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ANALYSIS OF ENERGY CONSUMPTION IN OFFICE BUILDINGS

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PREFACE

This is the last of three volumes of the General Electric Company's report on the Commercial Sector Energy Consumption Data Base Development Project, funded under a cost sharing contract with the Department of Energy.

In Volume I, the inventory of commercial buildings was estimated for the period 1925-1975 for each of fifteen building categories, and the 1975 inventory was distributed among the 173 Business Economic Areas. Volume II presents the results of a survey of readily available energy consumption data for the various building categories exclusive of office buildings.

In this third Volume, an effort is made on one of the major commercial building categories, office buildings, to initiate the development of a more accurate and comprehensive energy consumption data base than is currently available. It is hoped that this work will illustrate what can be achieved for the other building categories through the use of sample data in contrast to the collection of census information, a more expensive and time consuming alternative.

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SUMMARY

This volume presents the results of Task 2B of the Commercial Sector Energy Consumption Data Base Development Project, funded under a cost sharing contract with the Department of Energy. In Volume I of the report on this project, estimates were presented of the inventory of 15 commercial building categories and in Volume II the results of a survey was presented of readily available energy consumption data for 14 of these building categories. In this last volume of the report, the development of a more extensive energy consumption data base is initiated for the 15th building category than is readily available in the published literature. This building category, office buildings, is one of the major energy consumers in the commercial sector.

There were several parts to this analysis of energy consumption in office buildings. A survey was conducted of readily available energy consumption data and the literature that describes the factors which drive energy use in such buildings was analyzed. Information on heating, ventilating, and air conditioning (HVAC) systems was assembled. A number of building energy use simulation programs were reviewed to determine their suitability for estimating energy consumption by function and the effects of tradeoffs in building design and operating parameters on building energy use. Simulations using the AXCESS program were conducted. The 1975 data base of the Building Owners and Managers Association (BOMA) was obtained and analyzed. Data describing energy use on a regional and national basis were developed, and regression equations based on these were obtained. The ability of these equations to predict average energy use was then confirmed by applying them to four office buildings not in the BOMA data base. A number of proposals for the further improvement of the equations were developed, including additional data collection.

SURVEY OF AVAILABLE INFORMATION

Section 2 presents the information developed during the survey of energy use in office buildings. During the attempt to collect information by region and by end use function, it became clear that only a limited amount of information was

available. The published sources of data included both actual data and data generated by simulation models. Actual building energy use data were obtained from reports by Jack Faucett Associates (JFA), Hittman Associates, the National Electrical Manufacturers Association (NEMA), and Tishman-Syska and Hennessy (TSH). The JFA report analyzed the 1974 BOMA data base and presented the information by Census Division. The Hittman Associates report examined energy use in over 300 downtown Baltimore buildings, of which approximately 50 were office buildings. Detailed data were gathered by a team of engineers through on site questionnaires and examination. The NEMA report was based on a sample of approximately 50 Philadelphia office buildings, reporting both energy consumption and the characteristics driving energy consumption. The Tishman-Syska and Hennessy (TSH) report was based on a statistically representative sample of 44 office buildings in New York City selected from the population of approximately 1030 office buildings.

Energy use data based on information generated by simulation models were also obtained. Two ADL reports presented data on a Census Region basis for a typical three story, suburban type office building. The first ADL report, undertaken for the Council on Environmental Quality and the Federal Energy Administration, attempted to project residential and commercial energy use patterns for the time period 1970-1990. The office building energy use information was assembled as one part of the commercial sector information. In a subsequent report, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, ADL again simulated a low rise 3 story office building, using a different simulation technique from that previously used. A report by RAND presented simulations of a 20 story, high rise office building based on the ECUBE energy simulation model. In performing the simulation, RAND varied the hypothesized lighting levels, wall composition, and various building parameters to determine the effect on energy use.

The three studies presenting data for specific cities—New York, Philadelphia, and Baltimore—were reviewed in the investigation of the driving factors behind energy use. Although each of the studies only examined energy use in a specific city, the studies were intensive data gathering efforts, providing a basis for the determination of cause and effect relationships behind energy use. Each of the studies was based on detailed data gathered through questionnaires for individual buildings through on site inspection.

The JFA data were based on a relatively small sample of BOMA buildings, which are representative only of prime building space. Very little is known about the energy consumption characteristics of nonprime space. The studies of New York City, Philadelphia, and Baltimore compiled substantial data bases but yielded differing conclusions about the important factors driving energy use. Information on energy use by consuming function was not available except in cases where a simulation had been conducted. Detailed information on lighting levels, HVAC capacities and partial load characteristics, and building structural parameters was frequently inaccurately reported or not reported at all. These data would be needed in estimating energy use by function.

The data generated by the simulation models are also of poor quality. Some of RAND's input assumptions to the ECUBE model were unrealistic, resulting in probably inaccurate estimates of energy use. The simulations in the two ADL reports reached significantly different conclusions for office building energy use.

The available energy consumption data provided sufficient information to permit one to formulate an approach for the development of an office building data base. On the basis of the existing studies, it was possible to prepare a list of variables and hypothesize relationships that should be investigated in an energy analysis. The available data are, however, inadequate for energy policy formulation.

HEATING, VENTILATION, AND AIR CONDITIONING SYSTEMS

Section 3 presents information on the types of heating, ventilating, and air conditioning (HVAC) systems which are typically present in office buildings and how the choice of system can affect a building's energy consumption. The purpose of the presentation is to highlight the significant system characteristics which should be considered and analyzed when predicting or explaining energy use in commercial office buildings. There are four types of fuels which can be used in a building: electricity, gas, oil, or steam. The efficiency with which the fuel is utilized will depend upon the type of fuel, the maintenance and adjustment of the heating and cooling plants, and the performance of the equipment when operating at less than full capacity.

Two basic types of air conditioning are used in commercial office buildings: the compressor driven system, and the absorption driven system. The two system types are entirely different from each other, and the refrigeration cycle for each of the systems is reviewed. A compressor driven system will typically be powered by electricity, although both gas and steam powered turbines are possible. An absorption system can be powered by steam, natural gas, or even waste heat obtained from other building systems. The systems can be used separately in buildings or in combinations. A steam absorption system is frequently cited as having an efficiency of approximately .6; estimates of the efficiency for electrically driven chillers run from 1.67 to as high as 4.4.

The design of the building ventilating system is also an important factor in driving building energy use. The ventilating system is the system of pipes and ducts used to circulate the heating or cooling medium. Most large commercial office buildings have two ventilation systems: a perimeter system serving the outside offices, and an interior system serving the building's core. Each system will serve a number of zones; a zone is an area or group of areas in a building which experiences within the zone similar amounts of heat gain and loss from the interaction of the internal loads and the external loads. Zoning permits the simultaneous heating and cooling of the building. An office building will typically have at least five zones—an interior zone and one zone per wall, but may have many more.

Five basic types of HVAC systems are described. These are as follows:

Direct Expansion System: A self contained compact unit loacted within or next to the air conditioned space, consisting of the minimum elements essential to producing the cooling effect.

All Water System: A cooling medium, such as chilled water or brine instead of direct refrigerant, is supplied from a remote source and circulated through the coils of an air terminal within the conditioned space. The circulating medium is warmed to provide heating. An example of such a system is a fan coil system.

Air Water System: The air apparatus and refrigeration plant are separate from the conditioned space, and the cooling and heating of the conditioned space is effected in only a small part by air brought from the central apparatus. The major part of the room thermal load is balanced by warm or cooled water circulated through a coil in an induction unit.

All Air Systems: Hot or cold air is brought into the conditioned space through ducts and distributed within the space through outlets. Such types of systems can include single duct constant volume with reheat, single duct variable volume, and dual duct systems.

Heat Pump Systems: The adaptation of any of the systems to effect year round air conditioning utilizing the system's refrigeration plant as a heat generating plant is a heat pump system.

In view of the wide diversity of possible HVAC system options, one would expect that the type of system as well as the type of fuel plays an important role in determining building energy use. Section 3 reviews two sets of building HVAC simulations. In Energy Conservation in Nonresidential Buildings RAND examined how the choice of HVAC systems could affect energy use. RAND considered a total of seven system types, of which the first four were typical of systems commonly in use in 1974 and the last three typical of systems proposed as energy conserving alternatives. Energy use under each of the different systems was simulated using the ECUBE program for a New York City office building.

Tishman-Syska and Hennessy presented a number of AXCESS program simulations for a typical New York City office building under varying HVAC options in Energy Conservation in Existing Buildings. A variable volume system with and without economizer and a constant volume system were compared, and the operation of the variable volume system under varying policies was analyzed.

There can be substantial diversity in the design of HVAC systems, and the type and operation of the building's HVAC system will have a significant impact on the building's energy consumption. Any one of four fuels is possible for heating. Either electricity or steam are most frequently used for cooling; there are two types of steam cooling systems: Steam absorption and steam turbine. A wide variety of perimeter and interior air handling systems is possible. The zoning of a building, the presence of an economizer, and the installation of equipment to recycle waste heat all affect energy use.

HVAC COMPUTER SIMULATION PROGRAMS

Section 4 explores the possibility of using building energy simulation programs in the development of an energy use data base for commercial buildings. The programs are based on design calculations relating to heating, refrigeration, air conditioning, and ventilation equipment systems; the appropriate equations explaining the interaction of the energy flows are presented in the ASHRAE Handbook of Fundamentals and other ASHRAE publications. Interest in the programs was motivated by the following considerations.

1. To obtain estimates of building energy use in terms of end use.
2. To analyze building equipment options, such as HVAC system type, and building characteristics, such as hours of usage, air infiltration, etc. to serve as a basis for the prediction of future energy use which, in turn, can provide a basis on which to evaluate policies on the modification of buildings for energy conservation.
3. To simulate buildings' energy use for which data are not available.

One of the building energy use programs, the AXCESS program, was used to simulate energy consumption in five New York City office buildings for which TSH had developed an extensive data base as part of another DOE contract. Despite the substantial data gathering efforts which had been conducted by TSH, the data base lacked information on building zoning, HVAC equipment kw ratings, and information on the part load efficiency of the HVAC systems. Where a needed data item was not available, Syska and Hennessy Information Systems (SHIS) used a default value as an estimated input in performing the simulation; the AXCESS and other energy programs have a number of default values for cases in which data are lacking. The choice of which 5 buildings to simulate was made by TSH: as part of its separate DOE contract TSH simulated the same five buildings on the AXCESS program but had professional engineers conduct surveys of the building to verify and supplement the building information in lieu of using the information supplied by the building managers. Therefore, what was examined in this work was the possibility of simulating buildings based on the type of data which could conceivably be obtained from building managements.

The predictive power of the AXCESS program with incomplete input data for the individual simulations appeared to be limited: in most cases the predicted energy use was substantially different from the actual energy use. This appeared to be due to data deficiencies; when TSH ran the AXCESS program using data input verified by professional engineers the simulations had greater predictive value. The extensive data requirements of the AXCESS program were also highlighted in an experiment to gather data for the program from a building in Washington, D.C. Certain crucial data, including HVAC capacity information, part load characteristics, and certain structural data were not available.

Although the predictive power for the individual simulations was limited, Chapter 4 indicates that the program had adequate predictive power for the average energy use in the five buildings.

In addition to the AXCESS program, Section 4 also examines the ECUBE, TRACE, NECAP, and Ross Meriwether programs. Of particular interest during the review was the ability of the programs to predict energy use by function and to evaluate tradeoffs in building operating systems and operating practices.

Building energy simulation models appear to have the ability to predict building energy use provided that the correct inputs are specified for the model. Although the simulation of a specific building may result in some error between the estimated and actual values for energy consumption, it appears likely that the mean of a set of estimated values will be reasonably close to the mean of the actual values which are being estimated. The programs appear to have a substantial potential for estimating energy use by end use.

THE BOMA DATA BASE

Section 5 presents the analysis of the BOMA data base for 1975. BOMA collects annually from its membership data on commercial office building characteristics and operating performance. The data serve as the input to the Downtown and Suburban Office Building Experience Exchange Report, whose first edition contained data for the calendar year 1922. The 1975 data base contained information for 963 buildings in approximately 100 U.S. cities, representing a coverage of approximately 8% of the total square feet of commercial space in the

United States. It is believed that the BOMA member buildings tend to be the large, prime commercial space located in major metropolitan central city areas.

Access to the data base for 1975 was obtained, subject to certain proprietary restrictions. For purposes of analysis the data base was entered into the computer data bank and was then subjected to review and revision. The data base was first regionalized by Census Division and by city. The data were then audited and reviewed for completeness and reliability.

The data were divided into three subsamples. Subsample A consisted of 371 buildings for which, as far as could be ascertained, all data had been completely and accurately reported, subject to some minor adjustments for clerical errors. Subsample B consisted of 269 buildings for which building managers had reported the dollar expenditures for electricity use and fuel use but not the quantities of one or more of the energy sources. Energy use by these buildings was estimated on the basis of dollar/quantity relationships observed in Subsample A. In the case of data for the Arlington, Virginia/Washington, D.C. area the quantities of electric and fuel use were estimated on the basis of information available from rate tables.

The remainder of the buildings in the BOMA sample were not used; in these cases one or more data items either had not been reported completely or had not been reported at all and it was not possible to find a basis for the estimation of the appropriate amount of energy use.

A final review of Subsamples A and B was made to ascertain the reasonableness of the data, and in a few cases contact was made with the building managers through the BOMA staff to verify some of the data items.

Since the BOMA data base is collected to assist a building manager in comparing his building's performance against the performance of other buildings on an aggregate basis, the data base does not contain a number of the data items which one would like to have in performing an energy analysis. The data base has been designed for financial analysis. In order to supplement the data base for energy analysis purposes BOMA circulated to a selected group of buildings a questionnaire designed to obtain additional data. The respondents were able to answer most of the questions, which indicates that the data base could be supplemented as necessary.

The BOMA data base was then evaluated to determine the degree to which it was representative of commercial buildings in general. The regional distribution of commercial office buildings in existence in 1975 as developed in Volume I was compared with the distribution of the BOMA buildings. The age distribution of the office building stock from Volume I was also compared with the BOMA inventory of buildings. The samples of BOMA buildings in New York City, Philadelphia, and Baltimore were compared with the samples assembled by TSH, NEMA, and Hittman respectively to determine whether the BOMA buildings had energy use characteristics comparable with the average of the buildings in the three cities.

A number of tables of descriptive data were generated. In presenting energy consumption in the tables, both weighted and unweighted means and standard deviations were computed. It is believed that the weighted means and standard deviations are the more relevant, for they give greater importance to the data for the larger buildings, which make up the bulk of the square feet of space. Tables presenting information on a weighted basis are denoted by "A", and tables presenting information on an unweighted basis are denoted with "B".

Tables included information on the distribution of building square feet by fuel type and by region; the breakdown of space in terms of office, store, and other space on a regional basis; energy consumption by type of heating fuel; energy consumption by buildings by region; energy consumption in electrically heated buildings by region; energy consumption in gas heated buildings; energy consumption in oil heated buildings by region; energy consumption in steam heated buildings; energy consumption by downtown/suburban building location; energy consumption by policy of building management with respect to individual vs. central metering; and a comparison of electricity and fuel use in the 1974 and the 1975 BOMA samples.

On the basis of the initial analysis of the BOMA data base it was found that substantial care and effort had to be taken to verify, correct, and enter the data base into the computer. The BOMA data base lacks a number of the data items which would be necessary for energy analysis; however, the data base can be supplemented as necessary for energy analysis. It was found that energy consumption varied by fuel type, geographic region, age, and downtown/suburban location. Energy consumption was found to be relatively invariant by height. Direct metering apparently caused electricity consumption to be less than it would otherwise have been.

REGRESSION ANALYSIS OF THE BOMA DATA BASE

Section 6 presents equations developed to model the consumption of electricity, fossil fuels, and total energy for each of four groups of buildings categorized according to heating fuel—electricity, gas, oil, and steam. The equations were run on the 1975 BOMA subsample A on a cross section basis.

Various combinations of seven independent variables were used, and both linear and logarithmic equation forms were considered in modeling the independent variables. Problems of multicollinearity and the significance of the t, F, and R^2 statistics are discussed. A wide variety of equations was considered, and the best equations have been presented in a series of tables. Some consideration was also initially given to specifying the form of the dependent variable in terms of BTU/Sq. Ft. for electric use, fuel use, and total energy use. This approach, however, subsequently proved to be less desirable than the use of BTU's as the dependent variable. This resulted from the fact that square feet of building space were highly correlated with building energy use; thus, when the dependent variable was specified on a per square foot basis, the most important variable was eliminated as an explanatory variable.

After the equations had been developed they were used to predict energy consumption for four steam heated New York City office building which were not in the BOMA sample. These were the four steam heated buildings modeled with the AXCESS programs, as reported in Section 4. The equations were used to predict electric, steam, and total energy use in each of the four buildings; the predicted values were compared with the actual energy use. In addition, the averages of the estimates of energy consumption by the four buildings were compared with the means of the actual energy consumption by the four buildings.

The regression analysis indicated that it is possible to develop equations using a small set of independent variables to show the close relationships between the independent variables and energy consumption. The regression equations which were reported appeared to have reasonably good predictive power with adequate F and R^2 values, significant t values, and acceptable standard errors. In general, the equations predicted energy consumption for aggregates of buildings reasonably well; the predictive power for specific buildings, was poor, as would be expected due to the unavailability of data for some of the factors which drive energy use e.g., level of lighting, HVAC capacity, building window and wall areas.

In reviewing the equations, it became apparent that the single most important variable was square feet of building area. Reasonable estimates of energy consumption can be obtained from a knowledge of only the square feet of space. Although the use of the regression equation in simulating particular buildings is probably not warranted, the equations properly applied may be used to estimate consumption in populations of buildings. It is believed that additional research could improve the equations and yield better energy use estimates for a population of buildings or even for individual buildings.

In summary, this report has assembled the available information on energy use in office buildings. Building energy simulation programs have been evaluated for their ability to model building energy use. The BOMA data base was acquired as an initial first step towards improving commercial office building information. It is expected that the information reported in this volume will serve as a basis for the formulation of a plan for the complete development of energy use information for the commercial office building sector and that similar procedures can be repeated for other commercial building types.

SECTION 1
INTRODUCTION

In Volume I of this report on the Commercial Sector Energy Consumption Data Base Development Project, the square feet of floor space and the number of buildings are estimated for each of 15 building types from 1925 to 1975, and the 1975 inventory is distributed to the 173 Business Economic Areas of the nation. In Volume II of the report, a survey is presented of readily available energy consumption data by building type and by function within each building type.

The purpose of this third volume is to provide the results of an effort to develop for one of the 15 building types -- office buildings -- more comprehensive and reliable energy consumption data than are readily available in the published literature. The results of the survey of office building data are also presented in this volume, rather than in Volume II, because of the close relationship between the survey and the more in-depth analysis.

During our survey of the available sources on energy use in office buildings we obtained three distinct types of information.

- Actual data: as reported by the Building Owners and Managers Association (BOMA), Hittman Associates, Jack Faucett Associates, National Electrical Manufacturers Association, Ross and Baruzzini, and Tishman-Syska and Hennessy.[1)]

[1)] Patrick M. McCarthy, Rusi F. Patel, and Burton Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, prepared under Federal Energy Administration Contract CO-04-51888-000, Columbia, Maryland, Hittman Associates, February 1977.

Jack Faucett Associates, Energy Consumption in Commercial Industries By Census Division - 1974, Federal Energy Administration, National Energy Information Center, March 1977, PB-268 851.

National Electrical Manufacturers Association in cooperation with the National Electrical Contractors Association, Energy Consumption in Commercial Buildings in Philadelphia, New York, NEMA, no date.

Ross and Baruzzini, Energy Conservation Applied to Office Lighting, prepared for Federal Energy Administration, St. Louis, April 15, 1975, PB-244 154.

Tishman-Syska and Hennessy, Energy Conservation in Existing Office Buildings prepared for the U.S. Energy Research and Development Administration under contract number EY-76-C-02-2799.000, June 1977.

- Simulated data: as reported by Arthur D. Little, MATHEMATICA, RAND, and Ross and Baruzzini.[1)]

- General information on building energy use and building heating, ventilating, and air conditioning (HVAC) systems: as reported by the previously mentioned sources, the Carrier Corporation, and the Building Owners and Managers Association.[2)]

The survey of actual and simulated data on a regional basis is reported in Section 2. During our work we found that various sources in the published literature were not in complete agreement on what factors drive building energy use. Section 2 summarizes some of the areas of agreement and disagreement.

There appears to be general agreement that the choice, design, and operation of the building heating, ventilating, and air conditioning (HVAC) system has an important role in the overall determination of building energy use. We found that there are a wide variety of types and uses of HVAC equipment, and we have extracted from the available literature those characteristics which we believe to be of greatest importance. HVAC systems are discussed in Sections 3 and 4.

[1)] Arthur D. Little, Residential and Commercial Energy Use Patterns 1970-1990, Report to the President's Council on Environmental Quality and the Federal Energy Administration, November 1974; denoted as "ADL-1".

Arthur D. Little, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, FEA Conservation Paper Number 43B; denoted as "ADL-2".

J. A. Orlando, L. G. Spielvogel, and H. Weed, Feasibility of an Energy Index for Office Buildings, prepared under FEA Contract CO-04-50238-00, Princeton, New Jersey, MATHEMATICA, August 10, 1976.

Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, Santa Monica, RAND, October 1976, R-1623 NSF.

Ross and Baruzzini, Energy Conservation Applied to Office Lighting, prepared for Federal Energy Administration, April 15, 1975, PB-244 154.

[2)] Carrier Air Conditioning Company, System Design Manual, 7th printing, Syracuse, New York, 1966. LeRoy E. Varner, Sr., Engineering and Building Structures, two volumes, Rosemont, Pennsylvania, Building Owners and Managers Institute International, 1973.

The selection of the office building category for intensive analysis in this study was based largely on the existence of the BOMA data base. BOMA obtains annual data on about 1000 buildings covering such items as location, floor area, height, age, average occupancy rate, average number of employees, types of tenants, type of air conditioning, and energy consumption by fuel. The purpose of analyzing these data is to provide more comprehensive and reliable information on energy consumption in office buildings than was found in the survey task reported in Section 2 of this volume, and, more importantly, to demonstrate the value of developing similar data bases, and performing similar analyses, for the other 14 building categories. The description and analyses of the BOMA data are in Sections 5 and 6, respectively.

SECTION 2

SURVEY OF ENERGY USE IN OFFICE BUILDINGS

This section presents data on energy use in office buildings that were gathered during our survey of the readily available information. Data were found during this survey by region of the nation, by building function, for alternative lighting levels, for different roof and wall structural characteristics, and by building height. Also, limited data were obtained to indicate the change in energy use that results from energy conservation modifications.

ENERGY USE BY REGION AND FUNCTION

The Arthur D. Little (ADL) report, Residential and Commercial Energy Use Patterns 1970-1990, presented energy simulations, summarized in Table 2-1, for a low rise electrically heated office building (ADL-Electric), a low rise gas heated building (ADL-Gas), and a low rise oil heated building (ADL-Oil) for the four Census regions.[1] The technical aspects of the simulations were discussed in Volume 2. Although the data are based on simulations, ADL verified that the resulting energy use estimates were in good agreement with actual practice via a survey of a limited sample of buildings.

The ADL report, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, also provided data on a low rise office building as simulated through the Ross Meriwether energy model; the data are reported in Table 2-1 as "ADL-74".[2] The reasonableness of the output of an energy simulation model is a function of the input specifications for building construction and usage. The output in this case is not in good agreement with either the first ADL report described above or the rest of the available building energy use estimates; consequently, we place less confidence in these data than in those in the other reports.

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[1] Arthur D. Little, Residential and Commercial Energy Use Patterns 1970-1990, Report to the President's Council on Environmental Quality and the Federal Energy Administration, November 1974.

[2] Arthur D. Little, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, FEA Conservation Paper Number 43B, no date.

The Jack Faucett Associates (JFA) study, Energy Consumption in Commercial Industries by Census Division-1974, provided estimates of office building energy use based on the data base of the Building Owners and Managers Association.[1] In reviewing the JFA data reported in Table 2-1, the following limitations should be considered.

1. The BOMA data base is not representative of office buildings in general. This will be more fully discussed in Section 5.

2. The JFA data were based on a limited sample of BOMA buildings (we understand that fewer than 180 buildings were used), and in many cases dollar amounts of energy were converted to quantities of energy through the use of rate tables. Such estimates are subject to error, and JFA did not present an analysis of the statistical validity of the estimation procedures. We raise these matters, not to fault JFA for not having made good use of a data base, but, rather, to indicate that the data base is subject to limitations.

RAND used the ECUBE energy simulation model to simulate a 20 story, high rise office building, as reported in Energy Conservation in Nonresidential Buildings.[2] RAND also conducted simulations for a limited number of low rise cases. In performing the simulations RAND varied the hypothesized lighting levels, wall composition, and various building parameters to determine the effect on energy use. A review and analysis of the procedures used by RAND follows.

1. Building Specifications: 360,000 square feet, 20 stories, square plan configuration; gas heating (80% efficiency), and electric chillers (coefficient of performance = 4.4). Occupancy of 100 sq. ft./person; lighting = 44% of continuous; ventilation/infiltration of .125 cu. ft. per minute per square foot of building space. Temperature of 72 degrees for heating and cooling; half of square footage allocated

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[1] Jack Faucett Associates, Energy Consumption in Commercial Industries By Census Division-1974.

[2] Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, RAND.

to the interior zone of the building; five exterior zones. Heating system off from June-September. During the entire weekend and for eight hours each night during the working week, the thermostat was set back two degrees from November through April and set up two degrees from May through October. The cooling temperature was allowed to remain the same throughout the year. No outside air was used for ventilation of the conditioned space during weekends, and shutoff was in effect for ten hours each weekday night.

2. A number of simulations were run with building loads calculated based on the ECUBE program. For buildings with the prefix B in Tables 2-1 to 2-4, the loads were converted by RAND to building energy use, allowing for a fuel utilization efficiency of .8 and an air conditioning COP[1)] of 4.4. For buildings with the prefix A, we calculated the projected energy use on the basis of the projected loads in a manner consistent with the RAND calculations. Heating and cooling loads were converted to energy use as indicated, and an "other" usage for electricity was calculated for "A prefix" buildings based on the comparable "other" electric usage used by "B prefix" buildings. Since the RAND program did not calculate hot water use, we arbitrarily added 7,100 BTU/Sq. Ft. for hot water usage to obtain total building energy usage.[2)]

The RAND simulations for buildings with a lighting level of 2.7 watts/Sq. Ft. are reported in Table 2-1.[3)] The building specifications for the RAND simulations reported in Table 2-1 are presented in Table 2-2, including wall U values, roof U values, building location, and building variant.

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1) Coefficient of Performance.

2) This figure was obtained from ADL-2, op. cit.

3) In a survey of approximately 300 buildings throughout the United States Ross and Baruzzini found an average level of lighting close to the 2.7 watts/sq.ft. figure. In the case of New York City, Tishman-Syska and Hennessy found an average level of lighting of 2.84 watts/sq. ft. Therefore, the 2.7 watts/sq. ft. is reasonably representative of current practices.

The RAND simulated data in Table 2-1 may significantly understate actual building energy use. The assumption of 80% efficiency for gas heating is overly optimistic: 80% efficiency would be an upper bound for boiler efficiency under full load conditions. Older equipment probably does not attain this efficiency, and boilers generally do not operate under full load conditions. A COP of 4.4 for the refrigeration system appears to be high; one finds much of the literature quoting 2.0-2.7 as the actual COP obtained under the partial load conditions frequently confronted by the typical refrigeration plant. The COP will also vary with the age of the plant. Absorption air conditioning, which is an entirely different type of air conditioning from that under discussion in this section, will typically have an efficiency of only 60%. Section 3 discusses the refrigeration cycle in detail.

ENERGY USE FOR ALTERNATIVE LIGHTING LEVELS AND STRUCTURAL CHARACTERISTICS

The RAND simulations for office buildings with levels of lighting other than 2.7 watts/sq. ft. are reported in Table 2-3, and the accompanying building specifications are reported in Table 2-4. Both Tables 2-3 and 2-4 have a column labeled "Cooling Requirement During May-October as a Percent of Yearly Total Requirements." Many office buildings must be air conditioned throughout the year to provide refrigeration for computer installations, refrigeration for exposed walls on sunny winter afternoons, and refrigeration for the building core, which is a net generator of heat. The building management can accomplish this through the use of the refrigeration plant or the use of an economizer, a device which will admit cold air to the building's HVAC system during the winter as appropriate to compensate for cooling loads. The tables therefore provide a measure of the potential refrigeration savings from the use of an economizer.

Table 2-5 presents a selection of the data from Tables 2-1 and 2-3, comparing energy use in high rise office buildings with varying levels of lighting for five cities. Ceteris paribus, the level of lighting affects the level of energy use.

Comparing the New York, Atlanta, and Los Angeles cases for constant levels of lighting and permitting wall composition to vary, it is clear that building energy use for heating is also a function of the thermal conductivity of the wall. A glass wall offers significantly less protection against cold weather than does a wall with U = .19.

Table 2-6, "Relative Influence of Load Components Determined by Regression Studies", was obtained by RAND on the basis of a regression analysis of the data base reported in Tables 2-1 to 2-4. The percentage values are based on the sizes of the coefficients in the regression equations. (The absolute values of these percentages sum to 100%)

ENERGY USE AS A FUNCTION OF BUILDING HEIGHT

Table 2-7 compares the level of energy use as a function of building height, comparing a 20 story high rise with a 2 wall and 4 wall 2,000 square foot single zone store. A low rise building, in general, uses more energy per square foot than does a high rise building.

IMPACT OF BUILDING MODIFICATIONS FOR ENERGY CONSUMPTION

Table 2-8 is based on the ADL report, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, and compares energy use on a conventional and modified basis for three types of buildings: an office building, a retail store, and a school. ADL attempted to determine the maximum impact which might result from the implementation of the ASHRAE Standard 90-75. Two sets of calculations were made: one set for the "conventional" building, and one set for "ASHRAE 90 modified" building.

In specifying the conventional building prototypes, ADL selected configurations, materials composition, physical characteristics, and HVAC system types which are typical in new construction. The principal criterion for making the decision among alternatives during modification of the "conventional" building to specify the "ASHRAE 90 modified" building was to select from among the various possible building modifications that alternative which offered the minimum effect on initial building costs. The types of changes made in specifying the building modifications included reduced exterior glass areas, increased insulation, reduced lighting levels, and decreased HVAC system capacities. The specifications for the prototypical "conventional" and "modified" buildings may be found in the ADL report. The energy use in each type of building was then simulated using the Ross Meriwether energy simulation model. ADL indicated that substantial savings in building energy use could result from the implementation of the standard.

> "If instituted by all states, ASHRAE 90 could reduce the annual energy consumed in new construction about 27%, and if instituted in 1976, the standard would reduce ADL estimates of the growth of energy consumption in the building sector over the period 1976 to 1990 from 2.3% to 1.4%.
>
> The potential energy which could be saved by the adoption of ASHRAE 90 equals 4%, 8%, and 12% of total estimated annual energy conservation in the nation's buildings for the years 1980, 1985, and 1990, respectively."[1]

We have previously expressed concern over the estimated level of the office building energy use as generated by ADL in the ADL-2 report: the figures differ significantly from those of BOMA (actuals), RAND (simulations), and even the ADL report Residential and Commercial Energy Use Patterns 1970-1990. Therefore, estimates of energy savings based on the model in the ADL-2 report are subject to question. It would be of interest to know whether the results from the implementation of ASHRAE 90 would continue to show the same percentage decrease as occurs in the report if the energy simulation inputs were revised to yield estimates of gross energy use for a conventional building more consistent with other data. ADL's approach appears to be useful, but the model's estimated levels of energy use, since they differ from those of several other sources, leave the results open to question.

RAND also concluded that there was a substantial opportunity for energy conservation.[2] The following reasons are cited for this conclusion:

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[1] ADL-2, op. cit., p. 8.

[2] RAND, op. cit., p. vi.

1. Energy use intensity (i.e., BTU/Sq. Ft.) in the commercial sector can be reduced 40 to 50 percent compared to pre-embargo practice.

2. Building shell design constraints are only effective in reducing annual heating use and thus are appropriate in cold climates. In other locations, they may be counterproductive for overall energy savings.

3. Most of the savings can be achieved by changes in operating procedures rather than by modified building or equipment designs.

Although both RAND and ADL indicate that substantial savings are possible in the overall level of building energy use, the hypothesized savings are the result of different types of actions. ADL's contract was concerned with the effect of building modifications and did not address the question of modifications of building operating policies. RAND considered both building modifications and changes in operating policies, primarily through the use of widened deadbands to reduce heating and cooling energy use.

OTHER STUDIES

In addition to the previously mentioned studies which provide data on a regional basis, we found a number of other studies that provide information on energy use.

Tishman-Syska and Hennessy: Energy Conservation in Existing Office Buildings.

The purpose of the TSH effort was to assemble a statistically representative sample of New York City office buildings and to gather information on the buildings in terms of their physical and operating characteristics and energy consumption. TSH examined the stock of approximately 1030 New York City office buildings, as determined from information obtained from the Building and Fire Departments of New York City and from information obtained from the Real Estate Board of New York. Through a preliminary questionnaire, a data base was assembled on 436 buildings. On the basis of a statistical analysis, a sample of 44 buildings was chosen to represent the population of New York City office buildings, and an extensive data base for the 44 buildings was established by additional questionnaires and follow-up interviews by TSH engineers. Two basic conclusions emerge from the TSH work.

1. The major determinants of energy consumption appeared to be building age, hours of lighting, hours of perimeter heating and cooling, and type of perimeter systems

2. Normalized for weather and occupancy/utilization factors, the 12% decrease in consumption when comparing 1971/72 with 1974/75 was largely due to simple adjustments in building operating temperatures and lighting practices. The savings based upon raw data were 19%.

> "This achievement has occurred despite the fact that owners and managers have little quantitative perception and knowledge of any precision relating to energy consumption patterns in their buildings. In general, they do not know how much they saved, how they compare with others, or what the potential benefits of further energy consumption measures can be. Without the widespread practice of continuous and accurate tracking of consumption, it will be difficult to achieve the next level of energy savings and easy for them to retrogress, as is demonstrated in individual cases in the report. And it will be very difficult to establish and maintain current rational energy conservation policies and to guide decision makers in both the public and private sectors. It is essential that government concentrate its early efforts on overcoming this fundamental information deficiency."[1]

<u>National Electrical Manufacturers Association in cooperation with the National Electrical Contractors Association:</u> <u>Energy Consumption in Commercial Buildings in Philadelphia.</u>

The NEMA study was based on a random sample of 50 downtown Philadelphia office buildings, approximately 25% of the city's commercial office building stock. 40% of the buildings were Class A buildings: modernized, kept up-to-date, and well-maintained buildings. 58% were Class B: well-maintained but not completely modernized. 2% (one building) was Class C: an older building not well maintained. Building age, number of stories, condition of building, average annual occupancy, type of HVAC system (central or package) and occupant type (owner occupied or leased) were found to have less effect on office building energy consumption than had been anticipated. NEMA found that the major factors affecting energy consumption were the extent and type of building use, and the presence or absence of computer and data processing systems.

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[1] Tishman-Syska and Hennessy, <u>op. cit.</u>, Executive Summary.

Hittman Associates: Empirical and Simulation Analyses of Energy Use in Commercial Buildings.

Hittman Associates performed a study of the physical and institutional factors related to energy use in commercial buildings, based on a survey of 383 Baltimore Central Business District commercial establishments. A substantial number of office buildings were included in the sample. Detailed information on the structural, equipment, and operational features related to energy use was obtained. Data were obtained through on-site inspection by Hittman Associates' engineers. The basic conclusions are as follows:

1. Heating and cooling degree days have an effect on office building energy use.

2. The presence or absence of computer and data processing services (CDS) has an impact on energy use.

3. Occupant type--whether the building is occupied by a tenant or owner--has no impact on energy use.

4. Gross area of the building has no impact on energy use per square foot.

5. Condition of the building--whether it is Class A, B, or C has no effect on energy use.

6. The age of the building has no effect on energy use.

7. There were insufficient data to determine the effect of average building occupancy.

8. Building height has no effect on energy use per square foot.

9. The choice of central vs package HVAC has no effect on energy use.

10. The use of an economizer has no effect on energy use.

11. The per cent glass does not affect energy use. However, the flux factor--a weighted combination of the heat transfer characteristics of a building's exterior surfaces as defined by Hittman--does affect energy use.

12. Infiltration and ventilation significantly affect energy use.

Ross and Baruzzini: Energy Conservation Applied to Office Lighting.

The purpose of this study was to make recommendations and suggestions for changes that could be instituted to make lighting design and installation responsive to the needs for energy conservation. Ross and Baruzzini circulated a questionnaire on lighting practices to 2,800 members of the Building Owners and Managers Association and obtained 307 replies.

The BOMA buildings reported a lighting level of 9.8 kwh/Sq. Ft./year (33,438 BTU/Sq. Ft.) for lighting, of which 1.56 kwhr (.45 watts/Sq. Ft.) appeared to be used by equipment connected to convenience outlets. This resulted in an actual yearly level of lighting of 8.24 kwh (28,115 BTU/Sq. Ft.). Ross and Baruzzini stated that the lighting data were based on building usage of 3,035 hours per year and that a more universal value would be 2,517 hours per year for non-BOMA type buildings, believed to be 82% of the total population of office building floor space. The adjusted value of kwh/yr./Sq. Ft. of lighting (excluding convenience outlets) would be estimated at 7.1 kwh/Sq. Ft./yr. (24,225 BTU/Sq. Ft.) for the total population of buildings.[1)]

Ross and Baruzzini examined the levels of lighting in a building in terms of building energy use. The energy simulation programs used and the output are reported in Section 3-4 of this report. Two major conclusions emerge from the Ross and Baruzzini report.

