls | 2885 c.y. | 5.42 | 15640 | same | | 15640 |
| j. Slab on metal floor deck | 1027 c.y. | 214 | 220363 | 1167 c.y. | 214 | 249738 |
| k. Spandrels above window | none | | | 358 c.y. | 250 | 64500 |
| 3.2 Precast concrete | 6120 s.f. | 6.02 | 36860 | 4658 s.f. | 6.02 | 27948 |
| DIV. 3 TOTAL | | | 1469949 | | | 1475532 |
| DIV. 4 MASONRY | | | | | | |
| 4.1 Concrete unit masonry | | | | | | |
| a. Exterior 12 inch | 37000 s.f. | | | none | | |
| 8 inch | 3070 s.f. | 3.63 | 145350 | 750 s.f. | 3.20 | 33312 |
| 6 inch | none | | | 9660 s.f. | | |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST($) | NCFOB TOTAL COST($) | ECB QUANTITY | ECB UNIT COST($) | ECB TOTAL COST($) |
|---|---|---|---|---|---|---|
| b. Interior 12 inch | 360 s.f. | | | none | | |
| 8 inch | 37400 s.f. | 2.78 | 108612 | 37400 s.f. | 2.78 | 112423 |
| 6 inch | 600 s.f. | | | none | | |
| 4 inch | 750 s.f. | | | 3040 s.f. | | |
| 4.2 Cut Stone | | | | | | |
| a. Building facing | 54968 s.f. | 9.27 | 509553 | 40584 s.f. | 9.27 | 376214 |
| b. Plaza paving | | | | | | |
| exterior | 6900 s.f. | 6.00 | 54600 | same | | 54600 |
| interior | 2200 s.f. | | | 2200 s.f. | | |
| DIV. 4 TOTAL | | | 818115 | | | 576549 |
| DIV. 5 METALS | | | | | | |
| 5.1 Structural steel | 966 ton | 855 | 851262 | 810 ton | 800 | 648800 |
| 5.2 Misc. metals | | | | | | |
| a. Support brackets | 54968 s.f. | 2.59 | 142367 | 40584 s.f. | 2.25 | 91314 |
| b. Steel stairs | 405 riser | 75.44 | 30555 | same | | 30555 |
| c. Gratings | | | 4365 | same | | 4365 |
| d. Handrails ground | 480 l.f. | 14.23 | 6832 | same | | 6832 |
| e. Miscellaneous | | | 42750 | same | | 42750 |
| 5.3 Metal deck (all) | 84076 s.f. | 2.19 | 184300 | 118050 s.f. | 2.19 | 258530 |
| 5.4 Architectural metal exhibit case, seals | | | 5985 | same | | 5985 |
| DIV. 5 TOTAL | | | 1268416 | | | 1089131 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| DIV. 6 WOOD & PLASTIC | | | | | | |
| 6.1 Rough carpentry | | | 13847 | same | | 13847 |
| 6.2 Finish carpentry | | | 15826 | same | | 15826 |
| DIV. 6 total | | | 29673 | | | 29673 |
| DIV. 7 THERMAL & MOISTURE PROTECTION | | | | | | |
| 7.1 Waterproofing | | | | | | |
| a. Below grade | 51740 s.f. | 1.78 | 92150 | same | | 92150 |
| b. Above grade | 37653 s.f. | 1.12 | 41994 | same | | 41994 |
| 7.2 Building insulation | | | | | | |
| a. Interior | 69230 s.f. | .13 | 8730 | same | | 8730 |
| b. Exterior | 54968 s.f. | .39 | 21438 | 42438 s.f. | .20 | 8488 |
| 7.3 Insl. metal panel | 13817 s.f. | 9.54 | 131860 | 240 s.f. | 4.00 | 960 |
| 7.4 Roofing system | 206 s.f. | 190 | 39200 | 208 sq. | 130 | 27040 |
| 7.5 Sheetmetal & flashing | | | 37829 | | | 28372 |
| 7.6 Sealants | | | 26220 | | | 19665 |
| DIV. 7 total | | | 399421 | | | 227399 |
| DIV. 8 DOORS & WINDOWS | | | | | | |
| 8.1 Hollow metal frames | 225 each | 34.46 | 7754 | 265 each | 34.46 | 9132 |
| 8.2 Doors | 305 each | 91.67 | 27955 | same | | 27955 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| 8.3 Aluminum work | 2054 s.f. | 18.58 | 38160 | 2200 s.f. | 18.58 | 40876 |
| 8.4 Special doors | 2 each | 3000 | 17164 | same | | 6000 |
| DIV. 8 total | | | 216718 | | | 264751 |
| DIV. 9 FINISHES | | | | | | |
| 9.1 Gypsum drywall | | | | | | |
| a. Column fireproofing | 7781 s.f. | 4.01 | 31227 | 10320 s.f. | 4.01 | 41383 |
| b. Partitions | 24543 s.f. | 1.18 | 28889 | 46500 s.f. | 1.18 | 54870 |
| c. Wall furring | 8390 s.f. | .58 | 4867 | 19300 s.f. | .58 | 11194 |
| 9.2 Tile work | | | | | | |
| a. Ceramic tile | 8350 s.f. | 1.70 | 14191 | same | | 14191 |
| b. Quarry tile | 1000 s.f. | 4.24 | 4239 | same | | 4239 |
| 9.3 Acoustical ceiling | 93900 s.f. | 1.15 | 108300 | 91900 s.f. | .74 | 68006 |
| 9.4 Resilient flooring | | | | | | |
| a. Vinyl asbestos flooring | 15500 s.f. | .48 | 7421 | same | | 7421 |
| b. Stair treads | 405 ea. | 8.28 | 3353 | same | | 3353 |
| 9.5 Carpeting | 7550 s.y. | 8.30 | 62662 | same | | 62662 |
