PREPARATION AND DEVELOPMENT OF LAND
USE ENERGY CONSUMPTION DATA SETS

NO STOCK MASTER

VOLUME 1, Phase 1 Final Report

December 20, 1978

Prepared for:

U.S. Department of Energy
9800 South Cass Avenue
Argonne, Illinois 60439

Prepared by:

Urban Systems Research & Engineering, Inc.
36 Boylston Street
Cambridge, Massachusetts 02138

with:

Multi-Systems, Inc.
1050 Massachusetts Avenue
Cambridge, Massachusetts 02138

and,

EDAW, Inc.
50 Green Street
San Francisco, California 94111

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	Page
CHAPTER 1: INTRODUCTION.	1
1.1 Study Background and Objectives	2
CHAPTER 2: THE ISSUE OF COMMUNITY CLASSIFICATION	5
2.1 The "Community" Scale of Analysis	5
2.2 History of Land Use Classification.	7
2.3 The Basic Elements: Parcel-Based Dimensions of Interest.	16
2.4 Aggregation into Communities.	22
2.5 Limitations and Extensions.	38
CHAPTER 3: TYPES OF ENERGY USE	43
3.1 Significance of the Energy Use Categories and Resulting Frameworks.	46
3.2 Energy Use Measurements of Interest	47
CHAPTER 4: ANALYSIS OF ENERGY USE FOR THE COMMUNITY TYPES, BASED ON EXISTING DATA.	50
4.1 Analysis of Direct Energy Use in Buildings. . .	51
4.2 Summaries of the Analysis	65
CHAPTER 5: VARIATIONS IN ENERGY USE AMONG COMMUNITY TYPES	70
5.1 Direct Building Energy Use.	70
5.2 Embodied Energy in Buildings.	72
5.3 Transportation Operating Energy	74
5.4 Transportation Embodied Energy.	74
5.5 Total Energy Use for the Community Types. . . .	76
CHAPTER 6: CONCLUSIONS AND OPTIONS FOR DATA COLLECTION . .	85
6.1 The Microanalytic Approach.	86
6.2 The Community-Level Approach.	88
6.3 Recommendations	91

APPENDIX A:	DIRECT ENERGY USE.	93
APPENDIX B:	EMBODIED ENERGY IN STRUCTURES.	121
APPENDIX C:	TRANSPORTATION ENERGY USE.	123

//

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

This is Volume 1 of the Final report for Phase I of Department of Energy contract EC-77-C-02-4528, "Preparation and Development of Land Use and Energy Consumption Data Sets," which has been performed by Urban Systems Research & Engineering, Inc., in association with Multisystems, Inc., and EDAW, Inc. The two volumes together describe the results of an analysis of the potential usefulness of land-use-related data, the availability of relevant information in the literature, and potential approaches for data collection. Should DOE conclude on the basis of this report and other studies that such data collection is desirable and the option for Phase II exercised, the data collection plans will be finalized, the desired data collected, and the necessary analysis performed.

At this point, however, these two volumes stand as a final product for the contract to date. We anticipate that they will be useful to other researchers in locating and evaluating data for policy analyses in areas such as the relationship for land use policies to energy consumption, and in structuring and performing such analyses.

This volume describes the results of the analysis, with technical backup materials contained in Volume 2. The remainder of this chapter describes the purpose and objectives for this research in more detail. This is followed in Chapter 2 by a discussion of the issue of community classification: questions of classification and aggregation have been the most significant technical issues faced on the project, since they strongly affect the accuracy and usefulness of any data which are developed. In fact, there is a direct tradeoff between the accuracy of prediction of energy use and the ability of the predictions to be used in planning: more data characterizing

an area will lead, ceteris paribus, to better predictions, but will also make the results of the analysis more difficult to use in the field. This issue is considered in Chapter 2.

Chapter 3 is concerned with consistency of accounting, primarily in the measurement of energy use. Transportation patterns, energy transmission losses, and energy embodied in materials and structure can all be assigned to various land uses in a number of ways, and it is important to perform the assignment in a way that is valuable for the policies being evaluated. Thus, Chapter 3 forms the structure for the dependent variables of the system: the various types and patterns of energy use, while Chapter 2 described the structure of the independent variables, which are the land use patterns described, plus other factors such as climate.

Chapter 4 takes these two structures and presents computations of energy use for the various patterns of land uses, based on the literature, and Chapter 5 discusses the implications of these analyses for energy planning. This leads directly to Chapter 6, where recommendations are made regarding both data collection and use of existing data.

1.1 Study Background and Objectives

There is a large and growing literature on the ways planning can be used to affect energy consumption. It is generally assumed that reduced energy consumption implies higher density development, less per capital reliance on the automobile, some shift from operating costs to capital costs in construction, and other changes. Some of these (e.g. higher densities) complement other favored environmental and social planning goals.

The most significant defect of the current literature is its lack of technical justification for how much energy will be

saved through various planning initiatives. The reason for this lack of justification is often a paucity of real data. The existing data are fragmentary and difficult to compare: they cover heating or cooling or transportation or embodied energy; they cover the Northeast or the Southwest, new communities or older ones. Significant issues are slighted: there is only the slightest information available on the relationship between building height and normalized direct energy use (for elevators, etc.).

Similar problems occur in most other areas. The question of whether shopping malls or commercial strip developments are more energy efficient, for example, is still unanswered; the net energy impact of various types of residential development has only been assessed in a few studies, and these have used prototypical situations, without adjusting for construction practices in various parts of the country, or including off-site transportation in many instances (even though it may be dominant). Utilities and freight transportation are also commonly left out of the land use/energy consumption analysis, though they should be included for the sake of accuracy and comprehensiveness.

The Department of Energy is interested in both developing planning tools which can be used to reduce waste in energy consumption and in analyzing new technologies for their effectiveness in various land use patterns. The Community Systems Program has contracted for work on planning techniques and tools, evaluations of shared utility technologies, and similar areas; other offices in DOE, non-profit organizations, and private firms have engaged in similar efforts.

This study is intended to provide baseline information which can be used by the planners and analysts in answering questions about the appropriateness of new technologies or specific planning decisions. As such, it must be a compendium of existing data, structured for consistency, accuracy, and comprehensiveness. There are three sources of such data:

- o the published and unpublished literature on energy consumption (secondary sources);
- o primary source data collected by others, but available for use (for example, utility records or transportation surveys);
- o new primary source data (household interviews, etc.)

From a cost-effectiveness standpoint, it is clear that as much reliance should be put on secondary sources as possible, given constraints on compatibility and quality, if these data can be put in a useful form for further analysis. Therefore, one of the objectives of the study has been to gather as much information as possible from the existing literature, and to analyze it for compatibility, and place it into a useful structure. This allows the "holes" in the existing information to be identified as targets for data collection and analysis plans. At the conclusion of this project, the data will be made available to other users, both within the Department of Energy and in non-profit organizations, firms, and the academic community.

CHAPTER 2

THE ISSUE OF COMMUNITY CLASSIFICATION

2.0 THE ISSUE OF COMMUNITY CLASSIFICATION

2.1 The "Community" Scale of Analysis

From the perspective of defining energy use as it currently occurs, the two most reasonable levels of analysis are the individual parcel and the metropolitan area. The individual parcel is a distinct unit where most of the end use activity occurs (heating, cooling, cooking, consumption of goods and services, etc.). The metropolitan area can also be fairly well defined, and includes most of the relevant transportation between individual parcels. On a somewhat larger scale, use of the Bureau of Economic Analysis (BEA) basic trading areas might be even more accurate, since they are defined as markets where the within-market activity is maximized compared to exports and imports. Analysis of transportation in these types of areas will tend to be relatively simple--most of the activity will be within the area of interest, rather than between areas. A scale of analysis between the individual parcel and the metropolitan area appears, to some extent, to be inappropriate for data collection and manipulation since it involves many parcels, but relatively few of the interactions between them.

However, these in-between levels are the most important ones for the potential uses of data. In evaluating new technologies, the analysis may focus on the interactions among units: sun rights for solar systems and demands on shared utilities are only two examples. Similarly, in planning, it is not possible to be concerned only with individual units or areawide master plans: most of the actual work involves evaluating subdivision or other development plans, attempting to develop approaches

*But see C. Binkley and R. Tabors "A Single System of Sub-state Regions: Critique and Case Study" Growth and Change, 1976 for an evaluation of the BEA areas.

for neighborhood improvement, and working with areas which are aggregates of individual parcels but which are only a small portion of the region. Developing data which will be useful at these intermediate levels, is expensive: it is necessary to look at both the individual parcels (or classes and groups of them) for their energy use, and to analyze the transportation pattern between these areas and the rest of the region. It is also desirable to look at detailed interactions, and see whether, for example, dispersed-site commercial activities lead to more or less automobile use within the area than linear strips.

A comprehensive look at energy consumption at the intermediate "community" scale might involve the following steps:

- first, divide up the metropolitan region of interest into zones, either by natural areas, or perhaps by something as simple as a grid
- second, collect data on the transportation activity between each zone, and on the within-zone transportation activity and direct embodied energy use
- finally, analyze the relationships between total energy use related to a zone and the land use characteristics of that zone

Because of nonlinearities in the relationships, the results of this aggregate analysis would be applicable to other areas using the same size zones, but will not be stable across all zone sizes.* However, if the detailed data are kept, it would be possible to aggregate to any desired zone size, and develop the applicable relationships. Use of zones also eliminates some

*This has been the major justification for significant work on disaggregate models of transportation demand.

of the undesirable sources of error in the analysis, and simplifies data collection, since it allows stratification by the overall zone characteristics, making it possible to choose areas which are comparable across a set of exogenous factors.

This zonal approach, based on either fixed grids or administrative units, has been the conceptual model at the heart of this project. We have assumed that zonal estimates of energy use are required for planning purposes, and have discovered that the existing data are generally much more highly disaggregated, being based on individual parcels. Therefore, it has been necessary to develop typical "community" patterns of development as a basis for analyzing differences across community types. The scale of the analysis is fixed in deference to the needs of policy-makers and practicing planners; the data therefore need to be fit to the analytic scale, and this requires a careful classification of both individual land uses, and their aggregations into communities.

2.2 History of Land Use Classification

It is not germane to this interim report to go into the history of land use classification, except as it is relevant to the theory linking energy consumption to land use. As a science, land use classification is not well developed. The reasons are fairly simple: the practical need for a rigorous classification approach has been relatively small, and the data needs of a sophisticated system are complex beyond the capability and interest of traditional users (local cities and towns, and regional planning agencies). The most important theoretical work on the subject dates predominantly from the sixties and early seventies, when federally funded programs, notably the interstate highway program*, and HUD's 701

*Beginning with the Federal-Aid Highway Act of 1962, 23 U.S.C. 134.

planning program,* expanded both the need for, and the resources available for systematic, large scale, land use inventories.

Central to the approach that will be developed later in this section is the notion of multiple dimensions of land use classification. It is critical to observe that most past classification efforts have focused themselves, implicitly or explicitly, on a catalog of activities that may occur on a given piece of land and have attempted to suppress the virutally limitless range of alternate modes of classification.

In 1962, the Urban Renewal Administration, with the cooperation of the Bureau of Public Roads, started work on the project that was published in 1965 as the Standard Land Use Coding Manual.** Their awareness and concern with the issue is expressed as follows:***

...different characteristics or dimensions that describe land should not be combined into a single classification system if the system is to meet the objectives outlined above. For example, in some land use inventory projects, categories of activity have been combined with measures of intensity of use, such as the number of dwelling units in a structure, or with type of ownership, such as private and governmental. In other systems structural type, such as office buildings, has also been included. This mixing of characteristics restricts the use of any classification and coding scheme.

*See Amendments to Section 701 of the Housing Act of 1954 in 1959 and 1961, 40 U.S.C. 461.

**Urban Renewal Administration, Housing and House Finance Agency, and Bureau of Public Roads, Department of Commerce. Standard Land Use Coding Manual. Washington, D.C.: U.S. Government Printing Office, 1965.

***Ibid.

Figure 2-1, reproduced from the first edition of the Standard Land Use Coding Manual, illustrates a few of the alternative dimensions of land use classification of interest to planners. The black box, "Activity," is the domain of the book's approach, though interestingly enough, one of principal difficulties that we and others have noted about the URA/BPR system is that it fails to limit itself to a pure activity system.*

Perhaps the primary problem in the development of the basic land use classification schemes has been their relation to the Standard Industrial Classification (SIC) system developed and used by the Bureau of the Budget (now the Office of Management and Budget/OMB).** The SIC System is an economic function classification, and does not correlate completely to the activities of concern to physical planners. Wherever possible, the structure and numbering of the SIC codes were adapted or preserved by the Standard Land Use Coding Manual (hereafter referred to as the BPR manual).***

In practical use, the BPR manual has deficiencies in several areas beyond that noted above: it has been criticized both for unwarranted compression of SIC classification and

*Clark, A. Selected Reference on Land Use Invention Methods. Council of Planning Librarians Exchange Bibliography #92, Monticello, Illinois: Council of Planning Librarians, 1969. See Introduction, p. 6. We note particular divergencies away from activities and toward structures in the 4000 series, "Transportation Communications, and Utilities," though other instances are also troublesome.

**The URA/BPR system's first edition contained cross references to the then current edition, Standard Industrial Classification Manual - Supplement to 1957 Edition. Bureau of the Budget, U.S. Government Printing Office, Washington, D.C., 1963. The latest edition in use today is 1972 version now published by the Office of Management and Budget.

***URA/BPR, op. cit.

FIGURE 2.1

AN EXAMPLE OF CHARACTERISTICS COMMONLY USED TO DESCRIBE A PARCEL OF LAND¹

¹ This figure is neither definitive in the number of characteristics shown nor does the sequence indicate relative importance. It is presented to illustrate the type of characteristics that are considered by planning agencies when describing a parcel of land. The shaded block labeled "Activity" is the characteristic being given primary consideration in this coding system.

² These characteristics can be described by an actual figure or a range in figures representing magnitude. The other characteristics cannot be described numerically and therefore, each will need a series of "word description" categories.

for lacking a practitioner's "feel" for land use classification.* More important to our project, it lacks numbers of categories of land use that are of current interest. For this reason, we have relied where necessary on the updated version of the BPR manual prepared by the Southern California Area Government (referenced here as SCAG).** Other users have invented their own classification systems, which are worth reviewing briefly, since the premises on which they are constructed are revealing.

Our conclusion after studying a number of the other systems in use is that the (attempted) rigor of the BPR system, with its unidimensional classification by land use activity, does not answer the needs of users in the field. For the most part, these users are not theoreticians, but planners working for cities and towns. They need classifications for residential land use that, for instance, include some structural parameters (e.g., separating single family detached structures from single family "townhouses," and identifying a variety of multi-family apartment uses by building type). They also may need to classify by ownership (another justification of the "single family" category, which is highly correlated with owner-occupancy). One of the most popular classification schemes is the Detroit Metropolitan Area's Land Use Classification Manual,*** even though it was published in 1962, and therefore predates the BPR

*Clark, op. cit.

**Southern California Association of Governments. Classification of Land Use. Los Angeles, 1968.

***Land Area Classification Advisory Committee of the Detroit Metropolitan Land Use Classification Manual. Chicago, Illinois: Public Administration Service, 1962.

manual. Like similar efforts,* it defines land use in terms that are meaningful locally, though its system attempts to cover most urban activities even if they do not necessarily exist in the city or town developing the system.** Such systems are not shy about combining structural and use parameters, or making other adjustments for practical purposes.

The original proposal for this project referenced the Baltimore Regional Planning Council's study, Aerial Photo Interpretation and Land Use Classification,*** as an approach to classification adaptable to our present needs. Our enthusiasm for this system was based largely on its heavy emphasis on structure and spatial pattern as predominant classification parameters, issues which we have further rationalized beyond the scope of the Baltimore study. Although it does no more than point the way toward some dimensions of an energy-related classification system, the study, unlike those referenced above, does deal in part with classification above the parcel level, and deserves some comment here.

*See references, and of chapter.

**Two other comprehensive systems of interest, not developed for local use are: American Institute of Planners, Southeast Chapter, North Carolina Section. A Proposal for a Standardized Land-Use Classification System. Raleigh, North Carolina: Division of Community Planning, Department of Conservation and Development, State of North Carolina. undated, and

Chapin, F. Stuart, Jr., Urban Land Use Planning. Second edition. Urbana, Illinois: University of Illinois Press, 1965.

***Gwynn, A. P., Aerial Photo Interpretation and Land Use Classification. Baltimore, Maryland: Baltimore Regional Planning Council. undated.

None of the other studies we were able to review includes any treatment of land use spatial organization beyond that which can be reported parcel by parcel. Thus, while some (such as the Detroit scheme) include factors suggestive of development density, none has systemized this or introduced the concept into other than residential contexts. The Baltimore study organized commercial land use into:*

1. Nucleated
 - a. Planned (shopping centers)
 - b. Unplanned
2. Linear
 - a. Auto oriented
 - b. Other
3. Peripheral
4. Unstructured

Such a classification totally ignores sub-categories of activity, and thus is not sufficient for energy studies; it also largely ignores individual parcel developments, which for any practical data on development purposes are the reporting levels of choice. What such an approach does do is address, in a very limited way, the issue of defining a community, rather than defining its component parts. The subject of aggregating up from the parcel level to the "community" level (as opposed to metropolitan or regional levels) is addressed below.

*Ibid.

New Approaches to Land Use Classification

The most interesting theoretical work on land use classification is that of A. Z. Guttenburg.* In brief, Guttenburg recognizes the theoretical problems of multiple dimensions of land use classification. He seeks to rationalize these into three "modes" of classification:

- o Referential: This includes all "objective" descriptors of the site, and is broken down into "Observable Characteristics" (including site development, structures, and activities) and "Underlying Characteristics" (ownership and underlying economic function);
- o Appraisive: A qualitative approach to classification, which considers general concepts such as "quality" (overall physical condition, technological obsolescence, etc.), "economic durability" (entrepreneurial interest in land use), and "social impact" (issues of law enforcement, user protection, security of neighboring users, conservation of social resources), and
- o Prescriptive: This mode deals with policy toward a land use--should it be replaced, preserved, augmented, etc. Specified under the mode are the planning aim itself, the means to attain it, and the agent of implementation.