> 1. "The effect of electric lighting on the energy requirements of high rise office buildings for heating and cooling systems, as simulated by the computer model for the various climate regions of the country, shows differences for each region. The average for all regions, however, indicates no net change to the annual building energy requirements for the HVAC system as a function of changes in lighting energy (in the range of installed demands for lighting of 1 watt to 4 watts per square foot) when considered on the basis of 1 KWH = 3414 BTU."[2)]

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1) Ross and Baruzzini, op. cit., p. II-1.

2) Ross and Baruzzini, op. cit., p. II-7.

2. "An energy budget for new office lighting is recommended at 2 watts per square foot of gross area, average peak demand; with 5 kilowatt-hours per year per square foot for energy. Values approximately 10% greater should be permitted for existing buildings, but should be decreases to the same values in 5 years, maximum. A peak energy limit for lighting based on 220 gross square feet per office worker (1000 KWHRS/Yr./Worker) is also recommended for each office building."

SUMMARY

Table 2-9 summarizes the conclusions from five sources on office building energy usage as a function of building parameters and occupancy. In some cases a parameter—such as hours of lighting—was not mentioned in a report. In general, we were unable to determine whether the lack of mention indicated that the researchers had not considered the parameter or had simply not reported their findings. Furthermore, when an analysis failed to yield a meaningful correlation between building energy use and an independent variable, one can not necessarily assume that absolutely no correlation existed between the dependent and independent variables, but merely that no correlation existed which was strong enough to surface in an empirical study above the level of "background noise." We note that there is a substantial amount of disagreement among the sources as to what variables are the important ones in determining building energy use.

TABLE 2-1

ENERGY USE IN OFFICE BUILDINGS

BTU/Sq. Ft.

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Other(5)	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
North East												
ADL - 74(1)	54,000	11,300	9,100	4,300	15,700		40,400	94,400	148,700	7,100	155,800	250,200
ADL - Electric(2)	25,500			7,500	10,900	6,100	24,500	50,000	44,000	3,400	47,400	97,400
ADL - Gas	25,500			7,500	10,900	6,100	24,500	50,000	96,000	4,800	100,800	150,800
ADL - Oil	25,500			7,500	10,900	6,100	24,500	50,000	113,000	6,800	119,800	169,800
New England (JFA)3)								58,951			92,254	151,205
Boston (RAND)4)												
A-46	35.508				8,023	4,733	12,750	48,264	52,759	7,100	59,850	108,114
Middle Atlantic (JFA)3)												
New York (RAND)4)								59,844			99,590	159,434
B-3	35,508				9,682	5,239	14,921	50,429	44,800	7,100	51,900	102,329
B-6	35,508				8,955	4,226	13,181	48,689	5,960	7,100	13,060	61,749
A-16	35,508				8,705	4,733	13,438	48,946	37,000	7,100	44,100	93,046
A-19	35,508				9,091	4,733	13,824	49,332	13,625	7,100	20,725	70,057
North Central												
ADL-741)	54,000	13,100	8,800	6,300	16,200		44,400	98,400	175,400	7,100	182,500	280,900
ADL- Electric2)	25,500			7,500	10,900	6,100	24,500	50,000	51,000	3,400	54,400	104,000
ADL - Gas	25,500			7,500	10,900	6,100	24,500	50,000	113,000	4,800	117,800	167,800
ADL - Oil	25,500			7,500	10,900	6,100	24,500	50,000	113,000	6,800	119,800	169,800
East North Central (JFA)3)												
Detroit (RAND)4)	35,508							50,479			100,069	150,548
A-49					8,364	4,733	13,097	48,605	60,000	7,100	67,100	115,705
West North Central (JFA)3)								46,203			124,807	171,010
Minneapolis (RAND)4)												
A-42	35,508				7,773	4,733	12,506	48,014	70,250	7,100	77,350	125,364
St. Louis (RAND)4)												
A-44	35,508				10,773	4,733	15,506	51,014	48,875	7,100	55,975	106,989

TABLE 2-1, CONTINUED

ENERGY USE IN OFFICE BUILDINGS
BTU/Sq. Ft.

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Other	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
South												
ADL-74	54,000	11,800	5,900	5,000	20,500		43,200	97,200	136,800	7,100	143,900	241,100
ADL-Electric[2]	25,500			7,500	25,500	6,100	39,100	64,600	24,000	3,400	27,400	92,000
ADL-Gas	25,500			7,500	25,500	6,100	39,100	64,600	59,000	4,800	63,800	128,400
ADL-Oil	25,500			7,500	25,500	6,100	39,100	64,600	71,000	6,800	77,800	142,400
South Atlantic (JFA)[3]								95,430			84,170	179,600
Atlanta (RAND)[4]												
B-10	35,508				11,477	5,867	17,344	52,852	31,230	7,100	38,330	91,182
B-12	35,508				10,455	4,773	15,228	50,736	4,140	7,100	11,240	61,976
Miami (RAND)[4]	35,508				17,477	5,320	22,797	58,305	4,000	7,100	11,100	69,405
East South Central (JFA)[3]								71,596			58,684	130,280
Birmingham (RAND)[4]												
A-45[4]	35,508				12,795	5,320	18,115	53,623	28,750	7,100	35,850	89,473
West South Central (JFA)[3]								65,748			104,145	169,893
Dallas (RAND)[4]	35,508				14,432	5,320	19,752	55,260	26,000	7,100	33,100	88,360
West												
ADL-74[1]	54,000	11,600	16,200	3,000	16,300		47,100	101,100	140,000	7,100	147,100	248,200
ADL-Electric[2]	25,500			7,500	16,000	6,100	29,600	55,100	25,000	3,400	28,400	83,500
ADL-Gas	25,500			7,500	16,000	6,100	29,600	55,100	61,000	4,800	65,800	120,900
ADL-Oil	25,500			7,500	16,000	6,100	29,600	55,100	72,000	6,800	78,800	133,900
Mountain (JFA)[3]								72,930			110,045	182,975
Denver (RAND)[4]	35,508				9,432	5,070	14,502	50,010	55,875	7,100	62,975	112,985
A-48	35,508				16,704	5,070	21,774	57,282	18,875	7,100	25,975	83,257
Phoenix (RAND)[4]												
A-51												
Pacific (JFA)[3]								52,335			50,172	102,507
Los Angeles (RAND)[4]												
B-10	35,508				10,795	5,150	15,945	51,453	16,270	7,100	23,370	74,823
B-18	35,508				10,204	4,990	15,194	50,702	2,000	7,100	9,100	59,802
A-36	35,508				10,477	5,070	15,547	51,055	10,125	7,100	17,225	68,280
A-30	35,508				9,864	5,070	14,934	50,442	6,375	7,100	13,475	63,917
Seattle (RAND)[4]	35,508				7,273	5,070	12,343	47,851	41,375	7,100	48,475	96,326

FOOTNOTES, TABLE 2-1

ENERGY USE IN OFFICE BUILDINGS

1) Arthur D. Little, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, FEA Conservation Paper Number 43B.

2) Arthur D. Little, Residential and Commercial Energy Use Patterns 1970-1990, Report to the President's Council on Environmental Quality and the Federal Energy Administration, November 1974.

3) Jack Faucett Associates, Energy Consumption in Commercial Industries By Census Division - 1974, Federal Energy Administration, National Energy Information Center, March 1977, PB-268 851.

4) Richard G. Salter, Albert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, RAND, R-1623-NSF, October 1976.

TABLE 2-2

SPECIFICATIONS OF RAND ECUBE SIMULATED BUILDINGS APPEARING IN TABLE 2-1[1)]

Table and City	Wall (U Value)	Roof (U Value)	Lighting (Watts/Sq. Ft.)	Cooling Requirements during May - October as Percent of yearly total Requirements	Page Number (Rand Report)	Variant
Boston						
A-46	G	.12	2.7	71.39%	p. 106	Half Light
New York						
B-3	G	.12	2.7	73.24%	p. 139	Half Light
B-6	.19	.12	2.7	66.50%	p. 142	Half Light
A-16	.19	.12	2.7	87.47%	p. 75	4 wall store: 1 zone
A-19	.19	.12	2.7	76.75%	p. 78	2 wall store: 1 zone
Detroit						
A-49	G	.12	2.7	73.37%	p. 109	Half Light
Minneapolis						
A-42	G	.12	2.7	72.22%	p. 102	Half Light
St. Louis						
A-44	G	.12	2.7	75.32%	p. 104	Half Light
Atlanta						
B-10	G	.12	2.7	71.09%	p. 146	Half Light
B-12	.19	.12	2.7	63.70%	p. 148	Half Light
Miami						
A-50	G	.12	2.7	62.94%	p. 110	Half Light
Birmingham						
A-45	G	.12	2.7	71.58%	p. 105	Half Light
Dallas						
A-47	G	.12	2.7	72.60%	p. 107	Half Light
Denver						
A-48	G	.12	2.7	71.08%	p. 108	Half Light
Phoenix						
A-51	G	.12	2.7	70.75%	p. 111	Half Light
Los Angeles						
B-16	G	.12	2.7	61.26%	p. 152	Half Light
B-18	.19	.12	2.7	57.02%	p. 154	Half Light
A-36	.19	.12	2.7	54.98%	p. 95	4 wall store
A-39	.19	.12	2.7	55.26%	p. 98	2 wall store
Seattle						
A-52	G	.12	2.7	67.19%	p. 112	Half Light

1) Richard G. Salter, Albert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, RAND, R-1623-NSF, October 1976.

TABLE 2-3

ADDITIONAL RAND ECUBE ENERGY SIMULATIONS OF OFFICE BUILDINGS[1)]

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Other	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
North												
North East												
New York												
B-1	71,016				15,977	7,315	23,292	94,308	37,260	7,100	44,360	138,668
B-2	52,605				12,773	6,752	19,525	72,130	40,660	7,100	47,760	119,890
B-4	71,016				16,432	6,962	23,394	94,410	3,920	7,100	11,020	105,430
B-5	52,605				12,682	6,297	18,979	71,584	4,710	7,100	11,810	83,394
B-7	71,016				16,864	7,042	23,906	94,922	1,980	7,100	9,080	104,022
B-8	71,016				16,182	6,939	23,121	94,137	7,270	7,100	14,370	108,507
A-9	71,016				0	7,065	7,065	78,081	33,375	7,100	40,475	118,403
A-10	71,016				0	7,065	7,065	78,081	0	7,100	7,100	85,181
A-11	71,016				15,114	7,065	22,179	93,195	26,000	7,100	33,100	126,295
A-12	71,016				12,886	7,065	19,951	90,967	36,250	7,100	43,350	134,317
A-13	71,016				23,227	7,065	30,292	101,308	25,250	7,100	32,350	133,658
A-15	71,016				15,114	7,065	22,179	93,195	29,250	7,100	36,350	129,545
A-17	18,412				6,182	6,525	12,707	31,119	44,875	7,100	51,975	83,094
A-18	71,016				16,341	7,065	23,406	94,422	10,375	7,100	17,475	111,897
A-20	18,412				5,818	6,525	12,343	30,755	17,375	7,100	24,475	55,230
North Central												
Minneapolis 41	71,016				13,795	7,065	20,860	91,876	61,500	7,100	68,600	160,476
St. Louis 43	71,016				17,773	7,065	24,838	95,854	40,875	7,100	47,975	143,829
South												
Atlanta												
B-9	71,016				18,296	8,169	26,465	97,481	26,750	7,100	33,850	131,331
B-11	71,016				18,068	7,714	25,782	96,798	2,670	7,100	9,970	106,568
B-13	71,016				18,273	7,578	25,851	96,867	1,330	7,100	8,430	105,297
B-14	71,016				17,977	7,635	25,612	96,628	4,920	7,100	12,020	108,648
A-27	71,016					7,774	7,774	78,790	20,375	7,100	27,475	106,265

1) These data are obtained from the RAND report. R. G. Salter, R. L. Petruschell, K. A. Wolf, Energy Conservation in Nonresidential Buildings, RAND, R-1623-NSF, October, 1976.

TABLE 2-3, CONTINUED

ADDITIONAL RAND ECUBE ENERGY SIMULATIONS OF OFFICE BUILDINGS

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Other	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
West												
Los Angeles												
B-15	71,016				18,045	7,772	25,817	96,833	13,390	7,100	20,490	117,323
B-17	71,016				18,023	7,794	25,817	96,833	1,230	7,100	8,330	105,163
B-19	71,016				18,204	7,886	26,090	97,106	510	7,100	7,610	104,716
B-20	71,016				17,864	7,748	25,612	96,628	2,220	7,100	9,320	105,948
A-33	71,016				17,136	7,800	24,936	95,952	2,875	7,100	9,975	105,927
A-34	71,016				18,159	7,800	25,959	96,975	14,000	7,100	21,100	118,075
A-35	71,016				17,818	7,800	25,618	96,634	7,250	7,100	14,350	110,984
A-37	18,412				6,955	7,800	14,755	33,167	12,125	7,100	19,225	52,392
A-32	71,016				17,364	7,800	25,164	96,180	4,875	7,100	11,975	108,155
A-40	18,412				6,295	7,800	14,095	32,507	8,756	7,100	15,850	48,357

TABLE 2-4

SPECIFICATIONS OF BUILDINGS APPEARING IN TABLE 2-3[1)]

Table and City	Wall	Roof	Lighting	Cooling Requirements during May - October as Percent of yearly total Requirements	Page Number	Variant
New York City						
B-1	G	.12	5.4	67.85%	p. 137	Base - glass
B-2	G	.12	4.0	70.11%	p. 138	Three-fourths light level
B-4	.19	.12	5.4	60.30%	p. 140	Base - no glass
B-5	.19	.12	4.0	62.54%	p. 141	Three-fourths light level
B-7	.1	.08	5.4	58.62%	p. 143	Base - no glass
B-8	.3	.2	5.4	61.94%	p. 144	Base - no glass
A-9	G	.12	5.4		p. 68	Heating only
A-10	.19	.12	5.4		p. 69	Heating only
A-11	G	.12	5.4	70.98%	p. 70	Dead band -6°
A-12	G	.12	5.4	69.31%	p. 71	Dead band +6°
A-13	G	.12	5.4	66.63%	p. 72	Constant Lighting
A-15	.19	.12	5.4	76.09%	p. 74	4 wall store
A-17	.19	.12	1.4	93.01%	p. 76	4 wall store
A-18	.19	.12	5.4	66.76%	p. 77	2 wall store
A-20	.19	.12	1.4	86.72%	p. 79	2 wall store
Minneapolis						
A-41	G	.12	5.4	66.23%	p. 101	Location
St. Louis						
A-43	G	.12	5.4	68.67%	p. 103	Location
Atlanta						
B-9	G	.12	5.4	65.71%	p. 145	Base - glass
B-11	.19	.12	5.4	58.74%	p. 147	Base - no glass
B-13	.1	.08	5.4	57.59%	p. 149	Base - no glass
B-14	.3	.2	5.4	60.05%	p. 150	Base - no glass
A-27	G	.12	5.4	NA	p. 86	Heating Only
Los Angeles						
B-15	G	.12	5.4	57.68%	p. 151	Base - glass
B-17	.19	.12	5.4	54.48%	p. 153	Base - no glass
B-19	.1	.08	5.4	53.93%	p. 155	Base - no glass
B-20	.3	.2	5.4	55.22%	p. 156	Base - no glass
A-33	.3	.2	5.4	55.04%	p. 92	Base - no glass
A-34	G	.12	5.4	57.70%	p. 93	Orientation
A-35	.19	.12	5.4	59.95%	p. 94	4 wall store
A-37	.19	.12	1.4	69.61%	p. 96	4 wall store
A-38	.19	.12	5.4	57.72%	p. 97	2 wall store
A-40	.19	.12	1.4	66.06%	p. 99	2 wall store

1) These data are obtained from the RAND report. R. G. Salter, R. L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, RAND, R-1623-NSF, October, 1976.

TABLE 2-5

ENERGY USE IN HIGH RISE OFFICE
BUILDINGS WITH VARYING LEVELS OF LIGHTING
BTU/Sq. Ft.

	Lighting	Cooling	Other Electricity	Electricity Excluding Lighting	Heating	Total Energy Excluding Water Heating
New York City						
Glass Wall Building, Roof U = .12						
5.4 watts/Sq. Ft. B-1	71,016	15,977	7,315	23,292	37,260	131,568
4 watts/Sq. Ft. B-2	52,605	12,773	6,752	19,525	40,660	112,790
2.7 watts/Sq. Ft. B-3	35,508	9,682	5,239	14,921	44,800	95,229
Wall U = .19, Roof U = .12						
5.4 watts/Sq. Ft. B-4	71,016	16,432	6,962	23,394	3,920	98,330
4 watts/Sq. Ft. B-5	52,605	12,682	6,297	18,979	4,710	76,294
2.7 watts/Sq. Ft. A-16	35,508	8,705	4,733	13,438	37,000	85,946
1.4 watts/Sq. Ft. A-20	18,412	5,818	6,525	12,343	17,375	48,130
Minneapolis						
Glass Wall Building, Roof U = .12						
5.4 watts/Sq. Ft. A-41	71,016	13,795	7,065	20,860	61,500	153,376
2.7 watts/Sq. Ft. A-42	35,508	7,773	4,733	12,506	70,250	118,264
St. Louis						
Glass Wall Building, Roof U = .12						
5.4 watts/Sq. Ft. A-43	71,016	17,773	7,065	24,838	40,875	136,729
2.7 watts/Sq. Ft. A-44	35,508	10,773	4,733	15,056	48,875	99,889
Atlanta						
Glass Wall Building, Roof U = .12						
5.4 watts/Sq. Ft. B-9	71,016	18,296	8,169	26,465	26,750	124,231
2.7 watts/Sq. Ft. B-10	35,508	11,477	5,867	17,344	31,230	84,082

TABLE 2-5, CONTINUED

ENERGY USE IN HIGH RISE OFFICE
BUILDINGS WITH VARYING LEVELS OF LIGHTING - CONTINUED
BTU/Sq. Ft.

	Lighting	Cooling	Other Electricity	Electricity Excluding Lighting	Heating	Total Energy Excluding Water Heating
Atlanta						
Wall U = .19, Roof U = .12						
5.4 Watts/Sq. Ft. B-11	71,016	18,068	7,714	25,782	2,670	99,468
2.7 Watts/Sq. Ft. B-12	35,508	10,455	4,773	15,228	4,140	54,876
Los Angeles						
Glass Wall Building, Roof U = .12						
5.4 Watts/Sq. Ft. B-15	71,016	18,045	7,772	25,817	13,390	110,223
2.7 Watts/Sq. Ft. B-16	35,508	10,795	5,150	15,945	16,270	67,723
Wall U = .19; Roof U = .12						
5.4 Watts/Sq. Ft. B-17	71,016	18,023	7,794	25,817	1,230	98,063
2.7 Watts/Sq. Ft. B-18	35,508	10,204	4,900	15,194	2,000	52,702
1.4 Watts/Sq. Ft. A-37	18,412	6,955	7,800	14,755	12,125	45,292

This information is based on the simulations obtained from the RAND report, Energy Conservation in Nonresidential Buildings as reported in Tables 2-1 and 2-3 of the current report. It is important to note that there have been some modifications and adaptations of the RAND data. These adjustments are explained in the text of the current report.

TABLE 2-6[1)]

RELATIVE INFLUENCE OF LOAD COMPONENTS
DETERMINED BY REGRESSION STUDIES
(Percent of total effect
for entire data base[a])

Component	Heating	Cooling
Internal	(24)[b]	42
Solar	(5)	11
Cold Weather	57	(17)
Hot weather/humidity	0	10
Unexplained	14	20

[a]Averages: Glass = 0.42, wall coefficient (U) = 0.57
Lights = 4 W/Sq. Ft., 5 U.S. locations

[b]Parentheses indicate reducing effect

[1)]RAND, op. cit., p. 9.

TABLE 2-7

ENERGY USE IN LOW RISE AND HIGH RISE BUILDINGS UNDER VARIOUS LEVELS OF LIGHTING[1)]
BTU/Sq. Ft.

	Lighting	Cooling	Other Electricity	Electricity Excluding Lighting	Heating	Total Energy Excluding Water Heating
New York City						
Wall U = .19; Roof U = .12						
5.4 watts/Sq. Ft.						
4 wall store A-15	71,016	15,114	7,065	22,179	29,250	122,445
2 wall store A-18	71,016	16,341	7,065	23,406	10,375	104,797
High rise B-4	71,016	16,432	6,962	23,394	3,920	98,330
2.7 watts/Sq. Ft.						
4 wall store A-16	35,508	8,705	4,733	13,438	37,000	85,946
2 wall store A-19	35,508	9,091	4,733	13,824	13,625	62,957
High rise B-6	35,508	8,955	4,226	13,181	48,689	97,378
Los Angeles						
Wall U = .19; Roof U = .12						
5.4 watts/Sq. Ft.						
4 wall store A-35	71,016	17,818	7,800	25,618	7,250	103,884
2 wall store A-38	71,016	17,364	7,800	25,164	4,875	101,055
High rise B-17	71,016	18,023	7,799	25,817	1,230	98,063
2.7 watts/Sq. Ft.						
4 wall store A-36	35,508	10,477	5,070	15,547	10,125	61,180
2 wall store A-39	35,508	9,864	5,070	14,934	6,375	56,817
High rise B-18	35,508	10,204	4,990	15,194	2,000	52,702

This information is based on the simulations obtained from the RAND report Energy Conservation in Nonresidential Buildings as reported in Tables 2-1 and 2-3 of the current report. It is important to note that there have been some modifications and adaptations of the RAND data. These adjustments are explained in the text of the current report.

TABLE 2-8

A COMPARISON OF THE ENERGY IMPACT
OF ASHRAE 90-75 ON
VARIOUS TYPES OF BUILDINGS
BTU/Sq. Ft.[1)]

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
Northeast											
Conventional Office Bldg.	54,000	11,300	9,100	4,300	15,700	40,400	94,400	148,700	7,100	155,800	250,200
Modified Office Bldg.	38,300	4,500	600	2,700	9,700	17,500	55,800	35,600	5,000	40,000	96,400
Conventional Retail Store	89,200	96,000	0	5,700	33,700	135,400	224,600	50,900	2,600	53,500	278,100
Modified Retail Store	61,100	55,100	0	3,800	30,400	89,300	150,500	10,100	1,800	11,900	162,300
Conventional School Bldg.	34,100	1,500	0	3,800	6,700	12,000	46,100	80,600	13,500	94,100	140,200
Modified School Bldg.	27,300	1,000	0	1,700	3,700	6,400	33,700	33,200	9,500	42,700	76,400
North Central											
Conventional Office Bldg.	54,000	13,100	8,800	6,300	16,200	44,400	98,400	175,400	7,100	182,500	280,900
Modified Retail Store	38,300	5,100	700	2,900	10,500	19,200	57,500	46,500	5,000	51,500	109,000
Conventional Retail Store	89,200	104,600	0	6,700	36,900	148,200	237,400	50,100	2,600	52,700	290,100
Modified Retail Store	61,100	51,100	0	3,900	30,500	85,500	146,600	18,100	1,800	19,900	166,500
Conventional School Bldg.	34,100	1,500	0	4,600	7,800	13,900	48,000	85,400	13,500	98,900	146,900
Modified School Bldg.	27,300	1,000	0	1,900	3,900	6,800	34,100	38,900	9,500	48,400	82,500

TABLE 2-8. CONTINUED

A COMPARISON OF THE ENERGY IMPACT
OF ASHRAE 90-75 ON
VARIOUS TYPES OF BUILDINGS
BTU/Sq. Ft.

	Lights and Power	Fans	Humidification	Auxiliaries	Cooling	Electricity Excluding Lighting	Total Electric	Heating	Hot Water	Total Fuel	Total
South											
Conventional Office Bldg.	54,000	11,800	5,900	5,000	20,500	43,200	97,200	136,800	7,100	143,900	241,100
Modified Office Bldg.	38,300	6,200	300	3,600	12,500	22,600	60,900	33,800	5,000	38,800	99,700
Conventional Retail Store	89,200	100,600	0	6,700	46,500	153,800	243,000	30,600	2,600	33,200	276,200
Modified Retail Store	61,100	58,200	0	4,300	38,600	101,100	162,200	7,500	1,800	9,300	171,500
Conventional School Bldg.	34,100	1,900	0	4,400	8,600	14,900	49,000	83,700	13,500	97,200	146,200
Modified School Bldg.	27,300	1,100	0	2,100	5,000	8,200	35,500	26,000	9,500	35,500	71,000
West											
Conventional Office Bldg.	54,000	11,600	16,200	3,000	16,300	47,100	101,100	140,000	7,100	147,100	248,200
Modified Office Bldg.	38,600	6,400	1,300	3,400	10,900	22,000	60,600	42,000	5,000	47,000	107,600
Conventional Retail Store	89,200	96,000	0	5,700	28,500	130,200	219,400	52,700	2,600	55,300	274,700
Modified Retail Store	61,100	56,300	0	4,100	34,100	94,500	155,600	11,500	1,800	13,300	168,900
Conventional School Bldg.	34,100	2,000	0	2,900	5,900	10,800	44,900	94,900	13,500	108,400	153,300
Modified School Bldg.	27,300	1,100	0	2,000	3,700	6,800	34,100	31,600	9,500	41,100	75,200

FOOTNOTES, TABLE 2-8

A COMPARISON OF THE ENERGY IMPACT OF ASHRAE 90-75 ON VARIOUS TYPES OF BUILDINGS

1) The data are based on the output from simulations of the Ross Meriwether building energy use simulation model. The conventional office building was defined to be a 3 story, 40,000 sq. ft., suburban office park type of building. The retail store was defined to be a small suburban shopping center discount variety type, with single story concrete block construction.

The school was defined to be a suburban single story structure with a capacity of 400-500 students. The ASHRAE modified buildings were specified based on an interpretation of the ASHRAE Standard 90-75 as it applies to the prototypical buildings. Additional information may be found in Chapter II of Arthur D. Little's Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75.

TABLE 2-9

SUMMARY OF DRIVING FACTORS BEHIND OFFICE BUILDING ENERGY USE

	Hittman Associates	NEMA	Tishman-Syska and Hennessy	RAND	Ross and Baruzzini	MATHEMATIC
Degree Days						
Heating	YES	YES		YES		YES
Cooling	YES	YES		YES		YES
Lighting Level				YES	YES	YES
Hours of Lighting			YES			
Building Condition	NO	NO				
Computer - Data Services	YES	YES				
Occupant type (Owner/tenant)	NO	NO				
Height	NO	NO		YES		
Gross Area	NO	NO				
Age	NO	NO	YES			
Flux Factor	YES			YES (U values)		
Amount of Glass	NO					YES
Internal Loads	YES	YES		YES		
% Occupied	?	?				
Type of HVAC System				YES		YES
Central/Packaged	YES	NO				YES
Perimeter type			YES			YES
Presence of Economizer	NO			YES		
Outside Air Intake	YES					YES
Hours of perimeter air conditioning			YES			

NOTE: YES = Factor affects energy consumption
NO = Factor does not affect energy consumption
Blank = Not considered or not reported

SECTION 3

HEATING, VENTILATION, AND AIR CONDITIONING SYSTEMS

INTRODUCTION

The type of heating, ventilation, and air conditioning (HVAC) system used to provide space conditioning in a building can have a significant effect on a building's' energy consumption. The importance of HVAC systems has been illustrated in the work by Tishman-Syska and Hennessy, RAND and Hittman Associates.[1] Consequently, we present in this section a general description of commercial office building HVAC systems. This discussion of HVAC systems is neither extensive nor complete.[2] This presentation is intended to only highlight the significant system characteristics which we believe should be considered and analyzed when predicting or explaining energy use in commercial office buildings.

An HVAC system is a collection of boilers, ducts, pipes, fans, compressors, and other types of equipment which utilize energy inputs to provide space conditioning in a building. Table 3-1 lists the types of components that could be found in an HVAC system; a subset of the components will be present in any specific system. Table 3-2 presents a list of some of the types of HVAC systems that are commonly used.

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1) Tishman-Syska and Hennessy, Energy Conservation in Existing Office Buildings prepared for the U.S. Energy Research and Development Administration under contract number EY-76-C-02-2799.000, June 1977.

Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, Santa Monica, RAND, October 1976, R-1623-NSF.

Patrick M. McCarthy, Rusi F. Patel, and Burton Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, prepared under Federal Energy Administration Contract CO-04-51888-000, Columbia, Maryland, Hittman Associates, February 1977.

2) A good source of information on HVAC systems is published by BOMA: Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Rosemont, Pennsylvania, Building Owners and Managers Institute International, 2 volumes, 1973. The text was developed for use in the curriculum for persons preparing for the examinations leading to Administrator of Real Property (ARP) designation. Specialists in engineering, architecture, and other areas prepared the basic text material. Several other good sources of information are also available: National Electrical Contractors Association, Total Energy Management, 1976; Carrier Air Conditioning Company, System Design Manual, Syracuse, New York, 1966; 7th printing 1975.

Alternative HVAC systems provide varying degrees of heating and cooling capabilities at various levels of cost. The criterion for selection may be either the lowest first cost, the lowest life cycle cost, or a compromise between the two. Energy simulation models and programs--such as the AXCESS or TRACE programs--are frequently used to evaluate the cost and performance options of alternative systems capable of providing space conditioning. The choice of HVAC equipment type and system configuration will vary widely from building to building. Our discussion is focused primarily on office building HVAC systems; however, the information which we present is relevant to HVAC systems for other types of commercial buildings.

HEATING

A building's heating plant uses one of four fuels: electricity, gas, oil, or steam. The latter may be purchased from a district steam supplier or from an adjoining building. The fuel is burned in a furnace or boiler or, in the case of steam, may be utilized via a heat exchanger or other type of conversion equipment. The efficiency with which the fuel is utilized will depend upon the type of fuel, the maintenance and adjustment of the heating plant, and the performance of the equipment when operating at less than full capacity. Well maintained, modern equipment, in general, is more efficient than older or less well maintained equipment. Since the heating system is usually designed to provide adequate heating during periods of maximum anticipated loads, the system frequently operates at a level substantially below maximum capacity. The system's load curve, which describes the level of efficiency at various fractions of full capacity and the duration of partial load conditions, also has an important impact on the overall efficiency with which fuel is consumed. Table 3-3 presents the possible ranges of heating equipment efficiency at full load as found in the literature.

AIR CONDITIONING

The heat flow cycle by which heat is caused to flow from one medium to another is the basis of every air conditioning system from a room air conditioner to the largest commercial application, with the exception of the absorption refrigeration system. An excellent presentation of the cycle is presented in BOMA's "Fundamentals of Air Conditioning."[1] The basis of the refrigeration cycle is the fact that when a refrigerant evaporates it absorbs heat, and when it condenses it gives up heat. The refrigeration cycle is composed of four basic components: the compressor, the condenser, the evaporator, and the refrigerant that circulates between the components. The relationship of the components in a direct expansion system is depicted in Figure 3-1.

1. The refrigerant evaporates in the evaporator by absorbing heat from the air passing over it. The refrigerant is heated, and the air is cooled.

2. After the refrigerant has absorbed the heat and has changed to gaseous form, the compressor pumps the gas along to the condenser.

3. In the condenser, the refrigerant gas condenses to a liquid, thereby releasing the heat it previously absorbed. The heat is exhausted to the atmosphere in the case of an air cooled condenser.

4. The refrigerant is then ready to flow back to the evaporator, where the process is then repeated.

The direct expansion system, with which most people are familiar in the form of a window air conditioner, is used in commercial applications requiring less than 20 tons of air conditioning capacity. These include such uses as small office buildings and single story roof top installations. A chilled water system is generally used in commercial office building applications.

In a chilled water system the chilled water rather than the refrigerant absorbs the heat of the air in the air cooler. The heat is then removed from the water by causing the water to flow through a water cooler where, as the liquid refrigerant evaporates, it absorbs heat from the water passing through the cooler. Figure 3-2 presents a chilled water system.

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[1] John K. Henderson, P.E., "Fundamentals of Air Conditioning," in Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Building Owners and Managers Institute International, 1973.

An air conditioning system requiring refrigerating capacities up to 80 tons generally uses a reciprocating compressor, which is a combination of pistons operated from a crank shaft. Each piston on its down stroke draws in refrigerant gas at low pressures and on the up stroke the gas is compressed and ejected. For intermediate capacities—80 tons to 200 tons—either reciprocating compressors or centrifugal compressors are used. For capacities in excess of 200 tons, centrifugal compressors or absorption refrigeration machines are used. A centrifugal compressor uses the spinning motion of a fan to raise the pressure of the refrigerant gas, causing a continuous flow of the gas from water cooler to the condenser. The compressor may be powered by an electric motor, steam turbine, gas internal combustion engine, or diesel engine.[1)]

Absorption refrigeration machines utilize heat as an energy source. The cooling effect of an absorption refrigeration machine is obtained through an "absorption" cycle rather than a refrigeration cycle. Absorption air conditioning is entirely different from compressor driven air conditioning. The refrigerant is water, and a vacuum is created in the chamber where the refrigerant is to evaporate. For absorption refrigeration, the boiling temperature is 38^{o} F. The absorbent is a substance readily capable of taking on and retaining moisture from the atmosphere. The salt that is used most frequently is lithium bromide; the dry salt crystals are dissolved in water, creating a lithium bromide solution which is the form in which the absorbent is applied to the absorption cycle. A basic absorption machine consists of an evaporator, absorber, generator, and a condenser. Figure 3-3 is a diagram of the absorption cycle.

> "The purpose of the evaporator is to cool the chilled water that is circulating to and from the air conditioning system by passing it through the evaporator inside a tube bundle. The refrigerant (water) is sprayed over the tube bundle. Since the evaporator is under a vacuum condition, part of the refrigerant (water) evaporates causing the remaining refrigerant to lower in temperature thereby cooling the chilled water inside of the tube bundle. The water vapor created by the evaporating

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[1)] In cities supplied with district steam one can find steam driven compressors frequently supplying building air conditioning. A small amount of gas turbine and gas absorption air conditioning also occurs.

refrigerant flows to the absorber section where it is absorbed into the lithium bromide solution. Heat is generated in this process which is called "heat of absorption". This heat is removed by condenser water flowing through the tubes in the absorber section. As more and more water vapor is absorbed by the lithium bromide, the solution becomes diluted and the diluted solution is pumped to the generator section where the diluted lithium bromide solution is heated by means of steam or hot water coils in order to "boil off" the water present in the solution thereby reconcentrating the solution. The reconcentrated solution is then returned to the absorption section. The water vapor that has been driven out of the lithium bromide solution in the generator section flows to the condenser section and is condensed by means of cooling tower water flowing through the condenser tubes. The condensed water, or refrigerant, is returned from the condenser section to the evaporator thus completing the absorption cycle."[1]

An absorption refrigerating machine uses heat directly without the use of a prime mover. Such a machine is compact and vibrationless. It can be powered by steam or natural gas, and can even be designed to use waste heat, either from a steam turbine chiller or from the building itself. Both absorption and compressor machines may be used in an installation.

In reviewing the literature we found a wide variety of estimates for the coefficient of performance (efficiency) of electric chillers, with estimates from 1.67 to as high as 4.4. A number of the estimates for electrically driven centrifugal chillers had COP values of approximately 2.2 to 2.5; i.e., the ability to accomplish 2.5 BTU's of cooling for every BTU of electrical input. Steam absorption cooling systems are frequently quoted as having a coefficient of performance value on the order of .6, i.e., 6 BTU's of cooling output for every 10 BTU's of input. Both steam turbine and steam absorption units can be found in use in a number of cities with large buildings and a district steam supplier, such as New York and Baltimore. According to Hittman Associates report,

"The preference of steam over electricity can be explained by comparing the costs of the two. (Table 3-4) shows the approximate average total costs (including the fuel adjustment clause and taxes) of steam and electricity at current rates. In spite of its inefficiencies it can be seen that steam for cooling is more economical for larger cooling plants, and hence its popularity in buildings with large gross floor areas."[2]

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1) "System Components" by John K. Henderson, P.E., Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Building Owners and Managers Institute International, Volume II, p. 10-81.

2) Hittman Associates, op. cit., p. 54. In the discussion Hittman is referring to steam absorption units. The COP of steam turbine units would be higher, but we do not have the figure.

The cost information used in the Hittman report was obtained from Baltimore Gas and Electric.

Many office buildings require air conditioning during the winter to provide cooling for the core, the computer and data processing rooms (if any), and some of the offices at some times. One option which some building managements use is to supply the air conditioning through the operation of the refrigeration plant. A second option, which is being used increasingly, is to supply the air conditioning through the use of an economizer, which is a sensing device that operates the appropriate dampers to admit cool outside air as needed to the HVAC system during the winter. A "dry bulb economizer" is activated by the outside temperature; an "enthalpy economizer" is activated on the basis of the outside temperature and humidity. The use of an economizer should result in some reduction in energy consumption.

VENTILATION

Perhaps the most significant element differentiating one type of HVAC system from another is the ventilating system. The leakage of outdoor air to a building through cracks and openings is called infiltration; the forcing of air into the building by means of fans is called ventilation. The introduction of outside air is necessary to dilute the odors produced by people, cooking, smoking, and other activities within the building; the amount of ventilation required is a function of the number of people present, the ceiling height, and the amount of smoking. Ventilation standards are frequently specified by the local building code. Table 3-5 presents some of the ventilation recommendations outlined in BOMA's Engineering and Building Structures. Ventilating air is usually introduced through the air conditioning system, having first been processed by the heating, filtering, or cooling equipment. The ventilation and infiltration loads significantly affect the level of energy use, because the external air puts a heating or cooling load on the building's systems.