| 9.6 Cementicious coating | 14935 s.f. | .79 | 11733 | same | | 11733 |
| 9.7 Spray fire protection | 84078 s.f. | .43 | 36100 | 118050 s.f. | .43 | 50762 |
| 9.8 Painting & finishing | | | 37001 | same | | 37001 |
| 9.9 Vinyl wall covering | | | 1890 | same | | 1890 |
| DIV. 9 total | | | 351883 | | | 368705 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| DIV. 10 SPECIALTIES | | | | | | |
| 10.1 Toilet partitions | | | 7581 | same | | 7581 |
| 10.2 Access flooring | | | 5000 | none | | |
| 10.3 Flag pole | 1 ea. | 2708 | 2708 | same | | 2708 |
| 10.4 Mail chute | 94 l.f. | 29.41 | 2765 | same | | 2765 |
| 10.5 Folding partitions | 1167 s.f. | 8.00 | 9336 | same | | 9336 |
| 10.6 Relocatable partitions | 22360 s.f. | 2.74 | 61370 | same | | 61370 |
| 10.7 Toilet room accessories | | | 7526 | same | | 7526 |
| 10.8 Misc. specialties | | | 13088 | same | | 13088 |
| DIV. 10 total | | | 109374 | | | 104374 |
| DIV. 11 EQUIPMENT | | | | | | |
| DIV. 12 FURNISHINGS | | | | | | |
| DIV. 13 SPECIAL CONSTRUCTION | | | | | | |
| 13.1 Radiation protection | | | 5990 | same | | 5990 |
| DIV. 13 total | | | 5990 | | | 5990 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| DIV. 14 CONVEYING SYSTEMS | | | | | | |
| 14.1 Dumbwaiters | 1 ea. | 7220 | 7220 | same | | 7220 |
| 14.2 Elevators | | | | | | |
| a. Freight 10 stops | 1 ea. | | 91748 | same | | 91748 |
| b. Passenger 9 stops | 2 ea. | | 178099 | same | | 178099 |
| DIV. 14 total | | | 277067 | | | 277067 |
| TOTAL OF ARCHITECTURAL & STRUCTURAL | | | 6147122 | | | 5706361 |
| DIV. 15 MECHANICAL | | | | | | |
| 15.1 Plumbing | | | 141913 | same | | 141913 |
| 15.2 Boilers/burners | | | 5036 | | | 20845 |
| 15.3 Pumps | | | 15250 | | | 3826 |
| 15.4 Oil tanks | none | | | | | 6928 |
| 15.5 Oil piping, values, etc. | none | | | | | 1318 |
| 15.6 H.W. heating piping | | | 33028 | | | 51593 |
| 15.7 Values incl.in 15.6 | | | | | | 11022 |
| 15.8 Heating specialties | | | 7058 | | | 5025 |
| 15.9 Radiators & unit heaters | | | 10541 | | | 39997 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| 15.10 Sheet Metal | | | 191304 | | | 85113 |
| 15.11 Insulation | | | 103429 | | | 75844 |
| 15.12 Fans | | | 10963 | | | 32387 |
| 15.13 Cooling coils | none | | | | | 36595 |
| 15.14 Condensing units | none | | | | | 101451 |
| 15.15 Refrig. piping & controls | none | | | | | 21635 |
| 15.16 Filters | | | 1195 | | | 9900 |
| 15.17 Air terminals | | | 90080 | | | 167004 |
| 15.18 Auto. temp. control | | | 199216 | | | 104100 |
| 15.19 Balancing & wtr. treat. | | | 16165 | | | 10199 |
| 15.20 Generator | | | 49657 | | | 25030 |
| 15.21 Waste ht. wtr. piping | | | 15693 | none | | |
| 15.22 Chilled wtr. piping | | | 14617 | none | | |
| 15.23 Condenser wtr. piping | | | 29564 | none | | |
| 15.24 Pan drain piping | | | 5441 | none | | |
| 15.25 Heat pump piping | | | 42137 | none | | |
| 15.27 Heat pumps | | | 30395 | none | | |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB TOTAL COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB TOTAL COST ($) |
|---|---|---|---|---|---|---|
| 15.28 Reciprocat. chiller | | | 20946 | none | | |
| 15.30 Closed circuit coolers | | | 23528 | none | | |
| 15.31 Fan coil units | | | 11270 | none | | |
| 15.32 Miscellaneous | | | 33328 | same | | 33328 |
| 15.33 Fire protection | | | 93977 | same | | 93977 |
| DIV. 15 total | | | 1195731 | | | 944028 |
| DIV. 16 ELECTRICAL | | | | | | |
| 16.1 Distribution system | | | | | | |
| a. Conduit & wire | | | 178352 | | | 217350 |
| b. Walker duct | | | 36000 | same | | 36000 |
| c. Switchgear & bus duct | | | 58500 | | | 60375 |
| d. Pulling wire | | | 39600 | | | 54338 |
| e. Trim & finish | | | 31500 | same | | 31500 |
| f. Panls. switch. & transform | | | 29825 | | | 42263 |
| 16.2 Lighting fixtures | | | 113400 | | | 163013 |
| 16.3 Snow melt & pipe tracing | | | 20539 | same | | 20539 |
| 16.4 Fire alarm system | | | 18000 | same | | 18000 |
| 16.5 Sound system | | | 18000 | same | | 18000 |

