Center for Advanced Computation

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NONRESIDENTIAL BUILDING ENERGY USE 1976-2010

by

Donna Amado
David A. Pilati

August 1976

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Abstract

A flexible computer model is developed to predict future energy use in nonresidential buildings. Historical floor space addition data are combined with a building decay scheme to calculate the age distribution of existing buildings. By specifying future floor space growth rates, the energy intensity of new structures over time and (if desired) a retrofit program to upgrade existing buildings, the model calculates future energy consumption. This energy use model is applied to four alternative futures that depend on assumed energy prices. Sensitivity to floor space growth rates for commercial, educational and government buildings is investigated. In each of a wide variety of technological improvements in new buildings and retrofit programs, a 2% increase in floor space growth rates over the 1976-2010 period results in essentially a doubling of energy use in 2010 when compared to the lower growth rate case.

Nonresidential Building Energy Use 1976-2010

Donna Amado and David A. Pilati

I. Introduction

This report documents the development of a simple computer model that predicts nonresidential building energy use through the year 2010. It can be used to investigate a number of possible futures and their impact on energy use in the buildings' sector. The model is based on historical floor space additions and on an assumed decay rate for the building stock. Given the energy intensities of new buildings, the energy intensities resulting from building retrofit programs (if desired), and the floor space growth rate of nonresidential buildings (separated into three subsectors: commercial, educational and government), this model calculates the overall energy intensity (Btu/ft^2-yr) and energy use by each subsector as a function of time.

Nonresidential buildings are considerably less homogeneous than residential structures. A recent study of commercial building energy use in Baltimore categorized buildings into 12 types.[1] The average energy intensity (Btu/ft^2-yr) of these building types differed by nearly a factor of five. As shown in Table 1, differences between energy intensities within a single building type are often greater than a factor of 10. Therefore, building energy use depends not only on the purpose of the building but on many other, as yet, undetermined factors.

The study cited above also discussed the energy intensity of commercial buildings as a function of age for three building types. Figure 1 illustrates the results of this comparison. This limited information implies that older

Table 1. Differences Between Energy Intensities (EI) of Similar Building Types in Baltimore

Building Type	Average EI (Btu/ft^2-yr)	Maximum EI/Minimum EI
Restaurants	300,000	14.1
Night Clubs	253,192	8.9
Drug Stores	232,672	6.2
Food Stores	206,986	4.5
Department Stores	164,412	6.6
Hotels/Motels	146,597	2.4
Banks	144,634	4.9
Offices	124,647	20.6
Personal Services	117,318	53.1
Small Stores	95,378	55.8
Theaters	75,844	4.1
Warehouses	61,973	41.0

Source: Ref. 1.

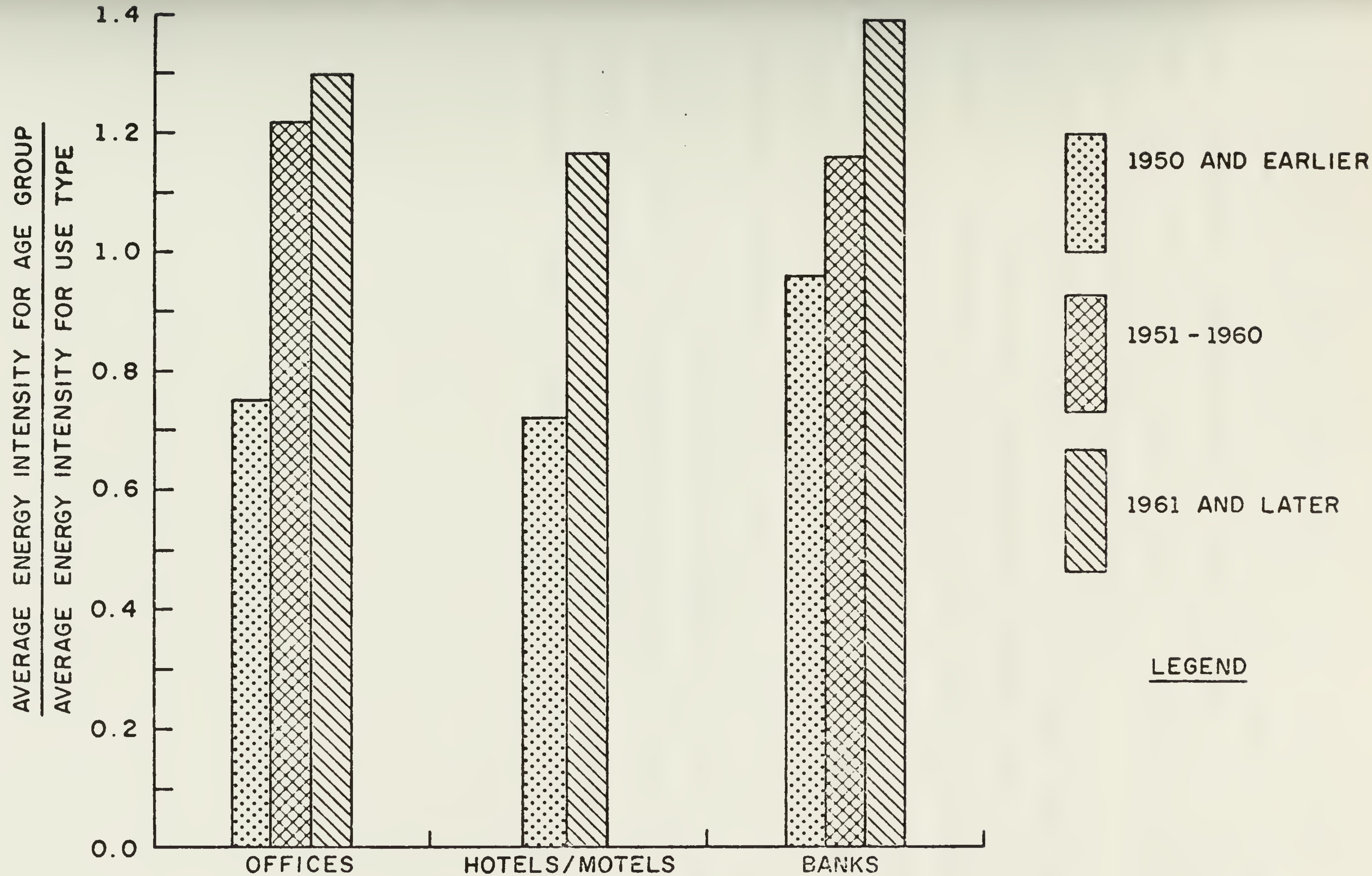

Figure 1. Energy Intensity of Several Commercial Building Types

Source: Ref. 1

buildings use less energy per unit floor area than newer buildings. This result, as well as the fact that older buildings will probably be retired sooner than new buildings, suggests that only newer buildings will be extensively retrofitted to reduce their energy consumption. Therefore, a predictive energy use model for buildings should reflect this belief.