Guttenburg's work seems to us to have relevance to this project only in the first two modes, and principally in the first. What he recognizes is the need for multiple classification dimensions, and his suggestions open up the possibilities

*Guttenburg, Albert Z., "A Multiple Land Use Classification System," Journal of the American Institute of Planners, Vol. XXV, No. 3, 143-150, 1959. See also:

New Directions in Land Use Classification. Chicago, Illinois: American Society of Planning Officials, 1965.

considerably from those of concern under alternative classification approaches. Though he does not spell out specifically the dimensions of concern to this project, he does implicitly promote the idea of classifying land by multiple physical and non-physical parameters. The nature of this project is such that we deal mostly in the referential mode. We must also, however, be aware of the appraisive mode, principally, we feel, in relation to technological "quality." For example energy consumption data sets should be useful in assessing whether a given land use is amenable to technological upgrading for energy conservation or not. A classification scheme that submerges the shadowing and roof design issues that are of interest to solar energy planning should be avoided.

So far, the only previous work we have found which addresses land use classification along the multiple dimensions of concern to energy studies is Kaminsky's work for the Baltimore Regional Planning Council, Environmental Characteristics Planning.^{*} Here, two critical dimensions of classification relevant to a systematic analysis of community energy use, trip generation and floor area ratios are singled out as separate classification vectors. This study works toward a prescriptive policy, however, and our interest has been to expand on this approach and the unidimensional approach to define, as rigorously as possible, the full range of classification vectors that might be included in a comprehensive data set. It is important to note, in the light of the succeeding discussions, that trip generation is not present in our class of independent land use variables--it occurs as a

^{*}Kaminsky, Jacob. Environmental Characteristics Planning: An Alternative Approach to Physical Planning. Regional Planning Council. Baltimore: August, 1972.

dependent variable. Kaminsky addresses it as a classification variable, since his approach is prescriptive rather than descriptive.

2.3 The Basic Elements: Parcel-Based Dimensions of Interest

The rest of this section limits itself to the description of those land use factors that can be discussed and reported at the parcel level.

We are not interested in classifications that do not ultimately relate to, or are not inextricably entangled with, the interrelation of energy use and the pattern, structure, and community distribution of land uses. For instance, while we cannot avoid including counting in the energy used by a refrigerator as part of observed household electric use, we would like to separate it out: since 99+% of households have refrigerators, this energy use is found to be associated with the activity of residential use itself, and would occur whether a household were located in a high-rise apartment building or in a detached suburban house. The first step toward separating such activity-related uses from total location-related energy use is to group together land use activities with roughly similar activity-related energy uses.

When addressing the energy embodied in different land uses, it is quite easy to disaggregate activity-related goods, such as refrigerators, from the site-and structure-related aspects of development, which we define as site preparation and development energy, and energy embodied in the structure, envelope, and finishings of buildings. For embodied energy, a clear picture of the structural development of a parcel is mandatory, but this will not be complete without some notion of how difficult a building was to construct: a twin level foundation blasted into bedrock clearly involves more energy use than one excavated from agricultural-grade soil.

Of course, the site itself affects many other energy uses--for example, its orientation may influence heating or cooling loads (a location use).

Limiting ourselves to land use factors reportable at the parcel level, it is convenient to think in terms of the diagram in Figure 2.2. The principal concepts of ACTIVITY, STRUCTURE, SITE together account for much of the parcel land use/energy consumption variation that can be observed purely at the parcel level. The orthogonality of the variables implied by this diagram is more wishful than real, but by striving for independence along these principal dimensions much can be clarified.

Each of the axes in Figure 2.2 in reality consists of a further cluster of axes, each of which, again, we strive to make as independent as possible.

ACTIVITY FACTORS

Figure 2.2 illustrates that the ACTIVITY axis of Figure itself has three principal sub-axes: Type, Scale, and Timing. It is not enough to know what activity occurs on a parcel. One must also know how intense it is, as well as its hours and seasons of operation, before one has adequate data to account for the influence of ACTIVITY on energy consumption.

Type

As suggested above, it is necessary to know the type of activities occurring on a site in order to grasp the nature of the energy consumed for purely activity-related functions, which presumably would occur independently of where and how a use is situated on the land. The residential refrigerator example is a case in point, and is only one of many considerations

that lead us to class all residential households as a single activity (though structure and site characteristics vary, as do exogenous factors). Transportation behavior also depends on the type of activity.

Timing

The number of hours any activity occurs within a given period influences the amount of energy used on the premises, as well as the amount of wear and tear given to the structures and the site, which in turn influences maintenance/repair/replacement. Hours of operation, for many uses, also tend to explain transportation behavior associated with site use and are based on the assumption that large operations will use energy differently than small ones.

Scale

Measures of scale are the third critical measure of land use activities. Many of the most useful measures are related to economic function, and so seem virtually colinear with some of the activity dimensions discussed above--for instance, one might measure retail trade by dollar sales per year, while such a measure is meaningless to residential land use, where total household income and number of residents are more appropriate factors. While the appropriate measures may vary among activities, the scale of a particular activity will affect its energy use, and should be measured.

STRUCTURAL FACTORS

Data on structural development is crucial for the quantification of embodied energy on site; it is also central to some analyses of location energy use, since climate conditioning involves complex interactions between site activities, climate, and structures. Figure 2.2 shows the three general dimensions of concern within the principal STRUCTURES axis: Design, Materials, and Mechanical Equipment.

FIGURE 2.2

DETAILED PARCEL LAND USE CLASSIFICATION AXES

Design

The form (or design) of a structure is too complex to categorize on a comprehensive basis for all land uses, though certain of its dimensions are relatively straightforward, such as measurements of height, floor area, volume, and the like.

Size: Most of these dimensions can be grouped under the category of "size." Such measurements as volume give much information relating to total climate conditioning and ventilating loads. Height is also useful to know, since it influences shadow effects both on and off the site, and floor area may be significant.

Design Program: Many traditional land use classification systems wind up dealing in some detail with the physical appearance of structures. It is necessary, then, to identify the various classes of structures that are found to exist across the United States, a task quite similar to land use activity classification.

Unfortunately, there is very little precedent for a comprehensive structural classification system based on design programs. Elements of it exist, such as in the residential sector: here it is relatively easy to categorize structures, since the number of variants is relatively small--they are all dominated by a remarkably uniform design program (bedrooms, bathrooms, kitchens, living spaces, dining spaces, and storage areas--including garages--pretty much exhaust the component parts; specifications vary within well-defined bounds). In the commercial sector (trade, services, amusements, sports) variations on programs and design are almost limitless, and often space is designed to serve multiple functions over time: a storefront may be an office one day, a food store the next, a restaurant some other time. Furthermore, spaces designed to serve one specific use are now frequently recycled into altogether different ones. In Boston, one finds apartment houses converted from spaghetti and piano factories.

Materials

An accurate measure of the energy embodied in any structure requires reasonably detailed knowledge of the materials and construction forms included in that structure, and their quantity. As discussed above, we are principally interested in four components of embodied energy on any building site: foundation and site preparation, structure, envelope, and finishes. In addition, the embodied energy in vehicles principally garaged at any site can be accounted for here.

Mechanical Equipment

Mechanical equipment is the last major dimension of concern with structures. Mechanical equipment has its own embodied energy; it is also a major consumer of direct energy. While much of the mechanical equipment that goes into a building is not discretionary (it is impossible to imagine the World Trade Center without elevators), a great deal is (single family homes may or may not have central air conditioning). Mechanical equipment can be divided into three general categories: movement systems, climate control, and activity-support equipment.

SITE-RELATED FACTORS

The third major axis of concern is the site itself. A wide variety of site-related factors, measurable at the parcel level, can influence direct on-site energy use, embodied energy use, and transportation.

Exhibit 2-2 shows two major dimensions of concern related strictly to the site: size and quality.

Size

Parcel size can be directly measured, and is an essential piece of data. Both three and two dimensional measurements may be of interest, and the necessary facts are few: total parcel size (hectares, acres, square feet), total undeveloped

area (same units), total developed area (same units, of special importance if it turns out to be larger than structural ground area coverage), segment dimensions of sides (meters, feet). For irregular parcels, some measures of shape may also be required.

Quality

Site quality covers many issues, some affecting embodied energy in structures and site development, others affecting direct energy use on the site. The discussion following breaks these down along these two dimensions of concern.

Factors Affecting Embodied Energy: Site factors that affect energy embodied in site and structures development include slope/topography, soils characteristics, geological characteristics, and types of materials covering the site (vegetative and manmade).

While modern construction technology allows the construction of buildings under a wide variety of sub-optimal conditions, it is well established that, outside of a conventional range of parameters, the costs of development in terms of labor and materials and the amount of energy required for construction increases.

Factors Affecting Energy Use On-Site: Site factors of interest here include slope/orientation and degree and types of site cover. The most important site characteristics in this category are topography, shadowing and microclimate. The two most important features are likely to be the slope of the site and its general orientation.

2.4 Aggregation into Communities

The problem with the dimensions shown in Exhibit 2-2 is that they are not useful for practical policy analysis. They simply require detailed data on too many individual units to be usable for local or national policy-making. While they provide a good description of the parcel energy use when combined with data on exogenous factors such as macro- and micro-climate, the amount of

data collection is unmanagable. Therefore, it has been necessary to develop a set of measures for the characteristics of typical parcels and groups of parcels that cover the full range of structure, activity, and site possibilities. These characteristics are simplifications of the major axes, and there is some loss of information involved in using them, though we have attempted to minimize this.

These characteristics include an aggregate description of the activity, and structure measures such as the total usable floor area, and the ground level cross-section; together, they can be used to measure the mix of activity groups in an area, and the Community Floor Area Ratio (CFAR) and Building Coverage (BC). We have used these three measures to develop classes of communities, with two specific goals:

- o they must be directly related to the parcel-level factors affecting energy use (in other words, they must have some causal relation to the actual energy use determinants);
- o they must span the range of development types of interest, and include as much of the real variation as possible: we wish to maximize between-group variance when applying the patterns to the real world.

The analysis described in the remainder of this report is based on an initial set of community patterns, which could also form the basis for data collection. This set of patterns, however, has not been proven to be optimal, but further data would be required to define these improvements. The data collection task would be twofold: first, the data would have to be used to derive the optimal set of community types, and then it would be used to develop forecasting methods for estimating the energy use of those community types. Chapter 6 returns to this issue, and the data collection implications.

Exhibit 2-3 shows the initial set of community classifications, which are derived from a consideration of community and building measures such as floor area ratios and building coverage, as well as aggregate activity classes and transportation network characteristics. The two simplest classes: "Guideways" and "Open Space" are necessary for completeness, but do not form an important part of the analysis. Exhibits 2-4 to 2-15 describe the other classes in more detail, and present typical patterns for them.

EXHIBIT 2-3

COMMUNITY CLASSIFICATIONS

CLASS	COMMUNITY FAR (CFAR)	BUILDING COVERAGE (BC)	BUILDING FAR (CFAR/BC)	TYPICAL ACTIVITIES (Comments)
I	0	NA	NA	<u>Open Space</u> : Agriculture, forestry, extraction, park, vacant. Occasional small buildings may exist, but are the exception.
II	0	NA	NA	<u>Major Guideways</u> : Roads, railroads, etc. Structures do not end user activities.
III	<.05	NA	NA	<u>Very Low Density</u> : Maximum typical level of development would be a large lot subdivision or similar residential area.
IV	.05 - .15	<.05	>1	<u>Low Density</u> : With restricted building coverage, this category may often include isolated major buildings.
	.05 - .15	>.05	1-3	With more generous building coverage, category is likely to include a large number of small buildings.
V	.15 - .30	<.1	>1	<u>Low/Moderate Density</u> : With restricted building coverage, this category would typically include moderate density, low elevation residential development.
	.15 - .30	>.1	1-3	With unlimited building coverage, this category captures much higher density suburban development, including shopping malls, dense residential areas, etc.
VI	.30 - .60	<.1	>1	<u>Moderate Density</u> : With limited building coverage, this category includes such uses as suburban office parks with high rise buildings.
	.30 - .60	.1-.2	1.5-6.0	With intermediate building coverage, this category includes most suburban office uses. Buildings average less than six stories.
	.30 - .60	>.2	1-3	With unlimited building coverage, the most extensively built uses are included, such as warehousing and goods transshipment points.
VII	.60 -1.2	<.1	>1	<u>High Density</u> : With restricted building coverage, this category is rarely encountered. It could include fairly large, well-spaced buildings sometimes found in modern planned communities or new towns.
	.60 -1.2	.1-.2	1-12	In the intermediate range of building coverage, this category can include higher density areas such as university campus, older commercial districts, etc.
	.60 -1.2	>.2	1-6	With unlimited building coverage, the category includes suburban centers and other dense uses with building heights less than six stories.
VIII	>1.2	<.2	>6	<u>Very High Density</u> : This is an open-ended category with limited ground coverage. This type can include all isolated large buildings. With large CFARs, the category is seldom encountered in reality. (It would include structures like NASA's enormous vehicle assembly building.)
	>1.2	>.2	>6	With unrestricted building coverages, this category includes all highest density communities, such as major metropolitan downtowns.

DEFINITIONS:

CFAR: Total floor area in structure $\div$ total community area.
 BC: Total first floor cross-sectional area of structures $\div$ total community area.
 Building FAR: Total structure floor area $\div$ total first floor cross-section.

EXHIBIT 2-4

COMMUNITY CATEGORY III: LOW DENSITY SUBDIVISION

Community Floor Area Ratio: 0.03 (67,500 ft.²)
 Building Coverage: N/A
 Building Floor Area Ratio: N/A

Description: a) 44 single-family units, 3.5 persons/unit,
 66,000 ft.² total floor area;
 b) gas station, 1500 ft.² total floor area.

COMMUNITY CATEGORY IV (a): CORPORATE HEADQUARTERS

Community Floor Area Ratio:	0.1 (225,000 ft ²)
Building Coverage:	0.08 (180,000 ft ²)
Building Floor Area Ratio:	1.25

Description: 1 large private office building, total area 225,000 ft², 1050 workers, no transit available

COMMUNITY CATEGORY IV (b): MIXED AGE RESIDENTIAL

Community Floor Area Ratio:	0.1 (225,000 ft ²)
Building Coverage:	0.08 (180,000 ft ²)
Building Floor Area Ratio:	1.25

Description: 137 single family units, (85 @3/unit, 20 @5/unit, 32 @4/unit) 162,683 ft²; church, 3,600 ft²; parish house/community space (3 residents) 9,750; light retail 9,600 ft²; food 5,000 ft²; restaurant 2,000 ft².

COMMUNITY CATEGORY V (a): GARDEN APARTMENTS

Community Floor Area Ratio:	0.24 (540,000 ft ²)
Building Coverage:	0.08 (180,000 ft ²)
Building Floor Area Ratio:	3.0

Description: 528 garden apartments in 88 buildings 534,000 ft²;
 food store 3,500 ft²; light retail 2,500 ft²;
 no bus service.

COMMUNITY CATEGORY V (b): SHOPPING MALL

Community Floor Area Ratio: 0.24 (540,000 ft²)
 Building Coverage: 0.16 (360,000 ft²)
 Building Floor Area Ratio: 1.5

Description: 1 enclosed wall (540,000 ft²) containing light retail 258,000 ft², department store 253,000 ft²; food stores 9,700 ft²; restaurant/bars 14,500 ft², bank 5,000.

COMMUNITY CATEGORY VI (a): STRIP HIGH RISE

Community Floor Area Ratio: 0.5 (1,125,000 ft²)
 Building Coverage: 0.077 (173,250 ft²)
 Building Floor Area Ratio: 6.5

Description: 12 private office buildings 1,125,000 ft²;
 5,000 employees; no transit service.

COMMUNITY CATEGORY VI (b): SUBURBAN OFFICE PARK

Community Floor Area Ratio: 0.5 (1,125,000 ft²)
 Building Coverage: 0.15 (337,500 ft²)
 Building Floor Area Ratio: 3.33

Description: Private offices 790,000 ft²; public offices
 72,000 ft²; small stores 50,000 ft²; restaurants/bars
 25,000 ft²; total employees 4,350.

COMMUNITY CATEGORY VI (b): VERSION II, HIGH DENSITY SUBURB

Community Floor Area Ratio: 0.24 (540,000 ft²)
 Building Coverage: 0.16 (360,000 ft²)
 Building Floor Area Ratio: 1.5

Description: Total residential space 460,000 ft²; 320 townhouses @2.5/unit, 85 single family units (50@4/unit, 30@3.5/unit; light retail 40,000 ft²; food stores 35,000 ft²; restaurant 5,000 ft²; bus service available.

COMMUNITY CATEGORY VI (c): SUBURBAN WAREHOUSING

Community Floor Area Ratio:	0.5 (1,125,000 ft ²)
Building Coverage:	0.5 (1,125,000 ft ²)
Building Floor Area Ratio:	1.0

Description: 4 warehouse buildings (2 @94,600 ft²), 1 @ 428,750 ft², 1 @507,050 ft²); 1 building air conditioned (94,600 ft²)

COMMUNITY CATEGORY VII (b): UNIVERSITY CAMPUS

Community Floor Area Ratio: 1.0 (2,250,000 ft²)
 Building Coverage: 0.15 (337,500 ft²)
 Building Floor Area Ratio: 6.67

Description: University Library, 838,625 ft²; classroom space 84,950 ft²; Administrative (office) 325,250 ft²; gymnasium 82,775 ft²; no transit available.

COMMUNITY CATEGORY VII (c): DOWNTOWN SUBURBAN CITY

Community Floor Area Ratio: 1.0 (2,250,000 ft²)
 Building Coverage: 0.5 (1,125,000 ft²)
 Building Floor Area Ratio: 2.0

Description: Residential 202,500 ft² (180 low rise apts. @2/unit, 35 townhouses @2.5/unit; 10 automotive service establishments 22,500; light retail/service 468,000 ft²; restaurants/bars 62,000 ft²; food stores 8,000 ft²; department store 272,000 ft²; banks (public office) 100,000 ft²; private office 1,115,000 ft², bus transit available.