Table A.4 Continued

| ITEM | NCFOB QUANTITY | NCFOB UNIT COST ($) | NCFOB COST ($) | ECB QUANTITY | ECB UNIT COST ($) | ECB COST ($) |
|---|---|---|---|---|---|---|
| 16.6 Grndg. & ltg. protection | | | 18000 | same | | 18000 |
| 16.7 Equip. connect. HVAC | | | 14465 | | | 19320 |
| DIV. 16 total | | | 576181 | | | 698698 |
| SUMMARY | | | | | | |
| Architectural/Structural | | | 6147122 | | | 5706361 |
| Mechanical | | | 1195731 | | | 944028 |
| Electrical | | | 576181 | | | 698698 |
| Total | | | 7919034 | | | 7349087 |
| G.C. Overhead/Profit | 7.6% | | 601847 | | | 558531 |
| TOTAL CONSTRUCTION COST | | | 8520881 | | | 7907620 |

Table A.5

Demonstration Items In NCFOB

| Item No. | Building: NCFOB | Building: ECB | Dollar Cost Differential |
|---|---|---|---|
| 8.5 | Large area of interior glazing used around monitoring computer room for viewing by the public. | No computer monitoring system. | -3,091 |
| 9.3 | Two types of acoustical ceiling systems used to demonstrate and comparatively evaluate various light fixtures. | Single system of ceiling and lighting used. | -40,294 |
| 10.2 | Access flooring required for monitoring computer room. | No monitoring system. | -5,000 |