"The summertime cooling load imposed on the air conditioning system by ventilation air is approximately four tons of refrigeration for every 1000 cfm of outside air introduced based on outside design conditions of 95° F. dry bulb and 75°

F. wet bulb and inside design conditions of 75° F. dry bulb and 50% relative humidity. For example, in a 100,000 square foot building requiring a ventilation of .25 cfm per square foot, the outside air ventilation load would be 100 tons. It is therefore evident that the external load for ventilation is a significant one."[1]

Recent trends in building ventilation have included the reduction of the number of air changes per hour, the curtailment of HVAC operation to a time period adequate for the normal business day, and the use of scheduled ventilation—which consists of reducing the fresh air intake to the space conditioning system when peak loads are experienced and of compensating for the curtailment of fresh air with additional flushing of the building after business hours. [2]

The ventilation system is the system of pipes and ducts used to circulate the heating or cooling medium. Most large commercial office buildings have two ventilation systems: a perimeter system serving the outside offices, and an interior system serving the building's core. Each system will serve a number of zones.

ZONING

A zone is an area, or group of areas, in a building which experiences, within the zone, similar amounts of heat gain and loss from the interaction of the internal loads (people, equipment, and lighting) and the external loads (heat loss to or gain from the outside environment).

Zoning is the division of the heating and cooling systems into sections to permit the independent control of room temperatures in the zones served by each of the sections. Zoning of an air distribution system is necessary to compensate for fluctuating heating and cooling loads.

To maintain an environment in the zone acceptable for comfort, regardless of the seasons, outside climate conditions and internal building usage, heat is added to or subtracted from the zone. A building may have one or more zones. For example, a single family residence typically has one zone. A church might have 3

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1)John K. Henderson, "Fundamentals of Air Conditioning", in Engineering and Building Structures, LeRoy E. Varner, Sr., Ed., Volume II, pp. 9-34. A ton of air conditioning is equivalent to the removal of a load of 12,000 BTU/hr from a space.

2)The "normal business day" generally runs from 8 a.m. to 6 p.m.; therefore the HVAC system would be operated from 7 a.m. to approximately 5:30 p.m.

zones--one for the main gathering place, one for offices, and one for other areas. An office building will typically have at least 5 zones-an interior zone and one zone per wall, but may have many more. Zoning permits the simultaneous heating and cooling of the building. On a sunny winter afternoon, three sides of a commercial office building may require heating while a fourth side requires air conditioning due to the intense rays of the sun. Special purpose areas, such as computer, restaurant, and retail store areas, are usually zoned separately from office areas; this permits the building management to provide for special space conditioning requirements and to curtail space conditioning to the office areas after normal business hours while continuing space conditioning to the other areas.

TYPES OF HVAC SYSTEMS

We will summarize the five basic types of HVAC systems as described in Part 9, "Systems and Applications", of the Carrier System Design Manual.[1]

1. Direct Expansion System: A self contained compact unit located within or next to the air conditioned space, consisting of the minimum elements essential to producing the cooling effect is a direct refrigerant or direct expansion system. A heating coil can be added to the system where necessary to provide heating. A room air conditioner is one example of a direct expansion system. A direct expansion unit with a water cooled condenser and central cooling tower can be obtained in units larger than window size, with capacity up to 20 tons.[2] In such cases a ducted distribution system is used to deliver the supply of air throughout the conditioned space. This type of unit is used in "economy" type construction for small, single story office buildings. Roof top units available in capacities ranging from 10 to 60 tons are also used in single story construction.

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[1] Carrier Air Conditioning Company, "Systems and Applications," System Design Manual, Syracuse, New York, 1965; part of our discussion is also drawn from NEMA's Total Energy Management and BOMA's Engineering and Building Structures.

[2] A "condenser" is a vessel or arrangement of pipe or tubing in which a vapor is liquefied by the removal of heat.

A "cooling tower" is an enclosed device used to cool water by evaporating part of it into the atmosphere and by direct contact with air.

2. All Water System: A cooling medium, such as chilled water or brine instead of direct refrigerant, is supplied from a remote source and circulated through the coils of an air terminal within the conditioned space. The circulating medium is warmed to provide heating. An example of such a system is a fan coil system. This system is commonly applied to buildings with all exterior zones, or to the exterior zones only of larger buildings. Cooling and heating effect is normally supplied to the coil by a network piping system from a remote centralized refrigerating and heating plant.

The fan coil system is applicable to many types of buildings and can be applied to a low grade air conditioning system at minimum first cost, or it can be included in the overall scheme of a high grade air conditioning system. Fan coil units may be supplied by two pipe, three pipe, or four pipe distribution systems, depending on the quality and flexibility desired in the end result. For a two pipe system, the cold water is supplied to the unit for summer cooling, and hot water is supplied for winter heating. At any given time only heating or cooling can be supplied, for only hot or cold water is supplied at a given time. During seasons when requirements can switch from heating to cooling during a day's operation or when simultaneous heating and cooling requirements may exist in different zones, the system's performance is poor. To overcome the disadvantage of poor space temperature control inherent in the two pipe system, a three or four pipe system can be used, making both heating and cooling simultaneously available. In a three pipe arrangement there is a chilled water supply, a hot water supply, and a common return pipe for both supplies. Either cooling or heating water can be admitted to the unit coil; the principal disadvantage of the three pipe system occurs during those periods when simultaneous heating and cooling are required, for the return water from both the heating and the cooling coils are mixed in a common return pipe before being divided to pass through either the boiler or refrigeration machine. Each piece of equipment is therefore being falsely loaded by the input of the other, creating higher operating costs. In the four pipe arrangement two separate water distribution systems feed each terminal unit, and there is no intermixing of the cooling and heating liquids. The four pipe system is higher in first cost but offers operating economy along with flexibility in space dry bulb temperature control.

3. Air-Water System: The air apparatus and refrigeration plant are separate from the conditioned space, and the cooling and heating of the conditioned space is effected in only a small part by air brought from the central apparatus. The major part of the room thermal load is balanced by warm or cooled water circulated either through a coil in an induction unit or through a radiant panel. An induction system supplies heated or cooled primary air at high pressure to induction units located on the outside walls of each space served. The high pressure primary air is discharged within the unit through the nozzles, inducting room air through a cooling or heating coil in the unit. The resultant mixture of primary air and induced air is discharged to the room at a temperature dependent upon the cooling and heating load requirements of the space.

Both induction units and fan coil units are generally used for perimeter space conditioning.

4. All Air System: Hot or cold air is brought into the conditioned space through ducts and distributed within the space through outlets. Such a system is termed an all air system. There are a wide variety of all air systems, three of which are as follows:

a. Single duct constant volume with reheat: The central heating and cooling units provide air at a given temperature to all zones served by the system. Secondary terminal heaters then reheat the air to a temperature compatible with the load requirements of the space involved.

b. Single duct, variable volume (VAV): A variable air volume system provides air at a constant temperature to all zones served. VAV boxes located in each zone or in each space adjust the quantity of air reaching each zone or space depending on its load requirements.

c. Dual duct system: The central unit provides hot and cold air, each at a constant temperature. Each space is served by two ducts that are carrying hot and cold air. The ducts feed into a mixing box in each space which, by means of dampers, mixes the hot and cold air to meet the temperature requirements.

5. Heat Pump Systems: The adaptation of any of the systems to effect year round air conditioning utilizing system refrigeration as a heat generating plant is a heat pump system. Heat pumps are effective providers of year round air conditioning in buildings with a favorably balanced ratio of cooling-heating load, particularly where the two load values are almost equal.

HVAC SYSTEMS AND ENERGY USE

Our discussion of HVAC systems has been superficial, for many variations on the types of systems which we have mentioned are possible. However, even with the limited information which we have presented, it is clear that there may be substantial diversity in the design of HVAC systems. Consequently, differences in energy consumption among otherwise similar office buildings could be explained by differences in HVAC systems.

1. Any one of four fuels is possible for heating.

2. Either electricity or steam may be used for cooling.[1] There are two types of steam cooling systems - steam absorption and steam turbine.

3. A wide variety of perimeter and interior air handling systems is possible.

4. The zoning of a building, the presence of an economizer, and the installation of equipment to recycle waste heat all affect energy use.

In view of the wide diversity of possible HVAC system options, one would expect that the type of system as well as the type of fuel plays an important role in determining building energy use. We discuss below the findings of RAND and Tishman-Syska and Hennessy on this subject and provide some information which we have developed on the basis of our work with the BOMA data base.

The RAND Report

In Energy Conservation in Nonresidential Buildings, RAND examined how the choice of HVAC systems could affect energy use. RAND considered a total of seven systems of which the first four were typical of systems commonly in use in 1974 and the last three typical of systems proposed as energy conserving alternatives.[2]

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[1] Gas is also used for cooling although relatively few buildings in the BOMA sample, reported in later sections, were gas cooled.

[2] RAND, op. cit., Appendix C.

1. The reference system: electric air conditioning, gas fired hydronic (hot water heating), and a single duct variable-volume air distribution system.

2. The absorption system: the reference system with absorption rather than electric air conditioning.

3. The reheat system: the reference system with a double duct constant volume air distribution system. Warm air is circulated through one duct and chilled air is circulated through the other, the two being blended at the outlet.

4. The electric system: the reference system with electric heating.

5. The economy system: the reference system with a ventilation economizer cycle used to take advantage of favorable outside temperature conditions and with a heat wheel.

6. The central plant system: differs from the reference system by having prime mover driven centrifugal chillers along with piggyback absorption chillers utilizing the heat rejected from the prime movers.

7. The total energy system: this system uses prime mover engines to generate required electricity on site; air conditioning is provided by absorption chillers. Both cooling and heating are fueled by waste heat recovered from the prime movers if available, or, alternatively, from gas fired boilers. The system uses a single duct variable volume air distribution system.

Energy use under each of the different systems was simulated using the ECUBE program for a New York City office building. Table 3-6 presents the projected energy use for a full lighting level (5.4 watts/sq. ft.) and a half lighting level (2.7 watts/sq. ft.) case. Choice of HVAC system clearly has an impact on energy consumption.

The Tishman-Syska and Hennessy Analysis

Tishman-Syska and Hennessy presented a number of AXCESS program simulations for a typical New York City office building under varying HVAC options in Energy Conservation in Existing Buildings. A variable volume system with and without economizer and a constant volume system were compared, and the operation of the variable volume system under varying policies was analyzed. The results are presented in Table 3-7.

The Boma Data Base

In reviewing energy use by buildings in the BOMA data base we observed that BTU/Sq. Ft. varied substantially from building to building, holding city (climate) and fuel type constant. Some of this variation is probably caused by the differences in the types of HVAC equipments present in the buildings. BOMA's current data collection efforts do not obtain the data one would need for an HVAC analysis, i.e., information on types of interior and exterior HVAC systems, zoning, type and capacity of heating and refrigeration plants, capacity of various system components, and types of controls. This type of data was obtained by BOMA from a limited sample of buildings by the use of a supplementary questionnaire, as described in Section 5. We believe that additional data gathering efforts would be useful and, for the type of data being sought, not very time consuming for the respondent. Initially, one could attempt to gather the data for the 10 cities for which information on the largest number of buildings was available. If the results should prove to be useful, the survey could be extended.

CONCLUSIONS

We have indicated that a wide variety of HVAC systems are possible, that based on a limited analysis by RAND and TSH, the choice of HVAC system can significantly affect energy use, and that the type of fuel has an important impact in determining the efficiency of fuel utilization. Since the RAND and TSH conclusions are based on a very limited number of simulations obtained from energy simulation models, we believe that a thorough simulation analysis for various types of perimeter and interior systems, various types of heating and refrigeration plants, and various types of fuels would be appropriate. Furthermore, an examination of actual—not simulated—data would be desirable. This could be conducted using the BOMA data base as supplemented by a questionnaire to gather additional information.

TABLE 3-1

EQUIPMENT TYPICALLY FOUND IN AN HVAC SYSTEM

System Components	Functions Performed
Air Side	
1. Outdoor Air Intake (screen, louvers, dampers)	Path for outdoor air used for ventilation and marginal weather cooling
2. Preheater	Preheats air
3. Return Air Intake	Path for return and/or recirculated air to appartus
4. Filter	Removing contaminants from air
5. Dehumidifier (direct spray washer or cooling coils)	Cooling and dehumidifying (air washing with sprays)
6. Heating Coil	Heating in winter and reheat for temperature and/or humidity control
7. Humidifier	Humidifying
8. Fan	Air propulsion
9. Duct System	Path for air transmission
10. Air Outlet	Air distribution within air conditioned space
11. Air Terminal (with outlet)	Enclosure for air handling; may be equipped with air mixing chamber, heating coil, coil, acoustic treatment, and outlet
12. Refrigeration machine (compressor, condenser, cooler and refrigerant piping)	Means for cooling
Water Side	
13. Pump	Water for brine propulsion
14. Water or Brine Piping	Path for transmission of water or brine between heat exchangers
15. Cooling Tower	Heat disposal from water used
Heating Side	
16. Boiler and Auxiliaries	Provide steam or hot water
17. Piping	Path for transmission of steam or hot water

Source: Carrier System Design Manual, Part 9, Systems and Applications, Syracuse, New York, Carrier Air Conditioning, 1965, Third Printing 1971, P. 9-7.

Table 3-2 Typical Systems in Various Types of Commercial Spaces

APPLICATIONS	Individual Room or Zone Unit Systems				Central Station Apparatus Systems[3]						
	DX Self-Contained		All-water		All-Air					Air-Water	
	Room	Zone	Room Fan-Coil		Single Air Stream					Prim. Air Systems	
						Reheat					
	1/3 to 2 tons	2 tons and over	Recir. Air	With Outdoor Air	Variable Volume	Bypass	At Terminal	Zone in Duct	Multi Zone Single Duct	Secondry Water H-V H-P Induction	Room Fan Coil with O.A.
Restaurants											
Medium[1]		X						X			
Large[1]		X				X	X	X	X		
Department Stores[2]						X					
Shopping Centers[2]		X				X			X		
Office Building[2]					X				X	X	
Schools and College Classrooms[2]				X	X	X	X	X			
Laboratories - Small Bldg.[2]		X			X			X	X		
Large Bldg.					X		X			X	
Libraries and Museums[2]								X	X		
Hospitals[2]				X				X		X	
Houses of Worship[1]		X				X			X		
Bowling Alleys[1]		X				X					
Country Clubs[1]		X				X		X	X		
Radio/TV Small[1]		X				X		X	X		
Studios Large[1]		X				X		X	X		
Theaters[1]						X					
Auditoriums[1]						X					
Dance and Roller Skating[1]		X			X	X					
Motels[2]			X								
Hotels, Dormitories[2]			X	X						X	X

1. Single-Purpose Occupancy
2. Multi-purpose occupancy
3. There are several systems used on many of these applications when higher quality air conditioning is desired (often at higher expense). These include Dual Duct, Dual conduit, 3 pipe Induction and Fan Coil, 4-pipe Induction and Fan Coil. and Panel-Air.

Source: Carrier System Design Manual, Part 9, "Systems and Applications," Syracuse, New York, Carrier Air Conditioning Company, 1965, Third Printing 1971, P. 9-22.

TABLE 3-3

FUEL CONSUMPTION EFFICIENCIES FOR HEATING AT FULL CAPACITY[1)]

	Existing Construction (More than 2 years old)	New Construction
Gas (ADL)	.60	.70
Gas (RAND)	-	.80
Oil (ADL)	.50	.60
Electric Furnace (ADL)	1.0	1.0
Electric Heat Pump (ADL)	1.67	1.67
Steam	.85-.90	.85-.90

1) Sources for this information include the RAND report, the Hittman Associates report, and the ADL report Residential and Commercial Energy Use Patterns 1970-1990. Some consideration of partial load performance is necessary in projecting energy consumption.

TABLE 3-4[1)]

FUEL COSTS

		$/Unit	$/Million BTU
Steam for Heating	$	0.49/clb	5.10
Steam for Cooling	$	0.38/clb	3.96
Electricity	$	0.45/kwh	13.18

1) Hittman Associates, op. cit., p. 54.

TABLE 3-5

VENTILATION STANDARDS FOR SOME TYPES
OF COMMERCIAL SPACE

Application	Smoking	CFM Per Person Recommended	CFM Per Person Minimum[1)]	CFM Per Sq. Ft. of Floor Minimum[1)]
Department Stores	None	7½	5	.05
Retail Shops	None	10	7½	
Restaurant Kitchen	-	-	-	4.0
Restaurant Dining Roon	Considerable	15	12	-
General Office Space	Some	15	10	-
Private Office Space	Considerable	30	25	.25
Private Office Space	None	25	15	.25
Meeting Rooms	Very Heavy	50	30	1.25
Laboratories	Some	20	15	-
Hospitals				
Private Rooms	None	30	25	.33
Operating Rooms	None	-	-	2.0
Theaters	None	7½	5	-
Hotel Rooms	Heavy	30	25	.33

1) When minimum is used, the larger of CFM per person or CFM per sq. ft. x sq. ft. per person should be used.

Source: Engineering and Building Structures, LeRoy E. Varner, Sr. Ed., Volume II, p. 9-35.

TABLE 3-6

ALTERNATIVE ENERGY SYSTEMS IN A NEW YORK CITY OFFICE BUILDING[1)]
BTU/Sq. ft.

	Lights	Other Electric	Total Electric	Total Fossil	Total
Full Lighting (5.4 Watts/Sq. Ft.)					
Reference	71,016	23,193	94,209	37,222	131,431
Absorption	71,016	7,176	78,192	149,472	228,664
Economy	71,016	16,369	87,385	33,583	120,968
Reheat	71,016	28,027	99,043	67,139	166,182
Electric	71,016	52,195	123,211	0	123,211
Central Plant	71,016	7,176	78,192	77,500	155,692
Total Energy	(2)	(2)	(2)	297,500	297,500
Half Lighting (2.7 Watts/Sq. Ft.)					
Reference	35,508	15,009	50,517	44,722	95,238
Absorption	35,508	5,341	40,849	112,500	153,349
Economy	35,508	10,649	46,157	40,333	86,490
Reheat	35,508	18,041	53,549	80,556	134,105
Electric	35,508	50,740	86,248	0	86,248
Central Plant	35,508	5,341	40,849	58,056	98,905
Total Energy	(2)	(2)	(2)	191,111	191,111

(1) The building's location is New York City; square plan configuration; 20 stories tall; 360,000 gross sq. ft.; glass curtain wall; lighting is 44 percent of continuous. Electric cooling COP of 4.4. Absorption cooling COP of .64. Gas boiler efficiency of .8. Electric heating efficiency of 1.00; electric generation efficiency of .34. A summary of the data may be found in Appendix C, pp. 157-170 of the RAND report Energy Conservation in Nonresidential Buildings, by Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf.

(2) No electricity is purchased.

Source: Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, R-1623 NSF, RAND, October 1976; Appendix C.

TABLE 3-7

ENERGY USE UNDER VARIOUS CONSERVATION OPTIONS
IN A TYPICAL STEAM HEATED NEW YORK OFFICE BUILDING
BTU/Sq.Ft.

Case	Grand Total Energy	Energy By Fuel: Electricity	Energy By Fuel: Steam	HVAC Energy: Cooling (Incl. Aux.)	HVAC Energy: Heating (Incl. Aux.)	Fans	Non HVAC Energy: Lights	Non HVAC Energy: Dom. HV & Misc. Elec.
1	72,458	47,663	24,795	9,663	21,245	6,050	30,097	5,409
2	110,308	57,415	52,893	14,405	49,515	10,890	30,097	5,409
5	73,812	46,419	27,393	8,804	23,940	5,568	30,007	5,409
6	81,524	58,366	23,158	9,854	19,566	6,582	40,117	5,409
7	63,473	36,749	26,724	9,413	23,160	5,416	20,064	5,409
10	78,836	54,048	24,788	16,053	21,245	6,050	30,097	5,409

Building Specifications: Occupancy of 100 Sq. Ft./person. Gross floor area of 290,129 Sq. Ft. Additional building specifications may be found on p. D-1.1 of the TSH report.

Case 1: Base Case: Variable air volume with reheat; 75^{o} summer temperature; 70 degree winter; winter night set back temperature 65^{o}; outside air supply 20%; dry bulb economizer at 65^{o} F; lighting of 3 watts/Sq. Ft.

Case 2: Base Scheme with system changed to constant volume reheat. All other system parameters the same.

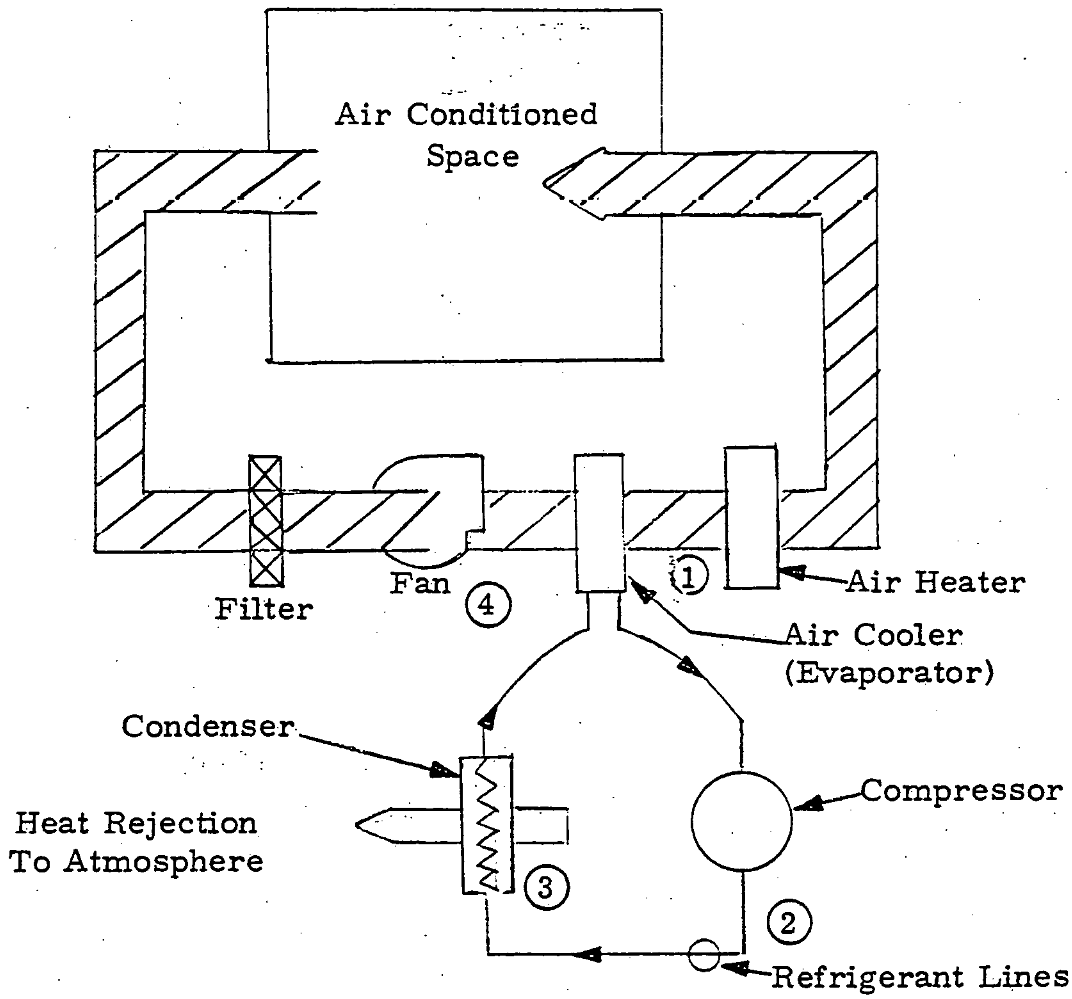
Case 5: Base Scheme with the summer set point temperature at the perimeter zones increased to 80^{o} F. The air volumes and coil leaving temperature were left the same.

Case 6: Base Scheme with the lighting level increased from 3 watts/sq. ft. to 4 watts/sq. ft.

Case 7: Base Scheme with the lighting level decreased to 2 watts/sq. ft.

Case 10: Base Scheme without an economizer cycle.

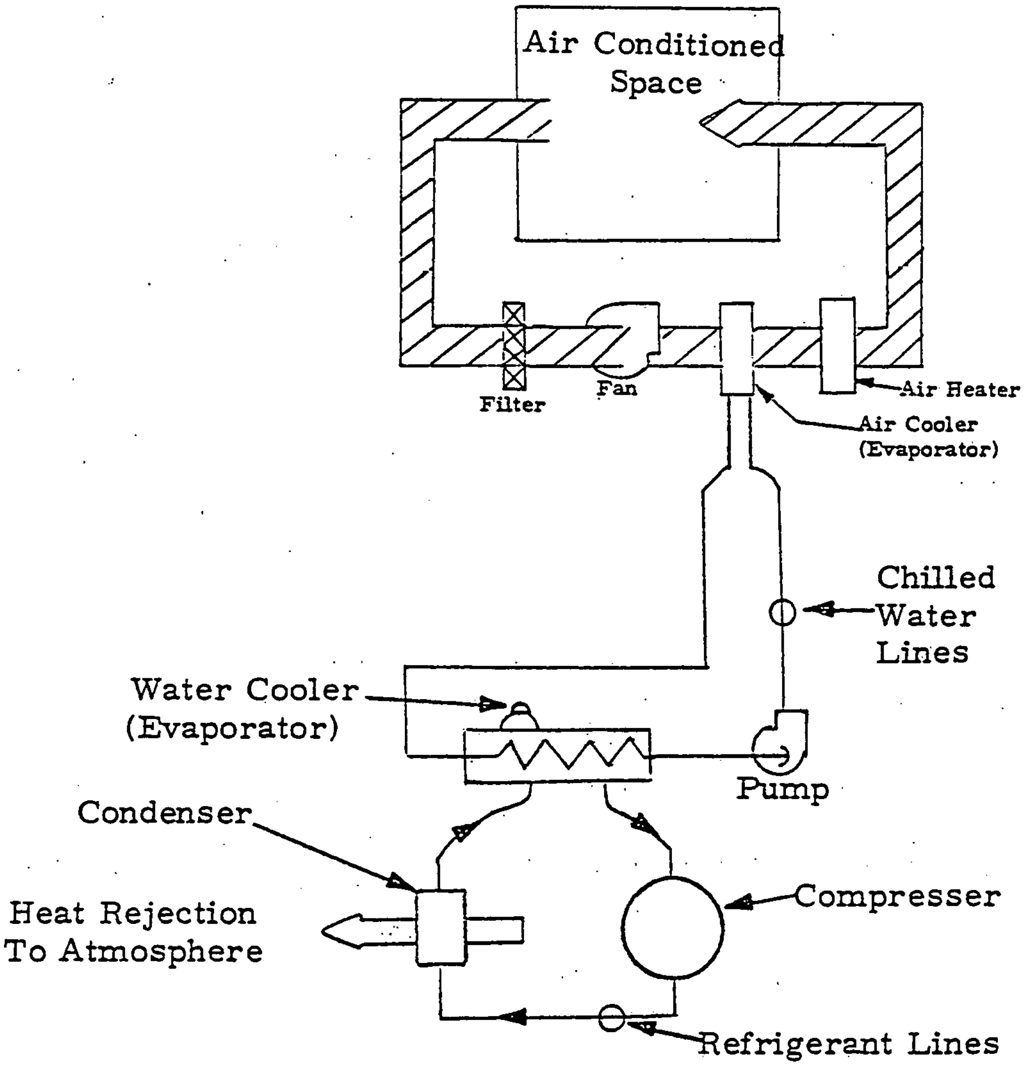
The source of this information is a series of AXCESS simulations conducted by Syska and Hennessy for the report Energy Conservation in Existing Buildings, ERDA Contract EY-76-C-02-2799.00, June 1977.



Refrigeration System
Direct Expansion

Figure 3-1

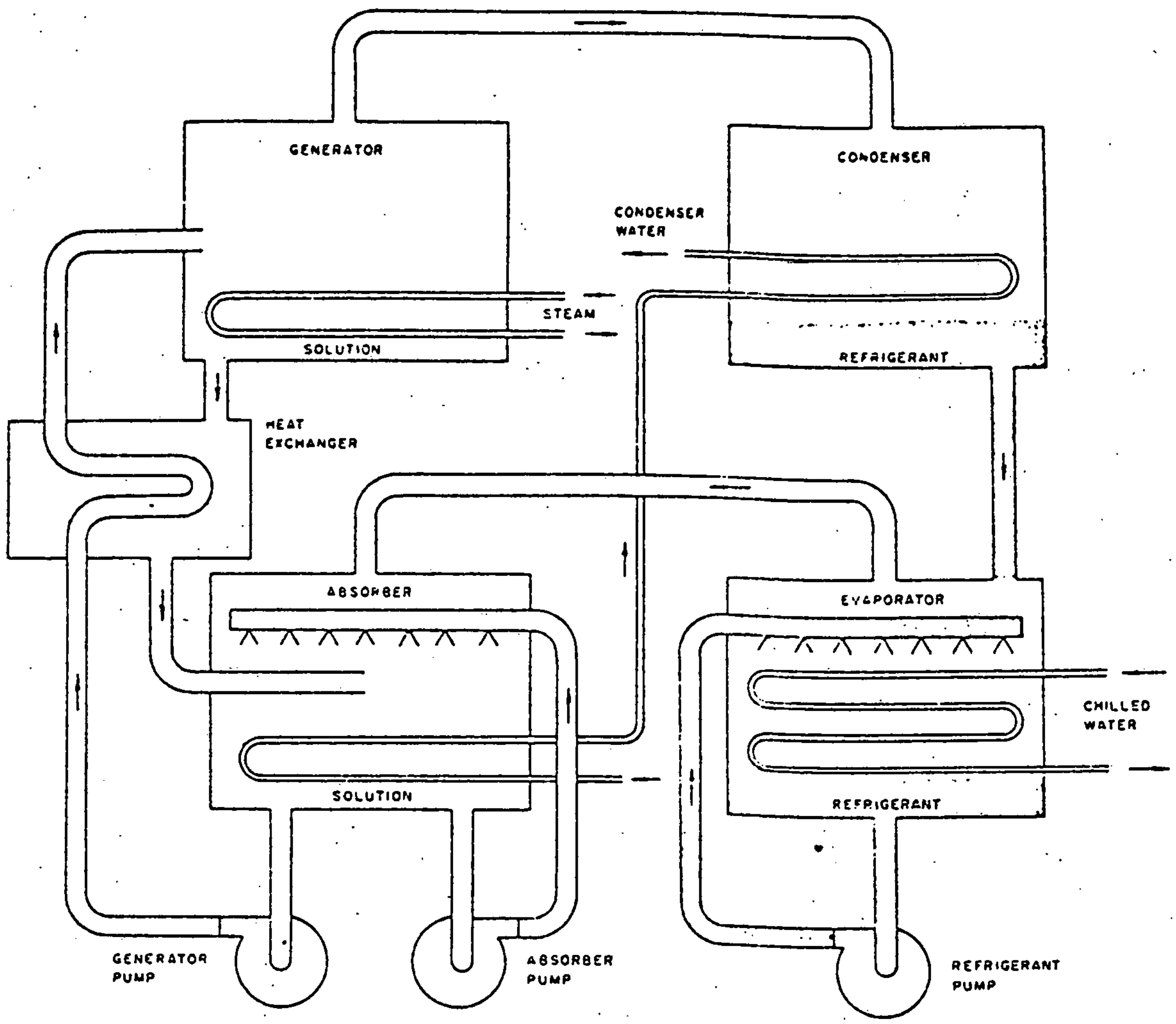
Source: John K. Henderson, P. E., "Fundamentals of Air Conditioning," in Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Rosemont, Pennsylvania, Building Owners and Managers Institute International, 1973, pp. 9-19; used with permission.



Refrigeration System
Chilled Water

Figure 3-2

Source: John K. Henderson, P.E., "Fundamentals of Air Conditioning," in Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Rosemont, Pennsylvania, Building Owners and Managers Institute International, 1973, pp. 9-19; used with permission.



Basic Absorption Cycle

Figure 3-3

Source: John K. Henderson, P.E., "Fundamentals of Air Conditioning," in Engineering and Building Structures, LeRoy E. Varner, Sr., Editor, Rosemont, Pennsylvania, Building Owners and Managers Institute International, 1973, pp. 10-80, used with permission.

SECTION 4

HVAC COMPUTER SIMULATION PROGRAMS

INTRODUCTION

We explored the possibility of using building energy simulation programs in the development of an energy use data base for commercial buildings.[1] The programs are based on design calculations relating to heating, refrigeration, air conditioning, and ventilation equipment and systems; the appropriate equations explaining the interaction of the energy flows are presented in the ASHRAE Handbook of Fundamentals and other ASHRAE publications.[2] The programs simulate building energy use on an hourly basis by end use function under various building equipment, systems, and structural configurations and usages. A life cycle cost analysis which considers the tradeoffs between the capital costs of various possible HVAC systems and the operating costs of the systems is also available. Some of the programs--such as the AXCESS, ECUBE, Ross Meriwether, and TRACE programs--are proprietary, and others--such as the NASA Energy Cost Analysis Program (NECAP) and the CAL-ERDA program, presently under development--are in the public domain.[3] Our interest in the programs was motivated by the following considerations:

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1)A listing of such programs may be found in "Bibliography on Available Computer Programs in the General Area of Heating, Refrigeration, Air Conditioning, and Ventilation," prepared under NSF Grant SIA 75-10436 by the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.: Principal Investigator: J. F. Cuba; Subcontractor: Battelle Columbus Laboratories, Compiled and Prepared by G. Christopher P. Crall, October 1975, NSF-RA-760002 (5559).

2)American Society of Heating, Refrigerating, and Air Conditioning Engineers, Handbook of Fundamentals, New York, 1972.

3)The equations of a program in the public domain could be evaluated; such would not be the case for a proprietary program. Although a program may be in the public domain, there are substantial support costs involved in the implementation of a program on a computer system and its continual maintenance and revision. An interesting question which we have not examined is the relative efficiency and accuracy of the programs. In "Predicting Building Energy Requirements" J. Marx Ayres compared the four major proprietary programs and found that they yielded different answers for a given building. He indicated that "The reasons for the variations in the outputs of each program could not be examined because of the proprietary nature of the programs and were beyond the scope of the study. The variations were expected, however, because different calculation procedures were used in each program." Energy and Buildings, 1 (1977), May 1977, pp. 11-18.

1. Building managers are usually able to furnish data on electric use and fuel use only on a total basis; submetering by function--auxiliaries, hot water, heating, cooling, lighting, appliances, etc.-- generally does not occur, and building managers are only able to furnish possibly unreliable estimates and guesses of energy consumption by end use. A major advantage of the energy simulation programs is that they can provide estimates of end use energy consumption.

2. We observed widely disparate energy uses in the BOMA sample of buildings. An analysis of the equipment options--such as HVAC system type--and building characteristics--such as hours of usage, air infiltration, etc.--could provide an explanation of the differences, serve as a basis for the prediction of future energy use, and provide a basis on which to evaluate policies on the modification of buildings for energy conservation.

3. In the case of office buildings, most of the BOMA membership manages Class A, prime office space, and this is the type of space for which building data are available in substantial amounts. Only a limited amount of data is available for Class B and Class C building space, which are, however, an important part of the square feet of office space.[1] In examining energy use it is important to have data for these types of space. One therefore has the options of attempting to collect the data for a large sample of Class B and Class C buildings; or of simulating the data and comparing the results of the simulations to the energy use data for the limited sample of Class B and Class C space for which data are reported in the BOMA data bank. One would then have a basis for the estimation of energy use in Class B and Class C space via simulation and could avoid the implementation of an extensive survey.

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1) There are no statistics on what percentage of the total commercial building stock is Class A office buildings. A rough estimate is that approximately 1/3 of commercial office building space is Class A space. For the Philadelphia sample NEMA found that 40% of the buildings were Class A ("modernized building kept up-to-date); 58% were Class B ("well maintained; not completely modernized); and 2% were Class C ("older buildings not kept up-to-date); these percentages are based on numbers of buildings, not square feet of building area. National Electrical Manufacturers Association, Energy Consumption in Commercial Buildings in Philadelphia, no date.

4. It was shown in Volume II of this report that energy use data for other types of commercial buildings, such as libraries, warehouses, stores, etc., are presently of questionable reliability. If an energy use program were able to predict energy use in such types of space, one could avoid a substantial data gathering effort through the use of simulations and the comparison and possible calibration of the simulations with a selectively obtained sample of buildings. This is basically the approach which ADL adopted in attempting to project estimated energy use on the basis of design and operating usage parameters[1]. We understand that the AIA Research Corporation is using the AXCESS program to simulate the projected design performance of a number of types of commercial buildings around the country. The AIA has circulated a building energy performance design questionnaire to a number of architect-engineering firms in order to gather data inputs for the AXCESS program. A large number of short form simulations are planned.[2] The outputs of the program would be the projected energy use by various types of buildings based on their design parameters. Although there is no guarantee that the buildings will actually use the amounts of energy predicted, for the architect-engineering firm has no knowledge of how the buildings will actually be operated and used, the possible use of such programs is nevertheless attractive. If one could specify the building parameters and building usage, one might be able to generate a useful data base relatively quickly. Over time, one would have the option of improving, modifying, or eliminating the generated data through the implementation of special surveys and questionnaires.

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1) Arthur D. Little, Residential and Commercial Energy Use Patterns, 1970-1990; Report to the President's Council on Environmental Quality and the Federal Energy Administration, November 1974.

Arthur D. Little, Energy Conservation in New Building Design: An Impact Assessment of ASHRAE Standard 90-75, FEA Conservation Paper Number 43B, no date.

2) A short form simulation performs energy calculations on an every 3rd or 5th day basis and then extrapolates the results to the entire 365 day period of a year. A short form simulation also permits the use of default (assumed) values for some of the program inputs.