COMMUNITY CATEGORY VIII: HIGH DENSITY DOWNTOWN

Community Floor Area Ratio: 34 (76,500 ft²)
 Building Coverage: 0.7 (1,575,000 ft²)
 Building Floor Area Coverage: 48.57

Description: Private office space, 75,712,500 ft²; light retail/personal service 417,375 ft²; department store 244,125 ft²; food stores 15,750 ft²; restaurants/bars 55,125 ft²; bank (public office) 55,125 ft²; bus transit available.

2.5 Limitations and Extensions

Eight major axes of interest at the parcel level were hypothesized to have a significant impact on energy use. In addition, there are a number of community and regional factors which can be significant, such as:

Community Level

- o Development pattern and mix of structures, activities, and overall community densities; impact on transportation demand congestion;
- o Transportation modes available: location of transit stops, terminals and other transportation facilities;
- o Location of utility services and types of service available;
- o Shading of parcels and structures by natural topography and structures on adjoining parcels;
- o Location of windbreaks, water bodies, and other topography affecting temperature, humidity, and air movement;
- o Existence of heat islands, wind tunnels, and other structure/activity impacts on micro-climate.

Regional Level

- o Location of the community with reference to other activity centers and communities (regional trip types, numbers, lengths, modes, and times, utility transportation costs);

- o Climatic factors: winds, temperature patterns, precipitation, humidity, latitude, insolation;
- o Regional development density;
- o Regional location relative to other regions, which influence shipment of materials, products, and energy supplies.

Therefore, it is clear that a set of community classes cannot be expected to have all the explaining power that would be shown by detailed data about each parcel characteristic. The typical patterns shown in the previous section are also relatively homogeneous, and real land use patterns are likely to show more diversity.

These limitations imply that the community land use patterns shown here are only an initial approximation to those which should be used for energy-related planning, and that further data are required in establishing the optimal set of patterns for particular policy analyses. For example, it might turn out (as hypothesized) that the three measures--BFAR, CFAR, and Building coverage--can be combined with only a few activity classes and climate zones to explain most of the actual variance in energy use. However, the specific breakpoints used here might be the wrong ones, so that the classification would have to be adapted to fit the real patterns of development. Only by collection and analysis of data can the optimal classification for energy planning be designed, and the breakpoints between classes established (with, of course, their robustness across areas and climate zones checked). Such analysis will also allow possible extensions of the classification to be evaluated, potentially broadening or narrowing the measures currently used, or adding others if it appears desirable. Thus, such data

analysis will form the bridge between detailed models of parcel energy use, and community classes which can be actually used for planning.

REFERENCES

CHAPTER 2

Baltimore Regional Planning Council. A Regional Data System. Technical Report No. 10. Baltimore, Maryland: The Council, 1963.

Bureau of Municipal Research and Service, University of Oregon. Comparison of Selected Classification Systems. Eugene, Oregon: The Bureau, 1966.

Land Use Coding Index. Eugene, Oregon: The Bureau, 1967.

A Land Use Classification System. Eugene, Oregon: The Bureau, 1966.

Hamburg, John R. and Robert H. Sharkey. Determination of Land Use Categories. Chicago, Illinois: Chicago Area Transportation Study, 1957.

Inter-County Regional Planning Commission. Land Use Classification Manual. Master Plan Report No. 26, 2nd ed. Denver, Colorado: The Commission, 1966.

Northeastern Illinois Metropolitan Area Planning Commission. Land Use Handbook: A Guide to Undertaking Land Use Surveys. Chicago, Illinois: The Commission, 1961.

1965 Land Use Inventory Manual. San Jose: The Department, August, 1967.

San Diego City Planning Department. Manual of Procedures for Coding Land Use Inventory Data for Machine Analysis. San Diego, California: The Department, 1957.

Teitz, Michael B. Land Use Information for California Government: Classification and Inventory. Berkeley, California: Center for Planning and Development Research, University of California, 1965.

Tri-State Transportation Committee. The New Approach to the New York City Land Use Inventory. New York: The Committee, 1964.

Wilkins, E. B. Mapping for Planning. Chicago, Illinois: Public Administration Service, 1948.

Two other comprehensive systems of interest, not developed for local use, are:

American Institute of Planners, Southeast Chapter, North Carolina Section. A Proposal for a Standardized Land-Use Classification System. Raleigh, North Carolina: Division of Community Planning, Department of Conservation and Development, State of North Carolina. undated.

Chapin, F. Stuart, Jr., Urban Land Use Planning. Second edition. Urbana, Illinois: University of Illinois Press, 1965.

CHAPTER 3
TYPES OF ENERGY USE

3.0 TYPES OF ENERGY USE

In attempting to relate energy use patterns to land uses, it is important to distinguish among the various types of energy use which take place in communities. For example, energy can be used for heating or cooling, to run appliances or vehicles, or to move water or natural gas. Energy is lost for useful work in the transmission of electricity, and industrial energy use is embodied in products ranging from megastructures to toothbrushes.

From a policy analysis and planning viewpoint, we are interested in analyzing energy use across a number of dimensions. For example, we are interested in both gross and net energy use, and in both location use and the total energy embodied in products. We are concerned with the time and spatial patterns of some uses (transportation, electricity) and with seasonal cycles of others (heating and cooling). We may be interested in energy use by type of fuel, or in the levels of purchased energy vs. energy generated on the individual sites.

We have attempted to establish the major dimensions of energy use, and to differentiate between energy use patterns which are affected in different ways by land uses. We feel, for example, that energy embodied in objects through the production process is distinct from the energy used in heating, at least through its relationship to land use patterns in communities. In essence, there seem to be three major classes of energy use:

- o Transportation Energy, used in moving people, goods, energy, and information between sites.
- o Embodied, which is energy invested in goods used on-site; and
- o Direct On-Site, which is energy used as energy at the location, for example in climate conditioning and activities.

In addition, it is useful to distinguish between two types of on-site uses:

- o Activity-Related, which only depends on the activities taking place, not on structural or site characteristics; and
- o Complex, where energy use is influenced by a combination of structure, site, and activity factors

Direct energy use is easy to picture: it is the fuel or energy used on a particular site for heating, cooling, cooking, industrial processes, television operation, or the like. Embodied energy is also relatively straightforward: it includes the energy used in building and maintaining structures, guideways, and vehicles, and in the physical items consumed at particular land uses: toothbrushes, newspapers, iron ore, and so forth.

The transportation energy uses are more complicated, since they are caused by the interactions among end-users, but occur in single communities. For example, it would be perfectly possible to allocate all energy uses to the structures or sites where they occur: transportation energy use would be assigned to the roads, transmission losses to the electrical system, and heating to the home. This would be a consistent framework, but is not particularly causal or policy-sensitive. Policies changing transportation needs or electric demand would not have a major impact on such a model, because some of the relationships between demand and usage would be missing. As an alternative, the analysis could attempt to allocate energy uses for moving people, goods, or information to the activities which cause the movement: transportation energy use would be allocated to households, firms, and other activities rather than to roads and rails. For example, electrical transmission losses would be allocated to the users of the electricity, and energy used for wastewater treatment would be allocated to the generators of the wastewater. The disadvantage of this approach is that we lose the spatial connection

between the energy use and related activities; if we allocate, for example, electrical conversion losses to the end users of the electricity, we can no longer estimate the amount of energy actually spent at the generating plant, because the accounting framework will charge it to the end users.

The same issue arises with embodied energy, which can either be included as direct energy used by production and transportation firms, or as embodied energy used by the final consumer of the product. Double counting has to be avoided, and the framework must be consistent, but different policy analysis applications may require different accounting frameworks.

To give an example of each approach, a community might want to consider different development patterns for an area, or, it might wish to evaluate different energy supply technologies for one site. In the first case, it would wish to determine which development patterns would be the most energy efficient. The evaluation would include issues such as:

- o total transportation use related to trips to/from the site;
- o direct energy use on the site (except industrial processing for export);
- o energy embodied in the buildings and infrastructure;
- o energy losses in transmission, which might vary depending on the spatial allocation of activities on the site.

Energy used for processing materials for export would be largely irrelevant to this analysis, and embodied energy would therefore be handled consistently.

In the second case, the concern is solely with the energy used on the site:

- o direct energy used on the site, including industrial use;

- o potentially, transportation within the site area;
- o transmission losses within the site area.

Embodied energy would be irrelevant for this analysis, as would transportation and transmission energy used outside of the site boundaries. Consistency would again be kept, but under a different framework.

3.1 Significance of the Energy Use Categories and Resulting Frameworks

The analysis in Chapter 4, and the review papers in Volume 2 present data on the magnitudes of the various components of energy use. In general, these data make the two frameworks analyzed above much more closely related than they appear at first glance.

Both frameworks include direct energy use on-site as part of the energy to be counted, but they vary in their consideration of embodied and transportation energy. However, as is demonstrated in Volume 2, embodied energy in materials and construction is generally small, in relation to direct energy, and appears to be remarkably constant across building types (aside, of course, from extreme cases such as open space). The energy embodied per square foot is relatively stable, according to the best existing data, and is also relatively small, when discounted over the life of the structure. The same is true for embodied energy in guideways and utility infrastructure, and in vehicles, based on the accounting framework chosen. From a local policy analysis viewpoint, this embodied energy is only going to be significant only in a small number of special cases (e.g. police activities or utility guideways) and can generally be ignored without biasing the results in any major way.

With respect to the other energy uses which can be considered as derived demands, the individual study can easily determine whether to allocate the energy use to the site where it occurs, or to the site causing it to occur. For example, it is relatively

easy to assign sewage treatment plant energy to the plant, but almost equally convenient to assign it to the generators of waste, which cause that plant to use the energy. The same is true for transportation and energy transformation/transmission losses. However, only in the cases of personal and freight transportation and electricity transmission is this allocation likely to make any difference: the other effects are small. Therefore, we recommend two alternative allocations, which will be appropriate for different policy questions, as shown in Exhibit 3-1.

3.2 Energy Use Measurements of Interest

Ideally, in analyzing the relationships between land use and energy use, we would like to be able to estimate, for any community, the energy use. Beyond that, we would like to know how that energy use could be disaggregated according to:

- o fuel type;
- o temporal pattern (particularly seasonal and daily);
- o end use for which the energy was intended.

These measurements would have to be related to some normalizing measure, if comparisons across community types were desired: two basic measurements for normalizing are the total area of all structures in the community, and the total area of the community as a whole. Other normalizations, however, might be developed, and some dimensionless measures could also be useful, such as the peaking factor in demand for particular energy types.

For almost any analysis, though, it would be sufficient to get the following information, from which the desired energy use measurements could be derived:

- o energy use by fuel type by end use by class of end user, and with the temporal distribution; not that this requires obtaining activity information such as type and scale, and classifying it.

EXHIBIT 3-1

ALLOCATION OF ENERGY USE AND RELEVANT POLICIES

TYPE OF ENERGY USE	ALLOCATION #1 (TO SITES)	ALLOCATION #2 (TO USERS)
<u>Direct:</u> space conditioning lighting processing construction etc.	to site where energy use occurs	to site where energy use occurs
<u>Transportation:</u> passenger freight	to site where energy use occurs (roads, stations, etc.)	to origins and destinations, split equally
<u>Electrical:</u> production and distribution	to generating plants and transmission/distribution lines	to end-users of the electricity
<u>Typical Policies of Interest:</u>	policies affecting the spatial use of energy, or concerned with where that energy use occurs (e.g. zoning on siting questions)	policies concerned with controlling or modifying demand for energy (e.g. urban form; end use conservation; transit)

- o community characteristics, such as total size, BFAR, CFAR, and BC (see Chapter 2).

CHAPTER 4

ANALYSIS OF ENERGY USE FOR THE COMMUNITY TYPES, BASED ON EXISTING DATA

4.0 ANALYSIS OF ENERGY USE FOR THE COMMUNITY TYPES, BASED ON EXISTING DATA

A set of community patterns were hypothesized in Chapter 2 to be significant, and an energy use accounting framework was developed in Chapter 3 for classifying the types of energy use within those areas. Given these two efforts, then, it was necessary to see how much could be learned about the community patterns and energy use classes based on the existing data, and also to assess how much is still unknown. This chapter presents the results of four analyses, which have evaluated energy use for the "typical" communities shown in Chapter 2, in the four basic energy use categories described above:

- o direct on-site energy use;
- o embodied energy in structures;
- o transportation operating energy;
- o embodied energy in vehicles and guideways.

The details of the calculations are presented in the Appendix to this volume, and are based on the data sources described in Volume II. In essence, the relevant calculations are performed to evaluate the equation:

$$E_i = \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L \sum_{m=1}^M p_j q_{jk} r_{jkl} e_{jklm}$$

Where E_i = Total Energy Use in Type i (direct, embodied, etc.)

J = structure types in the community

K = activity types in each structure type

L = energy use type for each structure-activity combination

- M = technologies
 P_j = fraction of structures in type j
 q_{jk} = fraction of activities in type k , conditional on structure j
 r_{jklm} = fraction of technologies in type m for demand type l , given structure; and activity k e_{jk}^l unit energy use of technology m for demand l in structure j and activity k

This equation describes energy use as a function of the structure and activity characteristics, the types of final demand of interest for those structures and activities, and the technologies used to meet those demands, with their unit energy use. It is a relatively simple approach which assumes little interaction between the various types of demand (e.g. hot water heating and space heating), though the actual calculations do bring in some of those effects, as shown in the Appendix.

4.1 Analysis of Direct Energy Use in Buildings

Nine categories of communities based on structure were developed in Chapter 2, and 6 of these (those concerned with common structure types) have been selected for a test analysis. In addition, several typical members of each of these classes showing different activity mixes are included.

In essence, this section reports on the actual on-site energy use for the typical communities shown in Chapter 2, usually for only a single climate zone (based roughly on New York City). Two fuels are used to provide all building energy use for simplicity: natural gas and electricity, and the "input energy" shows the quantity of energy delivered to each community for each fuel type. "Demand energy" is the actual energy reaching the end users, which depends on the efficiencies of conversion on the sites, particularly for air conditioning and heating. Increases in efficiency (e.g. heat pumps) would lower the input

energy, leaving demand unchanged; so would shifts to solar or other technologies, where the net delivered heating or cooling would be constant, but the amount required from off-site sources would be modified.

Exhibits 4-1 to 4-12 present the typical community patterns and characteristics, and summaries of the input and demand energy use by fuel and end-user. Temporal patterns could also be computed, given basic data on the timing of use of end use devices by various activities, but such data are not available in sufficient detail for this analysis at this time. It would be possible, however, to use the hours of operation of the various activities to make some estimates of the daily patterns of energy use, and climate conditioning loads could be varied seasonally based on the climate of the area. This has not been done as yet, for these areas.

COMMUNITY CATEGORY III:
LOW DENSITY SUBDIVISION

Community Floor Area Ratio 0.07 (67 500 ft²)
 Building Coverage N/A
 Building Floor Area Ratio N/A
 Description a) 44 single family units 3.5 persons/unit
 55 000 ft² total floor area
 b) gas station 1500 ft² total floor area

SUMMARY OF BUILDING ENERGY USE (BTU/year)*

		New York	Detroit	Houston
Input energy	(gas)	3.55×10^9	4.73×10^9	1.02×10^9
Input energy	(electric)	2.94×10^9	2.71×10^9	3.97×10^9
Input energy	(total)	6.50×10^9	7.44×10^9	4.99×10^9
Demand energy	(exc. AC)	4.61×10^9	5.21×10^9	2.90×10^9
Demand energy	(AC)	1.61×10^9	0.78×10^9	4.04×10^9
Demand energy	(Total)	6.22×10^9	6.18×10^9	6.94×10^9

*1 BTU/year

COMMUNITY CATEGORY IV (a):

CORPORATE HEADQUARTERS

Community Floor Area Ratio	0.4 (225,000 ft ²)
Building Coverage	0.08 (100,000 ft ²)
Building Floor Area Ratio	1.25
Description	1 large private office building, total area 225,000 ft ² , 1050 workers, no transit available

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input energy	(gas)	16.05 x 10 ⁹
Input energy	(electric)	11.18 x 10 ⁹
Input energy	(total)	27.21 x 10 ⁹
Demand energy	(exc. AC)	17.97 x 10 ⁹
Demand energy	(AC)	9.1 x 10 ⁹
Demand energy	(total)	27.07 x 10 ⁹

COMMUNITY CATEGORY IV (b):

MIXED AGE RESIDENTIAL

Community Floor Area Ratio 0.4 (221 000 ft²)
 Building Coverage 0.08 (182 000 ft²)
 Building Floor Area Ratio 1.25

Description 137 single family units 485 sq/unit 20 45/unit
 32 84/unit 162 683 ft² church 3 600 ft² parish
 school/community space (3 residential) 8 750 Light
 retail 2 600 ft² food 5 000 ft² restaurant 2 000 ft²

SUMMARY OF BUILDING ENERGY USE (BTU/year)

		<u>Res.</u>	<u>Comm./Cult.</u>	<u>Total</u>
Input energy	(gas)	10.09 x 10 ⁹	1.32 x 10 ⁹	11.41 x 10 ⁹
Input energy	(electric)	7.96 x 10 ⁹	.702 x 10 ⁹	8.66 x 10 ⁹
Input energy	(total)	18.046 x 10 ⁹	2.02 x 10 ⁹	20.069 x 10 ⁹
Demand energy	(exc. AC)	13.41 x 10 ⁹	1.99 x 10 ⁶	15.40 x 10 ⁹
Demand energy	(AC)	2.77 x 10 ⁹	768.85 x 10 ⁹	3.54 x 10 ⁹
Demand energy	(total)	16.18 x 10 ⁹	2.76 x 10 ⁹	18.94 x 10 ⁹

COMMUNITY CATEGORY V (a):

GARDEN APARTMENTS

Community Floor Area Ratio 0.24 (540,000 ft²)
 Building Coverage 0.09 (180,000 ft²)
 Building Floor Area Ratio 1.0