Although tremendous disparties exist between building energy use at the micro level, our macro model is driven only by assumed overall energy intensities (for new and old buildings) and total floor space additions for commercial, educational and government buildings. The next section describes the methodology for constructing the model. The model is then used to project energy use by the three building types under four assumed futures. These futures are based on 2010 energy costs that are one-half, the same, two times and four times current petroleum fuel costs. (The energy price assumptions are based on preliminary scenarios generated by the Demand/Conservation panel of the National Academy of Sciences' Committee on Nuclear and Alternative Energy Systems.) Appropriate technologies and retrofit programs for each of the scenarios are assumed.

II. Methodology

For our purpose, nonresidential buildings are disaggregated into commercial, educational and government subsectors. The selection of this disaggregation scheme resulted from two reasons: 1) the desire to interact with existing input-output models and 2) future growth in these subsectors is probably dependent on different factors.

The existing floor space for nonresidential buildings is not known. However, it can be calculated given historical floor space additions and a decay scheme for these buildings. The period of historical data required depends on the decay scheme assumed. For this study, we have made the following *a priori* assumption about the disappearance of buildings over time: 1) no buildings are removed from the stock during the first 15 years of their life and 2) buildings disappear at a constant rate after 15 years of service until none exist after 85 years of service. This decay scheme is depicted in Fig. 2. As shown for appliances in Dole[2], a simple linear decay scheme is a somewhat rough approximation to more sophisticated schemes. Also, a median building lifetime of 50 years is consistent with other observations.[3]

For the assumed decay scheme, floor space additions for each subsector from 1890 to 1975 are required to project the building stock and age distribution into the future. Salter, et al.[3] give floor space additions from 1925 through 1971 for seven building types that can be appropriately aggregated to the three types used in this study. Floor space additions through 1974 are assumed to change in proportion to the changes given in the *Statistical Abstracts of the United States*[4] for each buiilding subsector. It is assumed

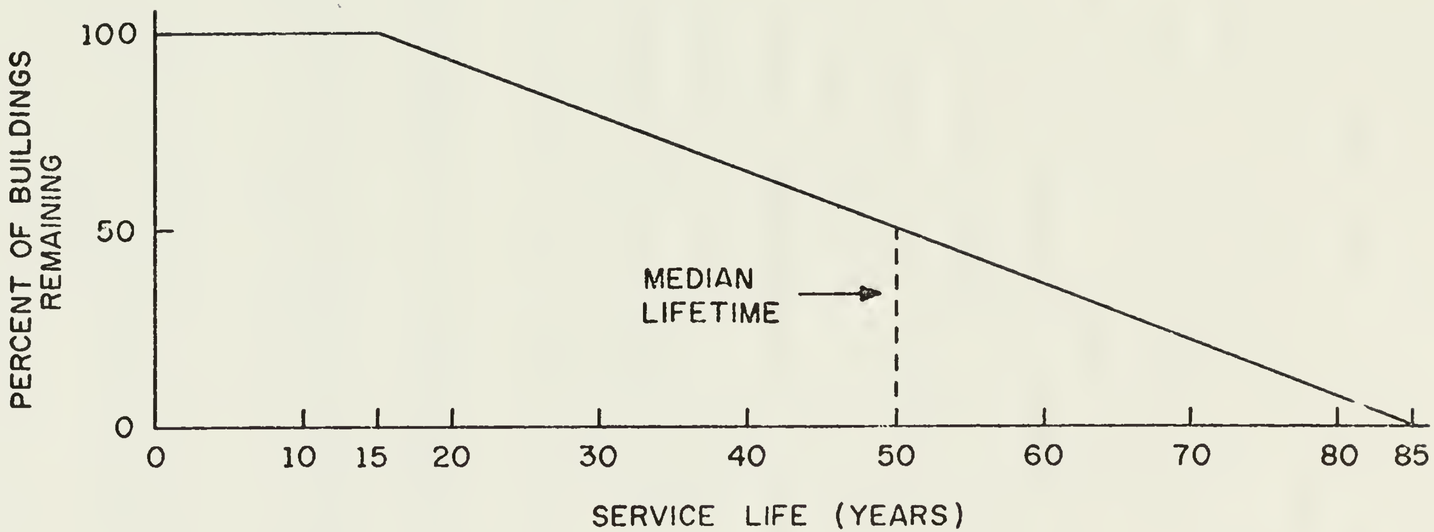

Figure 2. Assumed Decay Scheme for Nonresidential Buildings

that 1975 additions are the same as 1974 because of the economic recession during this period. Floor space additions for each subsector prior to 1925 are assumed consistent with the Rigleman-Isard building activity index (1915-1925) and the Newcomb building activity index (1890-1915).[5] Floor space additions for each subsector over the 1890-1975 period are given in Appendix A. Appendix A also gives the listing of a short computer program that calculates the 1975 inventory and age distribution of buildings. This information is required as input to the energy use model. The calculated 1975 floor space (inventory) for each subsector is also included in Appendix A.

A listing of the energy use model and user instructions for projecting building subsector's energy consumption are given in Appendix B. The following items are required as input to the program:

1) The age distribution and inventory of the existing building stock (calculated from program in Appendix A).

2) Subsector floor space growth rates with up to 5 separate growth periods.

3) The energy intensity of buildings constructed in each year from 1976-2010 (normalized to 1.0 for existing buildings).

