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# The Equipment R&D Benefits of Characterizing the Energy Requirements of Office Buildings and Multifamily Housing

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## ABSTRACT

*To plan and evaluate the research and development of equipment for residential/commercial buildings, descriptive information is needed at two levels: (a) generally descriptive demographic information to characterize the building populations and (b) specific, detailed technical information with which to match the end-use technologies. To various degrees, information exists at both levels; however, the linkage between the two levels of information is weak.*

*To meet these analytical needs, market-linked data bases of detailed energy requirements were developed for the office building and multifamily housing sectors. Applications include, but are not limited to, prediction and assessment of markets for energy service and supply equipment, energy demand forecasts, and conceptualization of new equipment configurations from this detailed data. Simple benefits from the use of these data bases are cost-effective and consistent market assessments, more focused equipment development, confidence in market size, and a better understanding of these energy markets.*

## INTRODUCTION

The computer simulation of energy end-use technologies in commercial and residential buildings provides insights into the technical and economic performance of these technologies, and these insights are valuable input to decisions that affect a wide range of activities. Thus, a great deal of time and effort is expended to generate these market insights and compete better in the energy markets. However, a key need at the start of this rather long and involved process is an accurate depiction of the energy loads (or building energy requirements, BER) of the buildings in which the technology can be applied. Better information on the building energy loads will result in better analyses for decision making.

To best resolve issues of analysis, information on the buildings is needed at two levels: (a) generally descriptive demographic information to characterize the building population in terms of location-climate, structure type, total floor area, or number of stories, and (b) the specific, detailed technical information such as space-heating loads and space-cooling loads with which to match the end-use technologies. To various degrees, demographic information exists in census-type reports, Energy Information Administration reports, building construction reports, or specific product market analyses. Information of a technical nature exists in reports of detailed computer simulations of buildings, single-building case histories, or field monitoring reports. However, there is typically no linkage or relationship between these two levels of information. Copious information available at one level is usually accompanied by little or none at the other level.

Several methods are available for the estimation of building end-use energy usage; however, each method has its advantages and limitations. The issue to resolve, input data availability, and personnel/funding resources will determine which option is best for the decision-makers and even eliminate some of the options.

The application of the degree-day method is limited to residential buildings, where the dominant factors are envelope transmission and air/moisture infiltration. Due to highly varying internal loads, complicated control systems, and multifaceted HVAC equipment layouts, the degree-day method is considered inadequate for commercial buildings. The equivalent full-load hour method considers only the cooling loads of buildings and ignores all effects of the operational characteristics of the building systems, which highly influence the energy usage in commercial buildings. The standard bin method has shortfalls in that the variation of solar energy transmission and the resultant loads are not accounted for.

A second group of building energy estimation methods surmounts the above difficulties. These comprehensive computer programs provide building energy analysis on an hour-by-hour basis and account for infiltration, solar effects, complex HVAC equipment, varying operational schedules, building orientation and geometry, and so on. These programs are considered to be very useful and provide reliable results. However,

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wide application of these programs is limited due to the requirements for large amounts of detailed input data, complexity of the algorithms, possible need for access to mainframe computers and for specially trained personnel, and cost of program execution (Knebel 1983).

At present, most energy end-use technology analyses are performed on an ad hoc basis. A reasonable description of a building for possible application is obtained and an energy estimation method is selected and used. The applicability of the results to the larger possible market remains a concern. In addition, other concerns arise relative to the management of the multitude of analyses and results obtained in an ad hoc manner. The consistency and comparability of the results over several technologies and/or building applications would be unknown. As-needed acquisition of descriptive data for a building represents an additional cost. Thus, the organization and control of the data and results are less effective.