COMPUTATIONS AND INPUTS

Energy simulation programs predict building energy consumption as a function of building use, characteristics of the HVAC and other building systems, and structure of the building shell. The energy required to heat and cool a building is determined by the net effect of the thermal loads acting upon the building. These loads include the thermal energy transferred by conduction through the building shell due to temperature differences between the outside and inside environments; energy transferred into the building from the effects of solar radiation; the energy exchanged due to the ventilation of the building with outside air; and the thermal energy generated within the occupied space of the building by lights, people, and equipment. The net effect of these thermal transfers will change the internal temperature of the building unless energy is added to or subtracted from the space. The programs simulate the loads on an hourly basis and convert the loads to energy use based on assumptions about equipment efficiency, capacity, and operation.

We have examined the types of data inputs required by the four major proprietary programs. The inputs are quite detailed; for example, the AXCESS program requires over 28 pages of data for a full simulation of a major building. Although each program requires slightly different inputs, the major types of data can be described.

1 Building characteristics
   - Roof and Wall areas
   - Amounts of glass
   - Square feet of building area by function
   - Building height
   - Infiltration

2 Building Operating Schedules
   - Lighting schedule
   - Heating schedule
   - Air Conditioning schedule
   - Holiday schedule

3 Building internal conditions

Building thermostat setting and set back

Building occupancy--number of people

Lighting levels

Equipment loads--computers, restaurant, equipment,

Ventilation settings

4 HVAC information

Zoning

Type of perimeter system and capacities of the equipment

Type of interior system and capacities of the equipment

Types of auxiliaries and capacities

Fuel information

5 Weather data

Weather tape with hourly data for appropriate city obtained from the National Oceanic and Atmospheric Administration.

A DATA GATHERING EXPERIMENT

In order to examine the data needs of the AXCESS program and any special problems which could arise in gathering data for the implementation of the program we gathered input data for the simulation of a building located in Washington, D.C. However, no simulation was actually conducted on the building for reasons that will be explained later. The building is operated by an owner-manager and has as its tenants a major industrial corporation, a number of small trade associations, other small offices, a news-wire service, a print shop, and a high volume cafeteria. The management of the building gathered the data for us. We did not encounter any problems in obtaining the tenants' assistance and cooperation, although we understand that such problems can occur.

Building Characteristics

Roof and wall areas, and building height were easily obtained from the building's plans. Amounts of glass wall area were obtained by counting the windows and doors and multiplying by the appropriate areas per unit. Square feet of building area by function were obtained from observation. No data on air infiltration were available. Infiltration occurs due to improperly fitted windows and doors and from the deterioration of the building's caulking over time. Even the best building caulking loses its effectiveness after a few years, and buildings are usually recaulked only when undergoing a major renovation. Recaulking the windows of a tall building is costly due to the extensive safety precautions which must be undertaken. One would therefore expect to find buildings which have not been recaulked within the last 10 years to be subject to substantial infiltration of outside air. Infiltration may be very important in determining building energy use. In Empirical and Simulation Analyses of Energy Use in Commercial Buildings, Hittman Associates found that, based on an energy simulation model, infiltration and ventilation made up nearly 80 percent of the total heating load.[1)]

Building operating schedules

The building management was able to furnish heating, cooling, and hall lighting schedules with no problem. Information on lighting use by the tenants was obtained directly from the larger tenants and by casual observation of the smaller tenants.

Building internal conditions

Thermostat settings and setbacks were obtained from the building management. Lighting levels in terms of watts/sq. ft. were obtained with substantial effort. Rather than conduct a limited sampling, we decided to count every lamp in the building, and we found some surprising results. As expected, the levels of lighting varied among office areas, corridors, the restaurant, and other areas. However, the level of lighting within office areas varied by as much as a factor of 3. The history of relamping, renovation, and tenant changes as well as type of office use has apparently had a significant effect on the installed watts/sq. ft. If we had based our lighting information on a limited sampling of the space we

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[1)] P. M. McCarthy, R. F. Patel, and B. Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, Final Report, Prepared under FEA Contract CO-04-51888-00, Columbia, Maryland, Hittman Associates, February 1977.

would not have made this discovery. We understand from TSH that building managers are generally unable to furnish accurate information on the watts/sq. ft. unless a special survey is conducted; our experience in examining lighting levels confirms the difficulty of obtaining accurate lighting data. In examining a number of the watts/sq. ft. data items furnished by building managers for the 44 building sample conducted in New York City, TSH found that the actual and reported watts/sq. ft. differed significantly.

Equipment loads were obtained with substantial effort. Most equipment has a plate giving the horsepower, ampere, or kw rating. We found approximately 100 pieces of equipment in the cafeteria for which we had to determine the kw capacity from the name plate and the hours of usage per day from the cafeteria management. In the rest of the building, we found photocopying machines, computer terminals, typewriters, printshop equipment, coffee pots, and various types of news-service equipment. We were generally able to obtain the kw ratings of the equipment but were not always certain of the usage per day.

Ventilation settings were obtained from the management; however, this data was less useful than one would have wished due to our lack of information on infiltration.

HVAC Information

The building engineer furnished the kw ratings for the various fans, pumps, and other parts of the HVAC system by noting the information on the equipments' name plates. In a number of cases we converted horsepower figures to kw figures. We were unable to determine whether the equipment was correctly sized for the loads in the building or to obtain information on the partial load efficiencies of the equipment. In a few cases, there was some difficulty in determining the equipment's hours of usage. The nameplates for the boilers were missing; we were unable to determine the capacities of the boilers. The lack of information on the boiler capacities, the partial load characteristics of the equipment, the sizing of some equipment, and certain usage schedules might have affected the results of the building simulation. Building zoning was furnished by the building engineer.

Weather data

A weather data tape for the Washington, D.C. area was obtained from the National Oceanic and Atmospheric Administration (NOAA). We understand that substantial effort is generally required to enter these tapes into a computer system, because errors in the NOAA tape must be corrected and problems of computer transferability solved.

For the 12 story office building we estimate that approximately 50 hours of effort went into the initial collection of the data and that another 40 hours of effort were involved in analyzing the data and collecting supplementary input for the AXCESS program. After we had collected the data we reviewed the results with Syska and Hennessy Information Systems (SHIS)[1]. We agreed that some data were deficient. The lack of information on the boiler capacities, information on the part load characteristics of the HVAC equipment, and information on whether the HVAC system had originally been sized correctly to meet the building loads could have significantly affected the accuracy of the AXCESS program in predicting energy use. SHIS's opinion was that without resolution of the data problems, a simulation of the building would not yield accurate results. Accordingly, no simulation of the Washington, D.C. building was conducted. However, we believe that the data gathering effort was useful in illustrating the lighting level, infiltration, and HVAC data gathering problems which occur in the analysis of energy use in a building. Inaccurate information for these crucial inputs may result in the simulations having a significant error.

THE AXCESS SIMULATIONS

We used the AXCESS program to simulate energy consumption in 5 New York City office buildings for which TSH had developed an extensive data base as part of another DOE contract. Despite the substantial data gathering efforts which had been conducted by TSH, the data base lacked information on building zoning, HVAC equipment kw ratings, and information on the part load efficiency of the HVAC systems. Where a needed data item was not available, SHIS used a default value in

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1) Syska and Hennessy Information Systems (SHIS) is a subsidiary of Syska and Hennessy.

performing the simulation; the program has a number of default values for cases in which data are lacking. The choice of which 5 buildings to simulate was made by TSH: as part of its separate DOE contract, TSH simulated the five buildings on the AXCESS program but had professional engineers conduct surveys of the buildings to verify and supplement building information in lieu of using the information supplied by the building managers and the default values available in the program. For our simulations we relied on default values and conducted an every third day simulation for budgetary reasons.[1)]

Our simulations represent the types of simulations that could be run based on information which could be obtained from a building manager with very limited on site inspection. As such, the simulations are not a test of the AXCESS program. What we are examining or testing is the possibility of simulating buildings based on a limited amount of data which could conceivably be obtained via questionnaire from a building's management. We then compared the predicted values with the actual values. The simulations conducted by TSH with substantially greater data input might very well be considered a test of the program's predictive ability.

A general description of the buildings in terms of their more important characteristics may be found in Table 4-1. The HVAC system characteristics are presented in Table 4-2. The results of the simulations for the 5 buildings are in Table 4-3.

The predictive power of the AXCESS program using only partial input data appeared to be limited, for in most cases the predicted energy use was substantially different from the actual energy use. Since we had a sample of five AXCESS simulations, we used the Smith-Satterwaite test to examine whether the means of the predicted and actual values could be stated to be statistically different. As can be seen from Table 4-4 the t values are such that one would not reject the hypothesis that the variations are due solely to chance. Therefore, on the basis of

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[1)] A short form simulation with every third day simulated was used. The assumptions by the analyst and by the computer program's automatic use of default values in estimating data items which were not in the data base may have reduced the program's accuracy.

the statistical analysis, one can not state that the AXCESS program was statistically shown to be unsuccessful in predicting building energy use (or to restate what we have done in more conventional, but statistically inaccurate, terminology, the experiment was a success).

Even though the experiment was a success, we were concerned about the substantial variations between predicted and actual values in individual cases, and we attempted to determine the reasons for the substantial variations between the actual and predicted values for energy use.

1. Data deficiencies: A nine section questionnaire designed to be executed in the field for each building under the direction of a professional team familiar with the construction and operation of office buildings was used to gather the information from building managers. Although the data were gathered carefully, TSH concluded that some of the data being furnished by the building managers had been estimated on the basis of various design standards, codes, and guesses rather than through an examination of the actual physical parameters of the buildings. TSH indicated to us several times that building managers do not have an accurate knowledge of their building operating systems and their usage. Accordingly, there was a substantial opportunity for errors to be recorded in the data bank. Based on additional work in the gathering of data for the intensive analysis of the five buildings, TSH found that the lighting levels had been significantly misspecified in some cases. Building managers frequently did not have an accurate perception of the overall levels of lighting in their buildings. The actual level of lighting in watts/sq. ft. as determined by TSH engineers became available subsequent to the running of the AXCESS program. A review of the data in Table 4-1 indicates that the level of lighting as perceived by the managers was significantly different from the actual level of installed lighting. Other parts of the data base used or assumed in the simulations may also have been in error. At this time we are unable to specify whether or which data misspecifications resulted in error; however, when the results of the 5 complete AXCESS simulations become available, it will be possible to compare the correct set of inputs with the inputs to the five simulations presented in this report. We may then have a better idea of some of the possible sources of error.

Recognizing that the AXCESS simulations were generating predicted values substantially different from the actual, historical values, SHIS ran the simulations for three of the buildings--472, 487, and 650--with different assumed levels of lighting than were reported in the data base collected from the building managers, holding all other variables and assumptions constant. The revised lighting assumptions are reported in Table 4-5, and the accuracy of the simulations improved. It is not clear why the results improved, because the revised lighting assumptions were in fact subsequently shown to be less accurate for buildings 487 and 650 than had originally been assumed. The results are presented in Table 4-6.

The AXCESS program is based on generally accepted and observed physical relationships and has a number of internal consistency and overall balance checks. One could therefore assume that if the BTUs specified on a total energy basis and by electric and fuel use were correct, the balancing relationships would permit one to fit the ratios of energy use by end use function to total actual energy use to obtain a reasonably close approximation of actual energy use by end use function. We took the results of Table 4-6 for buildings 472, 487, and 650 and the results of Table 4-3 for buildings 140 and 996 and fitted the ratios of energy use by function as determined by the simulations to the actual energy use in the buildings. The results are presented in Table 4-7.

In Energy Conservation in Existing Office Buildings, TSH simulated two buildings using the AXCESS program: one building--number 930--was considered to be a typical building for New York City; the other building was a hypothetical building with its characteristics based on the mean values for the buildings in the 44 building sample for 1975.[1)] Table 4-8 presents the results of the simulations. In the case of both buildings the values predicted by the AXCESS program were relatively close to the actual, observed values for total energy use. For building 930 the agreement of the predicted values with actual electric and actual steam use was substantially less. The errors apparently cancelled out on a total energy use basis. We were unable to compare computed and actual energy use for electricity and fuel in the case of the hypothetical building, for we were unable to find the mean values for electricity and fuel usage in the report.

[1)] Tishman-Syska and Hennessy, Energy Conservation in Existing Office Buildings, Prepared for the U.S. Energy Research and Development Administration under Contract Number EY-76-02-2799.000, June 1977, pp. D-1 - D-2.2.

One of our major reasons for wishing to use the AXCESS program was to be able to estimate the end uses of energy by function. Table 4-9 presents the end uses by function for the hypothetical "average" New York City office building reported in Table 4-8. The simulation of the hypothetical building predicted a level of energy use of 124,000 Btu/sq. ft., in comparison to the actual 1975 energy consumption of 115,000 Btu/sq. ft. In the report TSH simulated energy use by end use for the hypothetical building. We have ratioed the predicted energy end uses so that the total energy use equals the 115,000 Btu/Sq. Ft. actually incurred in 1975 by an "average" building.

INFORMATION ON OTHER ENERGY SIMULATION PROGRAMS

We also reviewed the available information on the General Electric SHACOB building thermal model and the ECUBE, NECAP, Ross Meriwether, and TRACE energy simulation programs. Our objective was to collect information on 2 aspects of the programs:

- how well the programs predict actual building energy use based on building characteristics and usage;
- to what degree attempts to create a data base through simulation of the models have been successful.

The General Electric Model

The Solar Heating and Cooling of Buildings (SHACOB) program was developed by the Energy Systems Programs Operation of GE's Space Division, with support from GE's Marketing Research Consulting Services, GE's Center for Advanced Studies (TEMPO), the University of Pennsylvania, and the Ballinger Company.[1)]

[1)] Solar Heating and Coooling of Buildings. Phase 0 Feasibility and Planning Study Final Report for the National Science Foundation. GE Space Division, Report NSF-RA-N-74-021, Document No. 74SD 4219; Valley Forge, Pennsylvania, May 1974.

One of the requirements of the SHACOB study was to analyze the potential market for solar systems that would be capable of providing all or part of the energy for heating and cooling buildings. In order to undertake this analysis, the GE SHACOB study team developed an inventory of various types of buildings which might be future candidates for SHACOB systems, and estimated their heating and cooling energy requirements. The thermal load program which was developed was used to calculate building heating and cooling loads on an hourly basis by summing conduction heat losses and gains, infiltration losses and gains, internal heat gains (sensible and latent for people, electrical appliances, etc.) and solar heat gains through the windows. The model was designed on the basis of information in the various ASHRAE publications. The resulting program was a load program rather than an energy use program. To obtain projected energy use on the basis of the program it was necessary to assume an energy efficiency factor for heating and cooling.

We took the load data obtained from the SHACOB work and attempted to develop a data base for 11 types of commercial buildings in terms of energy use for heating and cooling, hot water, lighting, equipment, and auxiliaries in 12 different climate areas. The results of a comparison of these data with those reported in Volume II of this report led to the conclusion that the level of error for a number of the building types in the data base was too high to permit the use of the data base. We discussed the SHACOB program with its developers and gained some insight into the modeling problems.

1. The specification of lighting levels and lighting usage is important. For most of the building types it is likely that the installed lighting meets whatever design standards were in effect at the time the structure was built. However, very little is known about the actual usage of the lighting.

2. Accurate data on what types of fuels are used by commercial buildings do not exist. At this time it is impossible to state with any accuracy the percent of the commercial building fuel supply market held by the different types of fuels in each area of the country.[1)] The four major fuels are also burned with different efficiencies.

3. The specification of the efficiencies of the boilers and furnaces in commercial buildings is difficult. Older equipment is less efficient than newer

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[1)] For a different view on this the reader can consult the JFA report. However, the fuel market in that report is at the commercial sector level, not at the building type level.

equipment, but there are no data on the age distributions of the equipment or their efficiency.

4. Information on the types of appliances and other equipment present in buildings and their usage is limited. Appliances and other equipment may consume significant amounts of energy in many types of buildings.

5. The types of HVAC auxiliaries will vary from building to building depending upon the types of air handling systems used. Although there is a substantial literature on the subject of auxiliaries, there are no easy "rules of thumb" which will permit the estimation of their energy usage for heating and cooling purposes. The actual development of data on energy use by auxiliaries requires a relatively complex set of calculations which are based on estimates of kw of installed fan and pump power and simulation for the hours of operation.

6. Finally, the SHACOB program was a simple load program designed to permit a large number of simulations inexpensively; the designers of the program were not interested in obtaining precision. In some cases the data which we obtained seemed to be of good quality; in other cases the data were clearly incorrect.

ECUBE Program

The ECUBE program is maintained by the American Gas Association. The program has been validated in a study of the Brooklyn Union Gas Company's general office building and the two adjoining bank buildings, which are supplied heating and cooling from the Brooklyn Union central plant. Table 4-10 presents the comparison of the simulated and actual values. The agreement is good for total gas and electric use.

The ECUBE program was used by the Rand Corporation in Energy Conservation in Nonresidential Buildings to simulate energy use in a number of hypothetical buildings located in various areas of the country.[1)] A 20 story office

[1)]Richard G. Salter, Robert L. Petruschell, and Kathleen A. Wolf, Energy Conservation in Nonresidential Buildings, R-1623-NSF, October 1976.

building with gas fired boiler and electric air conditioning was simulated under a variety of lighting level intensities and wall and roof U values. The ECUBE program is a proprietary program, and RAND had no way in which to evaluate its accuracy; however, RAND did evaluate the ability of the program to simulate the ASHRAE equations and concluded that the program was accurate in portraying the behavior predicted by the equations.

During a survey of available information on commercial office buildings as reported in Section 2 of this volume we collected information on the RAND simulations. In this section we are interested in examining how well the program simulated energy use in comparison to the stock of buildings actually in existence. Table 4-11 indicates a disparity in total energy use between the average BOMA building and the buildings postulated by RAND. However, this does not necessarily indicate any deficiencies in the RAND ECUBE simulations because the characteristics of buildings postulated by RAND may be different from those of the average BOMA building.[1)]

- The buildings in the BOMA data base are not new, may be subject to substantial infiltration of air, and probably do not have the highly efficient equipment hypothesized in the RAND study.
- The BOMA buildings are not predominantly gas fired. In fact, we found no gas fired commercial buildings in the New York City BOMA data base.
- The usage schedules of the BOMA buildings and the hypothetical building specified by RAND may be significantly different. Furthermore, there may be substantial differences between the equipment actually in place in the BOMA buildings and that hypothesized by RAND.

[1)] However, it should be noted that the hypothetical buildings specified by RAND would be considered to be Class A buildings, as is the case for the buildings in the BOMA sample.

In Energy Conservation Applied to Office Lighting, Ross and Baruzzini performed a number of simulations of the ECUBE program.[1] These are presented in Table 4-12 along with the actual 1975 data from the BOMA sample. The differences between the hypothesized energy use and the actual energy use was substantial. Here again, one could assume that the buildings actually in the stock of commercial buildings are designed and operated differently from that hypothesized by Ross and Baruzzini.

NECAP Program

Hittman Associates simulated and collected actual data on steam and electricity use in two buildings in Baltimore. The results are presented in Empirical and Simulation Analyses of Energy Use in Commercial Buildings.[2] Table 4-13 presents the comparison. For the office building the agreement was very good between the simulated and actual values. For the bank building the predicted usage for electricity was low by 15%. This error may have been the result of problems in estimating the loads generated in supporting heavy computer usage in the building.

Ross Meriwether Program

Both Arthur D. Little and MATHEMATICA used the Ross Meriwether program in analyzing office building energy use.[3] We were unable to find any direct comparisons of estimated and actual data for a building simulated by the program, but we understand that the program is generally accepted as being comparable to

1) Ross and Baruzzini, Energy Conservation Applied to Office Lighting, FEA Contract No. 14-01-0001-1845, April 15, 1975; the simulations are on p. III-17. The building simulated was a 20 story, 312,500 squ. ft. building with gas heat and electric air conditioning.

2) Patrick M. McCarthy, Rusi F. Patel, and Burton Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, prepared under FEA Contract CO-04-51888-00, Hittman Associates, Columbia, Maryland, February 1977.

3) Arthur D. Little, Energy Conservation in New Buildings Design, An Impact Assessment of ASHRAE Standard 90-75; FEA Conservation Paper No. 43B; J. A. Orlando, L. G. Spielvogel, and H. Weed, Feasibility of an Energy Index for Office Buildings, (prepared under FEA Contract CO-04-50238-00), Princeton, New Jersey, MATHEMATICA, August 10, 1976.

the other major energy simulation programs which we have examined. ADL used the program to simulate energy use in office buildings in 4 Census Divisions; the data were earlier reported in Table 2-1 and are reproduced in Table 4-14 along with some corresponding data items from the BOMA data base. There is a substantial difference between the ADL/Ross Meriwether simulations and the BOMA actual energy use numbers. The ADL simulations were based on a 3 story, suburban office park type of building, while the BOMA buildings are predominantly downtown, tall buildings. Nevertheless, the differences between the two data bases are so substantial that one would think that they were caused by other differences in addition to height: in our regression and other work we found that height was a relevant variable, but only one of a number of such variables.[1] The differences may be due to differences in building utilization, structural configuration, building maintenance, or program accuracy.

Trace Program

The TRACE program, which is marketed by the Trane Corporation is based on the U.S. Postal Service program TACS (Thermodynamic Analysis Computer System). The TACS has the potential to calculate the heat gain, heat loss, and energy requirements in buildings ranging from 3,000 square feet to millions of square feet. Trane modified the TACS program, by simplifying the input data, increasing the program's capability to handle alternative types of heating systems, and, in general, changing and simplifying the procedures which must be used to simulate a building. The program may be accessed via time share. Of the combined volume of energy simulations currently being performed on buildings, a significant proportion are run on the TRACE program. Trane has had experience with over 3,000 simulations with the program. Table 4-14 presents some additional simulations of the TRACE program as reported in TRANE's promotional literature.

Conclusions on Building Energy Use Simulation Programs

The objective of our examination of building energy use simulation programs was to determine whether a set of building specifications and operating parameters

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1) Height does not appear in the regressions subsequently reported in this volume due to its multicollinearity with square feet.

could be used to predict building energy use, both on a total basis and by function. This is an approach which has been used by both ADL and RAND, and --if correct-- could be used to generate a complete commercial sector data base on the basis of construction and operating data. When we reviewed the published literature on office building simulations we found cases in which the AXCESS, ECUBE, TRACE, and NECAP programs had been successfully used to predict office building energy use accurately.

In our simulations of five office buildings, we found that the simulated values for energy use were not close approximations of the energy use which actually occurred. We reviewed the results of the simulations with TSH and concluded that the two important factors apparently contributed to the differences between predicted and actual energy use: inaccuracies in the data base, and the absence of a number of crucial data items. The data base which served as the input to the simulations had been collected under a separate DOE contract by TSH from the building managers. A subsequent intensive investigation of the five buildings by TSH engineers found that some of the data had been inaccurately reported. In addition, technical data relating to the capacities of some of the components of the HVAC systems had not been collected. Such data are necessary for the running of the AXCESS program, and the program assumes certain "default" values when actual values are unavailable.

Even with these restrictions on data accuracy and availability, the means of the predicted energy usage were not statistically different from the means of the actual energy usage. SHIS subsequently ran an analysis of the five buildings using the corrected and supplemented data base, and we understand that the accuracy of the predicted energy use to the actual energy use was improved.

We wish to stress that we did not test the accuracy of the AXCESS program. What we did test was the accuracy of simulating building energy use with the AXCESS program using as inputs the types of data that could be readily gathered from building managers and using "default" values in the program wherever necessary. Although the individual simulations were not good predictors of building energy use--due to the inaccuracy of some data and the necessity of making "default" assumptions for some of the values, the five simulations were collectively on target, possibly due to the errors of estimation by various managers cancelling out.

Based on our review of the AXCESS and other energy simulation programs, our conclusion is that energy simulation programs appear to have the capability of accurately estimating office building energy use when the correct inputs for the building zoning, HVAC system, structural, equipment, and operating characteristics have been specified. However, the specification of the proper inputs requires a substantial amount of data collection. We suspect that the programs may be sensitive to misspecifications of the lighting level and the HVAC equipment capacities. The sensitivity of the output to various input specifications probably should be examined.

We believe that for energy analysis purposes, a building energy simulation model would be very useful in estimating end usage of energy, provided that the model were calibrated to the correct total fuel and electricity usages. Although end uses are not metered and one can not therefore know whether they are correctly estimated, the models have internal balancing relationships that provide some safety against incorrect estimation. We also believe that the models could be satisfactorily used for evaluating the results of system design tradeoffs and changing usage patterns. Building energy simulation programs have been designed for both of these purposes and appear to perform them adequately. Provided that the correct inputs are specified, the building models also appear to be able to reproduce actual energy use.

The program with which we have had the least experience is the TRACE program. On the basis of several meetings with TRANE personnel, we have concluded that one of the attractive features of using the TRACE program is the possibility of obtaining input information on current building practices from TRANE's field engineers who are familiar with operating and design practices throughout the country. Furthermore, since a large number of simulations have been conducted with the TRACE program, the home office personnel are also able to provide substantial information on what the characteristics of various types of buildings which are currently being simulated with the program are like, subject to confidentiality restrictions.

Therefore, we recommend that serious consideration be given to building simulations as a way of estimating the end uses of energy and the results of various structural tradeoffs and operating policies. However, we do not believe that such programs can substitute for data gathering efforts on electric and fuel usages in buildings, due to possible difficulties in calibrating the programs to reproduce energy use.

TABLE 4-1
BASIC CHARACTERISTICS OF FIVE BUILDINGS
SIMULATED BY THE AXCESS PROGRAM

Building Number	140	472	487	650	996
Building Age	14	46	24	6	65
Number of Floors - Total	43	25	13	48	25
Above Grade	41	23	11	45	22
Below Grade	2	2	2	3	3
Lighting - Watts/Sq. Ft. (TSH Data Base)	2.5	4.5	2.5	3	Unknown 1)
Actuals 2)	1.482	2.096	2.193	2.579	2.09
Occupancy					
No. of Persons Working in Building During Normal Hours	4,500	300	1,740	5,800	Unknown
Average % Occupancy of Gross Sq. Ft.	88%	98%	95%	100%	98%
Gross Sq. Ft.	968,449	125,000	391,673	1,842,494	136,000
Office Sq. Ft.	621,283	83,860	282,497	1,332,776	106,500
Computer Sq. Ft.	14,076	0	13,921	11,000	0
Commercial Sq. Ft.	65,892	3,000	5,745	52,316	9,500
Sq. Ft. of Wall Area (% Glass in Parantheses)					
North	90,327 (19%)	4,880 (18%)	34,975 (20%)	171,606 (44%)	12,000 (10%)
South	90,623 (19%)	21,300 (24%)	32,311 (23%)	171,536 (44%)	35,000 (29%)
East	62,087 (16%)	13,940 (13%)	14,808 (6%)	71,628 (45%)	13,000 (20%)
West	69,006 (17%)	12,640 (27%)	24,497 (21%)	68,573 (41%)	9,000 (29%)
Roof Area	36,845	5,000	29,600	56,422	7,400
Summer Design Temperature	77	NA	75	74	Unknown
Winter Design Temperature (Day/Night)	71/65	75/55	68/60	72/50	70/45
Hours of Perimeter Heating (Weekday)	10	24	16	13	6
Hours of Perimeter Cooling	10	0	16	13	8

1) A light level of four watts per square foot was assumed.
2) Actual light levels were determined by TSH engineers.

TABLE 4-2

HVAC SYSTEM CHARACTERISTICS OF FIVE SIMULATED BUILDINGS

	140	472	487	650	996
Heating System	Steam	Steam	Steam	Steam	Oil
Heating Auxiliaries (kw)[1]	43	6	20	82	6
Interior System	Variable Volume with reheat	Variable volume with reheat	Variable volume with reheat	Variable volume with reheat	Radiation heating
Fan Power of Iterior System	524	188 kw	245	1204 kw	
Perimeter Systems	Two pipe induction		Two pipe fan coil	Two pipe induction	Unitary Heat pump
Fan Power of Perimeter System[1]	732 kw		88	976 kw	
Cooling	Steam turbine chillers	Electric DX Units	Steam Turbine	Steam turbine and steam absorption	Local Air Conditioning of 50 tons, window units
Cooling Auxiliaries (kw)[1]	400	50	280	1500	-----
Economizer	Enthalpy	Below 65°DB	No	No	Enthalpy

[1] These values were assumed.

TABLE 4-3

RESULTS OF AXCESS PROGRAM SIMULATIONS
BTU/Sq. Ft.[1)]

	Building Number				
	140	472	487	650	996
al Actual Energy Use	128,729	65,960	111,320	160,570	86,986
otal Predicted Energy Use	89,297	84,920	75,117	114,291	82,365
/Actual	-.3063	.2874	-.3252	-.2882	-.0531
tual Electric Use	25,457	33,721	64,221	55,728	23,616
redicted Electric Use	34,390	61,031	37,891	50,272	28,537
/Actual	.3509	.8099	-.4100	-.0979	.2084
tual Fuel Use	103,272	32,239	47,099	104,842	63,370
dicted Fuel Use	54,907	23,888	37,227	64,019	53,828
Δ/Actual	-.4683	-.2590	-.2096	-.3893	-.1506
lectric Use by Function					
Lighting	23, 955	46,409	30,939	39,159	26,511
Auxiliaries	652	1162	1,409	2,376	68
Fans	9159	7063	4,915	8,106	
Other	634	633	630	632	633
Air Conditioning		5765			1,325
eam Use by Function					
Heating	33, 871	22,999	10,638	21,863	
Cooling	19,314		24,940	40,990	
Hot Water	1723	890	1,647	1,167	
Use					
Heating					50,925
Hot Water					2,903

1) Totals may not add due to rounding.

TABLE 4-4

EVALUATION OF FIVE AXCESS SIMULATIONS
USING SMITH-SATTERWAITE TEST[1)]
BTU/Sq. Ft.

	Mean of Five Cases	Standard Deviation for Five Cases	t´	Degrees of Freedom
Total Energy Use				
Actual	110,713	36,662	1.215	5
Predicted	89,198	14,941		
Electric Use				
Actual	40,549	18,384	.186	7
Predicted	42,424	13,093		
Fuel Use				
Actual	70,164	32,845	1.43	6
Predicted	46,774	16,033		

1) $t' = \dfrac{X_1 - X_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}}$; degrees of freedom are $\dfrac{\left(S_1^2/n_1 + S_2^2/n_2\right)^2}{\dfrac{\left(S_1^2/n_1\right)^2}{n_1 - 1} + \dfrac{\left(S_2^2/n_2\right)^2}{n_2 - 1}}$

TABLE 4-5

COMPARISON OF LIGHTING ASSUMPTIONS IN
AXCESS PROGRAM SIMULATIONS

Building Number	Original Lighting Assumption	Revised Lighting Assumption	Actual Lighting Level as Subsequently Determined by TSH Engineering
472	4.5	3	2.096
487	2.5	4	2.193
650	3	4	2.579

TABLE 4-6

ALTERNATIVE AXCESS SIMULATIONS
BTU/Sq. Ft.[1]

	Building Number		
	472	487	650
Total Actual Energy Use	65,960	111,320	160,570
Total Predicted Energy Use	72,348	100,849	122,535
Δ/Actual	.0817	-.0941	-.2369
Actual Electric Use	33,721	64,221	55,728
Predicted Electric Use	43,417	58,584	57,483
Δ/Actual	.2875	-.0878	.0315
Actual Fuel Use	32,239	47,099	104,842
Predicted Fuel Use	27,931	42,257	65,052
Δ/Actual	-.1336	-.1028	-.3795
Electric Use By Function			
Lighting	30,930	49,488	45,685
Auxiliaries	992	1,980	2,554
Fans	5,967	6,486	8,612
Other	632	630	632
Air Conditioning	4,896		
Steam Use By Function			
Heating	27,041	7,173	20,476
Cooling		33,437	43,410
Hot Water	890	1,647	1,167

[1] Totals may not add due to rounding.

TABLE 4-7

ENERGY USE IN FIVE NEW YORK CITY OFFICE BUILDINGS, END USES ADJUSTED TO EQUAL TOTAL ACTUAL USE BTU/Sq. Ft.[1]

Building Number	140	472	487	650	996
Total Actual Energy Use	128,729	65,960	111,320	160,570	86,986
Total Actual Electric Use	25,457	33,721	64,221	55,728	23,616
Estimated Electric Use by Function					
Lighting	17,733	24,023	54,250	44,290	21,939
Air Conditioning		3,803			1,096
Auxiliaries	483	770	2,171	2,476	56
Fans	6,774	4,634	7,110	8,349	
Other	469	491	691	613	524
Total Actual Steam Use[2]					
Estimated Steam Use by Function					
Heating	63,706	31,212	7,995	3,300	59,952
Cooling	36,327		37,268	69,962	
Hot Water	3,241	1,027	1,836	1,881	3,418

[1] Totals may not add due to rounding.
[2] For building 996 this is oil use.

TABLE 4-8

AXCESS SIMULATIONS FOR BUILDING
930 AND FOR HYPOTHETICAL NYC BUILDING
BTU/Sq. Ft.

	Building 930[1] BTU/Sq. Ft.	Hypothetical Building[2]
Electric Use		
Actual	56,609	
Estimated	47,663	
Δ/Actual	-.1580	
Steam Use		
Actual	18,384	
Estimated	24,795	
Δ/Actual	.3487	
Total Energy Use		
Actual	74,993	115,000
Estimated	72,458	124,000
Δ/Actual	-.0338	.0783

[1]Building 930 was 41 years old in 1975; 22 stories tall; 311,000 square feet of area; lighting level of 4 watts/sq. ft.; steam heat; electric air conditioning.

[2]The hypothetical NYC building was based on the average of the 44 buildings: 44 years old; 24 stories; 401,000 sq. ft.; 2.8 watts/sq. ft. of lighting; steam heat; electric air conditioning.

TABLE 4-9

ENERGY USE BY END USE FOR AN "AVERAGE" NEW YORK CITY OFFICE BUILDING, PREDICTED TOTALS ADJUSTED TO EQUAL ACTUAL TOTALS, 1975[1)]
BTU/Sq. Ft.

Total Actual Energy Use[2)]	115,000 244,000 primary
Total Actual Electric Use[2)]	54,231
Estimated Electric Use by Function	
Lighting	25,937
Air Conditioning	15,103
Fans	11,925
Other	1,271
Total Actual Steam Use[2)]	61,194
Estimated Steam Use by function	
Heating	58,784
Hot Water	2,409

1)Based on data found on p. D-2.2 of Energy Conservation in Existing Office Buildings. The sums of the end uses have been adjusted to equal the actual energy use, subject to rounding errors.

2)Totals may not add due to rounding.

TABLE 4-10

VALIDATION OF ECUBE PROGRAM
ON BROOKLYN UNION GAS COMPANY BUILDING[1)]

Electricity (kwh)	
Total Actual	6,336,000
Total Computed	6,044,255
Δ/Total Actual	-.0460
Gas (MCF)	
Total Actual	65,972
Total Computed	63,217
Δ/Actual	-.0418

[1)]The Brooklyn Union Gas Company building is a 14 story general office building; the 2 adjoining four story bank buildings were included in the study since they are supplied cooling and heating with chilled and hot water from the Brooklyn Union Central Plant. The combined air conditioned floor area of the buildings is approximately 270,000 square feet. The perimeter system is induction, the central fans have reheat. The building is gas fired.

COMPARISON OF RAND ECUBE SIMULATIONS WITH BOMA ACTUALS[1)]
MBTU/Sq. Ft.

City	Simulation Number	ECUBE SIMULATION Total Energy Use	BOMA ACTUALS Total Energy Use
New York	B -3	102.3	132.0
	B -6	61.7	
	A-16	93.0	
	A-19	70.0	
Detroit	A-49	115.7	133.0
Minneapolis	A-42	125.4	163.0
St. Louis	A-44	101.0	175.6
Atlanta	B-10	91.2	131.0
	B-12	62.0	
Dallas	A-47	88.4	209.8
Denver	A-48	113.0	240.5
Los Angeles	B-16	74.8	131.2
	B-18	59.8	
	A-36	68.3	
Seattle	A-52	96.3	122.9

1) The RAND simulations are from Section 2, Tables 2-1. All simulations are for a lighting level of 2.7 watts/Sq. Ft. The "BOMA Actuals" are for the year 1975. The numbers of buildings and types of buildings in the BOMA Actuals are as follows:

New York:	27 steam heated buildings
Detroit:	2 steam heated buildings
Minneapolis:	12 steam heated buildings
St. Louis:	4 steam heated buildings
Atlanta:	2 gas heated buildings
Dallas/Ft. Worth:	6 gas heated buildings
Denver:	8 gas heated buildings
Los Angeles:	7 gas heated buildings
Seattle:	17 steam heated buildings

Table 4-12

Comparison of Ross and Baruzzine ECUBE Simulations with BOMA Actuals[1]
MBTU/Sq.Ft.

City	Lights Watts/Sq.Ft.	ECUBE Simulation Total Energy Use	BOMA Actuals Total Energy Use
New York	2	67.8	132.0
	3	78.3	
Minneapolis	2	84.7	163.0
	3	92.7	
	4	102	
St. Louis	2	70.3	175.6
	3	79.2	
	4	90.6	
Atlanta	2	61.1	131.0
	3	70.6	
Houston	2	55.9	213.1
	3	66.4	
	4	75.1	
Denver	2	61.1	240.5
	3	70.6	
Los Angeles	2	58.3	131.2
	3	68.7	

[1] The numbers and types of buildings in the BOMA sample are the same as are reported in Table 4-11. In addition, we have included Houston with 21 gas fired buildings. Ross and Baruzzini, Energy Conservation Applied to Office Lights, FEA Contract No. 14-01-0001-1845, April 15, 1975.