Description 528 garden apartments in 88 buildings 534,000 ft²
 Road street 1,500 ft light street 2,500 ft
 no bus service

SUMMARY OF BUILDING ENERGY USE (BTU/year)

		Res.	Comm.	Total
Input energy	(gas)	13.77 x 10 ⁹	166.08 x 10 ⁶	13.94 x 10 ⁹
Input energy	(electric)	21.21 x 10 ⁹	407.18 x 10 ⁶	21.62 x 10 ⁹
Input energy	(total)	34.98 x 10 ⁹	573.26 x 10 ⁶	35.56 x 10 ⁹
Demand energy	(exc. AC)	29.92 x 10 ⁹	566.67 x 10 ⁶	30.48 x 10 ⁹
Demand energy	(AC)	5.06 x 10 ⁹	324.21 x 10 ⁶	5.06 x 10 ⁹
Demand energy	(total)	34.98 x 10 ⁹	890.88 x 10 ⁶	35.87 x 10 ⁹

COMMUNITY CATEGORY V (b):

SHOPPING MALL

Community Floor Area Ratio	0.24 1540,000 ft^2
Building Coverage	0.16 1365,000 ft^2
Building Floor Area Ratio	1.5
Description	1 enclosed, wall 1540,000 ft^2 containing light retail 250,000 ft^2 , department store 353,000 ft^2 , food store 4,700 ft^2 , restaurant/bar 14,500 ft^2 bank 5,000

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	35.46×10^9
Input	(electric)	30.78×10^9
Input	(total)	66.24×10^9
Demand	(exc. AC)	44.14×10^9
Demand	(AC)	24.14×10^9
Demand	(total)	68.27×10^9

COMMUNITY CATEGORY V (b):

VERSION II:

HIGH DENSITY SUBURB

Community Floor Area Ratio	0.24 (540 000 ft ²)
Building Coverage	0.16 (360 000 ft ²)
Building Floor Area Ratio	1.5
Description	Total residential space 460 000 ft ² 320 townhouses 42 5/unit; 85 single family units (1984/unit) 8043 5/unit light retail 40 000 ft ² food stores 25 000 ft ² restaurant 5,000 ft ² bus service available

SUMMARY OF BUILDING ENERGY USE (BTU/year)

		Residential	Comm.	Total
Input energy	(gas)	15.57×10^9	2.27×10^9	17.84×10^9
Input energy	(electric)	19.33×10^9	3.58×10^9	22.91×10^9
Input energy	(total)	34.86×10^9	5.85×10^9	40.75×10^9
Demand energy	(exc. AC)	32.41×10^9	5.77×10^9	38.19×10^9
Demand energy	(AC)	6.20×10^9	4.00×10^9	10.2×10^9
Demand energy	(total)	38.62×10^9	9.77×10^9	48.39×10^9

COMMUNITY CATEGORY VI (a):

STRIP HIGH RISE

Community Floor Area Ratio	0.941 125 000 ft ²
Building Coverage	0.071 171 250 ft ²
Building Floor Area Ratio	6.5
Description	12 private office buildings 1 125 000 ft ²
	5 000 employees no transit service

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input energy	(gas)	80.23 x 10 ⁹
Input energy	(electric)	54.77 x 10 ⁹
Input energy	(total)	135.00 x 10 ⁹
Demand energy	(exc. AC)	88.72 x 10 ⁹
Demand energy	(AC)	45.57 x 10 ⁹
Demand energy	(total)	134.23 x 10 ⁹

COMMUNITY CATEGORY VI (b):

SUBURBAN OFFICE PARK

Community Floor Area Ratio	0.1 (1125 000 ft ²)
Building Coverage	0.15 (137 500 ft ²)
Building Floor Area Ratio	1.13
Description	Private offices 790 000 ft ² public offices 22 000 ft ² retail stores 50 000 ft ² restaurants/bars 25 000 ft ² total employees 4 350

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	79.85 x 10 ⁹
Input	(electric)	57.76 x 10 ⁹
Input	(total)	137.62 x 10 ⁹
Demand	(exc. AC)	91.67 x 10 ⁹
Demand	(AC)	45.0 x 10 ⁹
Demand	(total)	136.67 x 10 ⁹

COMMUNITY CATEGORY VI (c):
SUBURBAN WAREHOUSING

Community floor area ratio 0.5 (11 125 000 ft²)
 Building coverage 0.5 (11 125 000 ft²)
 Building floor area ratio 1.0
 Description 4 warehouse buildings (2 @ 99 600 ft², 1 @ 428 150 ft²,
 1 @ 907 050 ft²) 1 building air conditioned (94 800 ft²)

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	22.68 x 10 ⁹	BTU/year
Input	(electric)	8.97 x 10 ⁹	BTU/year
Input	(total)	31.55 x 10 ⁹	BTU/year
Demand	(exc. AC)	22.62 x 10 ⁹	
Demand	(AC)	2.48 x 10 ⁹	
Demand	(total)	25.10 x 10 ⁹	BTU/year

COMMUNITY CATEGORY VII (b):

UNIVERSITY CAMPUS

COMMUNITY CATEGORY VII (b) UNIVERSITY CAMPUS

Community Floor Area Ratio	1.0 (2,350,000 ft ²)
Building Coverage	0.15 (127,500 ft ²)
Building Floor Area Ratio	0.57
Description	University Library 838,625 ft ² classroom space 80,950 ft ² administrative offices 125,250 ft ² gymnasium 82,775 ft ² no transit available

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	133.33 x 10 ⁹	BTU/year
Input	(electric)	111.39 x 10 ⁹	BTU/year
Input	(total)	244.72 x 10 ⁹	BTU/year
Demand	(exc AC)	135.90 x 10 ⁹	BTU/year
Demand	(AC)	105.43 x 10 ⁹	BTU/year
Demand	(Total)	241.33 x 10 ⁹	BTU/year

COMMUNITY CATEGORY VII (c):

DOWNTOWN SUBURBAN CITY

Community Floor Area Ratio: 1.0 (1,125,000 ft²)
 Building Coverage: 0.5 (1,125,000 ft²)
 Building Floor Area Ratio: 2.0

Description: Residential 302,500 ft² (180 low rise apt. @2/unit,
 75 townhouses @2.5/unit, 10 automotive service
 establishments @2,500, large retail/service 468,000 ft²,
 restaurants/bars 61,000 ft², food stores 9,000 ft²,
 department stores 172,000 ft², banks (public office)
 100,000 ft², private office 1,115,000 ft², bus terminal
 available.

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	160.44×10^9	BTU/year
Input	(electric)	112.14×10^9	BTU/year
Input	(total)	272.58×10^9	BTU/year
Demand	(ex. AC)	187.70×10^9	BTU/year
Demand	(AC)	71.33×10^9	BTU/year
Demand	(total)	259.03×10^9	BTU/year

COMMUNITY CATEGORY VIII:

HIGH DENSITY DOWNTOWN

Community Floor Area Ratio 24 (76,500 ft²)
 Building Coverage 0.7 (1,575,000 ft²)
 Building Floor Area Coverage 48.5%

Description: Private office space, 75,712,500 ft², light
 retail/personal services 417,378 ft², department
 store 244,125 ft², food stores 33,750 ft², restaurants/
 bars 15,125 ft², bank (public office) 25,125 ft²,
 bus transit available

SUMMARY OF BUILDING ENERGY USE (BTU/year)

Input	(gas)	5.51×10^{12}
Input	(electric)	3.86×10^{12}
Input	(total)	9.36×10^{12}
Demand	(exc. AC)	6.18×10^{12}
Demand	(AC)	3.13×10^{12}
Demand	(total)	9.31×10^{12}

4.2 Summaries of the Analysis

A similar analysis of the direct energy use presented above was performed for embodied energy in structures, and analysis was also carried out for transportation operating and embodied energy. The same limitations hold here as for the earlier analysis: the work is based on the best available data as described in the review papers, and on assumptions described there and in the worksheets in the appendix to this volume. However there are many unknown factors and data limitations. The most significant limitation in these computations is, undoubtedly, the lack of good disaggregated data on construction practices and on trip lengths, particularly for different formats of housing, employment, and commercial spaces.

The results are summarized in Exhibits 4-13 to 4-16, for direct, structure embodied, transportation operating and transportation embodied energy, respectively. Note, however, that the direct electric energy use should be scaled up by the generating and transmission factor to provide these results in comparable terms; this is done in Chapter 5, when comparisons are made across the land use categories and across the various types of energy use.

SUMMARY

DIRECT ENERGY USE

		Direct ₉ (BTUx10 ⁹)	Direct/ft ² of community (BTUx10 ³)	Direct/ft ² of structure (BTUx10 ³)
III	Low Density Subdivision	6.50	29	96
IVa	Corporate Headquarters	27.21	121	121
IVb	Mixed Age Residential	18.05	80	80
Va	Garden Apartments	34.98	155	65
Vb	Shopping Mall	66.24	294	123
VbII	High Density Suburb	34.86	155	65
VIa	Strip Highrise	135.00	600	120
VIb	Suburban Office Park	137.62	612	122
VIc	Warehousing	31.55	140	28
VIIb	University Campus	244.72	1086	109
VIIc	Downtown Suburban City	272.58	1211	121
VIII	High Density Downtown	9360	41600	122

SUMMARY
EMBODIED ENERGY IN STRUCTURES

		Total Embodied (BTUx10 ⁹)	Embodied/ft ² of community (BTUx10 ³)	Embodied/ft ² of community per year* (BTUx10 ³)	Embodied/ft ² of structure (BTUx10 ³)	Embodied/ft ² of structure per year (BTUx10 ³)
III	Low Density Subdivision	53	240	4.7	785	15.7
IVa	Corporate Headquarters	450	2000	40.0	2000	40.0
IVb	Mixed Age Residential	186	827	16.5	827	16.5
Va	Garden Apartments	414	1840	36.8	767	15.3
Vb	Shopping Mall	627	2787	55.7	1150	23.0
VbII	High Density Suburb	434	1928	38.6	796	15.9
VIa	Strip Highrise	2250	10000	200.0	2000	40.0
VIb	Suburban Office Park	1720	7644	152.9	1529	30.6
VIc	Warehousing	716	3182	63.6	636	12.7
VIIb	University Campus	3820	16978	340.0	1698	34.0
VIIc	Downtown Suburban City	3530	15689	314.0	1569	31.4
VIII	High Density Downtown	152210	676500	13530.0	1990	39.8

* 50 year life, straight line use, no discounting

SUMMARY

TRANSPORTATION OPERATING ENERGY

		Transport Propulsion (BTUx10 ⁹)	Propulsion/ft ² of community (BTUx10 ⁹)	Propulsion/ft ² of structure (BTUx10 ⁹)
III	Low Density Subdivision	11.7	52	173
IVa	Corporate Headquarters	43.5	193	193
IVb	Mixed Age Residential	42.1	187	187
Va	Garden Apartments	66.4	295	123
Vb	Shopping Mall	179.8	799	330
VbII	High Density Suburb	95.6	425	177
VIa	Strip Highrise	188.7	839	168
VIb	Suburban Office Park	195.3	888	174
VIc	Warehousing	125.4	557	111
VIIb	University Campus	1.3	6	.6
VIIc	Downtown Suburban City	958.7	4261	426
VIII	High Density Downtown	9677	43009	126

SUMMARY

TRANSPORTATION EMBODIED ENERGY

		Transport Embodied Annual (BTUx10 ⁹)	Annual Embodied/ft ² of community (BTUx10 ³)	Annual Embodied/ft ² of structure (BTUx10 ³)
III	Low Density Subdivision	0.8	4	12.0
IVa	Corporate Headquarters	0	0	0
IVb	Mixed Age Residential	2.2	10	10.0
Va	Garden Apartments	8.4	37	16.0
Vb	Shopping Mall	0.3	1	0.6
VbII	High Density Suburb	6.5	29	12.0
VIa	Strip Highrise	0	0	0
VIb	Suburban Office Park	0	0	0
VIc	Warehousing	0.2	1	0.2
VIIb	University Campus	0	0	0
VIIc	Downtown Suburban City	6.5	29	3.0
VIII	High Density Downtown	1.2	5	0

CHAPTER 5

VARIATIONS IN ENERGY USE AMONG COMMUNITY TYPES

5.0 VARIATIONS IN ENERGY USE AMONG COMMUNITY TYPES

This chapter analyzes how well the activities and community types distinguish areas with different energy use patterns, in essence addressing how much of the variation they seem to capture across areas. As described in the earlier exercise, this is a thought experiment: it does not use data from actual communities of these types, but rather looks at hypothetical areas, characteristic of each community type. In essence, therefore, these hypothetical areas are in the mid-range of each community type, and this is a weaker test than might be desired, though the strongest available.

The chapter discusses first the variation across community types for each type of energy use, and then summarizes these results for building energy, transportation, and total energy use.

5.1 Direct Building Energy Use

Exhibit 5-1 shows the total direct energy use for each community type, as well as the energy use per square foot of area in the community and the energy use per square foot of structure. As would be expected, there is a direct relationship between total energy used on the site and the developed density, measured by the community floor area ratio. There is much less variation in the energy use per square foot of structure, however, and higher densities do not seem to have lower energy use per unit area of usable space, shared walls notwithstanding. Major variations occur within community classes, with uses such as warehousing showing much lower energy consumption than other similar densities,*and with the fully climate conditioned shopping mall having much higher use than the garden apartments or high-density suburb which are in the same use class.

Other climate zones were considered for the low-density subdivision in Class II, and for the other classes. The basic result of these analyses and the literature is that

*as measured by community FAR.

EXHIBIT 9-1
BUILDING DIRECT ENERGY USE

areas where demands are highest, either for heating or cooling, show less variation among structure types than areas with limited demands, such as our base case of New York. The reason for this is simple: structure type has more influence on whether or not climate conditioning equipment is used, than on the actual load placed on it. For example, garden apartments in the South are centrally air conditioned, increasing energy use to a level comparable to that of the shopping mall, and this results in less difference in energy use per usable foot across structure formats and uses in the South than in the North. Thus, the relationship between density and total energy use is even stronger in areas with extreme climates, where technologies vary less by activity.

5.2 Embodied Energy in Buildings

Exhibit 5-2 shows the annual embodied energy (with no discounting and a 50-year life) per square foot of site and building, for the various community formats. There is remarkably little variation in embodied energy, as was shown in the review paper on this topic in Volume 2. The total amounts are relatively small, and the lowest is about 40% of the highest. Obviously, embodied energy grows directly with density, and across the various community formats. It stays relatively constant as a fraction of total building energy use, and as an annualized energy use per square foot of structure.

Since the errors in estimating embodied energy are likely to be significant and current data shows little aggregate variation, we believe that embodied energy estimates should not be used in setting development policies. It is possible that they could make slight differences in total energy use in construction and in future development, but the gains are likely to be insignificant. Attempts to reduce total embodied energy through improvements in construction practices and materials are likely to be much more fruitful, and will aid all development formats.

EXHIBIT 5-2
EMBODIED ENERGY IN STRUCTURE

5.3 Transportation Operating Energy

As described in the Appendix and in Volume 2, the transportation estimate used here are a combination of two major random variables: trips per square foot of structure per day, for the structures in each community type; and, trip lengths for trips between two types of activities. While these variables (and others, such as mode and occupancy) have been measured in many areas, they only have a weak relationship to actual behavioral factors, and vary considerably from area to area. Therefore, there is as much uncertainty about the transportation operating estimates as about the other contributors to energy use. Unfortunately, data are also lacking on the use of various classes of streets in communities with varying characteristics, so that a shift to the alternative accounting framework would not improve the quality of the existing information.

Exhibit 5-3 shows the operating energy used in transportation, in a format similar to that used in the previous exhibits. Transportation operating energy grows generally with density, as expected, but is also policy-sensitive, and sensitive to development format within a class. For example, use in the shopping mall is especially high, much higher than for the high-density-suburb case per square foot of usable space, largely because of long travel distances to the mall. Similarly, warehousing requires relatively little transportation, and that in large vehicles, while the university campus is specifically designed to minimize motorized vehicle transportation through support of walking and bicycling.

5.4 Transportation Embodied Energy

Embodied energy in buildings was small, but transportation embodied energy in vehicles and local streets is even smaller, reaching its maximum in the residential formats, and even here being consistently under 10% of total energy use. While there may be a major difference in embodied energy among formats (see, for example, the Fels and

EXHIBIT 5-3
TRANSPORTATION OPERATING ENERGY

CBO studies), this is likely to have only a small impact on total community energy use, for almost all of the community formats. Guideway and utility embodied energy, will have an equally small impact, as discussed in earlier reports and Volume 2. Exhibit 5-4 shows transportation embodied energy estimates for the development formats.

5.5 Total Energy Use for The Community Types

Exhibits 5-5 to 5-9 show our estimates of total energy use for these typical members of each community type. The first exhibit shows the total energy for the area, in annual BTUx10⁹; this is followed by a percentage breakdown across energy use types, and by estimate of energy use per square foot of site, and per square foot of structure, again averaged over the community and based on the limited available data. The conclusions of the previous sections are confirmed here: there is a general relationship between density and energy use, as expected, but there is also relatively little variation in energy use per square foot of structure and no evidence of a decline in unit energy use with higher densities. The activities occurring in an area do have an important impact, as shown strongly by the warehousing and university cases, while structure formats have a more limited influence, and this influence is reduced in harsher climates. Embodied energy, in general, shows little variation and is also a small portion of total energy use: it can be ignored for most planning purposes. The same is true for utilities such as sewage and gas pumping, and losses in the distribution of electricity (though generation losses should be included, and have been: see the Appendix).