## MARKET-LINKED BER DATA BASES—A SOLUTION

To address these concerns in performing technology assessments, data bases for office buildings and multifamily residential housing were developed with a linkage between the demographic market characteristics and the detailed end-use load profiles. In reference to the market, a reasonable number of building prototypes represents major market segments of the building stock and new construction (floor area and population) in each data base. For each building prototype, hour-by-hour load profiles (not fuel consumption) from the DOE-2 computer simulation program are available for the space heating, space cooling, water heating, and aggregate electricity. The DOE-2 program calculates the four load profiles with consideration for operating schedules, building characteristics (such as lighting levels, fenestration, and structural mass), and weather conditions (such as dry-bulb and wet-bulb temperature, insolation, and wind speed) for many locations in the country. In the BER data bases, these four load profiles are correlated in time with the hourly weather characteristics, which were previously used in their development. For increased flexibility, a subprogram (LOADCALC) aggregates the hourly data into user-specified bins by characteristics such as dry-bulb, wet-bulb, or hour of the day. The DOE-2 input files, the hour-by-hour load profiles for the year, and the LOADCALC subroutine are available on diskettes (Crawley 1989; Ritschard 1989) and compose the BER data base for each building group.

The four load profiles represent the point of interface of the needs of the building and/or occupants for energy-consuming services and the energy service equipment or plant (boiler, chiller, heat pump, water heater, etc.). The loads contain no end-use equipment efficiencies, as the description of this equipment is left to the user of the BER data bases. The hourly space-conditioning loads consider (1) the fully detailed interaction of the building, operating schedule, and weather and (2) the air-side delivery system where appropriate. Thus, these loads are, in effect, the coil loads. The aggregate electric load sums up all the consumption of electricity in the building (lighting, receptacle, etc.) for each hour, and the water heating profile considers an occupant hourly demand schedule with no water heating efficiencies or standby losses. The loads are established in the data bases and held constant; however, the response of the energy service equipment to these hourly service needs is entirely variable. (The objective is to use the load profiles as driver functions.) With the hourly load profiles, equipment studies can include on-off cycles, part-load performance, active use of thermal storage (ice storage, cold water storage, hot water storage, etc.), and other load/equipment response concepts.

To successfully develop these data bases for technological assessments, the BERs must represent the existing market very closely. For both data bases, substantial information was collected on market characteristics, which was segmented into building groups that contained similar traits yet still were a significant fraction of the market. A building prototype was constructed from the characteristics of each market segment. The prototypes cover all geographical regions, climates, and construction vintages and styles, and each prototype is linked to an estimated amount of the housing units or buildings. Thus, indigenous structure types are found for each region of the country. For the multifamily housing data base, data sources such as the DOE/EIA Residential Energy Consumption Survey, U.S. Census Bureau Characteristics of New Housing, U.S. Census Bureau Annual Housing Survey, U.S. Farm Home Administration, National Association of Home Builders, and F.W. Dodge Construction Statistics were referenced. The DOE/EIA Nonresidential Buildings Energy Consumption Survey, F.W. Dodge Construction Statistics, and ANSI/ASHRAE/90.1P were referenced for the office building data base.

As representative samples of the market segmentation process, Tables 1 and 2 provide a characterization of a small office building and a small multifamily building. The office building market segment consists mostly of very small, single-story, almost "residential-scale" office buildings. Most were built during the 1930s and 1940s and are located in the Midwest, Mid-Atlantic, and Mid-South regions. The climate has roughly 3500 to 5500 heating degree-days and 1000 cooling degree-days, and Indianapolis, IN, was identified as the most representative climate. These buildings have small amounts of glass, typically single-glazing with wooden frames, and roofs that are very poorly insulated. Typically, one-third of the floor area of these buildings is not cooled, and significant numbers of them rely on window air-conditioners. These buildings tend to have high energy consumption, primarily due to high heating needs. The estimated heating coil load (not fuel consumption) is 50.3 kBtu/ft$^2$ per year. Energy used for cooling, electric lighting, and HVAC fans is low, resulting in below average electricity consumption. The range of total energy use for these buildings is estimated at 54.4 to 172.1 kBtu/ft$^2$ per year.