4) A prescribed retrofit program, if desired. All buildings constructed between a specified year and 1975 can be retrofit over some specific time period. The energy intensities of retrofit buildings over time are input.

By combining the floor space growth rates, retired stock, new additions, and retrofitted building stock, the energy use model calculates building energy intensity and energy use over time.

III. Scenario Description

The building energy use model has been used to investigate a number of alternative futures that depend on energy prices and growth rates for floor space in each subsector. As energy prices increase, it is assumed that more energy efficient building design will be employed and that more extensive retrofitting of existing buildings will occur in response to these higher fuel prices. Table 2 gives the energy intensities of new nonresidential buildings as well as the retrofit programs for each energy price scenario (energy intensities are normalized to 1.0 for existing buildings). The Table 2 scenarios are used for each of the building subsectors.

Predicted building energy use also depends on the growth rates assumed for each building subsector. The energy use model has been used to investigate several growth rate assumptions for each building subsector. Table 3 gives the various growth rates investigated. The base case growth rate assumptions are also noted in Table 3.

Table 2. Energy Intensities of New and Retrofitted Structures for Each Scenario

Scenario I (Energy prices are halved by 2010)

Energy Intensity of New Structures (all subsectors)

1975	1980	1990	2000	2010
1.0	1.05	1.15	1.25	1.35

No Retrofit Program

Scenario II (Energy prices remain constant)

Energy Intensity of New Structures (all subsectors)

1975	1980	1990	2000	2010
1.0	1.0	1.0	1.0	1.0

No Retrofit Program

Scenario III (Energy prices are doubled by 2010)

Energy Intensity of New Structures

	1975	1980	1990	2000	2010
Commercial	1.0	.92	.60	.60	.60
Education	1.0	.90	.50	.50	.50
Government	1.0	.85	.40	.40	.40

Retrofit Program: Retrofit remaining buildings constructured between 1960 and 1975.

Energy Intensity of Retrofitted Structures (all subsectors)

1975	1980	1990	2000	2010
1.0	.90	.60	.60	.60

Scenario IV (Energy prices are quadrupled by 2010)

Energy Intensity of New Structures

	1975	1980	1990	2000	2010
Commerical	1.0	.80	.60	.51	.42
Education	1.0	.75	.50	.42	.35
Government	1.0	.70	.40	.34	.28

Retrofit Program: Refrofit remaining buildings constructed between 1950 and 1975.

Energy Intensity of Retrofitted Structures (all subsectors)

1975	1980	1990	2000	2010
1.0	.80	.60	.60	.60

Table 3. Building Subsector Growth Rates Investigated

Subsector	Annual Growth Rates (period)
Commercial	0.0% (1976-2010)
	1.0% (1976-2010)
	3.0% (1976-2010)[a]
	5.0% (1976-2010)
Educational	0.0% (1976-2010)
	-.7% (1976-1985), 0.0% (1986-1990), .8% (1991-2010[a]
	1.0% (1976-2010)
	3.0% (1976-2010)
Government	0.0% (1976-2010)
	1.0% (1976-2010)[a]
	3.0% (1976-2010)
	5.0% (1976-2010)

---

[a]Growth rate assumed for base case.

[b]Based on Series 2 projected population in the age group from 5 to 24 years. Source: U.S. Department of Commerce, *Projection of the U.S. Population: 1975-2030, Series P-25,* October, 1975.

IV. Results

Predicted overall energy use for the base case growth rates (see Table 3) is illustrated in Fig. 3. For all four scenarios nonresidential building energy use is higher in 2010 than in 1975. Because of the retrofit programs assumed in Scenarios III and IV, energy use remains essentially constant for some time. However, by the year 2010 the positive floor space growth rates assumed result in overall energy use continuing to increase at a level considerably above their 1975 values.

Table 4 gives detailed subsector projections of base case energy use. Although overall energy use increases for each scenario, both educational and government building energy use declines in Scenarios III and IV. This is due to the lower growth rates assumed for these subsectors. The higher commercial floor space growth rates (3% per year) results in this subsector increasing its energy use in all cases.

Because of the effects of floor space growth rate assumptions, it is interesting to compare subsector energy use for various assumed growth rates. Table 5 gives the 2010 energy use by subsector for the growth rates given in Table 3 for each scenario. Table 5 shows that each subsector's energy use is very sensitive to the assumed floor space growth assumption. In each of a wide variety of technological improvements in new buildings and retrofit programs, a 2% increase in floor space growth rate over the 1976-2010 period results in essentially a doubling of energy use in 2010 when compared to the lower growth rate case.