From the earlier chapters, it should be clear that two other questions arise besides the total energy use and its breakdown into end uses. Those are the peaking pattern of each use, and the fuels used. Both of these concerns are relevant only to buildings, except in the case where mass transit

EXHIBIT 5-4
TRANSPORTATION EMBODIED ENERGY

EXHIBIT 5-5
TOTAL ENERGY USE

TOTAL ANNUAL ENERGY USE (BTUx10⁹)

		Direct	Structure Embodied	Transport Operating	Transport Embodied	Total
III	Low Density Subdivision	6.5	1.1	11.7	0.8	20.1
IVa	Corporate Headquarters	27.2	9.0	43.5	0.0	79.7
IVb	Mixed Age Residential	18.0	3.7	42.1	2.2	66.0
Va	Garden Apartments	35.0	8.3	66.4	8.4	118.1
Vb	Shopping Mall	66.2	12.5	179.8	0.3	258.8
VbII	High Density Suburb	34.9	8.7	95.6	6.5	145.7
VIa	Strip Highrise	135.0	45.0	188.7	0.0	368.7
VIb	Suburban Office Park	137.6	34.4	195.3	0.0	367.3
VIc	Warehousing	31.6	14.3	125.4	0.2	171.5
VIIb	University Campus	244.7	76.4	1.3	0.0	322.4
VIIc	Downtown Suburban City	272.6	70.6	958.7	6.5	1308.4
VIII	High Density Downtown	9360	3044	9677	1	22082

PERCENTAGE BREAKDOWN OF ANNUAL ENERGY USE

		Direct	Structure Embodied	Trans- portation Operating	Trans- portation Embodied	Total
III	Low Density Subdivision	32	6	58	4	100
IVa	Corporate Headquarters	34	11	55	0	100
IVb	Mixed Age Residential	27	6	64	3	100
Va	Garden Apartments	30	7	56	7	100
Vb	Shopping Mall	26	5	69	0	100
VbII	High Density Suburb	24	6	66	4	100
VIa	Strip Highrise	37	12	51	0	100
VIb	Suburban Office Park	38	9	53	0	100
VIc	Warehousing	19	8	73	0	100
VIIb	University Campus	76	24	0	0	100
VIIc	Downtown Suburban City	21	5	73	1	100
VIII	High Density Downtown	42	14	44	0	100

ANNUAL ENERGY USE/FT² OF SITE (BTUx10³)

		Direct	Structure Embodied	Trans Operating	Trans Embodied	Total
III	Low Density Subdivision	29	5	52	4	90
IVa	Corporate Headquarters	121	40	193	0	354
IVb	Mixed Age Residential	80	16	187	10	293
Va	Garden Apartments	155	37	295	37	524
Vb	Shopping Mall	294	56	799	1	1150
VbII	High Density Suburb	155	39	425	29	648
VIa	Strip Highrise	600	200	839	0	1639
VIb	Suburban Office Park	612	153	888	0	1653
Vic	Warehousing	140	64	557	1	762
VIIfb	University Campus	1086	340	6	0	1432
VIIfc	Downtown Suburban City	1211	314	4261	29	5815
VIII	High Density Downtwon	41600	13530	43009	5	98135

ANNUAL ENERGY USE/FT² OF STRUCTURE (BTUx10³)

		Direct	Structure Embodied	Trans Operating	Trans Embodied	Total
III	Low Density Subdivision	96	16	173	12	297
IVa	Corporate Headquarters	121	40	193	0	354
IVb	Mixed Age Residential	80	16	187	10	293
Va	Garden Apartments	65	15	123	16	219
Vb	Shopping Mall	123	23	330	1	477
VbII	High Density Suburb	65	16	177	12	270
VIa	Strip Highrise	120	40	168	0	328
VIb	Suburban Office Park	122	31	174	0	327
VIc	Warehousing	28	13	111	0	152
VIIf	University Campus	109	34	1	0	144
VIIfc	Downtown Suburban City	121	31	426	3	58
VIII	High Density Downtown	122	40	126	0	288

becomes significant (types VII and VIII). For the purposes of this analysis, however, natural gas and electricity were the energy types chosen, and the major peaking effects arose from differences in time use patterns for different activities. Thus, adverse peaking effects would occur most often in areas with a single major use (e.g. residential, shopping mall) than in areas with more variation, while the breakdown in fuel use depends primarily on climate and technology. As densities increase, some shifts in fuels would be expected, of course: Exhibit 5-10 shows the relative percentage breakdown of natural gas, electricity, and gasoline resulting from the analysis, but these are based on constant choices for heating, cooling, and other uses, so those expected variations do not occur. Without actual data, therefore, it is impossible to establish much about fuel use and peaking patterns. This is a major concern in Chapter 6, below, where use of these results and potential data collection approaches are considered.

EXHIBIT 5-10

PERCENTAGE BREAKDOWN OF FUEL USE

CHAPTER 6

CONCLUSIONS AND OPTIONS FOR DATA COLLECTION

6.0 CONCLUSIONS AND OPTIONS FOR DATA COLLECTION

Based on the analysis of the hypothetical communities, using the data available in the literature, it appears that several conclusions can be reached:

- o embodied energy, in buildings, transportation, vehicles, guideways, and utilities, is a relatively small portion of community energy use; it is also not easily amenable to policy initiatives.
- o there is little evidence of a change in energy use per usable square foot as density increases, except perhaps through shifts in transportation technology to mass transit;
- o total energy appears to rise directly with density, as expected;
- o there is little useful information on fuel use or temporal patterns for different community types, and therefore our analyses showed few shifts;
- o the data on transportation demands are, if anything, even more limited than the data on direct energy use; this is especially true for analysis of the total travel within an area, as opposed to the travel generated by an area;
- o climate effects appear to be relatively well understood, at least according to the authors of the detailed literature, and for the level of aggregation we are considering (communities).
- o variations by activity appear significant; variations by structure type appear, at this point, to be less significant.

Given these conclusions, it is useful to consider what sorts of data collection would be likely to be useful for federal, state, and local planners concerned with community energy conservation planning and systems. It appears that the major areas where the data collection should be focused include:

- o testing the community density classification system, to test and improve the breakpoints between classes;

- o analyzing consumption patterns over time for communities of different density and activity;
- o testing the consistency of the density/total energy use relationship (or, equivalently, analyzing the robustness of the estimate of constant energy use per square foot of usable space, on the community level;
- o analyzing the effect of activity and structure mixes on energy use per square foot of space or community, as well as on peaking and fuel use patterns, to aid in explaining the density effect;
- o estimating the total transportation energy used within communities of various densities, and perhaps making or using other estimates of how this will change with metropolitan structure and size.
- o testing the robustness of the various conclusions for various climate zones.

There are two basic approaches for such data collection, and these are described further in Sections 6.1 and 6.2. Section 6.3 then presents our recommendations.

6.1 The Microanalytic Approach

In this approach, a few communities in a few metropolitan areas are chosen, for example, 3-5 communities in each of four cities. Detailed data are collected on structures, activities, and building energy use in each area, with traffic counts made to establish transportation use. By analyzing the individual parcels which combine together to make up a community, it will be possible to estimate the within group and between group variances for each community type, and establish the breakpoints between classes. In addition, detailed data on the relative importance of activity and structure types will be gathered, and transportation measurements on-site can be made. Fuel mixes for the limited areas will be available, and some climate effects can be measured, but there will be little information on peaking.

This study would be valuable in testing the basis for the density/total energy use relationship, and in testing the assumptions of the community classification system to see how accurately it describes the causal factors affecting energy use through measures such as CFAR and BC. It is, in essence, similar to the approach used here with the hypothetical communities, but based more in the real world where actual data can be aggregated to estimates for typical communities.

Data collection on this study would involve three related efforts:

- o collection of activity and structure data;
- o collection of parcel energy use data;
- o collection of transportation energy use data.

The metropolitan areas described in part II of Volume 2 would be chosen, because they have a range of climates and development patterns, and good data from cooperative utilities, with dominant use of gas and electricity. Sites would be selected based on land use maps and utility data collection areas, and each structure would be described with associated activities, through a windshield survey. Auto ownership would be included from the Census or local studies and local transportation surveys would be used for trip end and mileage estimates. Traffic counts would also be made by street type, if otherwise unavailable. The utility data would then be matched with structures with confidentiality assured by stripping off the address information, and the parcel data would be used to estimate community energy use, fuel splits, and the classification of activities and structures which would optimize explanatory power. This clustering step would then be followed by comparisons across community types, and aggregation into a set of community classes which would best explain energy use.

In essence, this approach would collect data useful for deriving a workable set of community classes, through gathering

information on the causal factors which must be at the basis of such classes. It is one alternative which could aid the goals of the project, and the planning needs from which those goals were derived.

6.2 The Community-Level Approach

In this approach, the community analysis is seen as empirical, and the goal is to derive a set of useful community classes and activity/structure classes through analysis of the set of communities of a particular scale. The activity and structure information, the transportation data, and the energy use data, would all be more aggregated than in the microanalytic study, but this would be counteracted by a much larger sample size of communities.

The study as envisioned would analyze the same four metropolitan areas as in the microanalytic study, but would look at a grid governing all communities within the metropolitan region, with the scale and shape of the cell depending on available utility data. Energy use measurements would be areawide, though disaggregated by time of day through metering records, and structure and activity data would be based on land use information and aerial photographs, with transportation data from the same photos and existing surveys. This study would be less useful in determining breakpoints in the community classes or aggregation procedures than the microanalytic study, but would provide a large sample of actual communities for testing the assignments of sites to classes, and for analyzing the total energy use, temporal breakdown, and fuel choice aspects. All four metropolitan areas selected in Volume 2 have sufficient data for this approach.

The community-level study would provide a good test of the consistency of communities and provide more information on the climate effect than the microanalytic study. It would be more

empirical, showing less causal basis, but would act more directly to test the classification procedure, while providing less information on how to optimize it if it turned out to be unsuccessful (since there would be less detail on the components of activity and structure).

The Data Collection Phase

Data collection for the community level study would rely primarily on utility records, existing land use information and parcel files, and aerial photographs. The utility data would be used to analyze the physical quantities of energy used in each community as fine temporal detail as possible. Specifically, cubic feet of natural gas measured at pumping points, and electricity flows measured at substations or other meters would be collected. The ideal level of detail would probably be community level metering, with hourly data so that energy use could be aggregated into daily patterns, and also compared with climatic data to establish the relationship between climate conditioning and total energy use.

Land use data could be collected for the communities based on municipal information, with aerial photos used as a backup. The air photos would provide structure information (with some ground data used to supplement them) while the municipal land use inventories would describe activity classes such as "commercial". In addition, some field work would probably be necessary to accurately estimate the mix of activities in the community, but this would be limited.

Transportation data could be collected from the same aerial photos, if there were sets available showing different times of day. Specifically, traffic on the various types of streets for each community could be estimated through counting vehicles. Overall metropolitan flow estimates from existing traffic studies would provide scaling factors for the different times of day. Vehicle types could also be identified, which would be valuable. Thus, it would be possible to estimate the flows on particular types of streets, based on standard coding methods, for particular community classes.

The Analysis Phase

Once the data were collected, the analysis would use statistical approaches to evaluate the classification, and to improve the breakpoints. The first stage in this analysis would be regressions of energy use patterns, by fuel and time of use, on the community characteristics, including CFAR, BC, activity mix, and others where appropriate. These analyses would allow us to estimate which variables were most important in affecting the various types of energy use.

Those variables would then be used to develop a clustering of communities into types, perhaps using discriminate analysis to better identify the breakpoints across classes. Closest neighbor clustering of the set of communities along the energy use axes, and along the independent variables, would present some information on the overall effectiveness of the approach. In addition, analysis of residuals would show which specific communities were outliers, and the reasons for these estimation difficulties would be assessed.

The final phase of the analysis would be an evaluation of pooling: in other words, we would test the robustness of the community classification across sites, seeing how the relevant variables and breakpoints varies from city to city. This stage would also require evaluation of the robustness of the approach across energy use classes, to see whether the relevant community classification for peak loading of electric use were the same as those for use of natural gas, or of gasoline in transportation.

Obviously, it is impossible to know now what results would arise from such an analysis. However, it is possible to make an analogy, and one can be made with EPA's publication AP-42, the Compilation of Air Pollution Emission Factors. This document provides detailed planning data on the amounts of pollution emitted from various sources, and provides the data at varying levels of detail. It includes large amounts of data, but it is difficult

to use for planning because of its lack of consistency or structure. For this reason, EPA has developed supplementary documents which provide land-use based emission factors, but the problem of developing the relevant classification of land uses for implementing air pollution policies has not yet been addressed. The situation is similar in the energy field, with numerous documents providing data on energy use, and energy use factors, but with the factors being largely irrelevant to the needs of planning studies. In this phase, we have attempted to develop a process for classifying uses and communities for energy use evaluation, but have not been able to test that process. We have also not been able to develop the analogue to "land use based emission factors" because of limitations in the existing data. Therefore, the data collection phase would be used to improve the planning structure, and also to develop careful estimates of the energy used by each member of this structure, which is a community type with its associated mix of activities.

It is worthwhile describing the community-level study in some more detail, stating what analyses would be performed, and on what data, and this is the objective of the remainder of this section.

6.3 Recommendations

The community-level study will provide a good test of the approach to energy planning, and give valuable information about temporal patterns of demand for different types of uses. It will use available data, and will answer almost all of the questions raised at the beginning of this chapter, rather than providing more complete answers to fewer questions, as the microanalytic study would. It appears to be a reasonable next step in the effort to develop an approach for energy planning

at the community scale, using density and other measures of use, and we recommend it. Based on the analysis of Volume 2, the four cities of choice should be: Dayton, OH; Miami, FL; Milwaukee, WI; Phoenix, AZ, and negotiations should begin with the utility companies there to obtain time-of-day demands for electricity and seasonal demands for natural gas, at the most disaggregate level possible, for as many years as available. These disaggregate areas can then be used as the analysis units, with information collected on the relative proportion of various activities, the community FAR and building coverage, and perhaps on the major structures or industrial processes which are included. The result of the analysis will be an improved community classification with estimates of the direct energy use by fuel for each community class, including temporal variation and the sensitivity to climate, which seems to us to be the overall goal of the effort. In addition, we should have an estimate of the proportion of communities which fit into each class and subclass, which will also be useful in planning.

APPENDIX A

DIRECT ENERGY USE

III. Low Density Subdivision

Direct Energy Consumption

A. 44 single family houses @1500 ft. -- 3.5/household

<u>Base Load</u>		<u>Ref.</u>
hot water	23.37x10 ⁶ Million BTU/household/year	(13)
refrigerator	6.25x10 ⁶ Million BTU/household/year	(3,13,2)
major appliances	8.0 x10 ⁶ Million BTU/household/year	(1,2,3,4)
lighting	6.09x10 ⁶ Million BTU/household/year	(13)
minor appliances	3.0 x10 ⁶ Million BTU/household/year	(1,3)
cooking	4.4 x10 ⁶ Million BTU/household/year	(2,3,4)

51.11x10⁶ Million BTU/household/year
2,248.84x10⁶ Million BTU/community/year

Heating

Assumes:

1. New York City climate: 4800 heating degree days
2. 50% of buildings to be well insulated, weather stripped and equipped with storm door and windows
3. gas heat
4. no energy conservation habits (thermostat setback, relaxed comfort conditions, etc.)
5. Hittman's research findings (19)

22 well constructed/insulated houses

$$16.14 \text{ BTU/HDD/ft.}^2 \times 1500 \text{ ft.}^2 \times 4800 \text{ HDD} \times .93 \times .45 \times .81 = 39.393 \times 10^6 \text{ BTU/unit}$$

22 poorly insulated houses

$$16.14 \text{ BTU/HDD/ft.}^2 \times 1500 \text{ ft.}^2 \times 4800 \text{ HDD} = 116.21 \times 10^6 \text{ BTU/unit}$$

Total residential input heating energy = 3423.2x10⁶ BTU/year

Total residential heating demand = 2.2264x10⁹ BTU/year

Cooling

Assumes:

1. New York City climate: 1050 CDD

2. 50% of buildings are well insulated, weather stripped, and equipped with storm doors and windows
3. electric cooling
4. no energy conservation habits
5. Hittman's research findings (19)

22 well insulated houses

$9.94 \text{ BTU/CDD/ft.}^2 \times 1500 \text{ ft.}^2 \times 1050 \text{ CDD} \times .95 \times .95 \times .88 = 12.434 \times 10^6$
BTU/unit/year

22 poorly insulated houses

$9.94 \text{ BTU/CDD/ft.}^2 \times 1500 \text{ ft.}^2 \times 1050 \text{ CDD} = 15.656 \times 10^6$ BTU/unit/year

Total residential cooling demand = 1.545×10^9 BTU/year

Total residential input cooling energy = 617.96×10^6 BTU/year

Total residential input direct energy budget = 6.29×10^9 BTU/year

Alternative Climates

input Detroit: 6380 HDD, 663 CDD

Base demand: 2.249×10^9 BTU heating: 4.55×10^9 BTU/cooling:
 390.2×10^6 BTU/year

Total residential: 7.1891×10^9 BTU/year

input Houston: 1408 HDD, 2748 CDD

Base demand: 2.249×10^9 heating: 1.0041×10^9 cooling:
 1.6173×10^9

Total residential: 4.8704×10^9 BTU/year

Detroit (demand)

Base: 2.25×10^9 heating: 2.96×10^9 BTU/year cooling:
 975.5×10^6 BTU/year

Total demand: 6.18×10^9 BTU/year

Houston (demand)

Base: 2.25×10^9 heating: 652.66×10^6 cooling: 4.04×10^9 BTU/year

Total demand: 6.95×10^9 BTU/year

B. Gas Stations: 1500 ft.²

Assume:

1. same energy demand as detached strip light retail services
2. BNL/SUNY research results

$$\text{Base load: } 34 \times 10^3 \text{ BTU/ft.}^2/\text{year} \times 1500 \text{ ft.}^2 = 51 \times 10^6 \text{ BTU/year}$$

Heating:

Assume:

1. New York City climate: 4800 HDD
2. gas heat

$$\begin{aligned} \text{Total input energy} &= 22 \text{ BTU/ft.}^2/\text{CDD} \times 1050 \text{ CDD} \times 1500 \text{ ft.}^2 \\ &\quad (-20 \times 10^3 \text{ BTU/ft.}^2 \times 1500 \text{ ft.}^2) \end{aligned}$$

$$\text{Total heating demand} = 83.59 \times 10^6 \text{ BTU/year}$$

Cooling:

Assume:

1. New York City climate: 1050 CDD
2. electric cooling

$$\begin{aligned} \text{Input cooling energy} &= 8.8 \text{ BTU/ft.}^2/\text{CDD} \times 1050 \text{ CDD} \times 1500 \text{ ft.}^2 \\ &\quad + (8 \times 10^3 \text{ BTU/ft.}^2 \times 1500 \text{ ft.}^2) = 25.86 \times 10^6 \text{ BTU/year} \end{aligned}$$

$$\text{Cooling demand} = 64.65 \times 10^6 \text{ BTU/year}$$

$$\text{Total direct energy for gas station} = 205.26 \times 10^6 \text{ BTU/year.}$$

Alternative climates

Detroit: 6380 HDD, 663 CDD

$$\text{Input base energy: } 51.0 \times 10^6 \text{ BTU/year/demand} = \text{same}$$

$$\text{Input heating energy: } 180.54 \times 10^6 \text{ BTU/year/demand} = 117.35 \times 10^6$$

$$\text{Input cooling energy: } 20.75 \times 10^6 \text{ BTU/year/demand} = 220.23 \times 10^6$$

Houston: 1408 HDD, 2748 CDD

Input base demand: 51.0×10^6 BTU/year/demand = 51.0×10^6 BTU/year

Input heating demand: 16.464×10^6 BTU/year/demand = 10.7×10^6 BTU/year

Input cooling demand: 48.274×10^6 BTU/year demand = 120.69×10^6 BTU/year

Input total gas station: 115.74×10^6 BTU/year/demand = 182.39
 $\times 10^6$ BTU/year

C. Total Community (Residential + Gas Station) Input BTU

New York City: 6.4953×10^9 BTU/year

Detroit: 7.4414×10^9 BTU/year

Houston: 4.9861×10^9 BTU/year

IV. Corporate Headquarters

A. Direct Energy Consumption: 225,000 ft.², 1050 workers

Base Load

Assumes:

1. Hittman and BNL/SUNY averaged results.

$$3.5 \times 10^3 \text{ BTU/ft.}^2/\text{year} \times 225,000 \text{ ft.}^2 = 7.5375 \times 10^9 \text{ BTU/year}$$

Heating Load

Assumes:

1. New York City climate: 4800 HDD
2. gas heat
3. BNL/SUNY and Hittman averaged results

$$\text{Input heating energy (Hittman)} = 7.4520 \times 10^9 \text{ BTU/year}$$

$$\text{Input energy BNL/SUNY} = 24.64 \times 10^9 \text{ BTU/year}$$

$$\text{Input heating energy mean} = 16.05 \times 10^9 \text{ BTU/year}$$

$$\text{Demand energy (heating)} = 10.43 \times 10^9 \text{ BTU/year}$$

Cooling Load

Assumes:

1. New York City climate: 1050 CDD
2. electric air conditioning
3. BNL/SUNY and Hittman averaged results

$$\text{Hittman: } 3.78 \times 10^9 \text{ BTU/year}$$

$$\text{BNL/SUNY: } 3.50 \times 10^9 \text{ BTU/year}$$

$$\text{Input mean: } 3.64 \times 10^9 \text{ BTU/year}$$

$$\text{Demand mean: } 9.1 \times 10^9 \text{ BTU/year}$$

Input energy (gas) 16.05×10^9 BTU/year
Input energy (elec.) 11.18×10^9 BTU/year
Input energy (total) 27.21×10^9 BTU/year
Demand energy (exc. ac) 17.97×10^9 BTU/year
Demand energy (ac) 9.1×10^9 BTU/year
Demand energy (total) 27.07×10^9 BTU/year

IV. Mixed Age Residential

A. Residential Units (all units combined)

<u>Base Load</u>		<u>Ref.</u>
hot water	3.222×10^9 BTU/year	(13)
refrigeration	856.3×10^6 BTU/year	(2,3,13)
major appliances	1.096×10^9 BTU/year	(1,2,3,4)
cooking	603.8×10^6 BTU/year	(2,3,4)
minor appliances	411×10^6 BTU/year	(1,3)
lighting	660.5×10^6 BTU/year	(13)

Total Residential Base Load 6.850×10^9 BTU/year

Heating Load

Assumes:

1. gas heat
2. 50% of each category of building is well insulated
3. New York City climate: 4800 heating degree days
4. no energy conservation habits (thermostat setbacks, relaxed comfort conditions, etc.)
5. Hittman's research findings (19).

3/unit:	5.9172×10^9 BTU/year
5/unit:	1.7635×10^9 BTU/year
4/unit:	2.4066×10^9 BTU/year
Total:	10.087×10^9 BTU/year input energy
	6.56×10^9 BTU/year demand energy

Cooling

Assumes:

1. New York City climate: 1050 cooling degree days
2. 60% of buildings in category are cooled
3. 50% of air conditioned buildings are well insulated, weather stripped, and equipped with storm windows and doors
4. electric cooling
5. no energy conservation habits
6. Hittman's research findings (19).

3/unit:	646.09×10^6 BTU/year
5/unit:	191.07×10^6 BTU/year
4/unit:	271.53×10^6 BTU/year
Total:	1.1086×10^9 BTU/year input electrical energy
	2.77×10^9 BTU/year demand energy

Total Residential Direct Energy: 18.046×10^9 input
 16.18×10^9 demand

B. Church/Parish House

Assume:

1. gas heat, no cooling
2. New York climate -- heating and cooling
3. no energy conservation

Church 3600 ft.²

direct energy demand = 169.34×10^6 input
input heating = 82.94×10^6
demand = 53.91×10^6
base = 86.4×10^6

Parish House

Base demand

hot water	20.01	$\times 10^6$
refrigeration	6.25	$\times 10^6$
major appliances	8	$\times 10^6$
lighting	14.972	$\times 10^6$
cooling	7.2	$\times 10^6$
minor appliances	3	$\times 10^6$
Total:	58.9	$\times 10^6$ BTU/year

Heating

755.35×10^6 BTU/year
 490.98×10^6 BTU/year

Total Church and Parish House = 924.69×10^6 input
 690.19×10^6 demand

C. Light Retail

Assume:

1. gas heat, electric cooling
2. New York City conditions (4800 HDD, 1050 CDD)
3. Hittman data

heating demand	200.68	$\times 10^6$
heating input	308.74	$\times 10^6$
cooling demand	327.6	$\times 10^6$
cooling input	131.04	$\times 10^6$
Base Input/Demand	192.0	$\times 10^6$
Total Direct Energy Use:	631.78×10^6	BTU/year
Total Demand:	720.28×10^6	BTU/year

D. Food Sales (5000 ft.²)

Assume:

1. gas heat, electric cooling
2. New York City conditions (4800 HDD, 1050 CDD)
3. Hittman data

heating demand	79.56	$\times 10^6$
heating input	122.4	$\times 10^6$
cooling demand	136.5	$\times 10^6$
cooling input	341.5	$\times 10^6$
Base Input/Demand	325	$\times 10^6$

Total Direct Energy Use: 583.90×10^6 BTU/year

E. Restaurant (2000 ft.²)

Assume:

1. gas heat, electric cooling
2. New York City conditions (4800 HDD, 1050 CDD)
3. Hittman data

heating demand	33.07	$\times 10^6$
heating input	50.88	$\times 10^6$
cooling demand	99.75	$\times 10^6$
cooling input	39.9	$\times 10^6$
Base Input/Demand	470	$\times 10^6$

Total Direct Energy Use: 583.90×10^6 BTU/year
Total Demand: 745.81×10^6 BTU/year

V. Garden Apartment

A. Residential 534,000 ft.²

528 units at 2.5/unit

Assumes:

1. New York climate (4800 HDD, 1050 CDD)
2. all units air conditioned
3. all have weather stripping, storm windows and doors

Base Load

Ref.

hot water	3.3 x 10 ⁹	(3)
refrigeration	3.3 x 10 ⁹	(2)
lighting	2.16 x 10 ⁹	(13)
major appliances	2.64 x 10 ⁹	(1, 24)
cooling	3.17 x 10 ⁹	(3)
minor appliances	1.58 x 10 ⁹	(1,3)

Total Residential Base Demand: 16.15 x 10⁹ BTU/year

Heating

Assumes:

1. gas heat

$$7.13 \text{ BTU/HDD/ft.}^2/\text{year} \times 4800 \text{ HDD} \times 534000 \text{ ft.}^2 \times .93 \times .81 = 13.77 \times 10^9 \text{ BTU/year}$$

Cooling

Assumes:

1. electric cooling

$$10.8 \text{ BTU/CDD/ft.}^2/\text{year} \times 1050 \text{ CDD/year} \times 534000 \text{ ft.}^2 \times .95 \times .88 = 5.06 \times 10^9 \text{ BTU/year}$$

Total Community Residential Input = 34.98 x 10⁹ BTU/year

B. Food Store (3500 ft.²)

Assumes:

1. air conditioning
2. Hittman (19) research results
3. gas heat/electric cooling

heating input	85.68×10^6
heating demand	55.69×10^6
cooling input	95.55×10^6
cooling demand	238.88×10^6
Base Input/Demand	277.5×10^6

Total Direct Energy Demand/Food Store	$= 408.73 \times 10^6$ BTU/year input
Total Demand	$= 522.07 \times 10^6$ BTU/year

C. Small Store (2500 ft.²)

Assumes:

1. air conditioning
2. Hittman (19) research results
3. gas heat/ electric cooling

heating input	80.4×10^6
heating demand	52.26×10^6
cooling input	34.13×10^6
cooling demand	85.33×10^6
Base Input/Demand	50×10^6

Total Direct Energy Demand/Small Store	$= 164.53 \times 10^6$ BTU/year
Total Demand	$= 187.59 \times 10^6$ BTU/year

V. Shopping Mall (540000 ft.²)

Assumes:

1. gas heat/electric cooling
2. average BNL/SUNY, Hittman results
3. New York City climate (4800 HDD, 1050 CDD)
4. total climate control in mall interior
5. public spaces pro-rated to the commercial space
(do not appear in calculations)

Hittman:

small store, personal service, drug store, etc. (258000 ft.²)

	<u>input BTU/year</u>	<u>demand</u>
Heating	8.30×10^9	5.39×10^9
Cooling	3.52×10^9	8.80×10^9
Base	5.16×10^9	5.16×10^9
TOTAL	16.98×10^9	19.35×10^9

department store (253000 ft.²)

Heating	6.68×10^9	4.34×10^9
Cooling	6.37×10^9	15.94×10^9
Base	13.92×10^9	13.92×10^9
TOTAL	26.97×10^9	34.20×10^9

food store (9500 ft.²)

Heating	232.56×10^6	151.16×10^6
Cooling	259.35×10^6	648.38×10^6
Base	617.50×10^6	617.50×10^6
TOTAL	1.11×10^9	1.42×10^9

restaurant/bar (14500 ft.²)

Heating	368.88×10^6	239.77×10^6
Cooling	289.28×10^6	723.19×10^6
Base	3.41×10^9	3.41×10^9
TOTAL	4.07×10^9	4.37×10^9

bank (5000 ft.²)

Heating	165.6×10^6	107.64×10^6
Cooling	84.00×10^6	210.00×10^6
Base	175.00×10^6	175.00×10^6
TOTAL	424.60×10^6	492.64×10^6

Total

	<u>input BTU/year</u>	<u>demand</u>
Heating	15.75×10^9	10.23×10^6
Cooling	10.52×10^9	26.13×10^9
Base	23.28×10^9	23.28×10^9
TOTAL	49.55×10^9	59.64×10^9

BNL/SUNY

Heating	55.16×10^9	35.86×10^9
Cooling	8.86×10^9	22.14×10^9
Base	18.90×10^9	18.90×10^9
TOTAL	82.92×10^9	76.64×10^9

Mean

Heating	35.46×10^9	23.05×10^9
Cooling	9.69×10^9	24.14×10^9
Base	21.09×10^9	21.09×10^9
TOTAL	66.24×10^9	68.27×10^9

V. (b) Version II high density suburb

Assume:

1. New York City climate (4800 HDD, 1050 CDD)
2. gas heat, electric cooling
3. Hittman, BNL/SUNY results averaged for all commercial use
4. commercial use considered to be in "strip" format

A. Residential

Base Demand (all units combined)

Ref.

hot water	6.82	$\times 10^9$	BTU/year	(4,13)
refrigeration	2.53	$\times 10^9$	BTU/year	(2,3)
lighting	1.86	$\times 10^9$	BTU/year	(13)
cooling	1.38	$\times 10^9$	BTU/year	(1,2,4)
major appliances	3.04	$\times 10^9$	BTU/year	(2,4)
minor appliances	1.215	$\times 10^9$	BTU/year	(1,3)
TOTAL	16.845	$\times 10^9$	BTU/year	

Heating

Assume:

1. for Hittman: half of units in each category have weather stripping, insulation, storm windows and doors

Total Heating Demand = 15.57×10^9 BTU/year

Cooling

Assume:

1. 60% of units are cooled
2. 50% of these units have weather stripping, insulation, storm doors and windows.

Total Cooling Input = 2.48×10^9 BTU/year

Total Residential Energy Demand = 34.891×10^9 BTU/year

B. Light Retail (40000 ft.²)

Assume:

1. all units cooled
2. Hittman results (19)

Heating:

input 1.29×10^9
demand 836.16×10^6

Cooling:

input	546.0	$\times 10^6$
demand	1.365	$\times 10^9$

Base:

input/demand 800×10^6

C. Food Stores (35000 ft.²)

Assume:

1. all stores cooled

Heating:

input	856.8	$\times 10^6$
demand	556.92	$\times 10^6$

Cooling:

input	955.5	$\times 10^6$
demand	2.39	$\times 10^9$

Base:

input/demand 2.275×10^9

D. Restaurant (5000 ft.²)

Heating:

input	127.20	$\times 10^6$
demand	82.68	$\times 10^6$

Cooling:

input	99.75	$\times 10^6$
demand	249.35	$\times 10^6$

Base:

input/demand 1.175×10^9

VI. (a) Strip High Rise (1,125,000 ft.²)

Assume:

1. New York City climate (4800 HDD, 1050 CDD)
2. gas heat, electric air conditioning
3. all units fully air conditioned
4. average Hittman and BNL/SUNY results
5. all private office space

	<u>input BTU/year</u>	<u>demand BTU/year</u>
Hittman:		
Heating:	37.26 x 10 ⁹	24.22 x 10 ⁹
Cooling:	18.9 x 10 ⁹	47.25 x 10 ⁹
Base:	39.38 x 10 ⁹	39.38 x 10 ⁹
TOTAL	95.54 x 10 ⁹	110.85 x 10 ⁹
BNL/SUNY:		
Heating:	123.2 x 10 ⁹	80.1 x 10 ⁹
Cooling:	17.51 x 10 ⁹	43.76 x 10 ⁹
Base:	33.75 x 10 ⁹	33.75 x 10 ⁹
TOTAL	174.46 x 10 ⁹	157.61 x 10 ⁹
Mean:		
Heating:	80.23 x 10 ⁹	52.16 x 10 ⁹
Cooling:	18.21 x 10 ⁹	45.51 x 10 ⁹
Base:	36.57 x 10 ⁹	36.57 x 10 ⁹
TOTAL	135.00 x 10 ⁹	134.23 x 10 ⁹

(b) Suburban Office Park

Assume:

1. New York City climate conditions (4800 HDD, 1050 CDD)
2. gas heat/electric cooling
3. all space air conditioned
4. average BNL/SUNY, Hittman results
5. retail space considered in "mall" format

A. Office Space (1,050,000 ft.²)

Hittman:

Heating:	34.78 x 10 ⁹	22.60 x 10 ⁹
Cooling:	17.64 x 10 ⁹	44.10 x 10 ⁹
Base:	36.75 x 10 ⁹	36.75 x 10 ⁹
TOTAL	89.17 x 10 ⁹	103.45 x 10 ⁹

	<u>input BTU /year</u>	<u>demand BTU/year</u>
BNL/SUNY:		
Heating:	115.02 x 10 ⁹	74.76 x 10 ⁹
Cooling:	16.34 x 10 ⁹	40.85 x 10 ⁹
Base:	33.60 x 10 ⁹	33.60 x 10 ⁹
TOTAL	164.96 x 10 ⁹	149.21 x 10 ⁹
Mean:		
Heating:	74.90 x 10 ⁹	48.68 x 10 ⁹
Cooling:	16.99 x 10 ⁹	42.48 x 10 ⁹
Base:	35.18 x 10 ⁹	35.18 x 10 ⁹
TOTAL	127.07 x 10 ⁹	126.33 x 10 ⁹

B. Small Stores

Hittman:		
Heating:	1.61 x 10 ⁹	1.05 x 10 ⁹
Cooling:	682.5 x 10 ⁹	1.71 x 10 ⁹
Base:	1.00 x 10 ⁹	1.00 x 10 ⁹
TOTAL	3.29 x 10 ⁹	3.75 x 10 ⁹
BNL/SUNY:		
Heating:	5.11 x 10 ⁹	3.32 x 10 ⁹
Cooling:	421.0 x 10 ⁹	1.05 x 10 ⁹
Base:	1.7 x 10 ⁹	1.7 x 10 ⁹
TOTAL	7.23 x 10 ⁹	6.07 x 10 ⁹
Mean:		
Heating:	3.36 x 10 ⁹	2.19 x 10 ⁹
Cooling:	551.75 x 10 ⁹	1.38 x 10 ⁹
Base:	1.35 x 10 ⁹	1.35 x 10 ⁹
TOTAL	5.26 x 10 ⁹	4.92 x 10 ⁹

C. Restaurants and Bars (25000)

Hittman:		
Heating:	636.0 x 10 ⁹	413.4 x 10 ⁶
Cooling:	498.75 x 10 ⁹	1.25 x 10 ⁹
Base:	5.63 x 10 ⁹	5.63 x 10 ⁹
TOTAL	6.76 x 10 ⁹	7.29 x 10 ⁹

v

	<u>input BTU/year</u>	<u>demand BTU/year</u>
BNL/SUNY:		
Heating:	2.55×10^9	1.66×10^9
Cooling:	410.00×10^9	1.03×10^9
Base:	850.00×10^9	850.00×10^6
TOTAL	3.81×10^9	3.54×10^9
Mean:		
Heating:	1.59×10^9	1.04×10^9
Cooling:	454.38×10^9	1.14×10^9
Base:	3.24×10^9	3.24×10^9
TOTAL	5.28×10^9	5.42×10^9
D. <u>Total</u>		
Heating:	79.85×10^9	51.91×10^9
Cooling:	18.00×10^9	45.00×10^9
Base:	39.77×10^9	39.77×10^9
TOTAL	137.62×10^9	136.68×10^9