**TABLE 1**

**Characterization of a Small Office Building**

| | |
|---|---|
| Year Built | 1939 |
| Building Square Footage | 6100 |
| Number of Floors | 1 |
| Heating Degree-Day Range (25%-75%) | 3760-5390 |
| Cooling Degree-Day Range (25%-75%) | 700-1130 |
| Representative City | Indianapolis, IN |
| Total Energy Use Range (25%-75%) (kBtu/ft2.yr) | 54.4-172.1 |
| Estimated Loads (kBtu/ft2.yr) | |
| Cooling Coil | 28.9 |
| Heating Coil | 50.3 |
| Lighting | 13.2 |
| Receptacles | 5.3 |
| Fans | 3.7 |
| Service Hot Water | 1.0 |
| Elevators | 0.0 |
| Representing | |
| Number of Buildings in Country | 58,455 |
| Million Square Feet of Floor Space | 168 |
| Percent of Office Sector Floor Area | 2.29 |
| Total Energy in Trillions of Btu/yr | 28.5 |
| Percent of Office Building Energy Use | 3.36 |
| NBECS Buildings in the Category | 59 |

Roughly 58,000 buildings in the country have physical and energy-related attributes similar to this category. These buildings constitute 2.3% of the office building sector and enclose 168 million $ft^2$ of floor space (Briggs 1987).

The sample multifamily housing market segment (Table 2) consists of small buildings of two floors with two to four housing units. The construction occurred before 1940 in the Northeast region, and each unit is relatively spacious at 1143 $ft^2$ of floor area. These buildings are constructed of wood with single glazing and no ceiling or wall insulation. They are heated by a central boiler with a hydronic delivery system but have no space cooling. The water heater is a single, central unit that supplies hot water to all the housing units. The notation of natural gas as the water-heating fuel and oil as the space-heating fuel is a better characterization of this market segment; however, the fuel type or equipment efficiencies do not enter into the calculation of the load profiles. Finally, this segment represents about 11% of the multifamily building population (Ritschard 1988; Zwack 1987).

Correlated to each of these prototypes or market segments is the hour-by-hour load profile. The demographic data were supplemented with other building data sources of a more detailed and technical nature to form the input data for the DOE-2 computer simulation program. Available sources of field-monitored end-use energy consumption data were appropriately integrated into the developmental process, either as DOE-2 input data or as a point of comparison for the output of hourly load profiles.

As examples from the multifamily data base, Figures 1, 2, and 3 show detailed energy requirements of the buildings (Ritschard 1989). Two consecutive days of hour-by-hour end-use load profiles for the heating season are shown in Figure 1 for the prototype/market segment described in Table 2. These load profiles include space heating, aggregated electric, and domestic hot water. The steep decline with a following peak in the space-heating load is due to the night setback of the thermostat. The aggregate electric load is created by appliances such as refrigerators, televisions, or lighting. Figure 2 shows a similar two-day display for another multifamily building on the Gulf Coast during the summer. Another sample display of the multifamily BER data base is the heating load duration curve found in Figure 3. This figure is created by aggregating the hourly heating loads for a prototype building in the BER data base. A very small number of hours in the heating season are at or near the peak load for the building. The majority of the heating season hours are below 40% of the peak load; for about 5500 hours of the year, there is a need for heating in this building.

Some examples of the detailed data from the office building BER data base are in Figures 4, 5, and 6 (Crawley 1989). The end-use load profiles for two consecutive days in the winter are shown in Figure 4 for the office building described in Table 1. The occupancy of the building on a weekday, relative to the weekend data, results in an increase in the heating loads and the aggregate electric load and the appearance of a load for hot water. Figure 5 shows similar information for two

**TABLE 2**

**Characterization of a Small Multifamily Building**

| | |
|---|---|
| Region | Northeast |
| Year Built | Pre-1940 |
| Number of Units/Building | 2-4 |
| Number of Floors/Building | 2 |
| Floor Area/Unit ($ft^2$) | 1143 |
| Population Represented | 10.6% |
| Envelope | |
| Number of Windows/Unit | 10 |
| Glazing Type | Single |
| Average Window Size ($ft^2$) | 12.3 |
| Number of Windows W/Storms Per Unit | 10 |
| Number of Sliding Glass Doors/Unit | None |
| Average Sliding Glass Door Size ($ft^2$) | N/A |
| Exterior Wall Facade | Wood |
| Wall Insulation | None |
| Ceiling Insulation | None |
| HVAC & Operation | |
| Heating Equipment Type | Baseboard/Radiator |
| Heating Equipment Configuration | Common |
| Space Heating Fuel | Oil |
| Cooling Equipment Type | None |
| Cooling Equipment Configuration | N/A |
| Space Cooling Fuel | N/A |
| Occupied Heating Setpoint (°F) | 68 |
| Heating Night-Setback (°F) | 64 |
| Other | |
| Number of Household Members | 1-2 |
| Cooking Fuel Type | Gas |
| DHW Fuel Type | Gas |
| DHW Configuration | Common |