TABLE 4-13

SIMULATION OF TWO BUILDINGS IN BALTIMORE[1)]

	Office Building[2)]	Bank Building[3)]
Electricity (10^6 kwh)		
Actual	7.02	8.00
Predicted	6.72	6.75
Δ /Actual	-.0427	-.1562
Steam (10^6 lbs)		
Actual	55.5	13.142
Predicted	58.2	11.365
Δ /Actual	.0486	-.1352

[1)]Patrick M. McCarthy, Rusi F. Patel, and Burton Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, Prepared under FEA Contract CO-04-51888-00, Hittman Associates, Columbia, Maryland, February 1977.

[2)]The office building contained a small computer facility. The building was operated 10 hours/day, 5 days per week. 681,000 square feet; 17 stories tall; 9 years old, District steam for heating, cooling, and hot water. Central HVAC is constant volume dual duct and perimeter is 2 pipe fan coil. Absorption cooling.

[3)]A large computer facility is in this building. Building is operated 24 hours per day, 7 days per week; 350,000 square feet, 11 years old, 11 stories. Constant volume reheat 2 pipe HVAC system; fan coil perimeter units. District steam heating and absorption cooling.

TABLE 4-14

COMPARISON OF MATHEMATICA/ROSS MERIWEATHER
SIMULATED DATA BASE WITH ACTUAL DATA
MBTU/Sq. Ft.

	Mathematica Estimates[1] Total Energy Use	BOMA Actuals[2] Total Energy Use
Philadelphia		151.6
Gas Heating, Electric Cooling	97.4	
Purchased Steam, Electric Cooling	87.1	
Absorption Cooling and Steam Heating	138.6	
Atlanta		
Gas Heating, Electric Cooling	92.2	131.0
Chicago		
Gas Heating, Electric Cooling	107.4	214.4

[1] J. A. Orlando, L. G. Spielvogel, and H. Weed, Feasibility of an Energy Index for Office Buildings, prepared under FEA Contract CO-04-50238-00, Princeton, New Jersey, MATHEMATICA, August 10, 1976.

[2] Computed on the basis of the 1975 BOMA data base.
Philadelphia: 15 steam heated buildings
Atlanta: 2 gas heated buildings
Chicago: 6 gas heated buildings.

TABLE 4-15

TWO VALIDATIONS OF THE TRACE PROGRAM

Office Building[1]	
Electricity	
Actual (kwh)	6,210,395
Predicted (kwh)	5,875,338
Δ /Actual	-.0540
Gas and Oil (therms)	
Actual	1,058,783
Predicted	1,033,133
Δ /Actual	-.0242
Industrial Plant[2]	
Electricity (kwh)	
Actual	16,725,402
Predicted	16,900,000
Δ /Actual	.0104
Coal (therms)	
Actual	1,172,100
Predicted	1,172,100
Δ /Actual	-.0001

[1] Trane Company LaCrosse, Wisconsin Administrative Building, 3 stories, 170,000 square feet; the figures are for 1972-1973.

[2] Located in Lexington, Kentucky; 1972 data.

SECTION 5

THE BOMA DATA BASE

INTRODUCTION

The Building Owners and Managers Association International (BOMA) collects annually from its membership data on commercial office building characteristics and operating performance. BOMA's membership is composed of approximately 4,000 owners and managers in the high-rise office building industry, and the combined office space operated by BOMA members exceeds 550 million square feet, or about 18% of the nation's total inventory of office building space in 1975.[1] As a trade association, BOMA and its local member groups sponsor seminars, workshops, publications, conventions, surveys, and other types of industry activities. The BOMA Downtown and Suburban Office Building Experience Exchange Report, whose first edition contained data for the calendar year 1922, is based on a questionnaire circulated to the membership; a copy of the form used to gather data for the 1975 edition is in Appendix A.

The 1975 edition of the Experience Exchange Report contained information for 963 buildings in approximately 100 U.S. cities with over 242 million square feet of space. This coverage is about 8 percent of the total square feet of commercial office space in the United States. Only aggregate data are reported; data on individual buildings are not released. Participation in the Experience Exchange Report is voluntary. Although in preparing the report the BOMA staff eliminates data which are obviously incorrect, the data base for 1975 was not subjected to extensive verification.

[1] The percent was computed on the basis of 3,082 million square feet of office space in existence in 1975 as reported in Volume 1 of this report. In addition to the U.S. buildings the 1975 BOMA data base contained 60 Canadian buildings with over 12 million square feet of office space.

DATA BASE DEVELOPMENT

Items from BOMA Data Base

We obtained access to the BOMA data base for the years 1974, 1975, and 1976. Table 5.1 presents a list of the data items which we obtained from BOMA on a building-by-building basis; all data were furnished in computer card deck form. We obtained weather data from the National Oceanic and Atmospheric Administration's "Local Climatological Data". [2)]

BOMA furnished the data under the following conditions:

- that we would not be furnished the building address, thereby preserving the anonymity of the individual buildings.

- that we would not release any data to a third party except in aggregate form.

- that we would return all data cards and any record containing individual building data at the conclusion of the work and would purge the BOMA data base from our computer system upon completion of the contract.

BOMA agreed to retain the data and all working papers returned to BOMA for three years and to provide for additional inspection and use of the data as necessary. In summary, we obtained only the right to use the data for a limited time. We also entered into a consulting arrangement with BOMA in order to obtain assistance in interpreting and verifying the data. All contact with individual owners and operators was made through the BOMA staff and BOMA's economic consultant.

Establishment of the 1975 Data Base in the Computer

We received the requested data items for the years 1974, 1975, and 1976 on decks of computer cards. However, only the 1975 data were processed and analyzed. Resource constraints precluded the examination of 1974 and 1976 data. All of the Canadian buildings were eliminated from the data base. All buildings for which no energy data were present—either in the form of dollars or quantities—were also eliminated.

[1)] The heating and cooling degree days for each city were based on the nearest weather station. In general, these stations are located at the airport.

The data base was regionalized by Census Division and by city in order to provide for easy access to all buildings in one city or to all buildings in a given region. We assumed that weather conditions within a city were uniform and that the differences in weather among Census Divisions were greater than the differences within Census Divisions. In some cases—such as the South Atlantic and Pacific divisions—this may have been a questionable assumption.

The data were then entered in the Statistical Package for the Social Sciences (SPSS) program, which was designed to handle large data bases in a relatively inexpensive and computationally efficient manner.[1] We proceeded to verify the accuracy and completeness of the data base.

We wished to have data for each building expressed in terms of BTU's of each fuel—electricity, gas, oil, or steam—used in 1975. The BOMA form provides for the reporting of energy consumption in terms of kwh of electricity, cubic feet of gas, gallons of oil, pounds of steam, and gallons of chilled water. We converted these measures to BTUs using the following factors:

Electricity: 3412 BTU/kwh
Gas: 1024 BTU/Cu. Ft.
Oil: 142,857 BTU/gallon
Steam: 1000 BTU/lb.

In retrospect, the steam conversion appears to have been deficient. The actual BTU content of steam will vary depending on pressure and temperature. The Energy Reference Handbook suggests 1000 BTU/lb., and this figure was also used in the NEMA and Faucett Studies.[2] The AXCESS energy use simulation program uses 1160 BTU/lb., and a steam engineer at Baltimore Gas and Electric stated that his utility furnished steam at 960 BTU/lb. Since steam is used in relatively few cities, we would contact the appropriated steam supplier in major cities in any future work to obtain the local BTU/lb. figure.

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1) Norman H. Nie, C . Hadlai Hull, Jean G. Jenkins, Karin Steinbrenner, and Dale H. Bent, Statistical Package for the Social Sciences, Second Edition, New York, McGraw Hill, 1975.

2) N. C . McNerney and T. F. P. Sullivan, Energy Reference Handbook, Washington D.C., Government Institutes, Inc., 1974; NEMA, op. cit.; Jack Faucett Associates, op. cit.

We eliminated all chilled water data from the data base; chilled water was reported by approximately 50 buildings. Based on conversations with approximately 25 building managers and assistants, it was determined that in most cases the chilled water figures were unreliable and that the chilled water was in general generated by purchased electricity, which was metered elsewhere. Chilled water usage may represent an area for future analysis, for its usage is directly related to the measurement of air conditioning loads.

At this point, the data base was divided into two subsamples: Subsample A contains buildings for which both dollar amounts and quantities of fuel usage were reported; and Subsample B contains buildings for which dollar expenditures but not fuel quantities were reported for electricity use, fuel use, or both. There are 371 buildings in Subsample A and 269 buildings in Subsample B.

Subsample A

After converting energy use to BTU's, we computed BTU/sq. ft. for electricity use, other fuel use, and total energy use. Studies by Arthur D. Little, RAND, NEMA, and Tishman-Syska and Hennessy provided us with some a priori judgments of what the order of magnitude of BTU/sq. ft. should be. Accordingly, we arbitrarily eliminated certain observations that were clearly outside of any reasonable range of expected values on the assumption that the building managers had not filled in properly the energy portions of the questionnaires. In other cases, we corrected the submitted values where there was a reasonable basis for doing so. This procedure was admittedly judgmental, but, in our view, an essential step in the analysis. The harm done by this procedure was far less than would have resulted from either retaining the submitted values or dropping a large number of observations.

In a number of cases, only electric use was reported for a building. Where the amount of electricity appeared to be sufficient for building heating as well as for building lighting and other purposes, we treated the building as an "all electric" building. In cases in which electric use appeared to be abnormally low and in which no other fuel use was reported, we eliminated the building. This may have resulted in the elimination from the data base of some electric buildings with individual tenant metering.

In a number of cases, predominantly occurring in New York City, fuel use appeared to be normal but electric use appeared to be abnormally low. After insuring that one or more zeros had not been rounded off in reporting electric use, we assumed that the building was one in which the individual tenants were metered. Based on our discussions with BOMA and Tishman-Syska and Hennessy, we were able to conclude that in cases in which an office building's tenants were individually metered, the building management might not have obtained total building electric use, and would therefore report kwh for only hall lighting, HVAC fans, and miscellaneous building equipment. These buildings were dropped from the data base.

For cases in which energy use appeared to be abnormal but the addition of three zeros would result in reasonable BTU/sq. ft., the data were adjusted accordingly. In some cases, building managers clearly reported mcf of natural gas rather than cubic feet, thousands of pounds of steam rather than pounds of steam, and thousands of gallons of oil rather than gallons of oil. In cases in which the adjustment of order of magnitude resulted in abnormally high or low figures, or in which the figures for other reasons appeared to be low or high, we eliminated the building from the data base. In conclusion, we eliminated a number of buildings for which we had questions about the order of magnitude of the energy data. We also adjusted a number of orders of magnitude. In doing this we may have statistically biased the sample by eliminating a number of correct observations, and we may have introduced errors in adjusting the orders of magnitude. In some cases we probably eliminated buildings which generate energy for their own use and for resale to other buildings. The adjustments to the data were made after conversations with the BOMA staff and, in a few cases, after conversations with the building manager by the BOMA staff; a substantial amount of judgment based on a priori knowledge was, however, involved. We believe that the remaining data base was reasonably accurate and that additional data verification was not warranted in view of the resources available.

Buildings were classified as "electric", "oil", "gas", or "steam" on the basis of their primary energy source for space heating. There were fewer than 10 buildings in our data base which used significant quantities of more than one fuel in addition to electricity in 1975.

Subsample B

The building managers of the buildings in Subsample B provided dollar expenditures for electricity and fuel but not the quantities of one or more of the fuels used. For example, the building manager of a steam building provided dollars spent on electricity and steam but not quantities of one or both of the fuels. Most of the responses by the building managers were incomplete because building operations and budgets are based on dollar figures, and these figures would be easily accessible to the manager when completing the BOMA questionnaire. In addition to auditing and verifying the figures, as was done for the Subsample A buildings, we also had to develop factors to convert the dollar figures in order to estimate quantities for Subsample B.

We converted dollars spent on electricity and fuel to quantities wherever possible. For each city, we developed price-quantity relationships for electricity and fuels based on the information obtained from Subsample A. We had to exercise substantial care in performing the conversions. For example, in the case of electric use, commercial buildings are billed under a commercial rate which contains a demand (kw) and an energy (kwh) charge. Furthermore, these charges vary depending upon the maximum level of demand, the amount of energy used, and possibly the time of day. Accordingly, it was necessary when making the conversions to use data for like buildings: i.e., buildings of approximately the same size and energy use. This was difficult. We had no data on kw; we had only kwh and dollar figures. In performing the conversions and making estimates, we divided the Subsample A buildings into a number of classes--such as small, medium, and large energy users--as distinguished by their relative energy use measured in dollars. In a few cities, we treated all buildings as one class when the rate schedule appeared to be flat. In other cities, we had as many as 5 classes. For a number of cities, we were forced to eliminate some or all of the buildings, because we believed the data available for the computations were insufficient or inaccurate. In general, we had difficulty in performing the conversions. For some cities, only dollar amounts were reported; with no quantity amounts, we had no basis for estimation.

In the case of the Arlington, Virginia/Washington, D.C. area, we had no basis for estimation because only dollar amounts were reported. For this area--and this area only—we used the Federal Power Commission rate book figures and FEA oil price figures to arrive at energy use. This procedure was, in our opinion, justified based on our knowledge of the area. A comparison with some aggregate data published by the Washington Apartment and Office Building Owners Association suggested that the estimation error was approximately 3 percent. In all other cases in which we had no quantity data, we dropped the city.

For some fuels, we had no basis of estimation in a city, while we might have a basis for estimation for other fuels. This eliminated many buildings. For some building sites we did not have enough complete data buildings of a specific fuel usage for estimation.

Once the estimates had been completed we again examined BTU/sq. ft. and eliminated those buildings which appeared to be in error. A major concern was distinguishing between buildings which were all electric and buildings for which only electric use was reported by the building manager.

After auditing, estimating and verifying the data for Subsample B, we then examined the statistical accuracy of the estimates by performing a Smith-Satterwaite test to verify that for a given region the means for electric, fuel and total energy use for Subsample A were not significantly different from the means for Subsample B. We wished to determine whether the estimates had biased the sample.[1)] In this test,

one tests the hypothesis

$$\mu_1 = \mu_2$$

against the hypothesis

$$\mu_1 \neq \mu_2$$

[1)]The Smith-Satterwaite test is described on page 174 of Probability and Statistics for Engineers by Irwin Miller and John E. Freund, Englewood Cliffs, Prentice Hall, 1965.

The test is performed by forming the test statistic

$$t' = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}}$$

and approximating its sample distribution by the t distribution with

$$\frac{(S_1^2/n_1 + S_2^2/n_2)^2}{(S_1^2/n_1)^2/(n_1 - 1) + (S_2^2/n_2)^2/(n_2 - 1)}$$

degrees of freedom.

Table 5-2 illustrates the results of the estimation procedure by building type in terms of electric, gas, oil and steam buildings. The estimates were acceptable for 199 buildings and unacceptable for 37 buildings.

Although we were able to confirm the statistical validity of the estimates, we were, nevertheless, concerned about using estimated data.

Additional Data Collection Efforts

Since the BOMA data base is collected to assist a building manager in comparing his building's performance against the performance of other buildings on an aggregate basis, the data base does not contain a number of the data items which one would like to have in performing an energy analysis. The data base appears to be designed for financial analysis purposes. After reviewing the data collection efforts of Tishman-Syska and Hennessy and NEMA, and analyzing the data input requirements of the AXCESS energy simulation program, we were concerned that we might be lacking sufficient data items for our analysis. Therefore, BOMA circulated to a selected group of buildings the questionnaire in Appendix B. A response rate well in excess of 75 percent was achieved, and most respondents were able to answer most of the questions. The response rate may be somewhat misleading, for we attempted to gather data only for those buildings which had completely and correctly answered the BOMA questionnaire and which appeared to be of substantial size in major cities.[1)] We had intended to use the

[1)]The questionnaire was considered to be correctly answered if the building survived our auditing procedure for retention in the data base.

additional data for the formulation of a subdata base for special analyses; however, resource constraints did not permit the incorporation of the data in the computer data base. Other than stating that the replies were reasonably complete we are unable to state whether they were accurate, because we did not contact any of the buildings to determine the basis for the replies.

Conclusions on Data Base Collection

The establishment of the verified data base in the computer was a tedious and time consuming task. If further use of the BOMA data were to be made, we would suggest the consideration of the following matters in establishing a data base for additional years.

1. Rather than eliminating buildings from the data base which do not "look correct" we would suggest contacting the building management for additional clarification. This would permit the identification of buildings which retail power to other buildings, buildings with incomplete reports of fuel or electric use, and any other buildings subject to special conditions and circumstances. Such additional effort could involve a substantial expenditure of resources.

2. One could investigate the use of the cost-quantity relationships for electricity and fuels collected by the DOE as a basis for estimation. If usable, the sample could be substantially expanded both in terms of number of buildings and in terms of regional coverage. One would first need to consider whether such estimations could be made: the Subsample A buildings could serve as a basis for determining the statistical validity of the procedure.

3. We made no attempt to meet directly with the buildings' operators to obtain their views on the various factors behind energy use in their buildings. A few meetings with the appropriate persons in several cities might be useful.

4. Additional data collection to supplement the BOMA questionnaire is necessary for a complete analysis. In obtaining data one must consider the tradeoffs between rate of response and length of questionnaire. The questionnaire which we have designed could be shortened for circulation to a large number of buildings, and a small sample of buildings could be selected to receive the entire questionnaire.

EVALUATION OF THE BOMA DATA BASE

An important question which must be addressed is the degree to which the buildings in the BOMA data base are representative of commercial office buildings in general and therefore, the degree to which conclusions based on the BOMA data base can be extrapolated to the general stock of commercial office buildings.

Comparisons Based on Data Generated in this Project

1. Geographic distribution of office buildings.

In Volume I of this report, we presented an estimate of the stock of commercial office buildings in existence in 1975 and an allocation of this stock to the 173 BEA areas. For purposes of comparison with the BOMA data base, we aggregated the data for the 173 BEA areas into the 9 Census Divisions. In some cases, it was necessary to assign a BEA area which lies in two Census divisions to a Census division; this was done on the basis of the location of the major city in the BEA area. We then computed the percent distribution of all office buildings with the geographic distribution of the BOMA building. The results are presented in Table 5-3. The distribution of the BOMA buildings is different from the distribution of commercial office building space. Accordingly, one would need to make some adjustments in arriving at estimates of national energy use based on the BOMA data.

2. Age distribution of buildings.

Volume I presents estimates of the square feet of office buildings that existed in each of the years 1925-1975. Based on estimates of the 1925 stock of buildings, estimates of removal rates, and a knowledge of the square feet of buildings added in each year, we developed an approximation of the 1975 age distribution of the buildings in the stock of commercial buildings. We caution that this information is only an approximation, for some rather crude assumptions were made regarding removal rates. Additional effort in developing the approximation would have yielded a better estimate; however, we believe that for the purpose of evaluating the BOMA data base this approach is adequate. Table 5-4 presents the comparison of the age distributions of the BOMA buildings and the total stock of office buildings. Although the BOMA sample is weighted somewhat heavily towards older buildings, it would be incorrect to state that the sample is unreasonably biased by age. Adjustments by age could be made if necessary in making an overall estimate of energy use.

Comparisons Based on the Published Literature

Studies of a representative cross section of buildings are available for 3 cities: New York, Philadelphia, and Baltimore.[1] We compared the sample of BOMA buildings in each of these cities with the statistically representative samples collected by other sources.

1. New York: Table 5-5 presents a comparison of the TSH sample of representative New York City office buildings and the BOMA data base of buildings for New York. The BOMA buildings are clearly unrepresentative of New York office buildings: in general, the BOMA buildings are larger, taller, and younger; and they use more energy than does a typical New York building.

2. Philadelphia: Tables 5-6 and 5-7 present a comparison of the BOMA sample of Philadelphia buildings with the NEMA sample. It should be noted that the NEMA sample covers the year 1973, and the BOMA data is for 1975. On the basis of the NEMA work one can state that statistically there is a difference between the NEMA and BOMA samples (t=1.86). Futhermore, there is a difference among the non-BOMA buildings between Class A buildings and Class B buildings in terms of their energy use (t=1.84). There is no difference between the BOMA and Class A buildings in terms of energy use (t=.6). There would appear to be a difference in energy use between buildings with and without computers; however, no standard

[1] Tishman-Syska and Hennessy, Energy Conservation in Existing Office Buildings prepared for the U.S. Energy Research and Development Administration under contract number EY-76-C-02-2799.000, June 1977.

[2] National Electrical Manufacturers Association and National Electrical Contractors Association, Energy Consumption In Commercial Buildings in Philadelphia.

deviation was reported, and we were unable to perform any statistical computations. NEMA indicated that the impact of the existence or absence of computer and data processing services on building energy use is due to the continuous operation of HVAC and lighting support services rather than due to the actual amount of electricity used by the data processing equipment.

3. Baltimore: Hittman Associates' study of downtown Baltimore included a sample of 58 central city office buildings.[1] The corresponding BOMA buildings in Subsample A were composed of four buildings. By including Subsample B buildings, we were able to raise the sample size to eight. Table 5-8 presents the results. In terms of energy use per square foot, there does not appear to be a statistically significant difference between the BOMA sample, with or without Subsample B, and the Hittman sample with CDS[2] (t=1.22 and 1.3 respectively). For the data collected by Hittman, there is a statistically significant difference between offices with and without computer space (t=3.57). There is also a significant difference between energy use by the buildings in the BOMA sample and the buildings in the sample of Baltimore buildings that do not have CDS space.

Analysis on the Basis of Rental Rates.

Most of the BOMA space is Class A, prime space. These are office buildings which are in the active rental market and are fully modernized. This type of space is typically leased for 5 years or more; the rent is, however, adjusted on a yearly basis through the use of escalator clauses. Other less desirable space is generally leased for one year. Automatic adjustment clauses are also used in this type of space for longer term leases. Therefore, one can measure the relative attractiveness of a building by the annual rental rate, and one would be correct in assuming that, for a given area, low rent buildings are, in general, less attractive, older and, less renovated than are higher rent buildings. Although the BOMA data base largely contains Class A space, there is some less desirable space—Class B or Class C[3]--in the data base.

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[1] Patrick M. McCarthy, Rusi F. Patel, and Burton Karpay, Empirical and Simulation Analyses of Energy Use in Commercial Buildings, prepared under Federal Energy Administration Contract CO-04-51888-000, Columbia, Maryland. Hittman Associates, February 1977.

[2] Computer and Data Processing Services.

[3] Class B space is space which is well maintained but not entirely modernized, and Class C space is space which is neither well maintained nor modernized.

If energy use in buildings were found to be a function of the class of building space, our conclusions about energy use in the BOMA office buildings could not be automatically applied to the complete stock of office buildings. We defined class of building space in terms of the rental rates and assembled data on rental rates and energy usage for five major cities: New York, Chicago, Pittsburgh, Minneapolis/St. Paul, and San Francisco. For purposes of comparison, the four or five highest rent buildings were compared with the four or five lowest rent buildings. In all cases, the high rent and low rent buildings were collectively less than 50 percent of the building population in our sample. The data are portrayed in Table 5-9. The differences in energy use between high rent and low rent buildings were statistically significant in some cities but not in others. Therefore, one can not conclusively state that high rent and low rent buildings in the BOMA data base always use different amounts of energy.

Conclusions on the Representativeness of the BOMA Data Base

In terms of age distribution and coverage of the geographical areas of the country, the BOMA data base is clearly unrepresentative of the stock of commercial office buildings. We have no data for the downtown/suburban breakout of the commercial office building inventory square feet but believe that the BOMA buildings are more heavily weighted toward downtown location than is the stock of office buildings in general. Our analysis of the BOMA data base, which is discussed in the next section, indicates that energy use varies as a function of building age, region of the country, and downtown/suburban location. Therefore, in terms of these factors, the energy use by the buildings in the BOMA data base is unrepresentative of energy use by the stock of commercial office buildings.

Although the BOMA space is believed to be predominantly Class A space, we have no conclusive information on whether energy use varies as a function of class of building space. Based on a number of studies previously mentioned, we know that building energy use varies as a function of the presence or absence of computer and data processing facilities. We have, however, no information on the amount of computer and data processing facilities present in the BOMA sample of buildings.

SUMMARY OF BOMA SAMPLE

Table 5-10 presents an outline of the 1975 BOMA office building sample. Subsample A contained buildings for which the managers had furnished complete data; in the case of Subsample B, we performed a number of calculations to obtain estimates of energy use. The largest sample of buildings was the "not used" category: for buildings in this classification we did not have sufficient fuel cost information to permit us to estimate quantities of fuel use. Our comments in this section deal primarily with Subsample A. The detailed computer output which served as the basis for the tables which are presented at the end of this section may be found in Appendix C.

The Computations

Most of the tables which are presented portray energy use in terms of BTU; we calculated this figure on a weighted and unweighted basis. In performing an unweighted computation, all buildings are assumed to be of equal importance regardless of size. A computation with the BTU for each building weighted by the area of the specific building relative to the total area of the sample places a greater importance on the larger buildings, which are the important ones in terms of the total stock of buildings. It was our finding that, in most cases, the weighted and unweighted means were approximately equal, but the weighted standard deviation was substantially smaller than the unweighted standard deviation. We believe that the weighted mean and weighted variance are the more important statistics for the presentation; however, in a number of cases both weighted and unweighted means and variances are presented. The weighted data are presented in a table with the letter "A" following the table number, and the unweighted data immediately follows in a table with the same table number but with the letter "B" following the table number.

The procedure used for the computations were as follows:

1. Define BTU for building i by the variable X_i.
2. Let n denote the number of buildings.
3. Let Y_i denote the area of the ith building.

Unweighted mean:

$$\bar{X} = \frac{\sum X_i}{n}$$

Unweighted standard deviation:

$$S = \sqrt{\frac{1}{n-1} (\Sigma X_i^2 - n\bar{X}^2)}$$

Weighted mean:

$$\bar{X}_w = \frac{\sum X_i Y_i}{\sum Y_i}$$

Weighted standard deviation:

$$S_w = \sqrt{\frac{1}{n-1} (\Sigma X_i^2 Y_i / \Sigma Y_i - n\bar{X}_w^2)}$$

In addition to providing useful information about energy use in office buildings, the data provide the basis upon which additional hypotheses concerning energy use could be formulated; investigation of the hypotheses would, however, require additional data collection efforts.

The BOMA Sample

The overall size of the BOMA sample is shown in Table 5-10. Subsample A consists of the 371 buildings for which the building managers reported both dollar amounts spent and physical quantities consumed for electricity and fuel, if any. The managements of the buildings in Subsample B reported dollar amounts of electric and fuel use but omitted one or more of the quantity amounts. Therefore, for the buildings in Subsample B, we made estimates as described earlier in this Section. In general, we found that we were able to make estimates which withstood a statistical test for accuracy. Nevertheless, we were sufficiently uneasy about the estimated data that we confined our analysis to Subsample A. We wanted to base this initial analysis on unadjusted data. In any further, more detailed analysis of office building energy use based on the BOMA data base or other similar data bases, it will probably be necessary to have a sample larger than Subsample A. It is likely that many building managers will continue to provide incomplete data. Our establishment of Subsample B indicates that estimates can be made with sufficient accuracy in many cases to permit the retention of buildings in the data base for which the energy use data is incomplete.

The "not used" category is our largest category in terms of number of buildings. Included in this category are a number of Canadian buildings with complete energy data. In future work, it may be desirable to include the Canadian buildings in the analysis in order to provide additional information on the consumption of energy in very cold winter climates. Also included in the "not used" category are a number of buildings for which we had no basis for estimating the energy data, since we were unable to find a comparable set of buildings in the same city with complete energy data. We have previously indicated that estimates of these data may be possible through the use of statistics collected on a city by city and regional basis by the Department of Energy. Buildings for which the managers failed to report energy data are also included in this category, and no estimation would be possible for these buildings.

Table 5-11 presents the distribution of Subsample A among the Census regions and among the heating fuels used by the buildings. The distribution of gas heated buildings among the regions is reasonably good. The oil heated buildings are concentrated in one region and steam heated buildings in four regions. There are three regions with no electrically heated buildings. Thus, the gas sample is probably adequate for the analysis conducted in Section 6. The results of the analyses of the other three energy sources must be treated with considerable caution.

In addition to office space, commercial office buildings also have stores, restaurants, garages, storage area, corridors, elevator shafts and other general areas. In Table 5-12, office space, store space (including restaurants), and an all other category are shown for Subsample A by region as well as by downtown and suburban location. As expected, downtown office buildings have more store space than do suburban buildings. Some of the regional figures for percent distribution of space by office, store, and other may be somewhat biased due to the a limited sample of buildings.

Energy Consumption by Type of Heating Fuel

Table 5-13A presents average energy use at the national level weighted by building size. The corresponding unweighted data are presented in Table 5-13B. These tables show that the level of total energy consumption varies by type of heating fuel. Since the physical designs of gas, oil, and steam plant equipment are different, one would expect to find different energy use by fuel. These data imply that oil heated buildings require the most total energy while steam heated buildings require the least. In Table 3-3 we presented some efficiency factors developed by Arthur D. Little; it is clear that the ADL relative fuel usages do not correspond to those in the BOMA sample. At the regional level, as presented in Tables 5-14 to 5-18, the fuel use differences persist. Important questions are: (1) what are the actual efficiencies by fuel type of heating systems; (2) whether and how the fuel utilization efficiency varies with building age, height, size, fuel type, maintenance policies, region of the country and other relevant factors; and (3) whether the choice of perimeter and interior HVAC systems impact energy use significantly. Some of these issues are addressed in Section 6.

With the exception of the all electric buildings, it is not clear why BTU of electric use varies by type of heating fuel. These differences also occur in a number of instances at the regional level and can not, therefore, be ascribed to climate. An examination of the HVAC system types might explain how the arrangement, sizing, and choice of equipment can affect building energy use. In the case of steam buildings, we know that a significant number of steam heated buildings also have steam turbine, steam absorption, or both types of air conditioning. Based on the limited air conditioning information we obtained from BOMA, we were able to determine that buildings with steam air conditioning used significantly more steam and significantly less electricity than do buildings with electric air conditioning. However, we were unable to distinguish between steam absorption and steam turbine air conditioning in the BOMA data base, and, for the majority of buildings in Subsample A, we had no information on type of air conditioning present.

Downtown and Suburban Buildings

Tables 5-19A and 5-19B present the average national energy consumption data, weighted and unweighted, respectively, for downtown and suburban buildings. Based on these data, downtown gas buildings use less total energy than suburban buildings while the reverse is true for electric, oil and steam buildings. It is not clear why downtown buildings use less energy than do suburban gas buildings, and why downtown electric, oil and steam buildings use more energy than do their suburban counterparts. Further analysis of building usage, systems, and maintenance is needed in order to address this question more fully.

In terms of square feet of space per building, downtown office buildings are larger than are suburban office buildings. Also, most of the BOMA space is downtown space; no figures are available on the breakdown at the national level between downtown and suburban office building space for the total stock of office buildings. However, based on conversations with BOMA personnel, we believe that suburban buildings are significantly under-represented in the BOMA sample.

Energy Consumption by Building Height

Tables 5-20A and 5-20B present, respectively, the weighted and unweighted average national energy consumption by building height. These data indicate that electric consumption is almost constant regardless of building height. Fossil fuel consumption is also almost constant by building height with the exception of buildings in excess of 50 stories. All of the 50+ story buildings are located in large cities, and most are steam fired. This may account for some, but not all, of the discrepancy.

Energy Consumption by Building Age

Table 5-21 presents, for the buildings in Subsamples A and B, the heating fuels used by the buildings of various ages. It is clear from these data that most of the square feet of electrically heated buildings have been constructed in recent years. A large amount of commercial space is gas heated while the amount of oil heated space is relatively small and over half of this space is relatively new. The amount of steam fired space is substantial and well over half is relatively new.

An examination of the fuel use data on a building-by-building basis indicates that the use of a specific fuel generally predominates in a given city. An important question which we have not explored is what set of factors determines the choice, in a given city, of heating fuel for a new building or for a renovated building.
city.

As Tables 5-22A and 5-22B indicate, energy usage varies by age, but not in a simple manner. Recently built buildings tend to be energy efficient,[1] although it is unlikely that much thought was given to the need for conservation when the buildings were built. The oil embargo and the concern with rising oil prices did not occur during the design period of these buildings. The decreased use of non-electric energy in new buildings may be due to the fact that more all electric buildings have recently been built. This is also reflected in the fact that these newer buildings show a higher use of electricity per square foot.

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[1] A high concentration of the all electric buildings in this category may play a role in determining the relatively high level of electric use by these buildings.

Buildings 10-19 years old are also prime space. Their greater fuel usage may be due to increased infiltration around aging caulking. Their electrical usage is less, suggesting possibly fewer all electric buildings, a lower level of air conditioning, or less extensive use of electricity for other purposes. This is a matter worth further examination.

Buildings 20-29 years old probably have not undergone major renovation and are beginning to near the end of their useful economic life without renovation. It would be instructive to compare the systems and equipment present in these buildings with those present in the younger buildings.

Buildings 30-39 years old are prime candidates for renovation. The NEMA study suggested that the decreased level of energy use in older, Class B and Class C space could be due to equipment breakdowns, less than full occupancy, the absence of computer facilities, and a generally lower level of building amenities. These hypotheses should be investigated. However, only 5 buildings 30-39 years old were in Subsample A. Consequently, the values for these buildings in Table 5-22 may not be reliable.

Buildings 40 years old and older have usually undergone renovation; the fact that they are still standing suggests that they were relatively well built and well maintained. It is not clear, however, why their fuel usage is so high for the 50+ category.

Air Conditioning Capacity by Building Age

Table 5-23 shows the average air conditioning capacity of the BOMA buildings by age. For buildings 10 years and older the degree of air conditioning capacity decreases with age. We are, however, unable to account for the smaller than expected amount of air conditioning present in buildings 1-9 years old. The large standard deviation indicates considerable variation around the average value shown, and this leaves some doubt as to its significance.

Electric Bill Policy of Building Management

With the exception of office buildings in a few large cities, the cost of electricity is typically included in the rent. In some large cities--such as New York City--each tenant in a building may be individually metered and will pay only for the electricity which he uses. The landlord pays only for the hall lights, the power supply for the HVAC system, and other common building systems, while the tenant pays for his own office power. In establishing the data base, we excluded a number of individually metered buildings, because the managements had provided extremely low BTU/Sq. Ft. figures for electric use. Apparently, they only reported electric consumption paid for by the management and did not obtain electricity used by the tenants. However, after the data base had been established, we still had a number of buildings with cases in which the tenants were individually metered and for which the managements had reported complete data. These latter buildings are reported in Table 5-24. Based on these data, it appears that in cases where the tenant is individually metered, he uses less electricity than he would if he were not directly billed for his electric use. This conclusion may be of substantial interest. We believe, however, that research remains to be done before we can be certain of the conclusion because a significant number of buildings whose tenants were individually metered were excluded from the data base on the grounds that their managers submitted incomplete data.

COMPARISON OF 1974 and 1975 BOMA DATA BASES

Tables 5-25 and 5-26 compare the regional office building energy use in 1975 presented in this Volume with the estimates on energy use in 1974 calculated by Jack Faucett Associates. Both sets of estimates were based on BOMA data and were computed as weighted averages. There appear to be a number of substantial differences between the estimates of energy use for the two years. We examined whether the differences were due to statistical error, weather, and changing trends in consumption.

We have previously outlined some of the statistical problems which we encountered in preparing the 1975 data base. Since 1974 was the first year for which BOMA collected energy data, the number of complete responses, i.e., those responses containing both dollar and quantity amounts of energy use was low. We understand that JFA was, therefore, forced to make estimates from energy use dollar figures for a number of buildings in order to obtain energy quantities. JFA estimated energy use by comparing similar buildings, where the actual energy use by one of the buildings was known; and by using as a basis for estimation the rate information collected by the Federal Power Commission, the American Gas Association, and the Federal Energy Administration. The total number of BOMA buildings in the JFA assembled data base for 1974 was somewhat under 250, several of which were based on estimated data. There may have been some unavoidable estimation errors. Furthermore, there is no way of knowing how many of the 371 buildings in the 1975 data base were also in the 1974 data base assembled by JFA. There are changes in the BOMA data base from year to year.

Although weather may affect building energy use, we found that 1974 and 1975 were quite similar in terms of climate.

Year	Heating Degree Days[1)]	Cooling Degree Days[1)]
1974	4,669	1,007
1975	4,705	1,075

It appears to be unlikely that the changes in the weather accounted for much of the discrepancy between 1974 and 1975 in terms of fuel or electric use.

The third possibility for the explanation of differences in 1974 and 1975 energy use is the existence of underlying trends and changing consumption patterns. In Energy Conservation in Existing Office Buildings, Tishman-Syska and Hennessy examined energy use over a 5 year period in a sample of 44 New York City office buildings and found that, adjusted for weather and occupancy, office buildings were

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1) Cooling degree days are reported on a calendar year basis. Heating degree days are reported on a heating season basis, which we recomputed to a calendar year basis in order to have the heating degree information consistent with the energy use information.

using less energy at the end of the period than was true at the beginning. The information developed by TSH is presented in Table 27. The change in energy use shown by the BOMA data is, however, in the opposite direction from the TSH observations. We are, therefore, unable to state that the observed changes in energy use in the BOMA data base are in agreement with the trends observed by TSH.

Since the discrepancies between 1974 and 1975 energy use would appear to be due either to statistical error or to a trend in energy consumption, it will be necessary to analyze the data for 1976 and 1977, and possibly to reexamine the 1974 data before concluding that either statistical errors or trends can explain the differences between the 1974 and 1975 data.