Table A.5 Continued

| Item | Building: NCFOB | Building: ECB | Dollar Cost Differential |
|---|---|---|---|
| 15.10 | Multiple mechanical system resulted in greater quantity of duct work and control dampers. | Single system resulted. | -106,191 |
| 15.18 | Multiplicity of systems resulted in more complex temperature control system. | Normal system. | -95,116 |
| 15.19 | Multiplicity of system resulted in much higher cost of balancing due to complexity. | Normal balancing cost. | -5,966 |
| 16.2 | Use of several kinds of light fixtures increased the cost estimated to be about 20% of total listed in Table A.4. | Use conventional lighting design. | -9,923 |

Table A.5 Continued

| | Building | | Dollar Cost Differential |
|---|---|---|---|
| | NCFOB | ECB | |
| None | The cost of the solar energy system[a] has not been included in the estimate | None | None |
| | | SUBTOTAL COST DIFFERENTIAL | -$265,581 |
| | GC Overhead/Profit 7.6% | | -20,184 |
| | | TOTAL COST DIFFERENTIAL | -$285,765[b] |

[a] This is a small system provided to supplement building heating requirements. To date, this solar energy system is not in full operation. This system will be used to measure the effectiveness and efficiency of solar collectors of various manufacturers.

[b] This total cost differential is used in Table 2.1.

# APPENDIX B

## ENERGY USAGE & PRICE DATA

The energy usage and price data are divided into the following categories: (1) NCFOB Actual Energy Usage And Prices; (2) NCFOB Computed Energy Usage; and (3) ECB Computed Energy Usage.

### B.1 NCFOB ACTUAL ENERGY USAGE & PRICES

The 1977 actual energy usage and energy prices for the NCFOB are derived from the monthly utility bills submitted to the Region I Office of GSA. Natural gas, fuel oil and electricity bills are included.

Monthly bills for natural gas, as submitted by the Manchester Gas Co., are used to obtain the usage and price data. These bills reflect the actual meter readings of the dates shown in Table B.1.

The price of natural gas in 1977 is $0.607 per therm or $6.07 per million Btu.

Billing for the fuel oil was submitted by the Union Petroleum Corporation and monitored for actual usage by GSA operating personnel. These bills were used to provide energy use data presented in Table B.2.

The price of No. 2 fuel oil in 1977 is $0.40 per gallon or $2.86 per million Btu.

Monthly electric bills were submitted by the Public Service Co. of New Hampshire. The electricity usage and price data are derived from these bills which reflect the actual meter readings on the dates shown in Table B.3.

Table B.1

Actual Usage Of Natural Gas For The NCFOB In 1977

| Billing Date | Unit Purchase (Therms) | Energy Content[a] ($10^9$ Btu) |
|---|---|---|
| 1/1 2/12 | 4,099.6 | 0.410 |
| 2/12 3/10 | 2,488.8 | 0.249 |
| 3/10 4/11 | 2,332.2 | 0.233 |
| 4/11 5/11 | 1,236.2 | 0.124 |
| 5/11 6/13 | 1,859.3 | 0.186 |
| 6/13 8/09 | 3,172.1 | 0.317 |
| 8/09 9/14 | 2,374.2 | 0.237 |
| 9/14 10/13 | 561.7 | 0.056 |
| 10/13 11/14 | 641.3 | 0.064 |
| 11/15 12/31 | 6089.4 | 0.609 |
| TOTAL | 24854.8 | 2.421 |

[a] One therm is $0.0001 \times 10^9$ Btu.

Table B.2

Actual Usage of No. 2 Fuel Oil For The NCFOB In 1977

| Month | Units Purchase Gallon | Energy Content[a] $\times 10^9$ Btu |
|---|---|---|
| January | 1,550 | 0.217 |
| February | 570 | 0.080 |
| July | 590 | 0.083 |
| August | 1,010 | 0.141 |
| September | 150 | 0.021 |
| December | 1,850 | 0.259 |
| TOTAL | 5,720 | 0.801 |

[a] One gallon of No. 2 fuel oil contains approximatly $0.00014 \times 10^9$ Btu.