VI. c) Warehousing (1,125,000 ft.²)

Assumes:

1. gas heat, electric cooling
2. New York climate (4800 HDD, 1050 CDD)
3. one building cooled: 94,600 ft.²
4. Hittman research results (19) for wholesaling

Heating

Total demand = 22.68×10^9 BTU/year 14.74×10^9

Cooling

Total demand = 993.3×10^6 BTU/year 2.48×10^9

Base

Total demand = 7.88×10^9 BTU/year

Total community input = 31.55×10^9 BTU/year

Total community demand = 25.10×10^9 BTU/year

VII. b. University Campus

Assumes:

1. gas heat, electric cooling
2. New York City climate (4800 HDD, 1050 CDD)
3. All spaces air conditioned
4. Hittman research results for library, classroom, and gym
5. BNL/SUNY and Hittman results averaged for administrative (office) use

Library (835,625 ft.²)

	<u>Input BTU/year</u>	<u>Demand BTU/year</u>
Heating	21.26x10 ⁹	13.82x10 ⁹
Cooling	14.04x10 ⁹	35.10x10 ⁹
Base	20.89x10 ⁹	20.89x10 ⁹
TOTAL	56.19x10 ⁹	69.81x10 ⁹

Classroom (509,700 ft.²)

Heating	41.59x10 ⁹	27.03x10 ⁹
Cooling	10.70x10 ⁹	26.76x10 ⁹
Base	8.16x10 ⁹	8.16x10 ⁹
TOTAL	60.45x10 ⁹	61.95x10 ⁹

Gymnasium (579,405)

Heating	47.28x10 ⁹	30.73x10 ⁹
Cooling	12.17x10 ⁹	30.42x10 ⁹
Base	9.27x10 ⁹	9.27x10 ⁹
TOTAL	68.72x10 ⁹	70.42x10 ⁹

Administrative (Office) 325,250

Hittman

Heating	10.77x10 ⁹	7.00x10 ⁹
Cooling	5.46x10 ⁹	13.66x10 ⁹
Base	11.38x10 ⁹	11.38x10 ⁹
TOTAL	27.61x10 ⁹	32.05x10 ⁹

BNL/SUNY

Heating	35.63x10 ⁹	23.16x10 ⁹
Cooling	5.06x10 ⁹	12.65x10 ⁹
Base	10.41x10 ⁹	10.41x10 ⁹
TOTAL	51.10x10 ⁹	46.22x10 ⁹

Mean

Heating	23.2×10^9	15.08×10^9
Cooling	5.26×10^9	13.16×10^9
Base	10.90×10^9	10.90×10^9
TOTAL	39.36×10^9	39.13×10^9

TOTAL

Heating	133.33×10^9	86.67
Cooling	42.17×10^9	105.43
Base	49.22	49.22
TOTAL	244.72	241.33

VII. c) Downtown Suburban City

Assumes:

1. New York City climate (4800 HDD, 1050 CDD)
2. gas heat, electric cooling
3. average Hittman/ BNL/SUNY results for all commercial space
4. residential units have weather stripping, storm doors and windows
5. 80% of commercial and 60% of residential space is air conditioned

A. Small Stores (468000 ft.²)

	<u>input BTU/year</u>	<u>demand BTU/year</u>
Hittman:		
Heating:	15.05×10^9	9.78×10^9
Cooling:	5.11×10^9	12.78×10^9
Base:	9.36×10^9	9.36×10^9
TOTAL	29.52×10^9	31.92×10^9

B. Restaurants (62000 ft.²)

Hittman:		
Heating:	1.58×10^9	1.03×10^9
Cooling:	989.52×10^6	2.47×10^9
Base:	14.57×10^9	14.57×10^9
TOTAL	17.14×10^9	18.07×10^9

C. Food Stores (8000 ft.²)

Hittman:		
Heating:	195.84×10^6	127.30×10^6
Cooling:	174.72×10^6	436.80×10^6
Base:	520.00×10^6	520.00×10^6
TOTAL	890.56×10^6	1.08×10^9

D. Department Store (272000 ft.²)

Heating:	7.18×10^9	4.67×10^9
Cooling:	5.48×10^9	13.71×10^9
Base:	14.96×10^9	14.96×10^9
TOTAL	27.62×10^9	33.33×10^9

E. A-D Uses (810000 ft.²)

	<u>input BTU/year</u>	<u>demand BTU/year</u>
BNL/SUNY:		
Heating:	106.67 x 10 ⁹	69.33 x 10 ⁹
Cooling:	11.17 x 10 ⁹	27.43 x 10 ⁹
Base:	27.54 x 10 ⁹	27.54 x 10 ⁹
TOTAL	145.88 x 10 ⁹	124.8 x 10 ⁹
Mean (with Hittman A-D):		
Heating:	65.34 x 10 ⁹	42.47 x 10 ⁹
Cooling:	11.46 x 10 ⁹	28.66 x 10 ⁹
Base:	33.48 x 10 ⁹	33.48 x 10 ⁹
TOTAL	110.28 x 10 ⁹	104.61 x 10 ⁹

F. Office (public and private) (1,215,000)

Hittman:		
Heating:	40.29 x 10 ⁹	26.16 x 10 ⁹
Cooling:	16.33 x 10 ⁹	40.82 x 10 ⁹
Base:	42.53 x 10 ⁹	42.53 x 10 ⁹
TOTAL	99.10 x 10 ⁹	109.51 x 10 ⁹
BNL/SUNY:		
Heating:	133.09 x 10 ⁹	86.51 x 10 ⁹
Cooling:	15.12 x 10 ⁹	37.81 x 10 ⁹
Base:	38.88 x 10 ⁹	38.88 x 10 ⁹
TOTAL	281.30 x 10 ⁹	163.20 x 10 ⁹
Mean:		
Heating:	86.67 x 10 ⁹	56.34 x 10 ⁹
Cooling:	15.73 x 10 ⁹	39.32 x 10 ⁹
Base:	40.71 x 10 ⁹	40.71 x 10 ⁹
TOTAL	143.10 x 10 ⁹	136.36 x 10 ⁹

G. Residential

<u>Base Load</u>		<u>Ref.</u>
hot water	2.80 x 10 ⁹ BTU/year	(4,13)
refrigeration	1.34 x 10 ⁹ BTU/year	(2,3,13)
lighting	820.13 x 10 ⁶ BTU/year	(13)
cooling	1.55 x 10 ⁹ BTU/year	(3)
major appliances	1.50 x 10 ⁹ BTU/year	(2,4)
minor appliances	645.0 x 10 ⁹ BTU/year	(1,3)
TOTAL	8.65 x 10 ⁹ BTU/year	

Heating (all units)

Total Input = 5.47×10^9 BTU/year Demand = 3.56×10^9 BTU/year

Cooling (all units)

Total input = 1.34×10^9 BTU/year Demand = 3.35×10^9 BTU/year

Total Residential Energy Input = 15.47×10^9 BTU/year
Demand = 15.56×10^9 BTU/year

H. Gas Stations (22500)

Assumes:

1. same as for BNL/SUNY "retail strip" above
2. no air conditioning

	<u>input BTU/year</u>	<u>demand BTU/year</u>
Heating:	2.96×10^9	1.93×10^9
Base:	765.0×10^6	765.0×10^6
TOTAL	3.73×10^9	2.70×10^9

I. Community Totals

	<u>input BTU/year</u>	<u>demand BTU/year</u>
Heating:	160.44×10^9	104.09×10^9
Cooling:	28.53×10^9	71.33×10^9
Base:	83.61×10^9	83.61×10^9
TOTAL	272.58×10^9	259.03×10^9

VIII. High Density Downtown

Assumes:

1. New York City climate (4800 HDD, 1050 CDD)
2. gas heat, electric cooling
3. all space is air conditioned
4. average of Rittman, BNL/SUNY results

A. Offices

	<u>input BTU/year</u>	<u>demand BTU/year</u>
Hittman:		
Heating:	2.53×10^{12}	1.65×10^{12}
Cooling:	1.28×10^{12}	3.21×10^{12}
Base:	2.68×10^{12}	2.68×10^{12}
TOTAL	6.49×10^{12}	7.54×10^{12}
BNL/SUNY:		
Gas Heating:	8.38×10^{12}	5.4468×10^{12}
Elec. Cooling:	1.19×10^{12}	2.98×10^{12}
Elec. Base:	2.45×10^{12}	2.45×10^{12}
TOTAL	12.02×10^{12}	10.88×10^{12}
Mean:		
Heating:	5.46×10^{12}	3.55×10^{12}
Cooling:	1.24×10^{12}	3.10×10^{12}
Base:	2.57×10^{12}	2.57×10^{12}
TOTAL	9.26×10^{12}	9.21×10^{12}

B. Small Stores

	<u>input (BTU x 10⁹)</u>	<u>demand (BTU x 10⁹)</u>
Hittman:		
Heating:	13.92	8.73
Cooling:	5.70	14.24
Base:	8.35	8.35
TOTAL	27.47	31.32
BNL/SUNY:		
Heating:	42.64	27.71
Cooling:	6.85	17.11
Base:	14.19	14.19
TOTAL	63.68	59.01

Mean:

Heating:	28.03	18.22
Cooling:	6.28	15.68
Base:	11.27	11.27
TOTAL	45.58	45.17

C. Department Store

input (BTU x 10⁹)

demand (BTU x 10⁹)

Hittman:

Heating:	6.44	4.19
Cooling:	6.15	15.38
Base:	13.43	13.43
TOTAL	26.02	33.00

BNL/SUNY ("mall format"):

Heating:	24.94	16.21
Cooling:	4.00	10.01
Base:	8.30	8.30
TOTAL	37.24	34.52

Mean:

Heating:	15.69	10.20
Cooling:	5.08	12.70
Base:	10.87	10.87
TOTAL	31.63	33.76

D. Food

input (BTU x 10⁶)

demand (BTU x 10⁶)

Hittman:

Heating:	385.56	250.61
Cooling:	929.98	1074.90
Base:	1023.80	1023.80
TOTAL	1939.34	2349.31

BNL/SUNY:

Heating:	1608.92	1045.80
Cooling:	258.30	645.75
Base:	535.50	535.50
TOTAL	2402.72	2227.05

Mean:

Heating:	997.24	648.21
Cooling:	344.14	860.33
Base:	779.65	779.65
TOTAL	2121.03	2288.19

E. Restaurant

input (BTU x 10⁹)

demand (BTU x 10⁹)

Hittman:

Gas Heating:	1.40	.912
Elec. Cooling:	1.10	2.750
Elec. Base:	12.95	12.950
TOTAL	15.45	16.610

BNL/SUNY:

Heating:	5.630	3.66
Cooling	.904	2.26
Base:	1.870	1.87
TOTAL	8.400	7.79

Mean:

Heating:	3.53	2.29
Cooling:	1.00	2.51
Base:	7.41	7.41
TOTAL	11.93	12.20

F. Banks, Public Office

input (BTU x 10⁹)

demand (BTU x 10⁹)

Hittman:

Heating:	1.830	1.19
Cooling:	.926	2.31
Base:	1.930	1.93
TOTAL	4.690	5.43

BNL/SUNY:

Heating:	6.040	3.92
Cooling:	.858	2.14
Base:	1.760	1.76
TOTAL	8.660	7.82

Mean:

Heating:	3.94	2.56
Cooling:	.89	2.23
Base:	1.85	1.85
TOTAL	6.67	6.63

G. Total Community Energy Use

Total gas: input BTU	5.51×10^{12}
Total electricity: input BTU	3.86×10^{12}
TOTAL INPUT BTU's:	9.37×10^{12}
TOTAL DEMAND:	9.31×10^{12}

APPENDIX B

EMBODIED ENERGY IN STRUCTURES

Embodied Energy

		Embodied	Total Direct	Total
III	Low Density Subdivision (BTU x 10 ⁹)			
	Single Family Residential:			
	66000 ft ²	46.34 x 10 ⁹	5.66 x 10 ⁹	52.00 x 10 ⁹
	gas station 1500 ft ²	1.16 x 10 ⁹	227.50 x 10 ⁹	1.38 x 10 ⁹
	TOTAL	47.50 x 10 ⁹	5.89 x 10 ⁹	53.38 x 10 ⁹
IVa	Corporate Headquarters (BTU x 10 ⁹)			
	office 225000 ft ²	369.39 x 10 ⁹	80.24 x 10 ⁹	449.63 x 10 ⁹
IVb	Mixed Age Residential (BTU x 10 ⁹)			
	single family units			
	195150 ft ²	137.00 x 10 ⁹	16.74 x 10 ⁹	153.74 x 10 ⁹
	parish house ¹ 9250 ft ²	6.85	.836	7.68
	church 3600 ft ²	4.52	.906	5.43
	light retail, food			
	restaurant 16600 ft ²	15.63	3.65 x 10 ⁹	19.27
	TOTAL	164.00	2.13	186.13
Va	Garden Apartments (BTU x 10 ⁹)			
	apartments 534000 ft ²	356.27	60.27	407.24
	food store,			
	small store 6000 ft ²	5.65	1.32	6.97
	TOTAL	351.92	62.29	414.20
Vb	Shopping Mall (BTU x 10 ⁹)			
	all stores 540,000 ft ²	508.33	118.60	626.93
Vb	VERSION II High Density Suburb			
	townhouses 352,000 ft ²	220.02	36.15	256.17
	single family 108,000 ft ²	75.82	9.26	85.09
	stores,			
	restaurants 80,000 ft ²	75.31	17.57	92.88
	TOTAL	371.15	62.98	434.14
Via	Strip High Rise (BTU x 10 ¹²)			
	office buildings	1.85	.401	2.25

¹ assume same as for residential

		Embodied	Total Direct	Total
VIIb	Suburban Office Park (BTU x 10 ¹²)			
	office buildings	1.42	.307	1.72
VIc	Warehousing (BTU x 10 ⁹)			
	warehouses	628.24	87.83	716.06
VIIf	University Campus (BTU x 10 ¹²)			
	educational (library, gym, class) 1,924,750 ft ²	2.67	.505	3.17
	administrative 325,250 ft ²	.534	.116	.650
	TOTAL	3.20	.621	3.82
VII	Downtown Suburban City (BTU x 10 ¹²)			
	stores/restaurants 810,000 ft ²	.7625	.178	.940
	offices 1,215,000 ft ²	1.99	.433	2.42
	low rise apts. 162,000 ft ²	.105	.018	.124
	townhouses 40,500 ft ²	.025	.004	.029
	automotive 22,500 ft ²	.017	.003	.021
	TOTAL	2.90	.631	3.53
VIII	High Density Downtown (BTU x 10 ¹²)			
	office building 75,712,500	124.3	27.0	151.30
	all other 787,500	.741	.173	.914
	TOTAL	125.04	27.173	152.21

APPENDIX C
TRANSPORTATION ENERGY USE

TRANSPORTATION

Assumptions

1. average (national) climate and other environmental factors assumed
2. average of 1.2 autos/h.h.
3. average lifetime of 10 years for autos and trucks
4. embodied energy of trucks calculated based on 10,000 lbs/truck (use embodied energy figure of 37,000 BTU lb.--from Fels & Emb. Energy Review Paper)
5. no data available on ave. trip length for warehouses; 10 mi. is used here
6. (days of operation, trip length, and vehicles/unit are shown on worksheets)
7. for university, assume that students walk or bike to campus area shown
8. propulsion energy = 9800 BTU/veh.-mi. for autos, 1300 BTU/veh.-mi. for small trucks, 2880 BTU/passenger-mi. for transit buses.
9. other values assumed:

small stores, personal service, miscellaneous:	4.4 veh-mile/trip 300 days/year	0.5 veh/unit
restaurants:	4.4 veh-mile/trip 365 days/year	no veh
food stores:	4.4 veh-mile/trip 325 days/year	no veh
department stores:	4.4 veh-mile/trip 300 days/year	4.0 veh/unit
banks:	4.4 veh-mile/trip 250 days/year	no veh
private office:	9.4 veh-mile/trip 250 days/year	no veh
residential:	8.9 veh-mile/trip 365 days/year	1.2 veh/unit
automotive:	4.4 veh-mile/trip 325 days/year	2.0 veh/unit
church:	4.7 veh-mile/trip 50 days/year	1.0 veh/unit
supermarket:	4.4 veh-mile/trip 300 days/year	1 veh/unit

Methodology Operating Energy

1. define mode
2. determine propulsion energy (BTU/veh-mi)
- *3. determine occupancy, or load wt (pax mi/veh mi, ton-mile/veh-mi)
- *4. determine energy intensiveness (BTU/pax-mile, BTU/ton-mile)
5. determine ave. trip length by type of structure at origin or destination
6. determine ave. trip generation rate " "
- *7. multiply EI x occupancy
8. multiply BTU/veh mi x trip length x no of trips/yr.
9. sum totals for each structure type and each mode type

* necessary only for mass transit

<u>type of structure</u>	<u>avg. trip length</u>	<u>avg. no veh./unit</u>
single family detached	8.9 mi	1.2 autos
gas station	4.4	
general office	9.4	
church	4.7	
light retail	4.4	
food store	4.4	
restaurant	4.4	
low-rise apartments	8.9	1.2 autos

Methodology

- III A-1) operating:
 9800 BTU/veh-mi x 8.9 veh-mi/trip x 78,800 veh trips/yr = 68.7×10^3 BTU/yr
 autos
 embodied:
 A-2) 1.32×10^8 BTU/veh x 53 veh = 70×10^8 BTU $\div$ 10 yrs = 7×10^8 BTU/yr
- operating:
 B-1) 13,000 x 4.4 veh/trip x 84,315 veh-trips/yr = 48.23×10^8 BTU/yr
 pickup trucks
 embodied:
 B-2) 3.7×10^8 BTU/veh x 2 veh = 7.4×10^8 BTU $\div$ 10 years = $.74 \times 10^8$ BTU/yr

IVa) trip rate = 1.73 trips/employee/work day

1) operating: $9800 \times 9.4 \times 472,420 = 435.2 \times 10^8 \text{ BTU/year}$

2) embodied: 0

IVb A-1) operating: $9800 \times 8.9 \times 245,230 = 213 \times 10^8 \text{ BTU/yr}$

A-2) embodied: $1.32 \times 10^8 \times 164 \div 10 = 21.65 \times 10^8 \text{ BTU/yr}$

B-1) operating: $9800 \times 4.9 \times 36,500 = 16.8 \times 10^8 \text{ BTU/yr}$

B-2) embodied: $1.32 \times 10^8 \div 10 = .132 \times 10^8 \text{ BTU/yr}$

C-1) operating: $9800 \times 4.4 \times 57,816 = 25 \times 10^8 \text{ BTU/yr}$

C-2) embodied: $.37 \times 10^8 \text{ BTU/yr}$

D-1) operating: $9800 \times 4.4 \times 335,800 = 144.8 \times 10^8 \text{ BTU/yr}$

D-2) embodied: 0 BTU/yr.