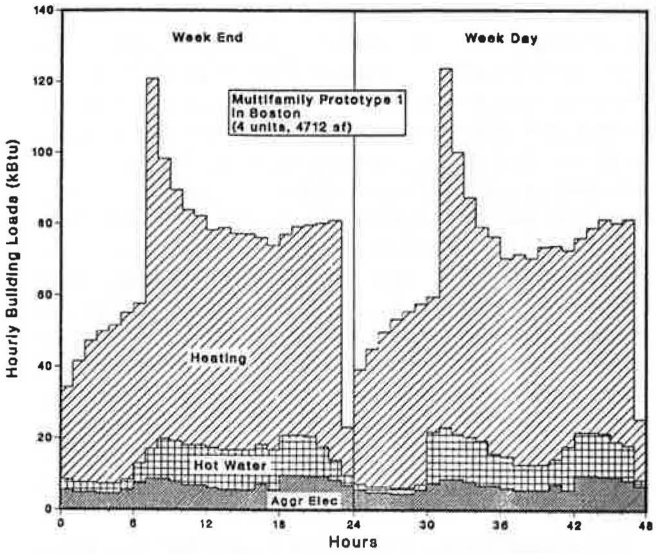


***Figure 1*** *Winter end-use load profiles—multifamily housing.*

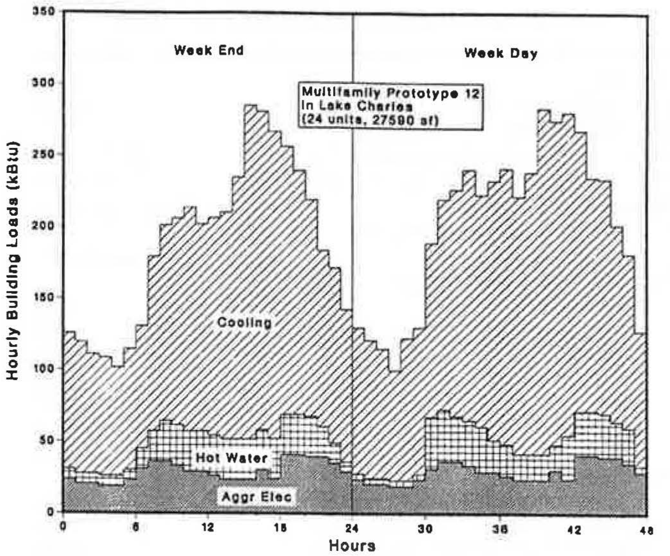


***Figure 2*** *Summer end-use load profiles—multifamily housing.*

summer days. The occupancy of the building, again, results in larger loads relative to the weekend. A third sample display (Figure 6) of the office building BER data base is the heating load duration curve for a large office in New York City. This building requires heating for less than 3000 hours in a year and has a peak load of about 16 million Btu per hour. The majority of the heating season hours are below 25% of the peak load.

## BENEFITS

The use of these market-linked data bases in technological assessments results in numerous benefits relative to the more ad hoc approach noted earlier. Four general groupings of benefits are used to organize this review.

1. Energy Estimating Method—The source of the hourly load profiles is the DOE-2 computer simulation program, which accounts for many of the intricacies in the calculation of a load profile and is considered to provide reliable results.

— Fewer errors—By use of the prepared DOE-2 files in the BER data base, there is less chance of computational errors. Furthermore, the provided load profiles offer an approach that circumvents all the difficulties of the preparation and execution of DOE-2.

— Fewer resources—With the load profiles, there is no need for the DOE-2 program or personnel with training on DOE-2; the benefits of the complexity of DOE-2 are derived without the labor.