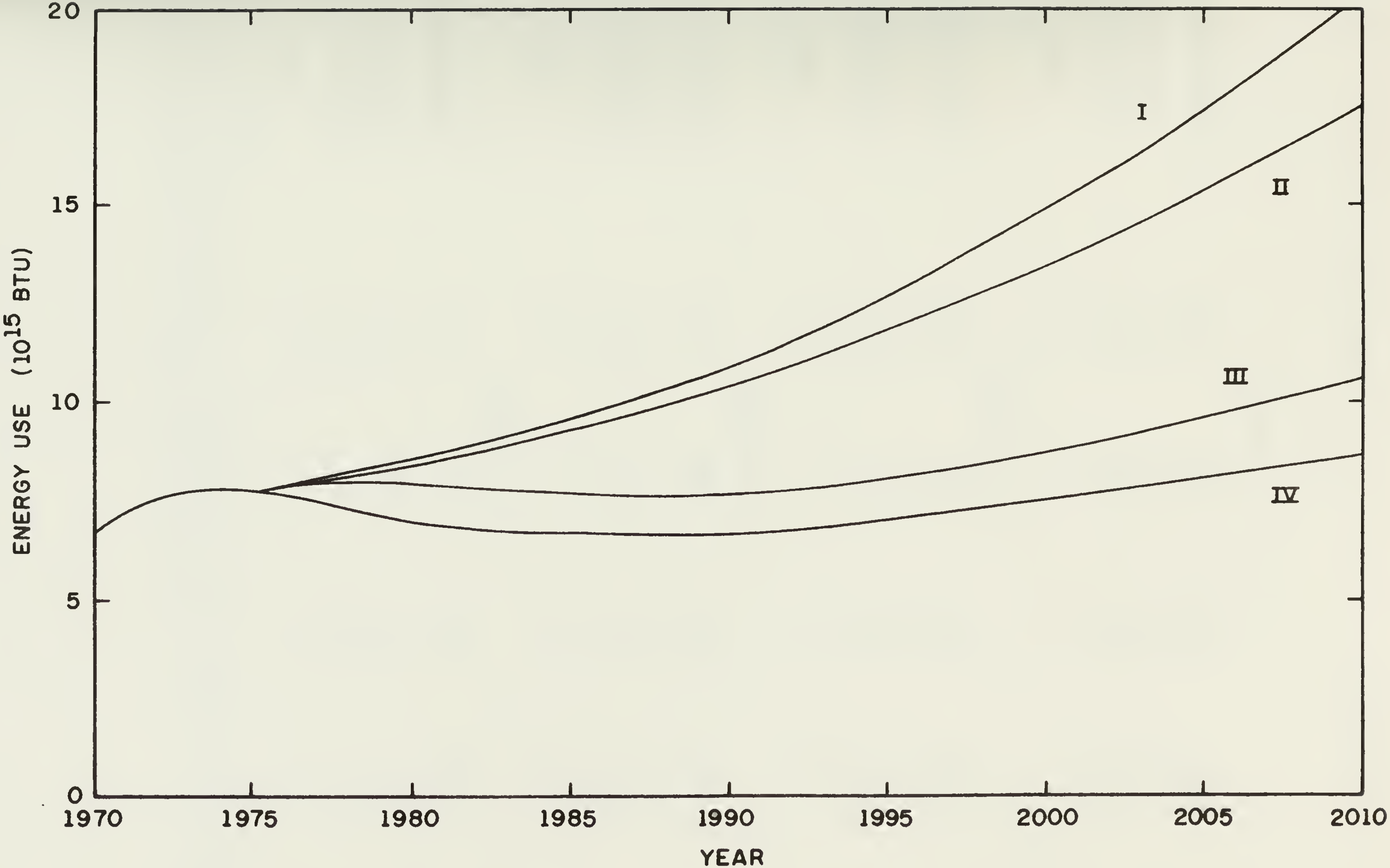

FIGURE 3: NONRESIDENTIAL BUILDING ENERGY USE

Table 4. Base Case Nonresidential Building Energy Use 1975-2010[a]

(10^{15} Btu)

Scenario I

Building Type	1975	1980	1990	2000	2010
Commercial	5.49	6.40	8.88	12.63	18.19
Educational	2.04	1.98	2.08	2.36	2.70
Government	.62	.65	.74	.85	.99
TOTAL	8.15	9.03	11.70	15.84	21.88

Scenario II

Building Type	1975	1980	1990	2000	2010
Commercial	5.49	6.36	8.55	11.49	15.45
Educational	2.04	1.98	2.05	2.22	2.40
Government	.62	.65	.72	.80	.88
TOTAL	8.15	8.99	8.61	10.05	12.17

Scenario III

Building Type	1975	1980	1990	2000	2010
Commercial	5.49	6.03	6.57	8.06	10.14
Educational	2.04	1.88	1.53	1.49	1.49
Governmental	.62	.61	.51	.50	.59
TOTAL	8.15	8.52	8.61	10.05	12.17

Scenario IV

Building Type	1975	1980	1990	2000	2010
Commerical	5.49	5.54	6.05	7.43	8.92
Educational	2.04	1.70	1.34	1.32	1.29
Governmental	.62	.56	.47	.46	.44
TOTAL	8.15	7.80	7.86	9.21	10.65

[a]Building energy use in 1975 is disaggregated by floor space fraction for each subsector. Total energy use in 1975 based on Eric Hirst and Jerry Jackson, *Historical Patterns of Residential and Commerical Energy Uses*, Oak Ridge National Laboratory Draft Report, September 1976.

Table 5. Building Subsector Energy Use in 2010 for Various Floor Space Growth Rate Assumptions

Commercial (10^{15} Btu)

Growth Rate (%)	I	II	III	IV
0.6	6.03	5.49	3.66	3.28
1.0	8.78	7.78	5.20	4.63
3.0	18.19	15.45	10.19	8.98
5.0	36.68	30.29	19.57	16.82

Educational (10^{15} Btu)

Growth Rate (%)	I	II	III	IV
0.0	2.24	2.04	1.31	1.15
-0.7, 0.0, -0.8[a]	2.70	2.40	1.49	1.29
1.0	3.27	2.89	1.82	1.38
3.0	6.76	5.74	3.42	2.96

[a]See Table 3.

Governmental (10^{15} Btu)

Growth Rate (%)	I	II	III	IV
0.0	.68	.62	.36	.33
1.0	.99	.88	.49	.44
3.0	2.05	1.74	.90	.74
5.0	4.14	3.42	1.65	1.42

References

1. H. M. Bernstein and P. M. McCarthy, *A Study of the Physical Characteristics, Energy Consumption, and Related Institutional Factors in the Commercial Sector,* Hittman Associates Report HIT-630, December 1975.

2. S. H. Dole, *Energy Use and Conservation in the Residential Sector: A Regional Analysis,* Rand Corporation, R-1641-NSF, June 1975.

3. R. G. Salter, R. L. Petruschell, K. Wolf, *Energy Conservation in Non-residential Buildings,* Rand Corporation, R-1623-NSF, October 1976.

4. U.S. Department of Commerce, *Statistical Abstract of the United States 1975,* 1975.

5. U.S. Department of Commerce, *Historical Statistics of the United States Colonial Times to 1957,* 1960.

APPENDIX A

AREA ADDED TABLE

LISTED BELOW IS THE ANNUAL AREA ADDED IN MILLIONS OF SQUARE FEET FOR THE COMMERCIAL SECTOR.