Table B.3

Actual Electricity Usage For The NCFOB In 1977

| Billing Dates | | Units Purchased (kWh) | Energy Content[a] ($10^9$ Btu) |
|---|---|---|---|
| 12/15 | 1/13 | 170,800 | 0.583 |
| 1/14 | 2/11 | 148,800 | 0.508 |
| 2/11 | 3/14 | 136,000 | 0.464 |
| 3/14 | 4/15 | 135,200 | 0.462 |
| 4/15 | 5/16 | 118,800 | 0.406 |
| 5/16 | 6/16 | 130,800 | 0.447 |
| 6/16 | 7/15 | 128,400 | 0.438 |
| 7/15 | 8/16 | 149,200 | 0.509 |
| 8/16 | 9/15 | 132,400 | 0.452 |
| 9/15 | 10/14 | 102,000 | 0.348 |
| 10/14 | 11/15 | 101,600 | 0.347 |
| 11/16 | 12/14 | 146,800 | 0.501 |
| TOTAL | | 1,600,800 | 5.465 |

[a] One kWh of electricity contains approximately 0.000003414 x $10^9$ Btu.

The price of electricity in 1977 is $0.0354 per kWh or $10.37 per million Btu.

## B.2 NCFOB PREDICTED ENERGY USAGE

The following NCFOB energy usage data were extracted from the NBSLD computer run for the final building design, as listed in a report, Tamami Kusuda, James E. Hill, Stanley T. Liu, James P. Barnett and John W. Bean, Pre-Design Analysis of Energy Conservation Options For A Multi-story Demonstration Office Building, U.S. Department of Commerce, National Bureau of Standards, Building Science Series 78, November 1975. Weather data for 1962 were used for the computation.

Table B.4

Annual Total Energy Usage For The NCFOB In $10^9$ Btu

| Month | Usage ($10^9$ Btu) |
|---|---|
| 1 | 0.776 |
| 2 | 0.726 |
| 3 | 0.607 |
| 4 | 0.470 |
| 5 | 0.420 |
| 6 | 0.357 |
| 7 | 0.364 |
| 8 | 0.401 |
| 9 | 0.314 |
| 10 | 0.470 |
| 11 | 0.545 |
| 12 | 0.726 |
| TOTAL | 6.176 |

According to data extracted from Figure 26 of the above referenced report, the predicted total annual energy usage of $6.176 \times 10^9$ Btu shown in Table B.4 can be divided into the heating energy of $2.290 \times 10^9$ BTU and the electrical energy of $3.886 \times 10^9$ BTU.

## B.3 ECB COMPUTED ENERGY USAGE

The following ECB energy usage data were extracted from the NBSLD computer run number 2, modified, as referred to in the report, Tamami Kusuda, James E. Hill, Stanley T. Liu, James P. Barnett and John W. Bean, Pre-Design Analysis of Energy Conservation Options For A Multi-story Demonstration Office Building, U.S. Department of Commerce, National Bureau of Standards, Building Science Series 78, November 1975. Weather data for 1962 were used for the computation.

For the ECB, the annual energy usage is estimated to be $12.260 \times 10^9$ Btu which is composed of $4.983 \times 10^9$ Btu for heating and $7.277 \times 10^9$ Btu for electricity.

Table B.5

Annual Heating Energy For The ECB In $10^9$ Btu

| | Function | | |
|---|---|---|---|
| Month | Space Heating | Hot Water | Total |
| 1 | 1.083 | .037 | 1.120 |
| 2 | 0.992 | .032 | 1.024 |
| 3 | 0.515 | .037 | 0.552 |
| 4 | 0.197 | .035 | 0.232 |
| 5 | 0.133 | .037 | 0.170 |
| 6 | 0 | .035 | 0.035 |
| 7 | 0 | .033 | 0.033 |
| 8 | 0 | .038 | 0.038 |
| 9 | 0 | .032 | 0.032 |
| 10 | 0.189 | .038 | 0.227 |
| 11 | 0.437 | .035 | 0.472 |
| 12 | 1.015 | .033 | 1.1048 |
| TOTAL | 4.561 | .422 | 4.983 |