TABLE 5-1

ITEMS IN BOMA BASE

General Data	Energy Data
City	Electricity
Floor Space	Cost
	KWH
Office	
Store	Gas
Other	Cost
	Cu. Ft.
Office Occupancy Rate	
Age	Oil
Height (Stories)	Cost
Owner Occupied?	Gals.
Tenancy (Medical, Utility, Bank, General)	Steam
Agency Operated?	Cost
Population in Building	Lbs.
Number of Building Employees	Chilled Water
Location in City	Cost
Electrical Billing Policy	Gals.
Energy Type for Air Conditioning	Coal
Central Air Conditioning Tonnage	Cost
	Tons

TABLE 5-2

Subsample A and Subsample B
Number of Buildings[1]

	ELECTRIC			GAS			OIL			STEAM		
	A	B	Was Estimation Reasonable?	A	B	Was Estimation Reasonable?	A	B	Was Estimation Reasonable?	A	B	Was Estimation Reasonable?
New England	0	0	-	0	0	-	2	0	-	0	0	-
Middle Atlantic	2	0	-	7	4	Yes	5	2	No	60	17	Yes
South Atlantic	19	5	Yes	5	6	Yes	2	0	-	4	4	Yes
East North Central	5	3	Yes	27	9	Yes	19	6	No	24	28	Yes
East South Central	0	0	-	4	5	No	0	0	-	1	0	-
West North Central	6	3	No	31	10	Yes	3	0	-	30	12	No
West South Central	10	7	Yes	42	30	Yes	1	0	-	4	0	-
Mountain	0	0	-	12	12	Yes	0	0	-	6	7	Yes
Pacific	6	9	No	30	31	Yes	0	0	-	38	26	Yes

1) A number of the Subsample A buildings were subsequently dropped from the data base due to inadequacy in other types of data.

TABLE 5-3

REGIONAL DISTRIBUTION OF COMMERCIAL OFFICE BUILDING SPACE BY CENSUS DIVISION[1)]

	Percent of Total Estimated Square Feet of Commercial Office building Space in Census Division	Percent of Space in Subsample A of BOMA Data Base in Census Division
NE	6.00	0.72%
MA	22.16	33.67
SA	14.47	5.53
ENC	18.14	19.02
ESC	3.98	0.29
WNC	6.69	9.55
WSC	9.36	13.78
MTN	3.95	1.94
PAC	15.24	15.51

1)Totals may not add due to rounding.

Source: Total square feet from F. W. Dodge Reports and distributed as described in Section 1 of this report; and BOMA data base.

TABLE 5-4

AGE DISTRIBUTION OF BUILDINGS IN TOTAL INVENTORY OF COMMERCIAL OFFICE BUILDINGS AND IN BOMA SAMPLE[1]

Building Age as of 1975	Total Square Feet of Commercial Office Buildings in Given Age Bracket[2]	Percent of Total	Total Square Feet in BOMA Sample in given Age Bracket	Percent of Total
1-9	1561	50.6%	85.3	42.0
10-19	784	25.4%	45.6	22.5
20-29	312	10.1%	10.0	4.9
30-39	121	3.9%	8.1	4.0
40-49	199	6.4%	24.4	12.0
50+	105	3.4%	29.6	14.4
	3082		203	

1) Totals may not add due to rounding

2) CFES Estimate

Source: F. W . Dodge reports and BOMA data base.

TABLE 5-5

COMPARISON OF THE TSH AND BOMA
SAMPLES OF NEW YORK CITY OFFICE BUILDINGS

	TSH Sample	BOMA Sample
Mean Area (Sq. Ft.)	401,143	1,141,564
Mean Height (Stories)	22	44
BTU/Sq. Ft. (000) in 1975		
Mean	115	145.8
Standard Deviation	39	56.0
Number of Buildings	44	30
Age	44	30

Source: Tishman-Syska and Hennessy, op. cit.; and BOMA data base.

TABLE 5-6

COMPARISON OF NEMA AND BOMA
SAMPLES OF PHILADELPHIA OFFICE BUILDINGS
BTU/Sq. Ft.

	NEMA Sample	NEMA Sample of Class A Buildings	NEMA Sample of Class B Buildings	BOMA Sample
Energy Use				
Mean	128,430	142,164	120,546	151,550
Standard Deviations	37,359	46,088	30,672	43,560
Number of Buildings	50	20	29	15

Source: NEMA, op. cit.

TABLE 5-7

EFFECTS OF COMPUTER AND DATA PROCESSING SERVICES
ON BUILDING ENERGY USE
BTU/Sq. Ft.

	Offices with CDS	General Offices (No CDS)
Class A	142,400	97,705
Class B	156,710	104,727

Source: NEMA, op. cit.

TABLE 5-8

COMPARISON OF HITTMAN ASSOCIATES AND BOMA
OFFICE BUILDING SAMPLES: BALTIMORE
BTU/Sq. Ft.

BOMA Sample:	Mean (000)	Standard Deviation (000)	Number of Buildings
Subsample A	215.9	87.8	4
Subsamples A and B	201.9	81.2	8
Hittman Sample with CDS	157.9	80.0	20
Hittman Sample without CDS	83.6	54.8	38

Source: Hittman Associates

TABLE 5-9

ENERGY USE IN HIGH RENT AND LOW RENT BUILDINGS
BTU/Sq. Ft.

	Mean	Standard Deviation	Number of Buildings	Rental Rate $/Sq. Ft.	Computed t Value
New York					
High Rent	141,762	86,949	5	11.42	.36
Low Rent	160,132	53,355	5	4.50	
Chicago					
High Rent	180,154	74,666	5	9.21	1.39
Low Rent	133,087	12,586	5	4.69	
Pittsburgh					
High Rent	157,344	54,284	5	8.38	2.5
Low Rent	95,378	6,589	5	4.30	
Minneapolis/St. Paul					
High Rent	216,573	120,188	4	9.66	1.46
Low Rent	127,175	22,394	4	4.69	
San Francisco					
High Rent	114,463	15,746	4	9.40	2.7
Low Rent	66,586	31,779	4	3.23	

Source: BOMA data base.

TABLE 5-10

THE 1975 BOMA OFFICE BUILDING SAMPLE

	NUMBER OF BUILDINGS	SQUARE FEET (000,000)
SUBSAMPLE A	371	139.3
SUBSAMPLE B	269	63.7
NOT USED	383	52.0
TOTAL	1023	255.0

TABLE 5-11

THE 1975 BOMA OFFICE BUILDING SAMPLE
BY TYPE OF HEATING FUEL AND REGION
SUBSAMPLE A
(SQUARE FEET IN MILLIONS)

	ELECTRIC			GAS			OIL			STEAM		
	Number of Bldgs.	Sq. Ft.	Sq. Ft./Bldg.[1] (000)	Number of Bldgs.	Sq. Ft.	Sq. Ft./Bldg.[1] (000)	Number of Bldgs.	Sq. Ft.	Sq. Ft./Bldg.[1] (000)	Number of Bldgs.	Sq. Ft.	Sq. Ft./Bldg.[1] (000)
New England	0	0	-	0	0	-	2	1.0	500.0	0	0	-
Middle Atlantic	2	.4	200.0	7	1.7	242.8	4	1.9	475.0	59	42.9	727.1
South Atlantic	12	4.2	350.0	3	1.1	366.7	2	1.7	850.0	4	.7	175.0
East North Central	5	6.5	1,300.0	22	7.9	359.1	18	6.2	344.4	22	5.9	268.2
East South Central	0	0	-	3	.3	100.0	0	0	-	1	0	-
West North Central	6	1.0	166.7	26	4.1	157.7	3	.5	166.7	30	7.6	253.3
West South Central	10	4.1	410.0	40	12.7	317.5	1	.8	800	4	1.6	400.0
Mountain	0	0	-	12	1.5	125.0	0	0	-	5	1.2	240.0
Pacific	6	3.5	383.0	26	10.1	388.5	0	0	-	36	8.0	222.2
Total	41	19.7		139	39		30	12.2		161	68.0	

[1] Square feet per building (000) based on division of square feet by number of buildings.

Source: BOMA Data Base.

TABLE 5-12

SQUARE FEET OF COMMERCIAL OFFICE BUILDINGS SPACE BY REGION
(SQUARE FEET IN MILLIONS)

SUBSAMPLE A

	Office		Store		Other		Total	
	Sq.Ft.	% of Total in Region	Sq.Ft..	% of Total in Regionn	Sq.Ft.	% of Total in Region	Sq.Ft.	% of Total in Region
New England	.8	80.0	0	0	.2	20	1.0	100
Middle Atlantic	41.9	89.3	2.0	4.3	3.0	6.4	46.9	100
South Atlantic	5.9	76.6	1.5	19.5	.4	5.2	7.7	100
East North Central	23.1	87.2	1.3	4.9	2.1	7.9	26.5	100
East South Central	.3	75.0	0	12.0	0	12.0	.4	100
West North Central	10.2	76.7	.7	5.3	2.3	17.3	13.3.3	100
West South Central	16.7	87.0	.6	3.1	1.8	9.4	19.2	100
Mountain	2.5	90.2	.1	3.6	.1	3.6	2.7	100
Pacific	19.4	89.8	1.0	4.6	1.3	6.0	21.6	100
Total	120.8	86.7	7.2	5.2	11.2	8.0	139.3	100
Total Downtown	109.2	86.4	6.8	5.4	10.3	8.1	126.4	100
Total Suburban	11.5	89.1	.4	3.1	.9	7.0	12.9	100

1) May not add due to rounding.

Source: BOMA Data Base.

TABLE 5-13A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
BY TYPE OF HEATING FUEL
SUBSAMPLE A

(BTU/SQ. FT. IN THOUSANDS; SQUARE FEET IN MILLIONS)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Heating Fuel									
	Electric		Gas		Oil		Steam		All Buildings	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Electric Btu/Sq. Ft.	137.2	8.1	94.3	3.8	58.5	3.9	65.5	2.4		
Gas Btu/Sq. Ft.			107.6	8.9	--	--	--	--		
Oil Btu/Sq. Ft.					154.9	22.7	--	--		
Steam Btu/Sq. Ft.							67.1	3.0		
Total Btu/Sq. Ft.	137.2	8.1	201.9	10.2	213.4	21.8	132.6	4.1	159.9	4.7
Total Square feet	19.7		39.4		12.2		68.0		139.3	
Number of Buildings	41		139		30		161		371	
Sq. Ft./Bldg. (000)[1]	480.5		283.4		406.7		422.4		375.5	

[1] Square feet per building based on division of total square feet by number of buildings.

Source: BOMA Data Base

TABLE 5-13b

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE BY TYPE OF HEATING FUEL SUBSAMPLE A

(BTU/SQ. FT. IN THOUSANDS; SQUARE FEET IN MILLIONS)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Heating Fuel									
	Electric		Gas		Oil		Steam		All Buildings	
Energy Consumed	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Electric Btu/Sq. Ft.	139.3	55.0	88.7	45.4	55.4	21.1	69.8	31.3		
Gas Btu/Sq. Ft.			112.6	100.3	-	-	-	-		
Oil Btu/Sq. Ft.					153.8	130.4	-	-		
Steam Btu/Sq. Ft.							71.0	45.4		
Total Btu/Sq. Ft.	139.3	55.0	201.4	113.1	209.8	125.8	140.8	56.5	168.9	93.2
Total Square Ft.	19.7		39.4		12.2		68.0		139.3	
Number of Buildings	41		139		30		161		371	
Sq. Ft./Bldg. (000)[1]	480.5		283.4		406.7		422.4		375.5	

1) Square feet per building based on division of total square feet by number of buildings.

Source: BOMA Data Base

TABLE 5-14A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
SUBSAMPLE A
(BTU/SQ. FT. 000)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Other Fuels		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	73.4	2.0	109.7	12.2	183.1	14.2
Middle Atlantic	61.1	3.5	70.3	6.7	131.5	7.7
South Atlantic	96.6	7.5	34.6	10.2	131.2	12.1
East North Central	88.4	6.5	95.1	12.1	183.5	10.5
East South Central	97.3	22.6	69.3	15.3	166.5	24.5
West North Central	81.2	4.4	99.1	9.3	180.3	9.7
West South Central	116.4	7.5	92.8	16.7	209.2	18.9
Mountain	77.4	5.6	182.7	35.9	260.2	38.3
Pacific	92.6	5.3	40.6	3.5	133.2	5.9
National Ave.	83.2	2.4	76.7	4.3	159.9	4.7

Source: BOMA Data Base.

TABLE 5-14B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
SUBSAMPLE A
(BTU/SQ. FT. 000)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Other Fuels		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	73.8	2.9	111.8	17.5	185.6	20.4
Middle Atlantic	69.9	31.0	71.7	59.4	141.5	64.6
South Atlantic	105.6	34.6	40.5	62.9	146.1	69.4
East North Central	72.9	42.3	123.0	105.7	195.8	102.4
East South Central	95.8	38.2	67.8	41.6	163.7	48.3
West North Central	81.9	41.7	102.6	78.5	183.9	82.4
West South Central	116.5	60.7	83.6	117.6	200.1	134.2
Mountain	68.8	22.6	144.8	107.5	213.6	118.0
Pacific	79.2	44.2	48.2	30.6	127.4	48.7
National Ave.	83.4	45.3	85.5	86.8	168.9	93.2

Source: BOMA Data Base

TABLE 5-15A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
ELECTRICALLY HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Other		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	93.8	16.9	0	0	93.8	16.9
South Atlantic	100.0	11.7	0	0	100.0	11.7
East North Central	165.2	10.9	0	0	165.2	10.9
East South Central	0	0	0	0	0	0
West North Central	155.5	8.5	0	0	155.5	8.5
West South Central	121.3	20.7	0	0	121.3	20.7
Mountain	0	0	0	0	0	0
Pacific	148.4	26.7	0	0	148.4	26.7
National Ave.	137.2	8.1	0	0	137.2	8.1

Source: BOMA Data Base.

TABLE 5-15B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
ELECTRICALLY HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Other		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	104.8	28.6	0	0	104.8	28.6
South Atlantic	114.0	35.1	0	0	114.0	35.1
East North Central	167.9	23.8	0	0	167.9	23.8
East South Central	0	0	0	0	0	0
West North Central	155.7	24.8	0	0	155.7	24.8
West South Central	136.4	84.3	0	0	136.4	84.3
Mountain	0	0	0	0	0	0
Pacific	166.0	58.9	0	0	166.0	58.9
National Ave.	139.3	55.0	0	0	139.3	55.0

Source: BOMA Data Base.

TABLE 5-16A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
GAS HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Gas		Total	
Region	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	82.8	9.8	93.3	14.5	176.1	22.1
South Atlantic	117.8	15.1	66.2	27.7	164.0	38.9
East North Central	71.2	8.5	124.1	15.8	195.2	19.3
East South Central	95.9	29.2	75.4	14.9	171.2	30.1
West North Central	84.4	5.7	148.2	17.8	232.6	19.9
West South Central	120.7	8.7	123.4	21.9	244.2	24.5
Mountain	80.5	6.5	209.3	54.4	290.0	57.0
Pacific	84.4	5.6	53.6	5.6	138.0	9.3
National Ave.	94.3	3.8	107.6	8.9	201.9	10.2

Source: BOMA Data Base.

TABLE 5-16B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
GAS HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Gas		Total	
Region	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	68.2	33.5	72.2	38.2	140.4	57.1
South Atlantic	118.4	33.2	66.4	72.1	184.8	102.9
East North Central	82.8	42.1	154.8	93.0	237.6	97.1
East South Central	91.5	45.6	84.2	31.8	175.7	51.4
West North Central	79.1	36.7	136.8	86.5	215.9	101.3
West South Central	116.2	55.4	105.1	129.5	221.2	145.7
Mountain	69.4	21.8	156.0	117.9	225.4	127.4
Pacific	71.9	31.6	64.1	35.3	136.1	49.7
National Ave.	88.7	45.4	112.7	100.3	201.4	113.1

Source: BOMA Data Base.

TABLE 5-17A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
OIL HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Oil		Total	
Region	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	73.4	2.0	109.7	12.2	183.1	14.2
Middle Atlantic	64.7	17.6	193.9	106.2	258.7	102.8
South Atlantic	75.4	10.1	80.9	5.1	156.3	5.0
East North Central	45.9	2.8	180.4	29.8	226.3	29.4
East South Central	0	0	0	0	0	0
West North Central	59.9	15.4	95.2	30.8	155.1	46.2
West South Central	87.2	Undefined[1)]	118.0	Undefined [1)]	205.3	Undefined[1)]
Mountain	0	0	0	0	0	0
Pacific	0	0	0	0	0	0
National Average	58.5	3.9	154.9	22.7	213.4	21.8

[1)]One building.

Source: BOMA Data Base

TABLE 5-17B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
OIL HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Oil		Total	
Region	Mean	Std. Dev.	Mean	Std . Dev.	Mean	Std. Dev.
New England	73.8	2.9	111.8	17.5	185.6	20.4
Middle Atlantic	68.9	35.4	173.5	195.6	242.4	186.7
South Atlantic	70.6	15.7	83.3	7.9	153.9	7.8
East North Central	45.8	12.8	172.9	141.5	218.8	137.4
East South Central	0	0	0	0	0	0
West North Central	62.0	26.3	99.1	53.2	161.1	79.4
West South Central	87.2	Undefined[1)]	118.0	Undefined[1)]	205.2	Undefined[1)]
Mountain	0	0	0	0	0	0
Pacific	0	0	0	0	0	0
National Average	55.4	21.1	153.8	130.4	209.2	125.8

[1)] One building.

Source: BOMA Data Base.

TABLE 5-18A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
STEAM HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Steam		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	59.8	3.8	64.7	4.4	124.5	6.2
South Atlantic	94.4	14.2	104.0	31.9	198.5	38.7
East North Central	71.6	5.9	71.2	7.0	142.9	9.7
East South Central	108.7	Undefined[1]	19.0	Undefined[1]	127.7	Undefined[1]
West North Central	71.0	5.1	86.0	9.2	157.0	9.6
West South Central	88.4	19.3	74.2	12.1	157.7	28.9
Mountain	73.7	11.4	150.5	32.9	224.2	39.0
Pacific	78.7	5.2	41.8	2.7	120.5	6.8
National Ave.	65.5	2.4	67.1	3.0	132.6	4.1

1) One building.

Source: BOMA Data Base.

TABLE 5-18B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
STEAM HEATED BUILDINGS - SUBSAMPLE A
(BTU/SQ. FT. 000)
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Electricity		Steam		Total	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
New England	0	0	0	0	0	0
Middle Atlantic	68.9	30.6	67.1	35.8	136.1	46.6
South Atlantic	88.2	31.2	121.3	75.6	209.5	97.7
East North Central	63.6	25.2	78.1	36.7	141.7	50.7
East South Central	108.7	Undefined[1)]	18.9	Undefined[1)]	127.7	Undefined[1)]
West North Central	71.6	35.1	92.5	60.1	164.1	63.6
West South Central	77.2	36.8	69.5	29.8	146.7	62.1
Mountain	67.3	26.9	117.8	82.0	185.0	98.2
Pacific	70.0	33.5	44.7	17.5	114.7	42.4
National Ave.	69.8	31.3	71.0	45.4	140.8	56.5

[1)] One building.

Source: BOMA Data Base.

TABLE 5-19A

DOWNTOWN AND SUBURBAN BUILDINGS IN THE 1975 BOMA
OFFICE BUILDING SAMPLE
SUBSAMPLE A
WEIGHTED MEANS AND STANDARD DEVIATIONS

Location of Buildings	Type of Heating Fuel: Electric	Gas	Oil	Steam	Average Across All Fuels
Downtown					
Total BTU/Sq. Ft. (000)	145.5	191.9	217.8	132.6	156.7
Standard Deviation (000)	10.8	12.0	24.9	4.1	5.0
Square Feet (000,000)	15.7	32.5	10.7	67.5	126.4
Number of Buildings	24	93	26	158	301
Sq. Ft./Bldg. (000)[1)]	654.2	349.5	411.5	427.2	419.9
Suburban					
Total BTU/Sq. Ft. (000)	104.7	248.8	181.5	128.9	191.6
Standard Deviation (000)	8.0	19.6	7.5	18.1	14.2
Square Feet (000,000)	4.0	6.9	1.5	.5	12.9
Number of Buildings	17	46	4	3	70
Sq. Ft./Bldg.[1)]	235.3	150.0	375.0	166.7	184.3

[1)] Square feet per building (000) based on division of square feet by number of buildings.

Source: BOMA Data Base.

TABLE 5-19B

DOWNTOWN AND SUBURBAN BUILDINGS IN THE 1975 BOMA
OFFICE BUILDING SAMPLE
SUBSAMPLE A
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

Location of Buildings	Type of Heating Fuel: Electric	Gas	Oil	Steam	Average Across All Fuels
Downtown					
Total BTU/Sq. Ft. (000)	154.2	191.0	214.3	141.1	163.9
Standard Deviation (000)	61.5	103.8	134.5	56.8	87.7
Square Feet (000,000)	15.7	32.5	10.7	67.5	126.4
Number of Buildings	24	93	26	158	301
Suburban					
Total BTU/Sq. Ft. (000)	118.3	222.6	175.7	128.2	190.5
Standard Deviation (000)	36.6	128.5	20.8	35.4	115.3
Square Feet (000,000)	4.0	6.9	1.5	.5	12.9
Number of Buildings	17	46	4	3	70

Source: BOMA Data Base.

TABLE 5-20A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
BY BUILDING HEIGHT
SUBSAMPLE A
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Stories						
	1-4	5-9	10-19	20-29	30-39	40-49	50+
Electric BTU/Sq. Ft. (000)							
Mean	84.2	80.2	87.0	82.2	79.0	82.8	83.5
Standard Deviation	6.7	5.0	4.2	4.8	6.0	10.9	12.1
Other Fuels BTU/Sq. Ft. (000)							
Mean	79.1	84.8	89.9	82.1	102.0	95.0	42.6
Standard Deviation	11.4	8.2	8.2	11.2	18.6	22.7	7.8
Total BTU/Sq. Ft. (000)							
Mean	163.3	165.1	176.9	164.4	181.0	177.8	126.1
Standard Deviation	13.0	9.0	8.7	11.9	19.7	26.1	10.6
Total Square Feet (000,000)	4.0	10.4	28.9	27.3	14.8	16.1	37.8
Number of Buildings	34	66	133	72	27	19	20

Source: BOMA Data Base

TABLE 5-20B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE
BY BUILDING HEIGHT
SUBSAMPLE A
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	Stories						
	1-4	5-9	10-19	20-29	30-39	40-49	50+
Electric BTU/Sq. Ft. (000)							
Mean	84.1	78.0	82.7	85.0	76.5	96.7	96.1
Standard Deviation	42.1	41.9	48.2	44.8	31.6	51.2	54.4
Other Fuels BTU/Sq. Ft. (000)							
Mean	96.8	81.4	85.4	86.3	100.2	99.6	44.0
Standard Deviation	90.9	64.0	84.6	106.2	92.8	105.1	40.4
Total BTU/Sq. Ft. (000)							
Mean	181.0	159.4	168.0	171.3	176.7	196.3	140.1
Standard Deviation	89.5	69.0	93.6	113.9	95.6	112.3	52.6
Total Square Feet (000,000)	4.0	10.4	28.9	27.3	14.8	16.1	37.8
Number of Buildings	34	66	133	72	27	19	20

Source: BOMA Data Base.

Table 5-21[1]

HEATING FUEL BY AGE OF BUILDING IN THE 1975 BOMA OFFICE BUILDING SAMPLE SUBSAMPLES A AND B COMBINED[2]

Heating Fuel

Age (Years)	Electric Sq. Ft. (000,000)	Electric Number of Bldgs.	Electric Sq. Ft./ Bldg. (000)[3]	Gas Sq. Ft. (000,000)	Gas Number of Bldgs.	Gas Sq. Ft./ Bldg. (000)[3]	Oil Sq. Ft. (000,000)	Oil Number of Bldgs.	Oil Sq. Ft./ Bldg. (000)[3]	Steam Sq. Ft. (000,000)	Steam Number of Bldgs.	Steam Sq. Ft./ Bldg. (000)[3]	Total Sq. Ft. (000,000)	Total Number of Bldgs.	Total Sq. Ft./ Bldg. (000)[3]
1-9	26.0	63	412.7	27.7	83	333.7	6.3	20	315.0	25.4	44	577.3	85.3	210	406.2
10-19	2.6	7	371.4	15.2	63	241.2	6.3	17	370.6	21.5	52	413.5	45.6	139	328.0
20-29	.4	4	100.0	6.6	29	227.6	.2	2	100.0	2.9	9	322.2	10.0	44	227.3
30-39	--	--		.8	5	160.0	.2	2	100.0	7.1	2	3,550.0	8.1	9	900.0
40-49	--	--		3.4	18	188.9	3.1	0	344.4	17.9	52	344.2	24.6	79	308.9
50+	1.2	3	400.0	7.9	48	164.6	5.2	14	371.4	15.3	94	162.8	29.6	159	186.2
TOTAL	30.2	77	392.2	61.5	246	250.0	21.3	64	333.0	90.0	253	355.7	203.1	640	317.3

[1] The source of this information is the BOMA data base.

[2] Totals may not add due to rounding.

[3] Square feet per building computed by dividing square feet by number of buildings.

TABLE 5-22A

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE BUILDING SAMPLE BY BUILDING AGE
SUBSAMPLE A - DOWNTOWN BUILDINGS
WEIGHTED MEANS AND STANDARD DEVIATIONS

	1-9 Years	10-19 Years	20-29 Years	30-39 Years	40-49 Years	50+ Years
Electric BTU/Sq. Ft. (000)						
Mean	99.2	82.4	79.0	32.4	71.9	62.0
Standard Deviation	6.1	5.4	5.8	5.4	4.3	2.4
Other Fuels BTU/Sq. Ft. (000)						
Mean	51.8	90.7	82.7	53.0	86.1	110.1
Standard Deviation	8.0	10.2	21.5	5.3	7.4	12.0
Total BTU/Sq. Ft. (000)						
Mean	151.0	173.2	161.7	85.4	158.0	172.1
Standard Deviation	8.3	13.0	23.2	9.3	8.7	12.0
Total Square Feet (000,000)	45.7	27.3	7.0	7.5	20.3	18.4
Number of Buildings	74	56	27	5	59	80
Sq. Ft./Bldg. (000)[1)]	617.6	487.5	259.2	1,500.0	344.1	230.0

[1)] Square feet per building based on division of total square feet by number of buildings.

Source: BOMA Data Base.

TABLE 5-22B

ENERGY CONSUMPTION IN THE 1975 BOMA OFFICE
BUILDING SAMPLE BY BUILDING AGE
SUBSAMPLE A - DOWNTOWN BUILDINGS
UNWEIGHTED MEANS AND STANDARD DEVIATIONS

	1-9 Years	10-19 Years	20-29 Years	30-39 Years	40-49 Years	50+ Years
Electric BTU/Sq. Ft. (000)						
Mean	104.8	93.5	81.6	39.9	67.6	57.6
Standard Deviation	55.2	43.0	33.4	25.2	39.1	23.5
Other fuels BTU/Sq. Ft. (000)						
Mean	64.8	90.9	86.4	96.4	90.6	91.1
Standard Deviation	77.7	66.4	95.9	33.8	70.8	91.7
Total BTU/Sq. Ft. (000)						
Mean	169.6	184.4	168.0	136.3	158.2	148.7
Standard Deviation	78.3	86.1	102.5	38.4	80.7	93.8
Total Square Feet (000,000)	45.7	27.3	7.0	7.5	20.3	18.4
Number of Buildings	74	56	27	5	59	80

Source: BOMA Data Base.

TABLE 5-23

AIR CONDITIONING CAPACITY OF THE 1975 BOMA
OFFICE BUILDING SAMPLE - TOTAL SAMPLE
BY BUILDING AGE
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Building Age in Years					
	1-9	10-19	20-29	30-39	40-49	50-
Square Feet/Ton						
Mean	486.2	279.0	323.9	435.6	1,123.7	1,958.5
Standard Deviation	2,261.7	156.0	179.0	548.6	2,363.8	9,742.1
Total Square Feet (000,000)	69.2	39.2	9.2	7.9	19.5	20.5
Number of Buildings	150	110	37	6	53	92

Source: BOMA Data Base.

TABLE 5-24

ELECTRIC BILL POLICY OF BUILDING MANAGEMENT IN
1975 BOMA OFFICE BUILDING SAMPLE
SUBSAMPLE A
WEIGHTED MEANS AND STANDARD DEVIATIONS

	Centrally Metered		
	No Response	Included in Rent	Individually Metered
Electric BTU/Sq.Ft.			
Mean (000)	68.8	91.1	64.0
Standard Deviation (000)	4.9	3.1	4.0
Square Feet (000,000)	12.5	89.0	32.3
Number of Buildings	33	239	85

Source: BOMA Data Base.

TABLE 5-25

COMPARISON OF 1974 AND 1975 BOMA DATA[1]
ELECTRICITY
MBTU/SQ. FT.
WEIGHTED MEANS AND STANDARD DEVIATIONS

	1974 Mean	1975 Mean	Standard Deviation	Number of Std. Deviations Between 1974 and 1975 Data
New England	58.9	73.4	2.0	-7.25
Middle Atlantic	59.8	61.1	3.5	-.37
South Atlantic	95.4	96.6	7.5	-.16
East North Central	50.5	88.4	6.5	-5.83
East South Central	71.5	97.3	22.6	-1.14
West North Central	46.2	81.2	4.4	-7.95
West South Central	65.7	116.4	7.5	-6.83
Mountain	72.9	77.4	5.6	-.80
Pacific	52.3	92.6	5.3	-7.60

[1] The 1974 BOMA data has been obtained from the Jack Faucett Associates Report. The 1975 data has been developed by GE-CFES.

TABLE 5-26

COMPARISON OF 1974 AND 1975 BOMA DATA[1)]
FOSSIL FUELS
MBTU/SQ. FT.
WEIGHTED MEANS AND STANDARD DEVIATIONS

	1974 Mean	Mean	Standard Deviation	Number of Std. Deviations Between 1974 and 1975 Data
New England	92.2	109.7	12.2	-1.43
Middle Atlantic	99.6	70.3	6.7	4.37
South Atlantic	84.2	34.6	10.2	4.86
East North Central	100.1	95.1	12.1	.41
East South Central	58.7	69.3	15.3	-.69
West North Central	124.8	99.1	9.3	2.76
West South Central	104.1	92.8	16.7	.68
Mountain	110.0	182.7	35.9	-2.02
Pacific	50.2	40.6	3.5	2.74

1) The 1974 BOMA data has been obtained from the Jack Faucett Associates Report. The 1975 data has been developed by GE-CFES.

TABLE 5-27

ENERGY USE IN A SAMPLE OF 44 NEW YORK CITY OFFICE BUILDINGS[1)]
MBTU/Sq. F t.

		Actual Energy Consumption	Normalized for Occupancy Utilization	Normalized for Weather	Normalized for Occupancy Utilization and Weather
1971	mean	142	133	135	126
	std. deviation	58	56	55	53
1972	mean	144	135	140	131
	std. deviation	58	56	56	54
1973	mean	132	128	126	123
	std. deviation	57	52	52	50
1974	mean	116	118	113	115
	std. deviation	41	42	40	41
1975	mean	115	112	115	112
	std. deviation	39	36	39	36

[1)] The source of this data is the Tishman-Syska and Hennessy report Energy Conservation in Existing Buildings, ERDA Contract EY-76-C-02-2799.000, June 1977.

SECTION 6

REGRESSION ANALYSIS OF THE BOMA DATA BASE

INTRODUCTION

In this section, we describe our use of regression analysis to determine and quantify the major factors influencing energy consumption in office buildings. Although there may be a large number of such factors, we were restricted to those for which data were available to us from the two sources at our disposal--BOMA data on energy consumption and building characteristics, and NOAA data on weather. Table 5-1 presented the information available in the BOMA data base. Each of the items was evaluated for its potential use as an explanatory or dependent variable.

An important reason for performing the regressions was to determine whether it was possible to predict energy consumption in office buildings on the basis of a small amount of input information. It was recognized at the outset that an equation of this type would probably not provide a reliable estimate of a single building's energy consumption, but might be quite good for estimating average consumption of building populations. If so, the problem of forecasting energy consumption in office buildings would become considerably more manageable.

Equations were developed individually for the consumption of electricity, fossil fuels and total energy for each of four groups of buildings categorized according to its heating fuel--electricity, gas, oil or steam.[1)]

The regressions were run using the 1975 BOMA Subsample A, and the corresponding city's 1975 heating and cooling degree days, i.e., a one-year cross sectional analysis. At a future date, it would be useful to run similar regressions for other years to test the stability of the coefficients or to determine whether the coefficients are changing in a systematic way.

[1)] In the case of steam buildings we also developed a fifth category, steam air conditioned buildings.

THE STATISTICAL MODEL

In order to investigate which variables and equation forms best explain energy consumption, we performed the following series of regressions:

- Electric, non electric, and total building energy use as a function of seven preselected variables.
  - On a total energy basis, linear regression.
  - On a total energy basis, exponential regression.
  - On an energy per square foot basis, linear regression.
- Electric, non electric, and total building energy use as a function of fewer than seven preselected variables.
  - On a total basis, linear regression.
  - On a total basis, exponential form.

The equations were then used to predict energy use in 1975 in a small sample of New York City office buildings for the purpose of comparing these predictions[2)] with actual consumption in that year.

In developing the equations, it was necessary to consider a number of statistical and econometric questions: the choice of equation form; the choice of dependent and independent variables; the possible existence of multicollinearity; the significance of the t and F statistics; the standard errors; and the magnitudes of the R^2 values. Before presenting the equations, we will discuss some of the estimating theory.

Choice of Equation Form

Two equation forms were used. The linear form:

$$1. \quad Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n$$

and the exponential form:

2-a. $Y = \delta_0 X_1^{\delta_1} \; X_2^{\delta_2} \; \ldots \; X_n^{\delta_n}$

which is equivalent to and was fited as a ln-ln equation:

2-b. $\ln Y = \delta_0' + \delta_1 \ln X_1 + \delta_2 \ln X_2 + \ldots + \delta_n \ln X_n$

Equation 1 presents the independent variables as having a linear, additive effect on the dependent variable; equation 2 indicates that the independent variables have an exponential, multiplicative effect on the dependent variable. In view of the possible interaction and feedback effects among the independent variables that characterize a building's structure, environment, and usage, we decided that both equation forms should be examined.

Selection of Independent Variables

In formulating the equations, we found that a selection of seven variables appeared to be appropriate for explaining and predicting building energy use. These were the independent variables remaining from the BOMA data base after other variables had been discarded, due to multicollinearity and other problems, during our regression analyses. We had the choice of expressing each dependent variable as a function of the complete set of independent variables, or of obtaining a "best fit" relationship in which a given dependent variable would be expressed as a function of some--but not necessarily all--of the independent variables. The choice of either method could be justified, depending on whether one is attempting to explain building energy use, or whether one is attempting to predict building energy use.

If our sample of electric, gas, oil and steam heated buildings were similar with respect to location, size, age, etc., there would be no a priori reason why the independent variables which drive energy use should vary from building type to building type; one could argue that an identical set of variables should be useful in explaining energy use in all types of buildings. Buildings require energy for lighting, heating, hot water, cooling, and various other uses. One would expect the significant variables--although not the level of usage represented by the variables--to be independent of building fuel type. Therefore, one could argue that energy use in all types of buildings should be explained in terms of an identical set of independent variables. Under such a procedure, the final equations could contain variables whose "t" values were statistically insignificant.

When one specifies that the same seven variables must appear in each equation one can obtain, however, meaningless results. For example, a negative sign for the coefficients of office space, store space, or "other" building space, has sometimes occurred in some of the equations, and this result is meaningless. Such results may occur because, in a given sample, say oil heated buildings, the observations available are not well distributed around the country and do not have a wide range of values for the characteristics of the buildings. Thus, if a sample contains buildings which are generally old and are located in cities which have essentially the same climate, neither age, nor weather would be likely to appear as important explanatory variables. With sufficiently low "t" values, "incorrect" signs would not be unexpected. If, however, a sample contains a broad range of ages and locations, these same variables might show up in the equations as quite significant. In addition to this type of problem, other factors such as multicollinearity, heteroscedacity, and the absence of important driving variables, may contribute to unexpected results.

The alternative to the inclusion of an identical set of independent variables in each equation is to use a subset of the independent variables in explaining a dependent variable. With this approach, variables would be retained only if they were statistically significant and their signs were what would be expected on an a priori basis. The resulting equation would be statistically correct and would yield the maximum R^2 for each equation. The problem with this approach is that the driving factors behind energy use would appear to differ from building to building. On an a priori basis, this is unrealistic; if heating degree days are important in determining energy use by a gas heated building, one would expect heating degree days to be important in determining energy use by other types of buildings. Variations in the significance of important variables could be caused either by the nature of the samples with which we are working, as noted above, or by the omission of important driving variables or other statistical problems.

The results of both approaches are presented in the following discussion. For each building type, with the exception of electric buildings, the tables[1)] present the equations on the basis of the inclusion of all independent variables in the equations, and on a "best fit" basis. Electric buildings have, of course, only one table of equations, because in electrically heated buildings it would be unusual to find oil, gas, or steam used.

Our initial approach was to attempt to explain energy use in terms of BTU/Sq. Ft. for electric use, fuel use, and total energy use by building type. We obtained low R^2 values in regressing energy use per square foot as a function of the independent variables. The R^2 values were greatly improved when we regressed total building electric use, total building fuel use, and total building energy use as a function of the independent variables. An examination of the regression equations indicated that square feet of building space are highly correlated with building energy use. Therefore, when the data are put on a per square foot basis the most important variable has been eliminated as an explanatory variable, and this results in a low R^2.