YEAR	AREA ADDED
1890	27.0
1891	27.0
1892	25.4
1893	25.4
1894	25.4
1895	27.0
1896	28.6
1897	25.4
1898	27.0
1899	23.9
1900	28.6
1901	30.2
1902	33.4
1903	35.0
1904	39.8
1905	47.7
1906	49.3
1907	44.5
1908	46.1
1909	49.3
1910	55.7
1911	58.8
1912	57.2
1913	52.5
1914	47.7
1915	50.1
1916	62.2
1917	39.9
1918	24.4
1919	74.3
1920	81.1
1921	100.8
1922	153.3
1923	187.6
1924	191.4
1925	225.3
1926	214.0
1927	211.3
1928	222.6
1929	215.1

YEAR	AREA ADDED
1930	142.7
1931	86.5
1932	40.2
1933	36.4
1934	41.6
1935	53.1
1936	84.8
1937	92.9
1938	82.0
1939	79.0
1940	1[illegible]
1941	144.7
1942	135.0
1943	56.0
1944	26.6
1945	87.2
1946	153.5
1947	146.4
1948	179.3
1949	174.1
1950	220.5
1951	151.5
1952	142.3
1953	130.8
1954	218.0
1955	330.3
1956	333.6
1957	439.9
1958	465.7
1959	524.5
1960	533.2
1961	590.9
1962	649.9
1963	656.4
1964	697.9
1965	800.5
1966	839.4
1967	760.1
1968	739.1
1969	776.7
1970	791.4
1971	875.4
1972	931.9
1973	1035.1
1974	920.9
1975	920.9

Calculated 1975 Inventory:

18.07×10^9 ft^2

AREA ADDED TABLE

LISTED BELOW IS THE ANNUAL AREA ADDED IN MILLIONS OF SQUARE FEET FOR THE EDUCATIONAL SECTOR.

YEAR	AREA ADDED
1890	7.0
1891	7.0
1892	6.6
1893	6.6
1894	6.6
1895	7.0
1896	7.4
1897	6.6
1898	7.0
1899	6.2
1900	7.4
1901	7.8
1902	8.6
1903	9.0
1904	10.3
1905	12.3
1906	12.7
1907	11.5
1908	11.9
1909	12.7
1910	14.4
1911	15.2
1912	14.3
1913	13.5
1914	12.3
1915	13.5
1916	16.7
1917	10.7
1918	6.6
1919	20.0
1920	21.8
1921	27.1
1922	41.2
1923	50.4
1924	51.4
1925	60.5
1926	53.8
1927	53.9
1928	61.5
1929	58.6

YEAR	AREA ADDED
1930	57.0
1931	36.6
1932	13.7
1933	5.5
1934	16.8
1935	26.0
1936	42.0
1937	36.5
1938	57.0
1939	34.4
1940	24.8
1941	24.5
1942	30.6
1943	12.0
1944	9.8
1945	12.5
1946	25.9
1947	41.0
1948	72.3
1949	79.0
1950	110.6
1951	109.5
1952	106.7
1953	124.2
1954	154.1
1955	241.9
1956	225.0
1957	250.7
1958	251.0
1959	227.7
1960	233.2
1961	252.3
1962	244.8
1963	264.0
1964	274.4
1965	297.3
1966	332.4
1967	342.7
1968	338.0
1969	294.5
1970	256.7
1971	231.6
1972	205.4
1973	205.4
1974	235.6
1975	235.6

Calculated 1975 Inventory:

6.72×10^9 ft^2

AREA ADDED TABLE

LISTED BELOW IS THE ANNUAL AREA ADDED IN MILLIONS OF SQUARE FEET FOR THE GOVERNMENT SECTOR.

YEAR	AREA ADDED	YEAR	AREA ADDED
1890	1.0	1930	17.0
1891	1.0	1931	24.3
1892	1.0	1932	16.2
1893	1.0	1933	9.5
1894	1.0	1934	9.4
1895	1.0	1935	13.5
1896	1.1	1936	14.3
1897	1.0	1937	12.5
1898	1.0	1938	15.6
1899	0.9	1939	15.1
1900	1.1	1940	11.9
1901	1.1	1941	14.5
1902	1.3	1942	19.8
1903	1.3	1943	4.8
1904	1.5	1944	2.0
1905	1.8	1945	1.9
1906	1.9	1946	2.2
1907	1.7	1947	6.3
1908	1.7	1948	6.2
1909	1.9	1949	7.7
1910	2.1	1950	7.5
1911	2.2	1951	10.8
1912	2.2	1952	14.7
1913	2.0	1953	13.1
1914	1.8	1954	15.8
1915	1.8	1955	50.7
1916	2.3	1956	52.2
1917	1.5	1957	55.4
1918	0.9	1958	57.3
1919	2.7	1959	63.9
1920	3.0	1960	62.4
1921	3.7	1961	70.0
1922	5.6	1962	73.1
1923	6.9	1963	80.3
1924	7.1	1964	91.1
1925	8.3	1965	99.0
1926	7.9	1966	86.5
1927	9.9	1967	94.4
1928	11.3	1968	95.0
1929	12.6	1969	102.4
		1970	81.6
		1971	91.9
		1972	109.0
		1973	137.0
		1974	132.0
		1975	132.0

Calculated 1975 Inventory:

2.06×10^9 ft^2

INPUT TO STEP 1

Cards 1 - 86: Year and area added, one of each per card, for 1890 thru 1975. The year is in I4 format in columns 1 thru 4. The area added is in F6.1 format and appears in different columns for the three different sectors as follows:

Columns 7 thru 12 - commercial sector

Columns 15 thru 20 - government sector

Columns 23 thru 28 - education sector

STEP 1

```
C
C   THIS PROGRAM READS IN THE AREA ADDED FOR 1890 THRU 1975 AND OUTPUTS
C   THE INVENTORY FOR YEARS 1974 AND 1975.
C
        REAL AA(86),INV74,INV75
        INTEGER YR(86)
C
C   INPUT THE YEAR AND AREA ADDED FROM CARDS, ONE SET OF EACH PER CARD.
C
        DO 10 I=1,86
10      READ(5,100) YR(I),AA(I)
100     FORMAT(I4,16X,F6.1)
C
C   SET THE 1974 INVENTORY EQUAL TO THE AREA ADDED FOR 1890 AND THE 1975
C   INVENTORY EQUAL TO AREA ADDED FOR 1975.  BLDG IS A FUNCTION SUBPROGRAM.
C
        INV74=BLDG(AA(1),1974,YR(1))
        INV75=BLDG(AA(86),1975,YR(86))
C
C   ADD TO BOTH THE 1974 AND 1975 INVENTORIES AREA ADDED FOR 1891 THRU 1974.
C   HENCE, THE 1974 INVENTORY IS DETERMINED FROM AREA ADDED IN1890 THRU
C   1974 AND THE 1975 INVENTORY IS DETERMINED FROM AREA ADDED IN 1891 THRU
C   1975.
C
        DO 20 I=2,85
        INV74=INV74+BLDG(AA(I),1974,YR(I))
20      INV75=INV75+BLDG(AA(I),1975,YR(I))
C
C   OUTPUT THE TWO RESULTING INVETORIES.
C
        WRITE(6,120) INV74
120     FORMAT(' ','1974 INVENTORY: ',F8.2)
        WRITE(6,130) INV75
130     FORMAT(' ','1975 INVENTORY: ',F8.2)
        STOP
        END


        REAL FUNCTION BLDG(AREA,Y,T)
C
C   THIS FUNCTION SUBPROGRAM DETERMINES THE NUMBER OF EXISTING BUILDINGS
C   IN YEAR Y THAT WERE BUILT IN YEAR T.  THE SCHEME IS AS FOLLOWS:
C   IF Y>=T>=Y-15 THEN THE NUMBER OF BUILDINGS BUILT IN YEAR T THAT EXIST
C   IN YEAR Y, IS THE AREA ADDED FOR YEAR T.
C   IF Y-85<T<Y-15 THEN THERE IS A DESTRUCTION RATE OF (1/70) EACH YEAR.
C   HENCE, THE NUMBER OF BUILDINGS BUILT IN YEAR T THAT EXIST IN YEAR Y IS
C   (1-(Y-15-T)/70.0)*AREA ADDED IN YEAR T.
C
        REAL AREA
        INTEGER Y,T
        IF (T .GE. Y-15) GO TO 50
        BLDG=(1.0-((Y-15)-T)/70.0)*AREA
        RETURN
50      BLDG=AREA
        RETURN
        END
```

APPENDIX B

INPUT TO STEP 2

Card 1: Up to 5 different time periods in format 5 (I2,1X). For example,

a) if 1976 - 2010 has only one growth rate, then card 1 contains 35 in columns 1 thru 2.

b) if 1976 - 1985 has one growth rate and 1986 - 2010 has a different one, then card one has a 10 in columns 1 thru 2 and a 25 in columns 4 thru 5.

Card 2: Up to 5 different growth rates, one for each time period on card 1, in format 5(F5.3, 1X). For example,

a) continuing example (a) above, suppose the growth rate for 1976 - 2010 is .03. Then card 2 would contain .030 in columns 2 thru 5.

b) continuing example (b) above, suppose the growth rate for 1976 - 1985 is .02 and for 1986 - 2010 is .005. Then card 2 would contain .020 in columns 2 thru 5 and .005 in columns 7 thru 10.

Card 3 thru 88: One area added per card in order of 1890 thru 1975. The number is in F6.1 format and appears in specific columns for specific sectors as follows:

Columns 7 thru 12 for commercial

Columns 15 thru 20 for government

Columns 23 thru 27 for education

Card 89: Retyr and Rettim where buildings constructed in Retyr thru 1975 get retrofitted for Rettim years after 1975. Retyr is a year and is entered as an I4 integer in columns 1 thru 4.

If no retrofit takes place, this should be left blank. Rettim is a number of years and is entered as an I2 integer in columns 7 thru 8. If no retrofit takes place, it should be left blank. In models with no retrofit, cards 89 and 90 should be input as a blank card.

Card 90 thru n: Retrofit energy intensities for 1976 thru 1976+Rettim. More than one card may be input and each card can contain up to 16 values, formatted as 16F5.1. Hence, columns 1 thru 5 contain EPSRET(1), columns 6 thru 10 contain EPSRET(2) and so forth.

Card (n+1) thru (n+3): Energy intensities for buildings constructed in 1976 thru 2010. Thirty-five energy intensities are input in format 16F5.1. Hence, for card n+1, columns 1 thru 5 contain EPSNEW(1), columns 6 thru 10 contain EPSNEW(2), and so forth. For card n+2, columns 1 thru 5 contain EPSNEW(17), columns 6 thru 10 contain EPSNEW(18), and so forth. Finally, for card n+3, columns 1 thru 5 contain EPSNEW(33), columns 6 thru 10 contain EPSNEW(34) and columns 11 thru 15 contain EPSNEW(35).