— Less cost—The load profiles eliminate the setup and operational cost (CPU) of DOE-2 and the affiliated labor costs.

2. Market-Linked Analysis—Each building prototype is linked to a market segment with estimated amounts of building population and floor area.

— Unified data bases—The set of prototypes/market segments was developed in a consistent manner with good coverage of the building market and no overlap of segments.

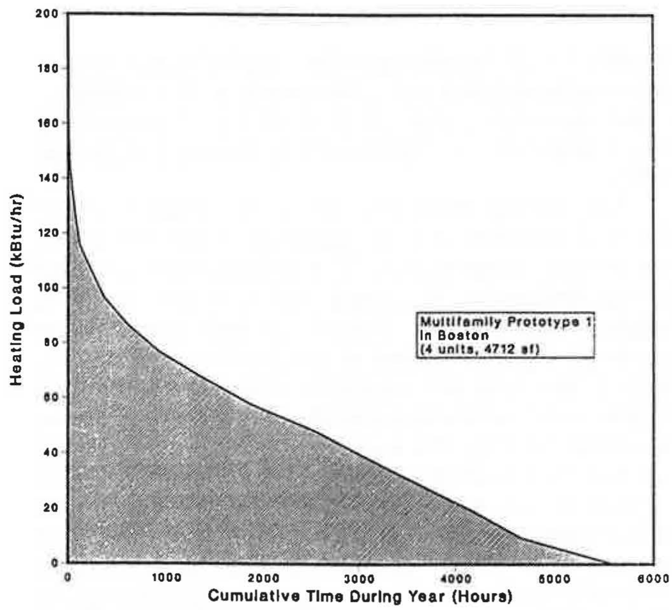


***Figure 3*** *Space heating load duration curve—multifamily housing.*

— Market-linked—Each prototype/market segment is described by demographic characteristics and specific energy needs; thus, a more complete understanding of the market will result.

— Presegmented market—A reasonable number of segments represents the buildings' markets.

— Less cost—As a completed market segmentation, there is no need to locate and correlate data or perform the segmentation of these markets.