Table B.6

Annual Electricity Usage For The ECB In $10^9$ Btu

| Month | Function | | | | | Total |
|---|---|---|---|---|---|---|
| | Cooling | Fans | Pumps | Lighting | Misc. | |
| 1 | .002 | .043 | .069 | 0.373 | .069 | 0.556 |
| 2 | .001 | .037 | .062 | 0.323 | .060 | 0.483 |
| 3 | .022 | .043 | .069 | 0.373 | .069 | 0.576 |
| 4 | .066 | .041 | .066 | 0.357 | .066 | 0.596 |
| 5 | .144 | .043 | .069 | 0.373 | .069 | 0.698 |
| 6 | .183 | .041 | .019 | 0.357 | .069 | 0.669 |
| 7 | .183 | .040 | .018 | 0.339 | .063 | 0.643 |
| 8 | .214 | .045 | .021 | 0.391 | .072 | 0.743 |
| 9 | .140 | .037 | .017 | 0.323 | .060 | 0.577 |
| 10 | .099 | .045 | .069 | 0.391 | .072 | 0.676 |
| 11 | .016 | .041 | .066 | 0.357 | .066 | 0.546 |
| 12 | .001 | .040 | .069 | 0.339 | .063 | 0.514 |
| TOTAL | 1.073 | .500 | .613 | 4.297 | .794 | 7.277 |

# Appendix C

## YEAR-BY-YEAR PRESENT VALUE COSTS

The following data are the year end present value costs of owning and operating (energy consumption only) the NCFOB and ECB calculated with various combinations of energy consumption and energy price increase explained in Sections 2.0 and 3.0. These data form the basis of Figures 3.1 through 3.4.

Table C.1

Present Value Cost Of The NCFOB At Year End ($1000)

| Year | Combination 1 1977 Consumption & GSA Price Rise | Combination 2 1977 Consumption & FEA Price Rise | Combination 3 1962 Consumption & GSA Price Rise | Combination 4 1962 Consumption & FEA Price Rise |
|---|---|---|---|---|
| 1976 | $8235.00 | $8235.00 | $8235.00 | $8235.00 |
| 1977 | 8302.01 | 8302.01 | 8284.27 | 8284.27 |
| 1978 | 8372.67 | 8363.61 | 8336.23 | 8329.61 |
| 1979 | 8447.18 | 8420.25 | 8391.03 | 8371.33 |
| 1980 | 8525.76 | 8472.35 | 8448.81 | 8409.73 |
| 1981 | 8601.48 | 8520.27 | 8504.49 | 8445.09 |
| 1982 | 8674.45 | 8564.35 | 8558.15 | 8477.65 |
| 1983 | 8744.76 | 8604.93 | 8609.86 | 8507.63 |
| 1984 | 8812.52 | 8642.27 | 8659.68 | 8535.25 |
| 1985 | 8877.81 | 8676.64 | 8707.70 | 8560.71 |
| 1986 | 8940.73 | 8708.30 | 8753.96 | 8584.16 |
| 1987 | 9001.37 | 8737.45 | 8798.55 | 8605.79 |
| 1988 | 9059.79 | 8764.30 | 8841.51 | 8625.72 |
| 1989 | 9116.09 | 8789.04 | 8882.92 | 8644.11 |
| 1990 | 9170.35 | 8811.84 | 8922.81 | 8661.07 |
| 1991 | 9222.63 | 8832.57 | 8961.26 | 8676.49 |
| 1992 | 9273.01 | 8851.41 | 8998.31 | 8690.51 |
| 1993 | 9321.56 | 8868.54 | 9034.01 | 8703.25 |
| 1994 | 9368.34 | 8884.11 | 9068.41 | 8714.83 |
| 1995 | 9413.43 | 8898.27 | 9101.56 | 8725.36 |
| 1996 | 9456.87 | 8911.14 | 9133.51 | 8734.94 |
| 1997 | 9498.73 | 8922.84 | 9164.29 | 8743.64 |
| 1998 | 9539.07 | 8933.47 | 9193.95 | 8751.55 |
| 1999 | 9577.95 | 8943.14 | 9222.54 | 8758.74 |
| 2000 | 9615.41 | 8951.93 | 9250.09 | 8765.28 |
| 2001 | 9651.50 | 8959.92 | 9276.63 | 8771.23 |
| 2002 | 9686.29 | 8967.19 | 9302.21 | 8776.63 |
| 2003 | 9719.81 | 8973.79 | 9326.86 | 8781.54 |
| 2004 | 9752.11 | 8979.80 | 9350.61 | 8786.01 |
| 2005 | 9783.24 | 8985.25 | 9373.50 | 8790.07 |
| 2006 | 9813.23 | 8990.22 | 9395.56 | 8793.76 |
| 2007 | 9842.14 | 8994.73 | 9416.82 | 8797.12 |
| 2008 | 9869.99 | 8998.83 | 9437.30 | 8800.17 |
| 2009 | 9896.83 | 9002.56 | 9457.03 | 8802.94 |
| 2010 | 9922.70 | 9005.94 | 9476.05 | 8805.46 |
| 2011 | 9947.62 | 9009.03 | 9494.38 | 8807.75 |
| 2012 | 9971.64 | 9011.83 | 9512.04 | 8809.84 |
| 2013 | 9994.78 | 9014.37 | 9529.06 | 8811.73 |
| 2014 | 10017.1 | 9016.69 | 9545.46 | 8813.45 |
| 2015 | 10038.6 | 9018.79 | 9561.27 | 8815.02 |
| 2016 | 10059.3 | 9020.70 | 9576.50 | 8816.44 |