STEP 2

```
C
C     THIS PROGRAM CALCULATES SECTOR OUTPUT, NEW CONSTRUCTION, THE AMOUNT
C     OF BUILDINGS REPLACED AND THE ENERGY INTENSITY OF EXISTING BUILDINGS
C     FOR 1976 THRU 2010.
C
C     ABOUT THE VARIABLES:
C
C     T(1)-T(5)  - PERIODS OF TIME WHERE T(1) REPRESENTS 1976 THRU 1976+T(1),
C                  T(2) REPRESENTS 1976+T(1)+1 THRU 1976+T(1)+T(2), AND SO FORTH.
C                  DIFFERENT GROWTH RATES OCCUR DURING DIFFERENT PERIODS.  T(2)
C                  THRU T(5) CAN BE EQUAL TO 0; HENCE, THERE IS ONE GROWTH RATE
C                  FOR 1976 THRU 2010.
C
C   GR(1)-GR(5)  - GR(I) IS THE GROWTH RATE FOR THE TIME PERIOD DESCRIBED BY T(I).
C   AA(1)-AA(121)- AREA ADDED FOR 1890 THRU 2010 (IS NORMALIZED TO 1975 INVENTORY
C                  BY PROGRAM).
C    S(1)-S(35)  - SECTOR OUTPUT FOR 1976 THRU 2010.
C   ST(1)-ST(6)  - ST(I+1) IS TOTAL SECTOR OUTPUT DURING PERIOD T(I) WHERE
C                  ST(1)=1 FOR 1975.
C    R(1)-R(35)  - REPLACEMENT AREA FOR 1976 THRU 2010.
C
C     B(T,I)     - BUILDINGS EXISTING IN YEAR (I+1975) THAT WERE BUILT IN YEAR
C                  (1975+T)-(86-I). FOR EXAMPLE,
C                  B(1,1)=BUILDINGS EXISTING IN YEAR 1976, BUILT IN 1916
C                  B(1,86)=BUILDINGS EXISTING IN YEAR 1976, BUILT IN 1976
C                  B(35,1)=BUILDINGS EXISTING IN YEAR 2010, BUILT IN 2010
C                  B(35,86)=BUILDINGS EXISTING IN YEAR 2010, BUILT IN 2010
C
C    EPSRET(1)-
C    EPSRET(35)  - ENERGY INTENSITY OF BUILDINGS BEING RETROFIT FOR YEARS 1976
C                  THRU 1976+RETTIM.
C
C     RETTIM     - NUMBER OF YEARS RETROFITTING TAKES PLACE AFTER 1975.
C
C     RETYR      - THE YEAR BUILDINGS WERE CONSTRUCTED FOR WHICH RETROFITTING
C                  FIRST TAKES PLACE.  ONLY BUILDINGS BUILT FROM RETYR THRU
C                  1975 GET RETROFITTED.
          INTEGER J1,N
C
C    EPSNEW(1)-
C    EPSNEW(35)  - ENERGY INTENSITY OF BUILDINGS CONSTRUCTED IN 1976 THRU 2010.
C
C    EPSOVR(1)-
C    EPSOVR(35)   -OVERALL ENERGY INTENSITY FOR 1976 THRU 2010.
C
C
          INTEGER T(5),RETYR,RETTIM
          REAL EPSOVR(35)/35*0.0/,NRGUSE(35),GROWTH(35)
          REAL S(35),AA(121),R(35),B(35,86)
          REAL EPSRET(35),EPSNEW(35),GR(5),TOTAL(35)
          REAL INV75/1945.95/
C
C     INPUT TIME PERIODS ON ONE CARD AS INTEGERS REPRESENTING THE LENGTH OF
C     EACH TIME PERIOD BEGINNING WITH 1976.
C
          READ(5,500) (T(I),I=1,5)
500       FORMAT(5(I2,1X))
C
C     SET N EQUAL TO THE NUMBER OF TIME PERIODS BY DETERMINING HOW MANY
```

```
C     PERIODS WERE READ IN AS ZERO.
C
         N=5
         DO 5 I=1,4
5        IF (T(6-I) .EQ. 0) N=5-I
C
C     INPUT N GROWTH PERIODS.
C
         READ(5,505) (GR(I),I=1,N)
505      FORMAT(5(F5.3,1X))
C
C     INPUT THE AREA ADDED, ONE PER CARD, FOR 1890 THRU 1975.
C
         DO 10 I=1,86
         READ(5,510) AA(I)
510      FORMAT(22X,F6.1)
C
C     NORMALIZE THE AREA ADDED FOR 1890 THRU 1975 BY DIVIDING BY THE 1975
C     INVENTORY.
C
10       AA(I)=AA(I)/INV75
C
C     INITIALIZE THE FIRST TOTAL SECTOR OUTPUT ELEMENT, ST(1), TO 1 FOR 1975.
C     OTHER TOTAL SECTOR OUTPUTS FOR EACH TIME PERIOD WILL BE CALCULATED NEXT.
C
C
C     CALCULATE SECTOR OUTPUT FOR EACH YEAR AND ACCUMULATE TOTAL SECTOR
C     OUTPUT FOR EACH TIME PERIOD.
C
         DO 15 I=1,N
         IF (I .NE. 1) GO TO 12
         J1=T(I)
         J2=0
         DO 11 J=1,J1
11       S(J)=(1+GR(I))**J
         GO TO 15
12       J2=T(I-1)+J2
         J1=T(I)
         DO 14 J=J2,J1
14       S(J)=S(J2)*(1+GR(I))**J
15       CONTINUE
C
C     CALCULATE THE AMOUNT OF REPLACEMENT FOR 1976 THRU 2010 AND THE AMOUNT
C     OF AREA ADDED FOR 1976 THRU 2010.
C
         DO 25 I=1976,2010
         R(I-1975)=0.0
         J1=(I-85)-1890
         J2=(I-16)-1890
         DO 20 J=J1,J2
20       R(I-1975)=R(I-1975)+(1/70.0)*AA(J)
         IF (I .EQ. 1976) GO TO 23
         AA(I-1889)=S(I-1975)-S(I-1976)+R(I-1975)
C
C     AT THIS POINT, IF AREA ADDED IS NEGATIVE, THEN RELEVANT
C     VARIABLES ARE PRINTED OUT AND EXECUTION IS TERMINATED.
C
         IF (AA(I-1889) .GT. 0.0) GO TO 25
         WRITE(6,300) I,AA(I-1889),S(I-1975),S(I-1976),R(I-1975)
```

```
300     FORMAT(' ','YEAR= ',I4,2X,4(E13.6,2X))
        STOP
23      AA(87)=S(1)-1+R(1)
25      CCNTINUE
C
C     CALCULATE B(T,I), THE EXISTING BUILDINGS IN YEAR (T+1975) THAT WERE
C     BUILT IN YEAR (1975+T)-(86-I).
C
        DO 40 I=1976,2010
        B(I-1975,36)=AA(I-1889)