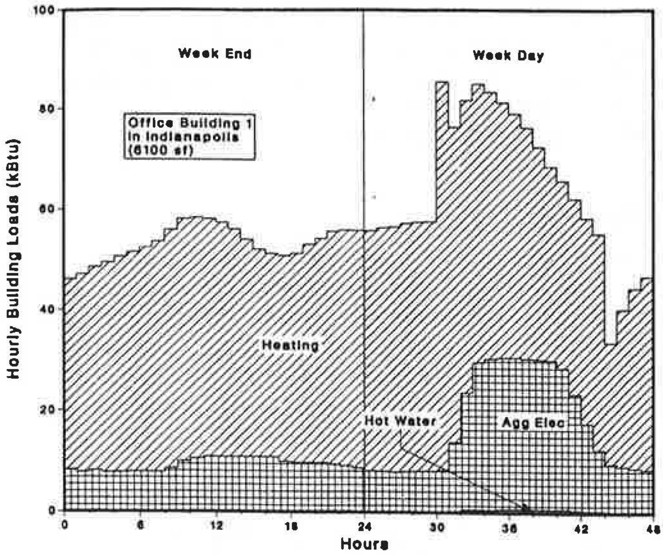


***Figure 4*** *Winter end-use load profiles—office building.*

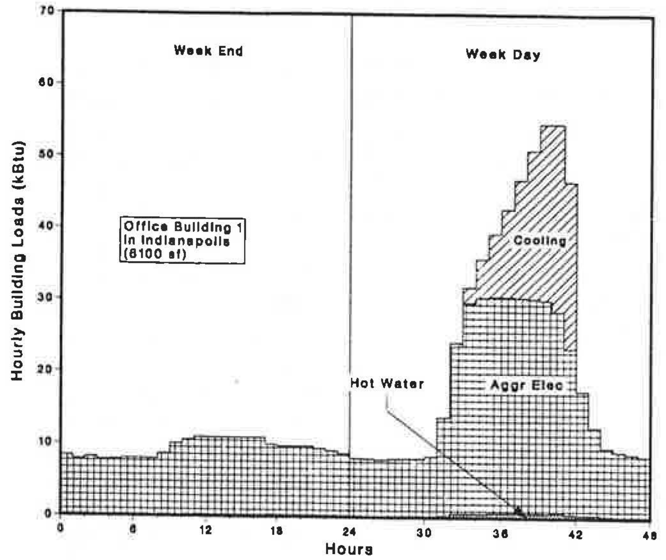


***Figure 5*** *Summer end-use load profiles—office building.*

3. Detailed Building Energy Requirements—For each prototype, hour-by-hour load profiles are available for space heating, space cooling, water heating, and aggregate electricity.

- —Reliability—The profiles were prepared on the DOE-2 program by knowledgeable and experienced users.
- —Simultaneous load profiles—The four load profiles are coincident, as would be the case in operating buildings; thus, analysis of more than one load is possible.
- —Multi-level analysis—The load profiles can be aggregated into many time intervals, thus allowing inspection of the data at daily, weekly, monthly, or yearly intervals and with bin procedures.
- —Wide application—The data bases can resolve a spectrum of analytical questions for a range of equipment types.
- —Weather-linked—For each hour of the year, the four loads are correlated with the weather conditions; thus, air-cooled condensers or cooling tower response may be calculated.
- —Time-linked loads—All loads are referenced to a clock for the full year; thus, analysis with time-of-day utility rates is possible.

4. Analysis Management—The control and organization of resources needed to perform the analysis and correlate the results are improved.

- —Consistent and comparable results—Due to the organized nature of these data bases, assessments of several technologies will be easily related. For heating technologies, the heating load profile is the starting point for an assessment of a furnace or a heat pump.
- —Flexible—The data bases are applicable to a wide number of end-use technologies.

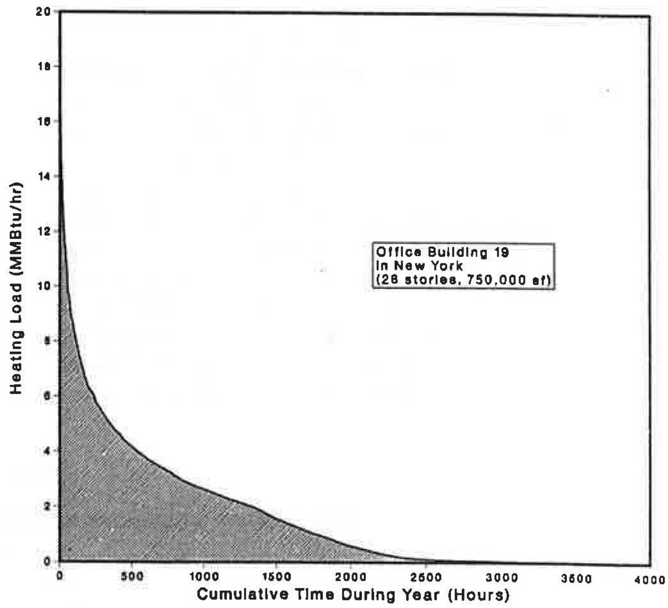


***Figure 6*** *Space heating load duration curve—office building.*

- —PC format—The data bases are compatible with MS-DOS systems, do not require elaborate equipment, will execute in a reasonable time wait, and are user friendly.
- —Transferable training—The training needed to operate one data base is transferable to the other.
- —Cost-effective—The requirement for fewer personnel and equipment resources, no need to perform a market segmentation, and ease of use provide for lower-cost technological assessments.

## APPLICATIONS OF THE BER DATA BASES

Evaluations that use these data bases can largely be grouped as technological assessments; however, many more focused applications are obvious and are delineated in Table 3. The design of equipment (column 1) with the load profiles could evaluate furnaces, boilers, water chillers, water heaters, etc. With the details of the load profile, part-load equipment performance may be studied completely. The use for technological assessments and market-size predictions (columns 2 and 3) was briefly reviewed above. As an example of cross-market studies (column 4), a cogeneration technology that provides electricity and hot water can be evaluated with the aggregate electric and hot water load profiles. The hour-by-hour load profiles of the aggregate electricity and the space cooling are well suited to investigate methods of energy-demand management (column 5) on these two building types. During the summer months, the aggregate electricity profile is the base electrical needs or load, and the hour-by-hour space-cooling profile can be satisfied on demand by gas-fired cooling technologies and/or cool storage (previously generated).