Table C.2

Present Value Costs Of The ECB At Year End ($1000)

| Year | Combination 1 1977 Consumption & GSA Price Rise | Combination 2 1977 Consumption & FEA Price Rise | Combination 3 1962 Consumption & GSA Price Rise | Combination 4 1962 Consumption & FEA Price Rise |
|---|---|---|---|---|
| 1976 | $7908.00 | $7908.00 | $7908.00 | $7908.00 |
| 1977 | 8013.73 | 8013.73 | 8004.09 | 8004.09 |
| 1978 | 8125.22 | 8111.10 | 8105.42 | 8092.59 |
| 1979 | 8242.80 | 8200.80 | 8212.28 | 8174.11 |
| 1980 | 8366.79 | 8283.44 | 8324.97 | 8249.21 |
| 1981 | 8486.27 | 8359.60 | 8433.56 | 8318.43 |
| 1982 | 8601.40 | 8429.80 | 8538.20 | 8382.22 |
| 1983 | 8712.35 | 8494.53 | 8639.04 | 8441.04 |
| 1984 | 8819.26 | 8554.22 | 8736.21 | 8495.28 |
| 1985 | 8922.29 | 8609.27 | 8829.85 | 8545.31 |
| 1986 | 9021.57 | 8660.06 | 8920.08 | 8591.46 |
| 1987 | 9117.24 | 8706.93 | 9007.03 | 8634.06 |
| 1988 | 9209.43 | 8750.20 | 9090.82 | 8673.37 |
| 1989 | 9298.27 | 8790.14 | 9171.56 | 8709.66 |
| 1990 | 9383.88 | 8827.02 | 9249.36 | 8743.17 |
| 1991 | 9466.37 | 8860.55 | 9324.34 | 8773.64 |
| 1992 | 9545.87 | 8891.04 | 9396.59 | 8801.33 |
| 1993 | 9622.47 | 8918.75 | 9466.21 | 8826.51 |
| 1994 | 9696.29 | 8943.94 | 9533.30 | 8849.40 |
| 1995 | 9767.43 | 8966.84 | 9597.95 | 8870.21 |
| 1996 | 9835.98 | 8987.66 | 9660.25 | 8889.13 |
| 1997 | 9902.03 | 9006.59 | 9720.29 | 8906.32 |
| 1998 | 9965.68 | 9023.79 | 9778.14 | 8921.96 |
| 1999 | 10027.00 | 9039.44 | 9833.89 | 8936.17 |
| 2000 | 10086.10 | 9053.66 | 9887.61 | 8949.09 |
| 2001 | 10143.10 | 9066.58 | 9939.37 | 8960.84 |
| 2002 | 10198.00 | 9078.34 | 9989.26 | 8971.51 |
| 2003 | 10250.90 | 9089.02 | 10037.3 | 8981.22 |
| 2004 | 10301.80 | 9098.73 | 10083.7 | 8990.05 |
| 2005 | 10351.00 | 9107.56 | 10128.3 | 8998.07 |
| 2006 | 10398.30 | 9115.59 | 10171.3 | 9005.36 |
| 2007 | 10443.90 | 9122.89 | 10212.8 | 9011.99 |
| 2008 | 10487.80 | 9129.52 | 10252.7 | 9018.02 |
| 2009 | 10530.20 | 9135.55 | 10291.2 | 9023.50 |
| 2010 | 10571.00 | 9141.03 | 10328.3 | 9028.48 |
| 2011 | 10610.30 | 9146.02 | 10364.0 | 9033.01 |
| 2012 | 10648.20 | 9150.55 | 10398.5 | 9037.13 |
| 2013 | 10684.70 | 9154.67 | 10431.7 | 9040.87 |
| 2014 | 10719.90 | 9158.41 | 10463.6 | 9044.27 |
| 2015 | 10753.80 | 9161.82 | 10494.5 | 9047.37 |
| 2016 | 10786.50 | 9164.91 | 10524.2 | 9050.18 |