We wished to examine the use of energy by end use—lighting, air conditioning, other electric use, hot water use, and heating--as a function of a number of independent variables. Many of the dependent and independent variables which we would have needed to conduct such an analysis were, however, unavailable, since energy use by end use is not generally metered. Furthermore, as noted previously, our data source for the analysis, the BOMA Experience Exchange Report and its accompanying data bank, is primarily oriented towards financial analysis rather than energy analysis. We have previously outlined in Table 5-1 the data available in the BOMA data base. Although we investigated the feasibility of supplementing the data via a questionnaire, we found it to be beyond the resources available to us. Hence, for the purpose of the current analysis, we limited our data base to the data

[1)] One table for electricity use; one table for other fuel use; one table for total energy use.

which were available in the BOMA report plus weather data available from the National Oceanic and Atmospheric Administration. In working with the BOMA data, we found that some of the variables were multicollinear: in such cases we were able to use only one of two or more multicollinear variables: the final selection of dependent and independent variables used in the analysis is presented in Table 6-1.

EVALUATION OF EQUATIONS IN TERMS OF R^2 VALUES

One of the criteria on which an equation can be evaluated is its R^2, the ratio of the explained variation around the regression line to the total variation. Other things being equal, the desirability of a regression equation is proportional to the size of its R^2.[1] In our regression analysis we have presented two basically different types of regression equations:

- regression equations run on a linear, additive basis, which we will denote as the "linear" case; and
- regression equations run on a logarithmic (ln-ln) basis, which we will denote as the "exponential" case.

The R^2 values of the two cases are not directly comparable due to the nature of the logarithmic transformation, which "compresses" the data. The compression from the data transformation results in the R^2 of an exponential equation tending to be significantly higher than is the R^2 of a linear equation run on the same data, regardless of whether the actual predictive ability of the exponential case is superior to the predictive ability of the linear case.

In order to establish a basis for the comparison of R^2 values of the exponential equations with the R^2 values of the linear case, we recomputed a number of the R^2's; these recomputations of R^2 values are denoted as "R^2 Transposed" in the accompanying tables.[2] In order to compare the exponential case with the linear case we computed "R^2 Transposed" by transforming the predicted

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1) The "other things being equal" phrase is a crucial qualification to the sentence. The choice and signs of variables, t values, F value, and standard error must also be considered in evaluating a regression equation.

2) The computation of "R^2 Transposed" for the exponential case, after the data had been transformed through the taking of antilogs, was based on the formula

$$R^2 = 1 - \frac{\sum (\hat{Y} - Y_i)^2}{\sum (Y_i - \overline{Y})^2}$$

values of ln Y into their antilogarithmic form. We then computed the "R^2 Transposed" on the transformed data; the resulting "R^2 Transposed" value for the linear equation was directly comparable with the R^2 of the exponential case.

In evaluating the regression equations, we computed "R^2 Transposed" for a number of the cases. We did not compute "R^2 Transposed" for either the electric or the oil heated buildings: We concluded that the linear form was clearly preferable for electrically heated buildings and that the sample of oil heated buildings was too small to warrant additional computations. Therefore, we performed the R^2 Transposed computations for only the gas and steam heated buildings. In general, we found that neither the linear nor the exponential form was consistently superior.

EVALUATION OF THE REGRESSION EQUATIONS

During our analysis we developed a wide variety of regression equations. The equations appearing in this volume are only a few of the many equations which we investigated. We discarded a number of equations with multicollinear variables; cases with poor t or F values; cases with poor R^2 values; and some cases with variables whose signs were meaningless. We also discarded those with the dependent variable expressed on a "per square foot" basis. Thus, all of the equations we are presenting have BTU's consumed as the dependent variable. The equations in the tables are those remaining after the exclusions and are considered the "better" ones. There is not, however, a "best" equation in most cases, for each equation has both strengths and weaknesses.

The equations appear in Table 6-2 for electrically heated buildings; Tables 6-3 to 6-5 for gas heated buildings; and Tables 6-6 to 6-8 for oil heated buildings. In the case of steam heated buildings, we know that a number of the buildings also have steam turbine or steam absorption air conditioning instead of electric air conditioning. We were unable, however, to determine in general which steam buildings were steam air conditioned, because building managers frequently omit in their reports to BOMA information on the types of air conditioning. Furthermore, building managers do not differentiate between steam absorption and steam turbine air conditioning in the reports. Tables 6-9 to 6-11 present the equations for 161 steam heated buildings, some of which are electrically air conditioned, some of which are steam air conditioned, and some of which may have no air conditioning. We were able to identify 18 buildings with steam air conditioning, but were unable to identify the type of steam air conditioning. Tables 6-12 to 6-14 present the resulting regression relationships for the 18 steam air conditioned buildings.

In recognition of the fact that thirteen tables of regression relationships provide a confusing array of information for comparison purposes, we have summarized the regressions in three tables:

Table 6-15: Summary of Regressions of Electric Use by Building Type.
Table 6-16: Summary of Regressions of Fuel Use by Building Type.
Table 6-17: Summary of Regressions of Total Energy Use by Building Type.

The summary tables provide the following information for each of the equations:

- t values for the regressors.
- signs of each of the regressors.
- R^2 for the equation.
- "R^2 Transposed" for those cases in which it was computed.
- F value of the equation.
- the fraction, standard error/mean.

Electricity Use

Table 6-15 summarizes the regression equations that estimate the consumption of electricity in office buildings using various types of heating fuel. As reflected by the values of R^2, despite the absence of detailed information on lighting kilowatts, building usage, "U" values, etc., good estimates of electricity consumption were obtainable from combinations of the seven independent variables available to us. In the case of electrically heated buildings, values of R^2 as high as .92 were obtained using only square feet (broken down into occupied office space, store space and other space) and heating degree days as explanatory variables. In fact, irrespective of the type of heating fuel, an equation could be found in which an R^2 of at least .86 occurred. Except in the case of electrically heated buildings, the R^2 values for the logarithmic form were generally either as good or better than the linear form.

For the linear form, the standard error of the regression was between .4 and .7 of the mean of the dependent variable, while the values for the logarithmic form were much lower -- between .036 and .054. The two sets of ratios are not directly comparable, since one is in terms of logarithms and the other in terms of natural numbers; a transposition of one form into the other would be necessary for a direct comparison. However, both because of the R^2 values and the much smaller standard error relative to the mean, the logarithmic form seems to be somewhat superior as an estimating device.

Among the coefficients, the total square feet (modified)[1)] appears to be the single most important explanatory variable. In every equation, its coefficient is strongly significant. In fact, used alone with no other explanatory variables, it resulted in R^2 values of over .8 in electrically heated buildings (for both linear and logarithmic forms) and steam heated buildings (in the logarithmic form only).

When total square feet (modified) was broken into its components, occupied office space was by far the most important variable, since its coefficient was statistically significant in every equation. The coefficient of the store area variable was marginally significant for electric buildings and steam heated buildings. It is not clear why this coefficient should be significant for these buildings but not for gas or oil heated buildings. The coefficient of the other square feet variable was similarly mixed -- it was statistically significant for electric and gas buildings, and in the logarithmic form for oil buildings, but not for steam buildings.

Because electricity is used for heating in electric buildings, the coefficient of heating degree days would be expected to be significant in such buildings; in the linear form, it is. However, for no apparent reason, in the logarithmic form, it is not. For other buildings, it is also generally not significant.

[1)] That is, total occupied office space plus store space (whether or not occupied) plus other space.

Cooling degree days is a significant variable in gas buildings and in some equations for oil buildings. This is a consequence of electric air conditioning in such buildings. In electric and steam buildings, the coefficients are not significant, in the former perhaps because of the greater importance of electric heating as a factor in electricity consumption and in the latter because of the presence of steam air conditioning.

The effect of building age on electricity consumption is mixed. The coefficient is not significant for electric buildings, perhaps because most such buildings in the sample are new. It is also not significant for oil buildings, perhaps because the sample did not contain a broad enough range of ages. It is significant in at least some equations for gas and steam buildings. Where it is, the sign is negative indicating that the younger the building, the more electricity it will consume.

In the logarithmic form, the coefficient for the variable, square feet (modified), (TSFHT), divided by height was significant for all types of buildings except electric buildings, where it was only marginally significant. The positive sign indicates that the more squat the building, the more electricity it will use. It is interesting to note, however, that except for oil heated buildings, where the sample was particularly weak, the coefficient in the linear form was not statistically significant.

Other Fuel Use

In general, the R^2 values in Table 6-16 indicating the relationship between oil, gas or steam use and the available independent variables, were considerably lower than the R^2 values obtained for electricity use. Perhaps, one reason is that, according to the literature on office building heating loads, the use of fuel in a commercial building is a function of the complex interactions between the types and hours of building usage, the building's physical characteristics, and the equipment in the building. More or different variables and a more complex formulation might very well improve the predictive power of the equations.

For gas buildings, the R^2 values for the linear case were particularly low. However, the logarithmic form for such buildings yielded R^2 values which were substantially higher. The R^2 values for the logarithmic form were very similar to those obtained by both types of equations for oil heated buildings. These, in turn were somewhat lower than those obtained for steam heated buildings. For the oil and steam buildings, there was little difference in R^2 values between the linear and logarithmic forms.

Along with the lower R^2 values, the standard errors for these equations were relatively larger than was the case for the electricity equations. This merely confirms the conclusions derived from the R^2 values, i.e., that the independent variables are better estimators of electricity use than they are of oil, gas or steam.

Despite the fact that the R^2 values are lower than they were when the regressions were applied to electricity consumption, they are far from insignificant in most instances. In general, the R^2 values imply that over half--three quarters in the case of steam heated buildings--of the variation in the consumption of fuels other than electricity is explainable by variations in the independent variables used in the regression.

Once again, total square feet modified and occupied office space are variables whose coefficients are strongly significant. In the logarithmic oil building equation and in both the linear and logarithmic steam heated equations, total square feet (modified) by itself yielded relatively good R^2 and standard error values. This implies that if all one knows about oil and steam heated office buildings is the total square feet (modified), one can still obtain a tolerable estimate of oil or steam usage. Breaking square feet (modified) into its components did not seem to add materially to the statistical effectiveness of the equations.

The heating degree days variable was significant for gas and steam heated buildings, but not so for the oil heated buildings. For the latter type of building, this may be a function of the geographical concentration of the sample buildings in areas of similar winter temperature.

The situation for the cooling degree day variable was similar to that of the heating degree day variable--nonsignificant coefficients for oil buildings, significant ones for gas and steam buildings. Because of steam air conditioning, the cooling and heating degree day coefficients in steam building equations had very similar t values; in gas buildings, the t values for heating degree days were somewhat greater than those for cooling degree days.

Age was not a significant variable in any equation except one for gas heated buildings. In this case, the positive sign indicated greater gas consumption associated with greater age. This is counter to the results in electric buildings.

The variable, TSHFT, presented a mixed picture. In about half the equations in which it appeared, its coefficient was significant or marginally so; in the remainder of the equations, it was not. Further, even where it was significant, for some buildings, the coefficient was negative, for others it was positive. Consequently, equations including this variable are probably not preferred ones for estimating energy consumption.

Total Energy Consumption

Table 6-17 concerns gas, oil and steam heated buildings, but here the dependent variable is the total of the heating fuel and electricity. This should improve the relationship resulting from the use of only gas, oil or steam consumption as the dependent variable since there is frequently assumed to be some interaction between building electric use and building fuel use. For example, part of the heating requirement of a building in winter may be met from the heat resulting from the operation of lighting, motors, and other types of equipment in the building. In buildings with electric air conditioning and terminal reheat the use of fuel in the building is actually dependent on the use of the air conditioning.

The addition of electricity does, in fact, improve the R^2 values and the standard error relative to the mean of the dependent variable. R^2 values above .85 are common for steam heated buildings. For gas heated buildings, where the R^2 values had ranged from .3 to .6 with just gas consumption as the dependent variable, the R^2 values now range from .6 to .8 with total energy consumption as the dependent variable. Improvements in the statistical indicators were also noted in oil fired buildings. The heating and cooling degree days variables had coefficients which were either statistically significant, or almost so, for gas and steam heated buildings. The same was true for the age and TSFHT variables. In the latter variable, it was the logarithmic form where the coefficients were most strongly significant.

CONCLUSION

It does appear possible to develop regression equations using a small set of independent variables which reveal a fairly close relationship between those variables and energy consumption. However, before such equations are put to use to actually estimate energy consumption, more research is needed to determine whether the coefficients are stable or whether they are changing. If the latter, it is important to determine whether the changes are taking place in a systematic way, for example, in response to economic factors such as price and income, so that the coefficients can be modified accordingly. Research might also develop new independent variables which would improve the relationships.

In addition, the building samples in most cases need improvement. Both the electrically heated and the oil heated building samples are relatively small and are concentrated in a few areas of the country. Also, for the most part, we were unable to distinguish for steam heated buildings between those which were steam air conditioned and those which were electrically air conditioned. Separating the two or, at least dealing with the two in some explicit way, could significantly improve the relationships.

Based on the equations presented, the most important variable affecting energy use appears to be square feet of space. Heating and cooling degree days, age, and profile (high and thin vs. short and squat) also affect energy consumption but to a lesser degree.

Except in the case of electric buildings, the relationship between energy consumption and the independent variables seems a little closer in most cases when expressed in logarithmic as opposed to linear form. However, the differences are generally not great.

APPLICATION OF THE REGRESSION EQUATIONS

In the preceding paragraphs, we concluded that the regression equations appear to have reasonably good predictive powers, with adequate F and R^2 values, significant t values and acceptable standard errors. We next investigated how well the equations could predict energy consumption for buildings which were not in the sample from which they (the equations) were developed.

Comparison of Estimated and Actual Consumption for Individual Buildings

In Section 5 of this report, we discussed the TSH simulation of 5 New York City office buildings. Four of the buildings were steam heated and one was oil heated. It is these steam heated buildings to which we applied the equations discussed above. The oil heated building was not used because the oil equations were deemed to have been based on too small a sample. The data which TSH gathered in conjunction with their simulation provided us with the information we needed for the independent variables of our equations; it also provided actual energy consumption with which to compare the estimates provided by the equations.

The values of the independent variables for the four steam heated buildings are presented in Table 6-18. A number of the steam equations were used to simulate energy use. Since all four of the buildings have both steam heating and steam air conditioning, we used the equations for steam air conditioned buildings. However, the steam air conditioning equations are of dubious value, since they are based on a relatively small sample of buildings. Therefore, we also used the equations which were based on the full sample of 161 steam heated buildings, even though that sample included buildings with both steam and electric air conditioning systems. The predicted and actual building electric use, steam use, and total energy use are presented in Tables 6-19 to 6-21.

In general, the equations did not predict energy consumption for each of the four buildings very well. In estimating electricity consumption (see Table 6-19), the equations for buildings with steam air conditioning, which had been considered to be unreliable, turned out that way; the estimates derived from such equations were, for the most part, quite poor. In fact, some values actually appeared with negative signs, implying that the buildings were net generators of energy. With respect to the other equations, no one of them did a demonstrably superior job than any of the others for all four buildings. Overestimates ranged up to 2½ times actual, while some of the underestimates were less than 20% of actual.

In general, buildings 140 and 650 tended to be overestimated and the other two buildings underestimated. From Table 6-18, it can be seen that Buildings 140 and 650 are both quite a bit larger and younger than the other two.

The steam consumption estimates generated by the regression equations tended to underestimate three of the four buildings. Only the steam consumption of building 650 was overestimated and that by four of the six equations shown. The other two equations, which underestimated steam consumption, were based on the admittedly weak steam air conditioning equations. Deviations from actual were again quite wide, although not quite as wide as in the case of the electricity estimating equations. Overestimates exceeded actuals in the worst case by 35% and underestimates were as low as 30% of actual.

For total energy, once again buildings 472 and 487 (the smaller, older buildings) were underestimated while building 650 was overestimated. Except for one equation, building 140 was also underestimated, the greatest deviations from actual occurring in the estimates of two of the steam air conditioned equations. As in the case of the electricity and steam equations, wide deviations also occurred here. On the low side, estimates as low as 15% of actual occurred while, on the high side, the equations yielded overestimates of over 150%.

Comparison of Estimated and Actual Average Consumption

Thus, the equations did not estimate consumption of individual buildings well. It is instructive, however, to average the actual consumption for the four buildings and compare that average with the corresponding average of the estimated consumption for the buildings. The results are shown in Table 6-22. None of the steam air conditioning equations were used in this comparison.

Four equations were used to estimate total energy consumption in each of the four buildings. The average of the estimates of total energy consumption of the four buildings, as computed by each of the equations, is shown in the second column of Table 6-22. Also shown is the average actual consumption for the four buildings. As can be seen from the table, the estimates range from 11% under actual to 5% over actual—a relatively close approximation of actual consumption. If the estimates are themselves averaged, the resultant value is only 6% below actual.

Five equations were used to estimate electricity consumption in the four buildings. The average of the estimates for the four buildings ranged from 12% below the average of the actual values to almost 30% above the average actual value. The average of the five estimates was only 5% above the corresponding actual value.

Estimates for steam were further from actuals than was the case for either electricity or total energy. Values computed by the three equations used to estimate steam consumption were between 12% and 14% below actual, the average of the estimates fell 13% below actual.

It is also of interest to note that whether for total energy, electricity or steam, the equations with the highest R^2 did not necessarily provide the best estimates. Also, the equation with the single variable, total square feet (modified), gave the best estimate for both total energy and electricity, although the equation in which it appeared as the single variable was logarithmic for total energy and linear for electricity. For steam, the equation with the logarithm of total square feet (modified) as the sole independent variable yielded estimates quite close to those provided by the other equations. Thus, it appears that reasonable estimates of energy consumption might be obtained from knowledge of only the square feet of space.

CONCLUSION

The use of the regression equations developed here for the purpose of estimating energy consumption in a particular building is probably not warranted at this time. However, such equations, properly applied, might be quite useful in estimating energy consumption in populations of buildings. However, as noted above, additional research can improve the equations and yield higher confidence estimates than those developed here not only for a population of buildings but possibly for individual buildings as well.

TABLE 6-1

VARIABLES USED IN REGRESSIONS

DEPENDENT VARIABLES

BELEC 6:	Total Building Electric Use in BTU's $\div 10^6$.
NELEC 6:	Total Building Fuel Use in BTU's $\div 10^6$.
TBTU 6:	Total Building Energy Use in BTU's $\div 10^6$.
ELSF:	Building Electric Use Per Square Foot in BTU's.
NESF:	Building Fuel Use Per Square Foot in BTU's.
BTUSF:	Total Building Energy Use Per Square Foot in BTU's.

INDEPENDENT VARIABLES

TSFM:	Total Square feet in the Building Adjusted for Occupancy: Office Area x Vacancy Rate + Commercial Area + Other Area.
OAOCC:	Office Area in Building x Vacancy Rate
STAR:	Total Commercial Area in Building
OSQFT:	Total Building Area Exclusive of Office and Commercial Areas.
HDD:	Heating Degree Days in the City in Which the building is Located.
CDD:	Cooling Degree Days in the City in Which the building is Located.
AGE:	Age of Building.
TSFHT:	Total Square Feet in the Building Divided by the Number of Stories in the Building.

TABLE 6-2

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING ELECTRICITY USE TO BUILDING CHARACTERISTICS AND WEATHER IN ELECTRICALLY HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
1-1.1		.170	.053	.578	7.762	10.396	-792.998	-.171	-52,669.798	.92		28,449.193	65,913.329	66
S.E.		.011	.028	.106	3.403	7.725	1319.551	.382						
t		14.97	1.90	5.44	2.28	1.34	.60	.45						
1.1-2	.173								-9,617.338	.83		41,419.368		195
S.E.	.012													
t	13.96													
1-1.3		.172	.041	.558	4.168				-29,605.152	.92		28,217.627	65,913.329	117
S.E.		.011	.023	.104	2.192									
t		15.46	1.78	5.38	1.90									
LOGARITHMIC EQUATIONS														
1-1.4		.164	.066	.082	.292	.025	-.076	.376	1.503	.33		.831	10.522	3.84
S.E.		.068	.032	.032	.284	.241	.221	.265						
t		2.40	2.04	2.59	1.03	.105	.364	1.42						
1-1.5	.945								-1.264	.86		.377	10.522	251
S.E.	.060													
t	15.89													
1-1.6		.142	.062	.077	.184				6.470	.35		.820	10.522	6.35
S.E.		.060	.031	.031	.200									
t		2.35	1.97	2.47	.92									

19[illegible] BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING ELECTRICITY USE TO BUILDING CHARACTERISTICS AND WEATHER IN GAS HEATED BUILDINGS

EQUATION NUMBER		COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSPOSED	STD ERROR	MEAN	F
LINEAR EQUATIONS															
2-1.1			.096	.076	.060	-.733	5.362	-71.957	.122	-2,665.600	.81	.71	15,165.682	26,760.945	87
	S.E.		.007	.069	.035	.793	1.876	61.312	.105						
	t		14.30	1.10	1.69	.929	2.86	1.17	1.16						
2-1.2		.094					5.820	-88.236		-4,347.376	.82	.69	15,107.720	26,760.945	204
	S.E.	.004					1.523	59.640							
	t	23.68					3.82	1.48							
2-1.3		.095					6.154			-7,089.865	.81		15,173.606	26,760.945	303
	S.E.	.004					1.512								
	t	24.03					4.07								
2-1.4			.100	.068	.068		6.292			-7,297.545	.81		15,236.434	26,760.945	150
	S.E		.006	.068	.034		1.527								
	t		15.46	1.00	2.01		4.12								
LOGARITHMIC EQUATIONS															
2-1.5			.838	.007	.029	-.066	.196	-.116	.222	-3.266	.84	.78	.510	9.515	101
	S.E.		.052	.010	.011	.083	.047	.044	.085						
	t		16.15	.704	2.66	.787	4.16	2.62	2.61						
2-1.6		1.042					.184	-.130		-3.890	.86	.71	.461	9.515	298
	S.E.	.037					.039	.037							
	t	28.59					4.68	3.51							

REGRESSION STATISTICS RELATING GAS USE TO BUILDING CHARACTERISTICS AND WEATHER IN GAS HEATED BUILDINGS

	COEFFICIENTS (10^6)													
EQUATION NUMBER	TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSPOSED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
2-2.1		.097	-.604	.346	3.597	6.170	84.076	-.124	-16,383.771	.37	.24	39,904.429	30,524.084	13
S.E.		.018	.181	.093	2.087	4.938	161.327	.277						
t		5.47	3.35	3.72	1.72	1.25	.52	.45						
2-2.2	.086				4.878	8.92			-25,075.078	.29		42,423.167	30,524.084	20
S.E.	.011				2.159	5.09								
t	7.59				2.26	1.75								
2-2.3		.091	-.596	.353	2.18				-1,334.383	.37		39,790.185	30,524.084	22
S.E.		.017	.179	.088	1.69									
t		5.31	3.34	4.03	1.29									
LOGARITHMIC EQUATIONS														
2-2.4		.714	.016	.030	.688	.139	-.048	.244	-7.972	.56	.24	.814	9.563	27
S.E.		.083	.017	.018	.133	.075	.071	.136						
t		8.61	.96	1.67	5.17	1.86	.673	1.80						
2-2.5	.928				.716	.130	-.048	.008	-8.251	.60	.25	.781	9.563	42
S.E.	.080				.125	.070	.066	.134						
t	11.66				5.71	1.86	.727	.063						
2-2.6		.713	.014	.030	.679	.145		.265	-8.238	.57		.813	9.563	31
S.E.		.083	.016	.018	.132	.074		.132						
t		8.62	.834	1.64	5.14	1.95		2.01						

REGRESSION STATISTICS RELATING TOTAL ENERGY USE TO BUILDING CHARACTERISTICS AND WEATHER IN GAS HEATED BUILDINGS

EQUATION NUMBER	TSFM	OAOCC	STAR	OSQSF	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
	COEFFICIENTS (10^6)													
LINEAR EQUATIONS														
2-3.1		.193	-.529	.406	2.864	11.531	12.120	0	-19.049.370	.63	.61	45,571.050	57,285.019	35
S.E.		.020	.206	.106	2.384	5.639	184.237	.316						
t		9.55	2.56	3.83	1.20	2.04	.06	0						
2-3.2		.187	-5.35	.425		7.62			-531.589	.64	.66	45,314.584	57,285.019	61
S.E.		.019	.203	.099		4.54								
t		9.74	2.63	4.25		1.68								
2-3.3	.176					8.671			-1,494.462	.59		47,870.024	57,285.019	102
S.E.	.012					4.771								
t	14.06					1.82								
2-3.4	.180				3.949	13.852			-26,323.730	.66		47,580.447	57,285.019	70
S.E.	.013				2.421	5.708								
t	14.16				1.63	2.43								
LOGARITHMIC EQUATIONS														
2-3.5		.766	.011	.028	.284	.188	-.086	.226	-4.54	.77	.53	.555	10.333	65
S.E.		.056	.011	.012	.091	.051	.048	.092						
t		13.55	.979	2.30	3.12	3.68	1.77	2.45						
2-3.6	.962				.298	.172	-.092		-4.572	.80	.53	.515	10.333	137
S.E.	.042				.082	.046	.042							
t	28.61				3.64	3.74	2.20							

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING ELECTRICITY USE TO BUILDING CHARACTERISTICS AND WEATHER IN OIL HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
3-1.1		.057	-.006	.037	-1.131	17.578	-4.395	.245	-15,511.446	.88		7,873.849	23,698.835	30.5
S.E.		.007	.072	.044	2.184	11.603	64.943	.070						
t		7.89	.089	.834	.518	1.51	.071	3.50						
3-1.2	.055					20.065		.266	-26,559.770	.89		7,441.056	23,698.835	79
S.E.	.006					7.848		.061						
t	9.56					2.56		4.34						
3-1.3		.058	-.008	.036		21.134		2.57	-26,711.825	.88		7,584.418	23,698.835	46
S.E		.007	.069	.042		8.964		.063						
t		8.66	.114	.861		2.36		4.08						
LOGARITHMIC EQUATIONS														
3-1.4		.586	-.012	.114	-1.186	.052	-.057	.167	10.616	.90		.285	9.687	40
S.E.		.115	.022	.028	.475	.368	.068	.137						
t		5.08	.559	4.09	2.50	.14	.84	1.22						
3-1.5	.839					.330		.331	-6.435	.86		.336	9.687	63
S.E.	.112					.298		.129						
t	7.48					1.11		2.56						
3-1.6		.685	-.018	.083		.529		.290	-5.994	.88		.311	9.687	45
S.E.		.113	.022	.027		.315		.138						
t		6.04	.80	3.03		1.68		2.10						

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING OIL USE TO BUILDING CHARACTERISTICS AND WEATHER IN OIL HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F.
LINEAR EQUATIONS														
3-2.1		.082	.932	.948	-12.926	-43.797	-136.379	-.617	133,358.349	.50		45,957.803	62,741.837	5.09
S.E		.042	.421	.256	12.749	67.726	379.057	.408						
t		1.95	2.22	3.70	1.01	.65	.36	1.51						
3-2.2		.069	1.040	.895					-6,629.035	.52		45,062.769	62,741.837	11
S.E.		.032	.374	.238										
t		2.12	2.78	3.76										
3-2.3	.128								12,994.118	.31		53,859.198	62,741.837	14
S.E.	.034													
t	3.74													
LOGARITHMIC EQUATIONS														
3-2.4		1.100	-.034	.105	-.712	-.498	.039	-.624	11.804	.55		.703	10.554	6.06
S.E.		.284	.055	.069	1.171	.907	.167	.338						
t		3.87	.607	1.52	.608	.549	.234	1.84						
3-2.5		1.113	-.035	.093				-.524	1.287	.59		.667	10.554	11.6
S.E		.243	.042	.058				.293						
t		4.58	.83	1.61				1.79						
3-2.6	1.324							-.431	-1.856	.70		.572	10.554	35
S.E.	.172							.178						
t	7.69							2.42						

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING TOTAL ENERGY USE TO BUILDING CHARACTERISTICS AND WEATHER IN OIL HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
3-3.1		.139	.926	.985	-14.057	-26.219	-140.764	-.372	117,846.734	.66		44,893.930	86,440.653	8.93
S.E.		.041	.411	.250	12.454	66.158	370.282	.398						
t		3.38	2.25	3.93	1.13	.396	.381	.935						
3-3.2	.197								9,476.836	.55		51.235.249	86,440.653	36.9
S.E	.032													
t	6.68													
3-3.3		.143	1.024	.924					-8,766.399	.68		43,274.114	86,440.653	21.66
S.E.		.031	.359	.228										
t		4.57	2.85	4.05										
LOGARITHMIC EQUATIONS														
3-3.4		.910	-.029	.111	-.927	-.271	.027	-.335	11.968	.67		.554	10.963	9.48
S.E		.224	.044	.054	.922	.714	.131	.266						
t		4.06	.662	2.04	1.00	.379	.207	1.26						
3-3.5	1.190							-.205	-1.984	.79		.447	10.963	54
S.E.	.134							.139						
t	8.87							1.48						
3-3.6		.812	.005	.074					.156	.70		.533	10.963	23
S.E.		.138	.023	.044										
t		5.90	.197	1.69										

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING ELECTRICITY USE
TO BUILDING CHARACTERISTICS AND WEATHER
IN STEAM HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
4-1.1		.072	-.254	.005	.225	.416	-92.728	.079	7,448.771	.79	.76	16,299.930	27,675.380	87
S.E.		.004	.041	.023	.989	3.141	58.164	.085						
t		17.77	6.15	.234	.228	.134	1.59	.931						
4-1.2	.045								9,537.178	.68	.52	20,151.356	27,675.380	338
S.E.	.002													
t	18.39													
4-1.3		.074	-.273	.003					6,312.030	.79	.69	16,310.428	27,675.380	201
S.E.		.004	.039	.015										
t		19.86	6.94	1.53										
LOGARITHMIC EQUATIONS														
4-1.4		.787	-.007	.004	-.223	.004	-.140	.254	.014	.85	.61	.435	9.625	136
S.E.		.048	.008	.009	.149	.048	.036	.069						
t		16.5	.840	.421	1.49	.08	3.91	3.68						
4-1.5	1.018								-2.895	.86	.42	.427	9.625	984
S.E.	.032													
t	31.38													
4-1.6		.943	-.015	.013					-1.790	.83	.71	.473	9.625	258
S.E.		.036	.009	.009										
t		26.36	1.73	1.48										

TABLE 6-10

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING STEAM USE
TO BUILDING CHARACTERISTICS AND WEATHER
IN STEAM HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
4-2.1		.064	.008	.078	2.332	7.704	-50.507	-.123	-11,632.033	.78	.46	20,500.264	28,337.571	82
S.E.		.005	.052	.029	1.244	3.951	73.152	.107						
t		12.57	.16	2.7	1.88	1.95	.691	1.15						
4-2.2	.060								4,406.571	.78	.60	20,633.619	28,337.571	562
S.E.	.002													
t	23.70													
4-2.3		.063	.024	.060					4,082.274	.78	.62	20,727.825	28,337.571	186
S.E.		.005	.050	.019										
t		13.16	.487	3.17										
4-2.4		.065	.005	.076	2.285	7.832		-.110	-13,631.262	.78		20,465.404	28,337.571	96
S.E.		.005	.052	.029	1.240	3.940		.105						
t		13.01	.105	2.65	1.84	1.99		1.05						
LOGARITHMIC EQUATIONS														
4-2.5		.794	-.010	.037	.563	.170	-.049	.127	-7.260	.71		.634	9.554	58
S.E.		.070	.012	.013	.218	.070	.052	.100						
t		11.41	.851	2.88	2.59	2.42	.932	1.26						
4-2.6	.965								-2.310	.72	.78	.629	9.554	408
S.E.	.048													
t	20.19													
4-2.7		.836	-.017	.049					-.814	.68	.72	.666	9.554	116
S.E.		.050	.012	.013										
t		16.60	1.34	3.86										
4-2.8		.802	-.011	.038	.556	.166		.136	-7.516	.71		.634	9.554	67
S.E.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]						

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING TOTAL ENERGY USE TO BUILDING CHARACTERISTICS AND WEATHER IN STEAM HEATED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6)													
	TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
4-3.1		.137	-.246	.084	2.557	8.120	-143.234	-.044	-4,183.267	.87	.77	26,802.611	56,012.944	153
S.E.		.007	.068	.038	1.626	5.166	94.641	.140						
t		20.42	3.62	2.21	1.57	1.57	1.50	.311						
4-3.2	.105								13, 943.742	.84	.68	29,914.713	56,012.944	826
S.E.	.004													
t	28.73													
4-3.3		.137	-.249	.083					10,394.297	.87	.77	27,024.833	56,012.944	350
S.E.		.006	.065	.025										
t		22.08	3.82	3.35										
4-3.4		.136	-.240	.075	2.472	8.104	-138.007		-4,427.989	.87		26,723.983	56,012.944	180
S.E.		.006	.065	.025	1.599	5.150	93.887							
t		20.71	3.68	3.00	1.55	1.57	1.47							
LOGARITHMIC EQUATIONS														
4-3.5		.790	-.010	.016	.202	.096	-.101	.188	-3.098	.88	.84	.380	10.352	163
S.E.		.042	.007	.008	.131	.042	.031	.060						
t		18.93	1.32	2.11	1.54	2.28	3.22	3.11						
4-3.6	.981								-1.717	.89	.78	.359	10.352	1295
S.E.	.027													
t	35.98													
4-3.7		.889	-.017	.027					-.487	.85	.86	.416	10.352	309
S.E.		.031	.008	.008										
t		28.28	2.20	3.47										
4-3.8		.872	-.014	.021	.304	.098	-.111		-3.161	.87		.391	10.352	178
S.E.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							

REGRESSION STATISTICS RELATING ELECTRICITY USE TO BUILDING CHARACTERISTICS AND WEATHER IN STEAM HEATED AND STEAM AIR CONDITIONED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6) TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
5-1.1		.092	-.554	-.067	2.264	-5.752	26.702	-.266	-3,857.526	.90		8,716.951	34, 139.702	22
S.E.		.011	.083	.112	2.956	24.422	111.920	.343						
t		8.34	6.71	.62	.766	.234	.239	.776						
5-1.2	.033								11,864.680	.56		17,869.471	34,139.702	23
S.E.	.077													
t	4.75													
5-1.3		-.055	-.540	.083					1,352.561	.91		7,954.473	34,139.702	60
S.E.		.089	.074	.007										
t		.617	7.33	12.03										
LOGARITHMIC EQUATIONS														
5-1.4		1.185	-.024	-.019	.648	-.934	.046	-.635	2.227	.87		.340	10.113	17
S.E.		.219	.020	.023	.765	.953	.098	.378						
t		5.41	1.20	.83	.85	.980	.470	1.68						
5-1.5	.806								-.348	.84		.376	10.113	89
S.E.	.086													
t	9.42													
5-1.6		.825	-.023	-.014			.013		-.265	.84		.357	10.113	26
S.E.		.090	.019	.023			.100							
t		9.22	1.19	.624			.130							

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING STEAM USE TO BUILDING CHARACTERISTICS AND WEATHER IN STEAM HEATED AND STEAM AIR CONDITIONED BUILDINGS

EQUATION NUMBER		COEFFICIENTS (10^6)													
		TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS															
5-2.1			.073	-.098	-.072	3.780	-2.319	-5.662	.177	-7,808.842	.40		35,366.964	53,949.464	2.69
	S.E.		.045	.335	.454	11.994	99.088	454.091	1.391						
	t		1.64	.292	.158	.315	.032	0	.126						
5-2.2		.057								14,760.939	.60		28,831.532	53,949.464	27
	S.E.	.011													
	t	5.18													
5-2.3			.069	-.073	.035					12,412.305	.55		30,565.551	53,944.464	8
	S.E.		.027	.283	.340										
	t		2.59	.257	.105										
LOGARITHMIC EQUATIONS															
5-2.4			.639	-.033	.011	.290	-.548	-.085	.074	3.303	.45		.623	10.583	3
	S.E.		.401	.036	.042	1.401	1.746	.179	.693						
	t		1.59	.903	.255	.207	.313	.47	.105						
5-2.5		.618								2.564	.59		.536	10.583	26
	S.E.	.122													
	t	5.07													
5-2.6			.635	-.029	.022			-.122		2.762	.53		.574	10.583	5.83
	S.E.		.144	.031	.037			.161							
	t		4.41	.93	.584			.76							

1975 BOMA BUILDING SAMPLE - SUBSAMPLE A

REGRESSION STATISTICS RELATING TOTAL ENERGY USE TO BUILDING CHARACTERISTICS AND WEATHER IN STEAM HEATED AND STEAM AIR CONDITIONED BUILDINGS

EQUATION NUMBER	COEFFICIENTS (10^6)													
	TSFM	OAOCC	STAR	OSQFT	HDD	CDD	AGE	TSFHT	CONSTANT	R^2	R^2 TRANSFORMED	STD ERROR	MEAN	F
LINEAR EQUATIONS														
5-3.1		.165	-.652	-.139	6.045	-8.072	21.040	-.089	-11,666.442	.65		40,334.972	88,089.154	5.46
S.E.		.054	.382	.518	13.678	113.006	517.877	1.586						
t		3.24	1.71	.270	.442	.071	.045	.055						
5-3.2	.090								26,625.618	.68		38,472.121	88,089.154	37
S.E.	.015													
t	6.09													
5-33		.152	-.613	-.020					13,764.877	.73		35,160.561	88,089.154	16
S.E.		.031	.326	.392										
t		4.97	1.88	.055										
LOGARITHMIC EQUATIONS														
5-34		.936	-.026	.005	.587	-.686	-.046	-.352	2.503	.78		.393	11.105	9
S.E.		.253	.023	.026	.884	1.102	.113	.437						
t		3.70	1.12	.18	.664	.623	.402	.804						
5-3.5	.707								1.94	.80		.368	11.105	71
S.E.	.084													
t	8.44													
5-3.6		.718	-.024	.012			-.081		2.158	.79		.382	11.105	17
S.E.		.096	.021	.025			.107							
t		7.44	1.18	.50			.75							