        DC 30 J=1,15
30      B(I-1975,36-J)=AA(I-J-1889)
        DO 40 J=16,85
40      B(I-1975,86-J)=(1.0-(J-15)/70.0)*AA(I-J-1889)
C
C     INPUT THE YEAR BUILDINGS WERE BUILT FOR WHICH RETROFITTING OCCURS AND
C     THE LENGTH OF TIME THAT RETROFITTING TAKES PLACE.
C
        READ(5,515) RETYR,RETTIM
515     FORMAT(I4,2X,I2)
C
C     INPUT ENERGY INTENSITIES FOR EACH OF THE RETROFIT YEARS.  THEN INPUT
C     ENERGY INTENSITIES FOR EACH YEAR FROM 1976 THRU 2010.
C
        READ(5,520) (EPSRET(I),I=1,RETTIM)
520     FCRMAT(16F5.1)
        READ(5,520) (EPSNEW(I),I=1,35)
        IF (RETTIM .EQ. 0) GO TO 63
        J1=1+RETTIM
        DO 45 J=J1,35
45      EPSRET(J)=EPSRET(RETTIM)
C
C     CALCULATE OVERALL ENERGY INTENSITIES ON ALL BUILDINGS CONSTRUCTED
C     BEFORE THE RETROFIT BUILDINGS WERE CONSTRUCTED.
C
        DO 55 I=1,35
        J1=RETYR-1890-I
        DO 55 J=1,J1
        IF (RETYR .LE. (1889+I+J)) GO TO 55
        EPSOVR(I)=EPSOVR(I)+B(I,J)
55      CONTINUE
C
C     CALCULATE OVERALL ENERGY INTENSITIES ON ALL BUILDINGS BEING RETROFITTED.
C
        DO 60 I=1,35
        J1=86-I
        J2=RETYR-1889-I
        DO 60 J=J2,J1
60      EPSOVR(I)=EPSOVR(I)+B(I,J)*EPSRET(I)
        GO TO 69
C
C     BRANCH HERE IF NO RETROFITTING IS DONE AND CALCULATE OVERALL
C     ENERGY INTENSITIES FOR BUILDINGS BUILT IN 1890 THRU 1975.
C
63      DO 65 I=1,35
        J1=86-I
        DC 65 J=1,J1
65      EPSOVR(I)=EPSOVR(I)+B(I,J)
C
```

```
C     CALCULATE OVERALL ENERGY INTENSITIES ON ALL BUILDINGS CONSTRUCTED AFTER
C     1975.
C
69          DO 70 I=1,35
            K=1
            J1=87-I
            DO 70 J=J1,86
            EPSOVR(I)=B(I,J)*EPSNEW(K)+EPSOVR(I)
70          K=K+1
C
C     CALCULATE THE TOTAL OUTPUT (BUILDINGS EXISTING) FOR 1976 THRU 2010
C     USING B(T,I).  COMPARE THIS TO TOTAL SECTOR OUTPUT, AS A CHECK, AND
C     CALCULATE OVERALL ENERGY INTENSITIES FOR 1976 THRU 2010.
C
            DO 85 I=1,35
            TOTAL(I)=0.0
            DO 80 J=1,86
80          TOTAL(I)=TOTAL(I)+B(I,J)
            IF (ABS(S(I)-TOTAL(I)) .LE. .0010) GO TO 85
            WRITE(6,700) I,S(I),TOTAL(I)
700         FORMAT(' ',I2,2(3X,E13.6))
85          EPSOVR(I)=EPSOVR(I)/TOTAL(I)
C
C     CALCULATE ENERGY USE AND GROWTH FOR EACH YEAR FROM 1976 THRU 2010.
C
            DO 75 I=1,35
            NRGUSE(I)=EPSOVR(I)*S(I)
75          GROWTH(I)=AA(I+86)-R(I)
C
C
C     PRINT THE RESULTS.
C
            WRITE(6,100)
100         FORMAT('1','THE SCENARIO IS DESCRIBED AS FOLLOWS')
            WRITE(6,105) N
105         FORMAT('0','THERE ARE ',I1,' TIME PERIODS, EACH WITH ITS OWN ',
         1   'GROWTH RATE')
            L1=1976
            DO 110 I=1,N
            L2=(L1-1)+T(I)
            WRITE(6,115) I,L1,L2,GR(I)
110         L1=L2
115         FORMAT('0','TIME PERIOD ',I1,' IS FROM ',I4,' THRU ',I4,' WITH'
         1   ,' A GROWTH RATE OF ',F5.3)
            J1=1975
            IF (RETYR .NE. 0) J1=RETYR-1
            WRITE(6,120) J1
120         FORMAT('0','BUILDINGS BUILT FROM 1890 THRU ',I4,' HAVE ENERGY ',
         1   'INTENSITY EQUAL TO 1.0')
            IF (RETYR .EQ. 0) GO TO 90
            WRITE(6,125) RETYR,RETTIM
125         FORMAT('0','BUILDINGS BUILT FROM ',I4,' THRU 1975 ARE ',
         1   'RETROFITTED FOR ',I2,' YEARS')
            WRITE(6,130)
130         FORMAT(' THE ENERGY INTENSITIES FOR THESE YEARS ARE AS ',
         1   'FOLLOWS:')
            I1=1975+RETTIM
            DO 140 I=1976,I1
140         WRITE(6,150) I,EPSRET(I-1975)
```

```
150       FORMAT(' ',10X,I4,3X,F5.3)
          GO TO 95
90        WRITE(6,155)
155       FORMAT('0','NO BUILDINGS ARE RETROFIT')
95        WRITE(6,160)
160       FORMAT('1','BUILDINGS BUILT FROM 1976 THRU 2010 HAVE THE ',
     1     'FOLLOWING ENERGY INTENSITIES:')
          DO 170 I=1976,2010
170       WRITE(6,150) I,EPSNEW(I-1975)
          WRITE(6,180)
180       FORMAT('1',42X,'GOVERNMENT SECTOR INVENTORY AND ENERGY USE')
          WRITE(6,190)
190       FORMAT('0',7X,'YEAR',13X,'SECTOR',49X,'AREA',13X,'ENERGY',
     1     12X,'ENERGY')
          WRITE(6,195)
195       FORMAT(' ',24X,'OUTPUT',12X,'GROWTH',10X,'REPLACEMENT',10X,
     1     'ADDED',11X,'INTENSITY',11X,'USE')
          DO 200 I=1976,2010
200       WRITE(6,205) I,S(I-1975),GROWTH(I-1975),R(I-1975),AA(I-1889),
     1     EPSOVR(I-1975),NRGUSE(I-1975)
205       FORMAT(' ',7X,I4,13X,6(F7.4,11X))
          STOP
          END
```