For better prediction of fuel consumption on a yearly or monthly basis, the detailed loads allow for a more accurate depiction of these building sectors. This attribute of better fuel consumption prediction is beneficial in evaluating the impacts from conservation incentives (column 7) and standard/codes changes (column 8) or estimating utility loads (column 6). With questions under consideration on sulfur dioxide emissions from central station electrical generation facilities or site emissions from boilers or other combustion processes in the buildings, these data bases can form a basis to review emissions due to energy consumption (column 9). In addition, the data bases can serve as a reference or point of comparison (column 10) due to the large amount of information that is available in an organized and detailed manner on these two building groups. Cross-referenced with these 10 possible applications in Table 3 are several business functions in which the data bases have logical application.

## SUMMARY

The evaluation (computer simulation) of energy end-use technologies in commercial and residential buildings provides valuable market insights relative to appropriate equipment characteristics, fuel consumption, etc. However, this activity usually falls short on several criteria. The end-use load profiles are not linked or representative of the major market. Thus, a technological assessment can be highly informative and germane to the sample building characterized in the analysis, but the results may not apply to the total market or a major segment of the market. As more buildings within a group and several technologies are evaluated, the consistency and comparability among the results become questionable. Furthermore, the ad hoc approach to assessments presents problems in the organization and control of results and increases in costs for the analyses.

To surmount the above shortfalls, stand-alone data bases for the office building sector and the multifamily housing sector were developed with a link between demographic market characteristics and detailed end-use load profiles. A reasonable number of building prototypes represents the major groups of buildings or market segments and, for each prototype/segment, hour-by-hour load profiles are available for the space-heating, space-cooling, water-heating, and aggregate electric loads. Each data base is a consistent, organized, market-segmented reference of the office building and multifamily housing markets.

**TABLE 3**

**Numerous Applications and Users for the BER Data Bases**

| | Applications | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| User Categories | Design of Equipment | Technology Market Assessment | Market Size Prediction | Cross Market Studies | Energy Demand Mgmt | Utility Load Forecasts | Energy/ Market Conservation Incentives | Standards/ Codes Development | Environmental Impact Assessment | Reference/ Point of Comparison |
| Researchers/ Developers of energy end-use equipment | X | X | X | X | | | | | X | X |
| Researchers/ Developers of building materials & construction | X | X | X | X | | | | | X | X |
| Government/ Regulatory | | X | X | | X | X | X | X | X | X |
| Marketing | | X | X | X | | | X | | | X |
| Planning | | X | X | X | X | X | X | | X | X |
| Energy Users | | X | | | X | | | | | X |
| Building Design | | X | | | X | | | | | X |

Many benefits are incurred from using these data bases in technological assessments. The data bases were generated with the DOE-2 computer simulation program to obtain a high-quality estimation of the load profiles. However, these data bases circumvent many of the difficulties of using DOE-2. Relative to simulating with DOE-2, these data bases eliminate most execution errors, require fewer personnel and equipment resources, and are less costly to operate. Each prototype/segment is linked to a market segment with estimated amounts of building population and floor areas. From this basis of demographic data, the data bases are a consistent and unified market representation, market-linked and presegmented. The simultaneous load profiles are weather-linked and time-linked. They allow for analyses at several time intervals (daily total, weekly totals, etc.) and find wide application in energy-analysis topics. Management of the analysis is made easier with these data bases, as they provide consistent and comparable results among technological options, are flexible relative to different technologies, are in a user-friendly PC format, and allow for easy user switching between data bases and thus, are also cost-effective.

These BER data bases will provide many benefits in the analysis of energy end-use equipment in the office building and multifamily housing sectors. Further efforts on other building sectors are under way to expand the coverage of the building market. Several related papers provide more information on the development, application, and specific examples of these two BER data bases (see bibliography).

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