TABLE 6-15

SUMMARY OF EQUATIONS FOR BUILDING ELECTRIC USE

Building Type, Equation Type, and Equation Number	TSFM t	TSFM sign	OAOCC t	OAOCC sign	STAR t	STAR sign	OSQFT t	OSQFT sign	HDD t	HDD sign	CDD t	CDD sign	AGE t	AGE sign	TSFHT t	TSFHT sign	R^2	R^2 TRANSPOSED	F	STANDARD ERROR MEAN
ELECTRICALLY HEATED BUILDINGS																				
Linear Equations - Building Electric Use																				
1-1.1			14.97	+	1.90	+	5.44	+	2.28	+	1.34	+	.60	-	.45	-	.92		66	.432
1-1.2	13.96	+															.83		195	.628
1-1.3			15.46	+	1.78	+	5.38	+	1.90	+							.92		117	.428
Logarithmic Equations - Building Electric Use																				
1-1.4			2.40	+	2.04	+	2.59	+	1.03	+	1.05	+	.364	-	1.42	+	.33		3.84	.079
1-1.5	15.89	+															.86		251	.036
1-1.6			2.35	+	1.97	+	2.47	+	.92	+							.35		6.35	.078
GAS HEATED BUILDINGS																				
Linear Equations																				
2-1.1			14.30	+	1.10	+	1.69	+	.929	-	2.86	+	1.17	-	1.16	+	.81	.71	87	.567
2-1.2	23.68	+									3.82	+	1.48	-			.82		204	.564
2-1.3	24.03	+									4.07	+					.81		303	.567
2-1.4			15.46	+	1.00	+	2.01	+			4.12	+					.81		150	.569
Logarithmic Equations																				
2-1.5			16.15	+	.704	+	2.66	+	.787	-	4.16	+	2.62	-	2.61	+	.84	.78	101	.054
2-1.6	28.59	+									4.68	+	3.51	-			.86	.71	298	.048
OIL HEATED BUILDINGS																				
Linear Equations																				
3-1.1			7.89	+	.089	-	.834	+	.518	-	1.51	+	.071	-	.350	+	.88		30.5	.332
3-1.2	9.56	+									2.56	+			4.34	+	.89		79	.314
3-1.3			8.66	+	.114	-	.861	+			2.36	+			4.08	+	.88		46	.320
Logarithmic Equations																				
3-1.4			5.08	+	.559	-	4.09	+	2.50	-	.14	+	.84	-	1.22	+	.90		40	.029
3-1.5	7.48	+									1.11	+			2.56	+	.86		63	.035
3-1.6			6.04	+	.801	-	3.03	+			1.68	+			2.10	+	.88		45	.032
STEAM HEATED BUILDINGS																				
Linear Equations																				
4-1.1			17.77	+	6.15	-	.234	+	.228	+	.134	+	1.59	-	.931	+	.79	.76	87	.589
4-1.2	18.39	+															.68	.52	338	.728
4-1.3			19.86	+	6.94	-	1.53	+									.79	.69	201	.589
Logarithmic Equations																				
4-1.4			16.5	+	.84	-	.42	+	1.49	-	.08	+	3.91	-	3.68	+	.85	.61	135	.045
4-1.5	31.38	+															.86	.42	984	.044
4-1.6			26.38	+	1.73	-	1.48	+									.83	.71	258	.049

TABLE 6-16

SUMMARY OF REGRESSION EQUATIONS FOR BUILDING FUEL USE

Building Type, Equation Type, and Equation Number	TSFM t	TSFM sign	OAOCC t	OAOCC sign	STAR t	STAR sign	OSQFT t	OSQFT sign	HDD t	HDD sign	CDD t	CDD sign	AGE t	AGE sign	TSFHT t	TSFHT sign	R^2	R^2 TRANSPOSED	F	STANDARD ERROR MEAN
GAS HEATED BUILDINGS																				
Linear Equations																				
2-2.1			5.47	+	3.35	-	3.72	+	1.72	+	1.25	+	5.22	+	.446	-	.37	.24	13	1.307
2-2.2	7.59	+							2.26	+	1.75	+					.29		20	1.390
2-2.3			5.31	+	3.34	-	4.03	+	1.29	+							.37		22	1.304
Logarithmic Equations																				
2-2.4			8.61	+	.96	+	1.67	+	5.17	+	1.86	+	.673	-	1.80	+	.56	.24	27	.085
2-2.5			11.66	+					5.71	+	1.86	+	.727	-	.063	+	.60	.25	42	.082
2-2.6			8.62	+	8.34	+	1.64	+	5.14	+	1.95	+			2.01	+	.57		31	.085
OIL HEATED BUILDINGS																				
Linear Equations																				
3-2.1			1.95	+	2.22	+	3.70	+	1.01	-	.65	-	.36	-	1.51	-	.50		5.09	.732
3-2.2			2.12	+	2.78	+	3.70	+									.52		11.3	.718
3-2.3	3.74	+															.31		14	.858
Logarithmic Equations																				
3-2.4			3.87	+	6.07	-	1.52	+	.608	-	.549	-	.234	+	1.84	-	.55		6.06	.067
3-2.5			4.58	+	.83	-	1.61	+							1.79	-	.59		11.6	.063
3-2.6	7.69	+													2.42	-	.70		35	.054
STEAM HEATED BUILDINGS																				
Linear Equations																				
4-2.1			12.57	+	.16	+	2.7	+	1.88	+	1.95	+	.691	-	1.15	-	.78	.46	82	.723
4-2.2	23.70	+															.78	.60	562	.728
4-2.3			13.16	+	.487	+	3.17	+									.78	.62	186	.731
4-2.4			13.01	+	.105	+	2.65	+	1.84	+	1.99	+			1.05	-	.78		96	.722
Logarithmic Equations																				
4-2.5			11.41	+	.851	-	2.88	+	2.59	+	2.42	+	.932	-	1.26	+	.71	.75	58	.066
4-2.6	20.19	+															.72	.78	408	.066
4-2.7			16.60	+	1.34	-	3.86	+									.68	.72	119	.070
4-2.8			11.62	+	.882	-	2.97	+	2.56	+	2.36	+			1.36	+	.71		67	.066

TABLE 6-17

SUMMARY OF REGRESSION EQUATIONS FOR BUILDING TOTAL ENERGY USE

Building Type Equation Type, and Equation Number	TSFM t	TSFM sign	OAOCC t	OAOCC sign	STAR t	STAR sign	OSQFT t	OSQFT sign	HDD t	HDD sign	CDD t	CDD sign	AGE t	AGE sign	TSFHT t	TSFHT sign	R^2	R^2 TRANSPOSED	F	STANDARD ERROR MEAN
GAS HEATED BUILDINGS																				
Linear Equations																				
TBTU 6 2-3.1			9.55	+	2.56	-	3.83	+	1.20	+	2.04	+	.06	+	0	+	.63	.61	35	.796
TBTU 6 2-3.2			9.74	+	2.63	-	4.25	+			1.68	+					.64	.66	61	.791
TBTU 6 2-3.3	14.06	+									1.82	+					.59		102	.836
TBTU 6 2-3.4	14.16	+							1.63	+	2.43	+					.60		70	.830
Logarithum Equations																				
LTBTU 6 2-3.5			13.55	+	.979	+	2.30	+	3.12	+	3.68	+	1.77	-	2.45	+	.77	.53	65	.054
LTBTU 6 2-3.6	22.61	+							3.64	+	3.74	+	2.20	-			.80	.53	137	.050
OIL HEATED BUILDINGS																				
Linear Equations																				
TBTU 6 3-3.1			3.38	+	2.25	+	3.93	+	1.13	-	.396	-	.381	-	.935	-	.66		8.93	.519
TBTU 6 3-3.2	6.68	+															.55		36.9	.593
TBTU 6 3-3.3			4.57	+	2.85	+	4.05	+									.68		21.66	.501
Logarithmic Equations																				
LTBTU 6 3-3.4			4.06	+	.662	-	2.04	+	1.00	-	.379	-	.207	+	1.26	-	.67		9.48	.051
LTBTU 6 3-3.5	8.87	+													1.48	-	.79		54	.041
LTBTU 6 3-3.6			5.90	+	.197	+	1.69	+									.70		23	.049
STEAM HEATED BUILDINGS																				
Linear Equations																				
TBTU 6 4-3.1			20.42	+	3.62	-	2.21	+	1.57	+	1.57	+	1.50	-	.31	-	.87	.77	153	.478
TBTU 6 4-3.2	28.73	+															.84	.68	826	.534
TBTU 6 4-3.3			22.08	+	3.82	-	3.35	+									.87	.77	350	.482
TBTU 6 4-3.4			20.71	+	3.68	-	3.00	+	1.55	+	1.57	+	1.47	-			.87			.477
Logarithmic Equations																				
LTBTU 6 4-3.5			18.93	+	1.32	-	2.11	+	1.54	+	2.28	+	3.22	-	3.11	+	.88	.84	163	.037
LTBTU 6 4-3.6	35.98	+															.89	.78	1295	.035
LTBTU 6 4-3.7			28.28	+	2.20	-	3.47	+		-							.85	.86	309	.040
LTBTU 6 4-3.8			26.19	+	1.95	-	2.73	+	2.34	+	2.37	+	3.48	-			.87		178	.038

TABLE 6-18

VARIABLES USED AS EQUATION INPUT FOR SIMULATIONS
REPORTED IN TABLES TO

Building Number	140	472	487	650
Age (Years)	14	46	24	6
HDD (Degree Days)	4715	4715	4715	4715
CDD (Degree Days)	868	868	868	868
TSF (Square Feet)	968,449	125,000	391,673	1,842,494
Height (Stories)	41	23	11	45
TSFHT (Square Feet/Stories)	23,621	25,435	35,607	40,944
OAR (Square Feet)	621,283	83,860	282,497	1,332,776
OCC (Percent)	.88	.98	.95	100.0
OAOCE (Square Feet)	546,729	82,183	268,372	1,332,776
STAR (Square Feet)	65,892	3,000	5,745	52,316
OSQRT (Square Feet)	281,274	38,140	103,431	457,402
TSFM (Square Feet)	893,895	125,000	377,548	1,842,494

TABLE 6-19

ACTUAL AND PREDICTED ELECTRIC CONSUMPTION IN A SAMPLE OF FOUR NEW YORK CITY OFFICE BUILDINGS
BTU/Sq. Ft.

Building Number	140	472	487	650
Actual Use[1]	25,450	33,711	64,203	55,728
Predicted Usages by Equation Number[2]				
4-1.1	33,472	10,381	27,839	96,508
4-1.2	49,762	15,162	26,527	92,449
4-1.3	29,625	11,699	24,913	92,027
4-1.4	44,981	5,972	26,795	117,830
4-1.5	63,259	8,536	26,318	132,058
5-1.1	-9,135	4,950	7,571	54,079
5-1.3	-40,953	2,898	-7,925	-62,237
5-1.4	28,883	9,159	10,562	55,659
5-1.5	44,002	9,054	22,070	79,221

1) Actual use was obtained from TSH, op. cit. Steam is converted on basis of 1000 BTU/cu. ft.; electricity is converted as 1 KWH: 3412 BTU.

2) The equation may be found in Tables

TABLE 6-20

ACTUAL AND PREDICTED STEAM CONSUMPTION IN A SAMPLE OF FOUR NEW YORK CITY OFFICE BUILDINGS
BTU/Sq. Ft.

Building Number	140	472	487	650
Actual Use[1]	89,028	27,792	40,603	90,381
Predicted Usages by Equation Number[2]				
4-2.1	59,895	11,318	25,748	122,104
4-2.2	58,041	11,906	27,059	114,956
4-2.4	58,305	11,560	25,254	120,634
5-2.1	25,305	11,662	25,748[3]	74,447
5-2.2	65,713	21,886	36,281	119,783
5-2.4	48,194	12,607	25,748[3]	96,664

[1] Actual use was obtained from TSH, op. cit.

[2] The equations may be found in tables

[3] We have doubled checked these values in view of the unexpected result of two different equations yielding identical values.

TABLE 6-21

ACTUAL AND PREDICTED TOTAL ENERGY CONSUMPTION IN A SAMPLE OF FOUR NEW YORK CITY OFFICE BUILDINGS
BTU/Sq.Ft.

Building Number	140	472	487	650
Actual Use[1]	114,478	61,503	104,806	146,109
Predicted Usage by Equation Number				
4-3.2	107,803	27,069	53,586	207,406
4-3.3	92,235	24,072	54,316	217,922
4-3.5	90,672	13,629	53,316	223,016
5-3.1	16,285	16,985	33,516	128,579
5-3.4	81,227	23,388	37,198	160,974
5-3.5	112,420	27,917	61,016	187,025

1) Actual use was obtained from TSH, op. cit.

2) The equations may be found in Tables

TABLE 6-22

COMPARISON OF AVERAGES OF ACTUAL AND ESTIMATED ENERGY CONSUMPTION IN FOUR NEW YORK CITY OFFICE BUILDINGS

TOTAL ENERGY

	Equation Number	BTU's	Estimate Divided By Actual	R^2
Total Energy				
Estimated:				
	4-3.2	98965	.93	.84
	4-3.3	97136	.91	.87
	4-3.5	95159	.89	.88
	4-3.6	111536	1.05	.89
	Avg .	100699	.94	
Actual Average		106724		
Electricity				
Estimated:				
	4-1.1	42050	.94	.79
	4-1.2	45975	1.03	.68
	4-1.3	39566	.88	.79
	4-1.4	48882	1.09	.85
	4-1.5	57542	1.29	.86
	Avg .	46803	1.05	
Actual Average		44773		
Steam				
Estimated:				
	4-2.1	54766	.88	.78
	4-2.2	52991	.86	.78
	4-2.4	53935	.87	.78
	Avg .	53897	.87	
Actual Average		61951		

SECTION 7

CONCLUSIONS

INTRODUCTION

Volume III has presented the effort to initiate the collection, organization, and development of an energy use data base for commercial office buildings. Three major efforts were involved in the data base development: the collection and organization of published data; the review of energy simulation programs; and an analysis of the 1975 BOMA data base. In this section, the conclusions that resulted from this work are summarized and their significance relative to the establishment of data bases for office and other types of buildings are examined.

The available information on office building energy use was surveyed, and the data base for 1975 of the Building Owners and Managers Association was collected and organized. The buildings in the BOMA membership are predominantly Class A, well maintained and modernized space. This type of space is believed to account for approximately one-third of the total commercial office building space. Therefore, the BOMA member buildings are not representative of the typical commercial office building. However, the BOMA data base provides information for the most important part of the active rental market, the large buildings with prime space.

The possible uses of building energy simulation programs were examined. The programs appear to have at least two applications for energy analysis purposes. The analysis of energy consumption by end use function is possible through the programs. Since end uses are not directly monitored, the programs appear to offer the best approach at present to obtaining estimates of energy consumption expressed in terms of end uses. The programs can also be used for the analysis of the effects on building energy consumption resulting from the selection of building structural parameters, choice of heating, ventilating, and air conditioning systems, and types of operating policies and building usage.

A literature search had indicated that studies analyzing building energy consumption were not in good agreement concerning the importance of the various factors which drive energy use. The analysis of the BOMA data base attempted to obtain information on the driving factors behind energy use. Tables of information on building energy use were developed, and a regression analysis of the BOMA data base was conducted.

The results developed in this volume do not provide sufficient information for a complete understanding of energy consumption in the commercial office building sector. The analysis is largely restricted to BOMA buildings, and the review of simulation programs only provides the necessary background information to permit the formulation of a plan for the analysis of the end uses of energy and the effects of HVAC, lighting, usage, structural, and equipment options on building energy use. Additional effort will be required to enhance our current understanding of energy consumption in office buildings.

THE DATA COLLECTION EFFORT

Data on office building energy use were obtained as a result of the survey of available information, reported in Section 2. Two types of data were available: actual data based on surveys and special studies; and simulated data derived from building energy use simulation programs. Studies of actual office building energy use in specific areas of the country have been conducted by Hittman Associates for downtown Baltimore, NEMA for Philadelphia, and Tishman-Syska and Hennessy for New York City. At the national level, the 1974 BOMA data base was summarized in the Jack Faucett Associates report, <u>Energy Consumption in Commercial Industries by Census Division - 1974</u>. A number of energy consumption data bases were developed through the use of energy simulation programs. These include two studies by Arthur D. Little and a report by RAND.

Much of the available data were deficient in one or more respects. For example, although Jack Faucett Associates made good use of the existing available BOMA data, it should be noted that the office building energy use data base assembled by JFA from the BOMA records was based on a limited sample of BOMA buildings. Since 1974 was the first year for which BOMA attempted to collect a significant amount of energy information, the number of buildings with adequate replies for energy analysis purposes was smaller than it was in 1975 and subsequent years. In a number of cases, JFA had to convert dollar amounts of energy into quantities of energy in order to retain some of the buildings in the data base. Even with the estimated data combined with the actual data, JFA found that the sample size was relatively limited. Due to possible errors of estimation and reporting, there may have been a significant number of errors in the data base even after it had been checked.

The office building energy use information which was obtained from the two separate ADL reports was not consistent, for essentially identical office buildings were found to have significantly different levels of energy use. The RAND simulations were for a hypothesized gas heated building with unrealistically high equipment efficiencies. Therefore, the RAND simulations probably underestimate energy use.

A review of the actual and simulated data presented in Section 2 indicated that a wide range of values for energy use could be found. The RAND, Hittman, Tishman-Syska and Hennessy, and NEMA reports assumed various design, usage, and operating parameters which can affect energy use. Some of the parameters influencing energy use were presented in Table 2-9.

In addition to the available data which were reviewed in Section 2, access was obtained to the BOMA data base for 1975. The collection and organization of the BOMA data base for 1975 resulted in a number of conclusions concerning its reliability, content, and adequacy of information.

Of the approximately 1000 buildings in the 1975 BOMA data base, a total of 371 were found to have complete and apparently accurate energy use data; these buildings were denoted as Subsample A. Dollar amounts were used in many cases to estimate quantities of energy use, based on the known dollar/quantity relationships in Subsample A. Those cases for which sufficient data existed to permit estimation were denoted as belonging to Subsample B.

A statistical test of the validity of the energy use estimates based on the data available in Subsample A indicated that many, but not all, of the estimations had yielded acceptable energy use information. Therefore, one can conclude that, subject to verification of estimate accuracy, energy use for buildings in the BOMA sample with incomplete energy information can be estimated.

An alternative estimation procedure could be based on the use of information which can be obtained from the DOE for electric, gas, and oil use prices. Due to the relatively limited selection of buildings in Subsample A, sufficient data did not always exist to permit the estimation of the quantity of energy consumed. An examination was made to determine whether accurate estimation could be performed on the basis of rate tables rather than by comparison with other buildings. The conclusion, based on the analysis of buildings in Washington, D.C. was that such estimations could be performed. This may be a useful technique in future work with building data.

Only a limited amount of information applicable to energy analysis was found to be present in the BOMA data base. For example, information on the types and capacities of the heating, ventilating, and air conditioning system components; building usage; and building design parameters was not available. In response to the need for additional information, BOMA circulated a questionnaire to a group of its members to request additional data. In general, responses to the request for additional information were received, indicating that the data base could be supplemented.

The BOMA data base was compared with other available information. It was found to be not representative of commercial office buildings in terms of age or geographic distribution of buildings, as determined from the inventory of building space presented in Volume I of this report. Based on comparisons of the BOMA data with that reported in the Hittman and NEMA studies and on conversations with BOMA employees, one can conclude that the BOMA buildings are predominantly prime, well maintained space located in central cities. Therefore, suburban space, older buildings, and non-prime space, composing possibly as much as two-thirds of all office building space are different from the majority of buildings in the BOMA data base. Any results based on an analysis of the BOMA data base may not apply to the other two-thirds of the commercial office building space.

HVAC SYSTEMS AND ENERGY SIMULATION PROGRAMS

Section 3 presented information on the various types of heating, ventilating, and air conditioning (HVAC) systems and how the choice of HVAC system can significantly impact energy use. Section 4 presents an analysis of the building energy simulation programs used to estimate energy use as a function of the HVAC system type, building parameters, and building usage. The programs are an attractive option for energy analysis purposes, for they permit the estimation of energy use by end use and the analysis of building energy use as a function of building parameters. The data requirements of the programs, their simulation accuracies, and the possible uses of the programs were examined.

Based on a number of simulations for various types of heating systems, as performed by RAND and Tishman-Syska and Hennessy, a building's energy use can vary substantially depending upon the type of HVAC system which is present and the way in which the system is operated. The substantial variations in actual building energy use as found in the BOMA data during the analysis reported in Section 5 may be a function to a substantial degree of the types of HVAC systems present in the buildings.

Section 4 presented a review of building energy use simulation programs. The programs simulate building energy consumption with information on building usage, construction parameters, the HVAC system, and types of equipment as inputs. The information requirements for building energy simulation programs were found to be extensive. Much of the required information is not available in accurate form from building managers. The assistance of a competent building operating engineer is necessary in obtaining the correct data as input to the modeling process. The determination of the components of the HVAC system and the system's configuration requires a prior knowledge of HVAC systems. Since building energy simulation programs appear to be quite sensitive to certain data items -- HVAC information, lighting levels, and hours of usage -- incorrect input may significantly bias the program.

In order to analyze the predictive ability of the AXCESS program, five New York City office buildings were simulated, based on the best information which one could reasonably expect to obtain from a building manager. In general, the five simulations did not accurately portray building energy use. An analysis of the discrepancies between actual and predicted building energy use was, therefore, conducted. Some of the information used as an input for the simulations had been incorrectly estimated by the building managers. In a number of cases, the inputs to the five simulations were, therefore, incorrect or were based on the use of default values used in place of information which had not been gathered from the building managers. The input data base had been gathered by Tishman-Syska and Hennessy from the building managers; under a separate government contract TSH resimulated the five building but used as input data gathered by teams of TSH's professional engineers. This time, the AXCESS program yielded improved results; the conclusion which emerged from this exercise was that the buildings could be adequately simulated by the AXCESS model, but that the data gathering necessary to use the model is extensive and that special care must be taken to assure that the data it collected are correct.

When a building has been correctly modeled, the programs are capable of simulating building energy use. The output consists of estimates of the total electric use, the total fuel use, and energy use by end use function and fuel type. The programs have a number of internal balancing and allocation relationships which should cause the end use estimates to be reliable provided that the total uses of electricity and fuel in the building are correctly estimated.

In estimating end use energy consumption for general policy purposes, it appears doubtful that specific buildings should be simulated, for each building is to some degree unique. Instead, simulations should be conducted on hypothetical buildings whose characteristics are based on averages for existing, known buildings. A sensitivity analysis of the estimated energy use due to variation in the input may also be desirable.

A second possible use of the programs is for the simulation of HVAC, building usage, and structural options. Examples of such an approach have been performed by both RAND and TSH. Provided that the initial specification of the building is properly calibrated so that predicted and actual electric and fuel use are in agreement, the programs should be useful in analyzing the choice of HVAC system, changes in building parameters -- such as lighting, wall composition, and fenestration — and changes in building usage — such as operating hours, internal temperature, and type of tenant. Here again, the running of the programs on the basis of building averages is probably appropriate for purposes of broad energy analysis. Energy simulation programs have been designed for both of these purposes and are presently so used by architect/engineering firms.

Information is not available to permit firm conclusions with respect to a third major use for which they were considered: the estimation of building energy use, for buildings for which very little actual energy consumption data are available, in order to create a data base.

ANALYSIS OF BUILDING ENERGY USE

A review of the currently available information on the driving factors behind energy use has illustrated that there is not general agreement on the factors which drive energy use. The disconcerting point is not that each study contradicts every other study, but, rather, that each study, in general, finds a separate set of factors to be important while not denying the potential importance of other factors and that the sets of factors are not identical. The only type of conclusion that can be drawn is that a large number of factors have been found to be important in analyzing energy use but that there is not general agreement on which factors are of the greatest importance.

In order to examine the factors driving energy use, an analysis of the BOMA data base was undertaken. This was done both through the development of tabular material, presented in Section 5, and through the development of regression equations, presented in Section 6. It should be noted that the analysis is at best only partially complete, because only one year was examined and the BOMA data base lacks a number of the relevant variables which may play an important role in driving energy use. The general conclusions which can also be drawn from the national level data hold true at the regional level. The conclusions which can be derived from each table have been analyzed in detail in Section 5 and will, therefore, be only briefly summarized.

1. In reviewing the regional distribution of Subsample A by fuel type, one notes that the geographic coverage is not good. Coverage for the gas and steam heated sets of buildings in Subsample A is significantly better than that for the sets of electric and oil heated buildings. For all buildings combined, coverage by Subsample A is very poor for 2 of the 9 Census Divisions and is marginal in the case of a third division. The poor geographic coverage results from the nature of the BOMA membership: BOMA's membership is largely located in cities with major concentrations of commercial space. BOMA does not have active chapters or a significant number of members in some areas.

The lack of adequate geographic coverage by the BOMA data base probably affected some of the results in the analysis, for one cannot investigate the effects of weather where there is not adequate variation. This was an important problem in the case of oil heated buildings, and to a lesser degree, in the case of electrically heated buildings.

2. Subsample A also has limitations in terms of the downtown/suburban mix of buildings, the age and the height distributions of the buildings. The BOMA membership is largely composed of large "young" buildings, which are prime space, and older buildings, which have been renovated and have again become prime space. The latter are predominantly located in downtown areas.

3. From Table 5-13A, in terms of energy use efficiency on a total use basis, the most efficient energy using buildings are the steam heated buildings, followed by electric, gas, and oil heated buildings. In terms of fuel use, steam heated buildings are significantly more efficient than are gas heated buildings. Oil heated buildings are significantly less efficient than are gas heated buildings. However, in the case of purchased steam, much of the conversion loss has already occurred

prior to the steam's entry into the buildings. No comparison of the efficiency of electric heating is directly possible, due to the lack of information on the breakout of electric use between heating and other uses in an electrically heated building. If some estimated use for purposes other than heating were subtracted from the total electric use for electrically heated buildings, it is likely that electric heating would show a high efficiency. These conclusions are based on empirical data and are in good agreement with similar conclusions from the engineering literature on the subject. No clear conclusions about the use of electricity in the various types of buildings are possible. We are unable to account for the differences in electric use between gas, oil, and steam heated buildings. It is possible that at least a part of the difference may be attributed to poor sample distributions. In the case of steam heated buildings, some of the difference may be due to the existence of steam air conditioning.

4. On the basis of Table 5-19A, downtown buildings in general use less energy per square foot than do suburban buildings in the BOMA sample. Due to the relatively limited number of suburban buildings in the sample, it is not clear how significant this finding is.

5. According to Table 5-20A, energy use is relatively constant by height. Only in the case of buildings in excess of 50 stories are any significant decreases in energy consumption noticed. This may be due to the concentration of tall buildings in a few large cities and the fact that most of the relatively tall buildings are steam heated. It was not possible to determine whether the relatively limited variability among the other height categories in terms of energy use was due to statistical chance or other factors.

6. Energy consumption appears to be a function of building age. Table 5-22A indicates that buildings in the 1-9 year category tend to use significantly more electricity than do any of the other building categories. This may be due either to the higher level of amenities in such buildings, or it may be due to the high concentration of electrically heated buildings in the category. This may also tend to explain the relatively low amount of fuel usage in the category.

7. According to Table 5-23, as measured in square feet/ton, the amount of air conditioning is inversely related to building age with the exception of the 1-9 years of age category. This one exception may be due to increased efficiency of new systems, or it may be due to some statistical problems with the data. The rest of the information is in good agreement with our perception that older buildings are less well air conditioned than are younger buildings.

8. In order of descending size, electrically heated buildings are the largest, followed by oil, steam, and gas heated buildings. It should be noted that both the electric and the oil heated buildings were built relatively recently.

9. In cases in which energy use is individually metered, less energy is used than in cases in which it is included in the rent. This appears to indicate that individual metering can result in some significant savings. Some additional analysis of the accuracy and completeness of the data would be desirable, however, before using this conclusion for policy purposes.

10. In reviewing energy consumption by building type on a regional basis, it can be noted that energy consumption varies by region as one would expect, with areas with hot weather tending to use relatively more electricity and areas with cold weather tending to use more fuel.

11. Tables 5-25 and 5-26 compare the energy use per square foot in office buildings as predicted by the BOMA data base for 1974 and 1975. Information for the 1974 data base was developed by JFA and information for the 1975 data base was developed in the present report. Although one would expect energy use to vary from year to year, one would not expect the means on a Census Division basis to experience such a degree of variation from year to year. The table may indicate some estimation errors due to small sample sizes, incorrect reporting in 1974, 1975, or both. This is a matter which should be subjected to further analysis and highlights the need to examine another year's worth of BOMA data.

Section 6 presented equations developed to model the consumption of electricity, fossil fuels, and total energy for each of four groups of buildings categorized according to heating fuel -- electricity, gas, oil, and steam. The equations were run on the 1975 BOMA Subsample A on a cross section basis.

For electricity use, in the case of all building types, an R^2 as high as .92 was obtained, and an R^2 of at least .86 always occurred. Although one would not expect the elementary equations developed to be particularly accurate for any specific building, it is interesting that "on average" a reasonably high R^2 could be found.

The R^2 values were lower for the case of the fuel use equations. According to the literature on office building heating loads, the use of fuel in commercial buildings is a function of the complex interaction between the types and hours of building usage, building physical characteristics, and the equaipment in the buildings. In the case of fuel use, it appears that some of the significant variables which drive energy use were missing and that a single regression equation may have proven to be inadequate for modeling building energy use. Although the equations were not particularly good, the R^2 values indicated that over half of the variation in the consumption of fuel, other than electricity, could be explained by variations in the independent variables.

The equations for total energy consumption allowed for the possibility of some interaction between building electric and building fuel use. The equations were run on the basis of a single equation to model total building energy use.

The regression analysis indicated that it is possible to develop equations using a small set of independent variables to show the close relationship between the independent variables and energy consumption. However, it is not known whether the coefficients are stable over time. The regression equation which were reported appeared to have reasonably good predictive power with adequate F and R^2 values, significant t values, and acceptable standard errors.

How well the equations could predict energy consumption for buildings which were not in the BOMA sample used to develop the equations was examined. Energy use in the four steam heated New York City office buildings, discussed in Section 4, was simulated using the equations. In general, the equations did not predict energy consumption by each of the four buildings very well. However, the averages of the estimates of energy consumption by the four buildings were better. The average energy use of electricity predicted by the equations was only 5% above the corresponding actual average value. The average of the estimates of steam use was 13% below actual average. For total energy consumption, the average of the four estimates was only 6% below actual.

In reviewing the equations, it became apparent that the single most important variable was square feet of building area. Reasonable estimates of energy consumption can be obtained from a knowledge of only the square feet of space. Although the use of the regression equations in simulating particular buildings is probably not warranted, the equations properly applied may be used to estimate energy consumption in populations of buildings. It is believed that additional research could improve the equations and yield better energy use estimates for a population of buildings or even for individual buildings.

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APPENDIX A

BOMA INTERNATIONAL 1976 OFFICE BUILDING EXPERIENCE EXCHANGE REPORT FORM

GENERAL INSTRUCTIONS

This form has been color-keyed to assist you in its preparation. RED indicates account and sub-account titles; BLACK shows general ons and blanks for dollar entries.

P SE REMEMBER— *use dollar amounts only.* If there is no expense under a heading, please report -0- rather than leaving it lank, to assure us that it was not overlooked. Please ignore the small computer entry numbers or blanks to the side of questions. laintain a copy of the completed form to assist in preparing next year's report, since much information remains the same from year to year.

For calendar year 1976 or Fiscal Year beginning ______ and ending ______
Building name ______
Building address ______
City ______ State ______ Zip ______
Please send individual building analysis to: ______
Address ______
City ______ State ______ Zip ______
Report prepared by ______ Phone ______ Date ______

SCHEDULE I BUILDING AND MANAGEMENT DATA

03 1. STATISTICAL AREAS
- Office Area ⌀ ______ 8-15
- Store Area ⌀ ______ 16-23
- Storage Area ⌀ ______ 24-31
- Special Area ⌀ ______ 32-39 Describe: ______
- TOTAL AREA ⌀ ______

2. Average Office Occupancy for 1976 ______ 40-43
3. Building Cleaning done by: Building staff ☐ 44 Outside Contractor ☐ 45 Tenant ☐ 46
   Note: More than one box may be checked
4. AREA SERVICED/ MAINTAINED AT EXPENSE OF BUILDING – whether done by building staff or outside contractor -

Service	Office ⌀	Other ⌀	Total ⌀
Cleaning 47-62			
Electrical			
Heating			
Air Cond.			63-70
Plumbing			
Alterations			
Repairs			
Decorations			

5. Full Assessed Value
   - Land $ ______
   - Building $ ______
   - Total $ ______

6. Age (in years) ______ 71-73 7. Height (in stories) ______ 74-76
8. Is Building "owner-occupied"? Yes ☐ No ☐ If yes, what percent? ______ %
9. Office Tenancy: Medical ______ % Utility ______ % Bank or S/L ______ % General Office ______ %
10. Is Building Agency Operated? Yes ☐ 77 No ☐ BC ______ 78 Pop ______ 79

04 11. Normal Building Populations (# of tenants' employees): Office Area ______ 8-13 All Other Areas ______ 14-19
12. Number of Tenants: Office Area ______ 20-23 All Other Areas ______ 24-27
13. Number of Building Employees ______ 28-31
14. Annual Payroll (Exclusive of Management) $ ______ 32-39
15. BUILDING OWNED AIR CONDITIONING

Type	Tons	Energy
Central	______ 40-45	______
Package	______	______
Other*	______	______

*Describe ______

Annual Depreciation $ ______ 46-53
Length of Life in Years: Compressors ______ 54-58 Fans ______ 59-62 Ducts ______ 63-66

16. Building Located: Central Business District ☐ Outlying ☐ Suburban ☐ 67
17. Building Type: General Office ☐ 68 Medical ☐ 69 Single Purpose ☐ 70 Office Park ☐ 71
18. Building Electrical Policy:
    - Office tenants – Included in rent ☐ Sold ☐ if sold metered basis ☐ or estimated ☐ 72
    - Other tenants – Included in rent ☐ Sold ☐ if sold metered basis ☐ or estimated ☐ 73

No ______ – ______ – ______ (74-79)

SCHEDULE II BUILDING INCOME

	Office Area	Store Area	Storage Area	Special Area	Electrical	*Miscellaneous	Total Operating Income
RENTAL INCOME	$	$	$	$	$	$	$
	08-15	16-23	24-31	32-39	40-47	48-55	56-63

*Include Service Profit (net basis) in Miscellaneous Income.

SCHEDULE A OPERATING EXPENSE

	08-15 Wages	16-23 Supplies/Materials	24-31 Contract Services	32-39 Miscellaneous	40-47 TOTALS
CLEANING COSTS A1	$	$	$	$	$
ELECTRICAL SYSTEM COSTS A2	$	$	$	$	$
HEATING COSTS A3a	$	$	$	$	$
AIR CONDITIONING VENTILATING COSTS A3b	$	$	$	$	$
"COMBINED" HVAC COSTS A3c	$	$	$	$	$
ELEVATOR COSTS A5	$	$	$	$	$
	Salaries, Mgt. Fees				
ADMINISTRATIVE COSTS A6b	$	$		$	$

GENERAL BUILDING COSTS A6a	$	$	$	$	$
	Plumbing	Water	Security	Landscaping	
	$	$	$	$	
	Electric	Gas	Oil	Steam	
ENERGY COSTS A7	$	$	$	$	$
	Kwhrs.	Cu. ft.	Gals.	Lbs.	
	Chilled Water	Coal			
	$	$			
	Gals.	Tons			

SCHEDULE B CONSTRUCTION EXPENSE
(Expenses for service provided to Tenant Area only)

	Wages	Supplies/Materials	Contract Services	Miscellaneous	
ALTERATIONS	$	$	$	$	$
DECORATING	$	$	$	$	$

SCHEDULE C FIXED CHARGES

Insurance	Real Estate Tax		Personal Prop. Tax, Etc.	
$	$	$	$	$
	Land	Bldg.		

TOTAL OPERATING EXPENSES
NET GAIN OR (LOSS)

Lease Expense	Amortized Tenant Alt.	Depreciation	
$	$	$	$
08-15	16-23	24-31	

TOTAL EXPENSES $

NET GAIN OR (LOSS) $

APPENDIX B

SUPPLEMENTAL BUILDING INFORMATION

1. What are the building's dimensions?

   In feet

   Length:

   Width:

   Height (from ground level up):

   Basement height:

2. Please describe the building's walls.

   What type of material?

   What percent (%) is windows?

3. On how many sides is the building adjacent to another building

   1; 2; 3;

4. At what temperature is the building kept?

	1974	1975	1976	Prior to 1974
Summer				
Winter				

5. Is there winter humidification?

6. What are the building's operating hours?

   a) 7 a.m. - 6 p.m.?
      Other?

   b) What % of building offices are lighted for work or cleaning during

      6 p.m. - 11 p.m.

      11 p.m. - 7 a.m.

7. How many air changes per hour are there?

How many cubic feet per minute for ventilation?

What % is outside air?

8. Please describe the Heating Ventilation Air Conditioning System (HVAC System).

A) Single duct?

Variable volume?

Constant volume?

Is there reheat?

B) Dual duct?

C) Multizone?

D) Chilled and hot water?

2 pipes?

3 pipes?

4 pipes?

E) Fan Coil System?

F) Induction System?

G) Is there an economizer?

9. How many zones does the HVAC System have?

10. Could you estimate the following maximum loads in terms of Btu output, Btu input, and kw?

1. Air conditioning system

   chiller -kw

   cooling tower - kw

   pumps - kw

2. HVAC fans - kw
3. Exhaust fans - kw
4. Lights - kw/sq. ft.
5. Computer - kw
6. Elevators - kw
7. Boiler (Btu input, Btu output)
8. Furnace (BTU input, Btu output)
9. Other major energy users.