Table C.3

Present Value Costs Of The ECB At Year End ($1000)

| Year | Combination 1A Adjusted 1977 Consumption & GSA Price Rise | Combination 2A Adjusted 1977 Consumption & FEA Price Rise |
|---|---|---|
| 1976 | $7908.00 | $7908.00 |
| 1977 | 8038.69 | 8038.69 |
| 1978 | 8176.52 | 8159.06 |
| 1979 | 8321.86 | 8269.94 |
| 1980 | 8475.13 | 8372.10 |
| 1981 | 8622.82 | 8466.24 |
| 1982 | 8765.15 | 8553.02 |
| 1983 | 8902.30 | 8633.03 |
| 1984 | 9034.46 | 8706.80 |
| 1985 | 9161.81 | 8774.86 |
| 1986 | 9284.54 | 8837.64 |
| 1987 | 9402.80 | 8895.58 |
| 1988 | 9516.76 | 8949.05 |
| 1989 | 9626.58 | 8998.42 |
| 1990 | 9732.40 | 9044.01 |
| 1991 | 9834.38 | 9085.45 |
| 1992 | 9932.65 | 9123.13 |
| 1993 | 10027.30 | 9157.38 |
| 1994 | 10118.60 | 9188.52 |
| 1995 | 10206.50 | 9216.83 |
| 1996 | 10291.30 | 9242.56 |
| 1997 | 10372.90 | 9265.96 |
| 1998 | 10451.60 | 9287.23 |
| 1999 | 10527.40 | 9306.56 |
| 2000 | 10600.50 | 9324.14 |
| 2001 | 10670.90 | 9340.12 |
| 2002 | 10738.70 | 9354.64 |
| 2003 | 10804.10 | 9367.85 |
| 2004 | 10867.10 | 9379.85 |
| 2005 | 10927.80 | 9390.77 |
| 2006 | 10986.40 | 9400.69 |
| 2007 | 11042.70 | 9409.71 |
| 2008 | 11097.10 | 9417.91 |
| 2009 | 11149.40 | 9425.36 |
| 2010 | 11199.90 | 9432.14 |
| 2011 | 11248.50 | 9438.30 |
| 2012 | 11295.30 | 9443.90 |
| 2013 | 11340.50 | 9448.99 |
| 2014 | 11384.00 | 9453.62 |
| 2015 | 11425.90 | 9457.83 |
| 2016 | 11466.30 | 9461.65 |

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The Norris Cotton Federal Office Building in Manchester, New Hampshire, has been constructed and occupied by the General Services Administration to demonstrate energy conservation techniques in the design and operations of a contemporary office building. This post-occupancy economic evaluation conducted by the National Bureau of Standards shows that additional construction costs incurred in order to reduce the energy consumption of the building are adequately offset by the present value of the resulting annual energy savings. In the economic model, the actual construction cost and energy consumption of the constructed building are compared with the estimated construction cost and energy consumption of a hypothetical equivalent conventional building. The present value costs of the two buildings are calculated for each year during a 40-year study period.

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