E-1) operating: $9800 \times 4.4 \times 50,005 = 21.6 \times 10^8 \text{ BTU/yr}$

E-2) embodied: 0 BTU/yr.

Va A-1) operating: $9800 \times 8.9 \times 616,850 = 538 \times 10^8 \text{ BTU/yr.}$

A-2) embodied: $1.32 \times 10^8 \times 633 \div 10 = 83.6 \times 10^8 \text{ BTU/yr}$

B-1) operating: $9800 \times 4.4 \times 235,425 = 101.5 \times 10^8 \text{ BTU/yr.}$

B-2) embodied: 0 BTU/yr.

C-1) operating: $9800 \times 4.4 \times 57,816 = 25 \times 10^8 \text{ BTU/yr}$

C-2) embodied: $.37 \times 10^8 \text{ BTU/yr}$

vb A-1) operating: $9800 \times 4.4 \times 4 \times 545,748 = 944 \times 10^8$

A-2) embodied: $4 \times 3.7 \times 10^8 \div 10 = 1.48 \times 10^8$

B-1) operating: $9800 \times 4.4 \times 916,296 = 395 \times 10^8$

B-2) embodied: 1.48×10^8

C-1) operating: $9800 \times 4.4 \times 580,450 = 250 \times 10^8$

C-2) embodied: $.37 \times 10^8$

D-1) operating: $9800 \times 4.4 \times 362,445 = 156.3 \times 10^8$

D-2) embodied: 0

E-1) operating: $9800 \times 4.4 \times 125,000 = 53.9 \times 10^8$

E-2) embodied: 0

VIA A-1) operating: (1.73 veh trips x 5000 emp - 8650 trips for 12 bldgs)
 $9800 \times 8.9 \times 2,163,000 = 1,887 \times 10^8 \text{ BTU/yr}$

A-2) embodied: 0

VIB A-1) operating: $9800 \times 9.4 \times 1,003,250 = 924.2 \times 10^8$

A-2) embodied: 0

B-1) operating: $9800 \times 9.4 \times 620,250 = 571.4 \times 10^8$

B-2) embodied: 0

C-1) operating: $9800 \times 4.4 \times 434,700 = 187.4 \times 10^8$

C-2) embodied: $.74 \times 10^8$

D-1) operating: $9800 \times 4.4 \times 624,515 = 269.3 \times 10^8$

D-2) embodied: 0

VIB2 A-1) operating: $9800 \times 8.9 \times 373,760 = 325 \times 10^8$

A-2) embodied: $1.32 \times 10^8 \times 384 - 10 = 50.7 \times 10^8$

B-1) operating: $9800 \times 8.9 \times 136,145 = 118.8 \times 10^8$

B-2) embodied: $1.32 \times 10^8 \times 102 - 10 = 13.5 \times 10^8$

C-1) operating: $9800 \times 4.4 \times 347,700 = 149.9 \times 10^8$

C-2) embodied: $.37 \times 10^8$

D-1) operating: $9800 \times 4.4 \times 713,700 = 307.8 \times 10^8$

D-2) embodied: 0

E-1) operating: $9800 \times 4.4 \times 124,830 = 53.8 \times 10^8$

E-2) embodied: $.37 \times 10^8$

VIC A-1) operating: $9800 \times 10 \times 1,279,690 = 1,254 \times 10^8$
 (no data on ave. truck trip lengths or truck trip generation rates)

A-2) embodied: $.37 \times 10^8 \times 6 = 2.22 \times 10^8$

VIIb A-1) embodied: 0

A-2) operating: 0

B-1) operating: 0

B-2) embodied: 0

C-1) operating: $9.4 \times 9800 \times 14190 = .13 \times 10^8$

C-2) embodied: 0

D-1) operating: 0

D-2) embodied: 0

VIIc - VIII (methodology for these scenarios included in next section - Transportation Energy Consumption).

TRANSPORTATION ENERGY CONSUMPTION

Scenario	No. & Type of units	Trips/ day/unit	Trips/ yr.	No. & Type Vehicle	Annual Prop. Energy	Annual Embodied Energy
III.)	44 single-family res.	4.9	78,800	53 autos	68.7×10^8 BTU/yr.	7×10^8 BTU/yr.
	1 gas sta.	231	84,315	2 small trucks	48.23×10^8 BTU/yr.	$.74 \times 10^8$ BTU/yr.
	<u>TOTAL ANNUAL ENERGY CONSUMPTION:</u>				<u>124.7×10^8 BTU</u>	
IVa.)	1 corporate hq. (general office)	1817	472,420	0	435.2×10^8 BTU/yr.	0
	<u>TOTAL:</u>				<u>435.2×10^8 BTU</u>	
IVb.)	37 single-family res.	4.9	245,230	164 autos	213×10^8 BTU/yr.	21.65×10^8 BTU/yr.
	1 church & parish house	100	36,500	1 auto	16.8×10^8 BTU/yr.	$.13 \times 10^8$ BTU/yr.
	1 lgt. retail	198	57,816	1 trucks	25×10^8	$.37 \times 10^8$
	1 food store	920	335,800	0	144.8×10^8	0
	1 restaurant	137	50,005	0	21.6×10^8	0
	<u>TOTAL:</u>				<u>443.4×10^8 BTU</u>	
Va.)	528 apts.	3.2	616,850	633 autos	539×10^8	83.6×10^8
	1 food store	645	235,425	0	101.5×10^8	0
	1 small store	198	57,816	1 truck	25×10^8	$.37 \times 10^8$
	<u>TOTAL:</u>				<u>748.4×10^8 BTU</u>	
Vb.)	4 small stores	1870	545,748	2 trucks	944×10^8	$.74 \times 10^8$
	1 dept. store	3138	916,296	4 trucks	395	1.48×10^8
	1 food store	1786	580,450	0	250×10^8	0

Scenario	No. & Type of Units	Trips/ Day/Unit	Trips/ Year	No. & Type of Vehicle	Annual Propulsion Energy	Annual Embodied Energy
Vb.) (cont.)	1 restaurant/ bar	993	362,445	0	156.3×10^8	0
	1 bank	500	125,000	0	53.9×10^8	0
	<u>TOTAL:</u>				<u>$1,801 \times 10^8$ BTU</u>	
Via.)	12 high- rise office	721	2,163,000	0	$1,887 \times 10^8$	0
	<u>TOTAL:</u>				<u>$1,887 \times 10^8$ BTU</u>	
Vib. (1)	private office	4013	1,003,250	0	924.2×10^8	0
	public office	2481	620,250	0	571.4×10^8	0
	small stores	1449	434,700	2 trucks	187.4×10^8	$.74 \times 10^8$
	restaurants/ bars	1711	624,515	0	264.3×10^8	0
	<u>TOTAL:</u>				<u>$1,953 \times 10^8$ BTU</u>	
Vib. (2)	320 town- houses	3.2	373,760	384 autos	326×10^8	50.7×10^8
	85 single family	4.9	136,145	102 autos	118.8×10^8	13.5×10^8
	light retail	1159	347,700	1 truck	149.9×10^8	$.37 \times 10^8$
	supermarket	2196	713,700	1 truck	307.8×10^8	$.37 \times 10^8$
	restaurant	342	124,830	0	53.8×10^8	0
	<u>TOTAL:</u>				<u>$1,021 \times 10^8$ BTU</u>	
Vic.)	Warehouse	3506	1,279,690	6 trucks	$1,254 \times 10^8$	2.22×10^8
	<u>TOTAL:</u>				<u>$1,256.2 \times 10^8$</u>	
VIIb.)	library*	0		0		0
	classroom space*	0		0	0	0

*Assume students walk or ride bicycles to class, library, or gym.

admin. office	43	14190	0	0
gymnasium	0		0	0

TOTAL: 13×10^8 BTU

VIIc.) Light Retail

$$(468,000 \text{ st. ft.}) \times \left(\frac{1 \text{ store}}{6400 \text{ sq. ft.}} \right) \times \left(\frac{0.5 \text{ trucks}}{\text{store}} \right) = 37 \text{ trucks}$$

$$\text{Embodied Energy} = (37 \text{ trucks}) \times \left(\frac{3.7 \times 10^7 \text{ BTU}}{\text{truck}} \right) = 13.69 \times 10^8 \text{ BTU/yr.}$$

Operating Energy

$$\text{Auto: } 13,560 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{300 \text{ days}}{\text{year}} = 1754 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 420 \frac{\text{trips}}{\text{day}} \times 4.4 \times \frac{2880 \text{ BTU}}{\text{pass.-mile}} \times 300 = 15.97 \times 10^8 \text{ BTU/yr.}$$

$$\text{Operating Energy} = 1770 \times 10^8 \text{ BTU/yr.}$$

TOTAL ENERGY: 1780×10^8 BTU/yr.

Restaurants (62,000 sq. ft.)

$$\text{Auto: } 4244 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{day}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{365 \text{ days}}{\text{year}} = 668.0 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 130 \text{ trips} \times 4.4 \times 2880 \times 365 = 6.013 \times 10^8 \text{ BTU/yr.}$$

TOTAL ENERGY: 674.0×10^8 BTU/yr.

Food Stores (8000 sq. ft.)

$$\text{Auto: } 1473 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{325 \text{ days}}{\text{year}} = 206.4 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 96 \times 4.4 \times 2880 \times 325 = 1.895 \times 10^8 \text{ BTU/yr.}$$

TOTAL ENERGY: 208.3×10^8 BTU/yr.

Department Stores

$$(272,000 \text{ sq. ft.}) \times \left(\frac{1 \text{ store}}{40,000 \text{ sq. ft.}} \right) \times \left(\frac{4 \text{ trucks}}{\text{store}} \right) = 27 \text{ trucks}$$

$$\text{Auto: } 7 \text{ stores} \times 3138 \frac{\text{trips}}{\text{store day}} \times \frac{4.4 \text{ veh.-mile}}{\text{Trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{300 \text{ days}}{\text{year}} = 2842 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 680 \frac{\text{trips}}{\text{day}} \times 3138 \frac{\text{store}}{\text{day}} \times \frac{4.4 \text{ veh.-mile}}{\text{Trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{300 \text{ days}}{\text{year}} = 25.85 \times 10^8 \text{ BTU/yr.}$$

$$\text{Operating Energy} = 2868 \times 10^8 \text{ BTU/yr.}$$

$$\text{Embodied Energy} = 27 \text{ trucks} \times \frac{3.7 \times 10^7 \text{ BTU}}{\text{truck}} = 9.99 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 2878 \times 10^8 \text{ BTU/yr.}$$

Banks (100,000)

$$\text{Auto: } 3000 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times 250 \frac{\text{days}}{\text{Yr.}} = 323.4 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 100 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{Trip}} \times \frac{2880 \text{ BTU}}{\text{veh.-mile}} \times 150 \frac{\text{days}}{\text{Yr.}} = 23.69 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 2633 \times 10^8 \text{ BTU/yr.}$$

Residential (215 units; 202,500 sq. ft.)

$$215 \text{ units} \times 1.2 \frac{\text{autos}}{\text{unit}} \times \frac{1.32 \times 10^7 \text{ BTU}}{\text{auto}} = 34.06 \times 10^8 \text{ BTU/yr.}$$

$$\text{Auto: } 688 \frac{\text{trips}}{\text{day}} \times 8.9 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{trip}} \times 365 \frac{\text{days}}{\text{yr.}} = 219.0 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 21 \frac{\text{trips}}{\text{day}} \times 8.0 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{trip}} \times 365 \frac{\text{days}}{\text{yr.}} = 1.965 \times 10^8 \text{ BTU/yr.}$$

$$\text{Operating Energy: } = 221.0 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 255.0 \times 10^8 \text{ BTU/yr}$$

Private Office (1,115,000 sq. ft.)

$$\text{Auto: } 11,328 \frac{\text{trips}}{\text{day}} \times 9.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times 250 \frac{\text{days}}{\text{yr.}} = 2609.0 \times 10^8 \text{ BTU/yr}$$

$$\text{Bus: } 350 \frac{\text{trips}}{\text{day}} \times 9.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{2880 \text{ BTU}}{\text{veh.-mile}} \times 250 \frac{\text{days}}{\text{yr.}} = 23.69 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 2633 \times 10^8 \text{ BTU/yr.}$$

VIIc.)

(cont.) Automotive (10 stations)

$$10 \text{ stations} \times 2.0 \frac{\text{trucks}}{\text{station}} \times \frac{3.7 \times 10^7 \text{ BTU}}{\text{truck}} = 7.4 \times 10^8 \text{ BTU/yr. Embodied Energy}$$

$$6323 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{325 \text{ days}}{\text{year}} = 886.1 \times 10^8 \text{ BTU/yr. Operating Energy}$$

$$\text{TOTAL ENERGY: } 893.5 \times 10^8 \text{ BTU/yr.}$$

SUMMARY, VII.c

Light Retail	13.69×10^8	1770×10^8	$1780 \times 10^8 \text{ BTU/yr.}$
Restaurants		674.0×10^8	$674.0 \times 10^8 \text{ BTU/yr.}$
Food Stores		208.3×10^8	$208.3 \times 10^8 \text{ BTU/yr.}$
Department Stores	9.99×10^8	2868×10^8	$2878 \times 10^8 \text{ BTU/yr.}$
Banks		326.6×10^8	$326.6 \times 10^8 \text{ BTU/yr.}$
Private Office		2633×10^8	$2633 \times 10^8 \text{ BTU/yr.}$
Residential	34.06×10^8	221.0×10^8	$255.0 \times 10^8 \text{ BTU/yr.}$
Automotive	7.4×10^8	886.1×10^8	$893.5 \times 10^8 \text{ BTU/yr.}$
	65.14×10^8	9587×10^8	$9652 \times 10^8 \text{ BTU/yr.}$
	EMBODIED	OPERATING	TOTAL

VIII. Office

$$\text{Auto: } \frac{388,622 \text{ trips}}{\text{day}} \times \frac{9.4 \text{ veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{trip}} \times \frac{250 \text{ days}}{\text{year}} = 89,500 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 12,000 \times 9.4 \times 2880 \times 250 = 812.2 \times 10^8 \text{ BTU/yr.}$$

Light Retail

$$(417,375 \text{ sq.ft.}) \times \left(\frac{1 \text{ store}}{6400 \text{ sq.ft.}} \right) \times \left(\frac{0.5 \text{ trucks}}{\text{store}} \right) \left(\frac{3.7 \times 10^7 \text{ BTU}}{\text{truck}} \right)$$

$$= \text{Embodied Energy} = 12.07 \times 10^8 \text{ BTU/yr.}$$

$$\text{Auto: } 12,093 \frac{\text{trips}}{\text{day}} \times 4.4 \frac{\text{veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{300 \text{ days}}{\text{year}} = 1564 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 374 \times 4.4 \times 2880 \times 300 = 14.22 \times 10^8 \text{ BTU/yr.}$$

$$\text{Operating Energy: } 1578 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 1590 \times 10^8 \text{ BTU/yr.}$$

VIII.)
(cont.)

Food Stores

$$\text{Auto: } \frac{2900 \text{ trips}}{\text{day}} \times \frac{4.4 \text{ veh.-miles}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{325 \text{ days}}{\text{year}} = 406.4 \times 10^8 \text{ BTU/yr.}$$

$$\text{Bus: } 90 \times 4.4 \times 2880 \times 325 = 3.707 \times 10^8 \text{ BTU/yr.}$$

$$\text{TOTAL ENERGY: } 4101 \times 10^8 \text{ BTU/yr.}$$

Restaurants

$$\text{Auto: } \frac{3777 \text{ trips}}{\text{day}} \times \frac{4.4 \text{ veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{365 \text{ days}}{\text{year}} = 594.0 \times 10^8 \text{ BTU/yr}$$

$$\text{Bus: } \frac{117 \text{ trips}}{\text{day}} \times \frac{4.4 \text{ veh.-mile}}{\text{trip}} \times \frac{2880 \text{ BTU}}{\text{veh.-mile}} \times \frac{365 \text{ days}}{\text{year}} = 5.412 \times 10^8 \text{ BTU/yr}$$

$$\text{TOTAL ENERGY: } 599.4 \times 10^8 \text{ BTU/yr}$$

Banks

$$\text{Auto: } \frac{1650 \text{ trips}}{\text{day}} \times \frac{4.4 \text{ veh.-mile}}{\text{trip}} \times \frac{9800 \text{ BTU}}{\text{veh.-mile}} \times \frac{250 \text{ days}}{\text{year}} = 177.9 \times 10^8 \text{ BTU/yr}$$

$$\text{Bus: } \frac{50 \text{ trips}}{\text{day}} \times \frac{4.4 \text{ veh.-mile}}{\text{trip}} \times \frac{2880 \text{ BTU}}{\text{veh.-mile}} \times \frac{250 \text{ days}}{\text{year}} = 1.584 \text{ BTU/yr}$$

$$\text{TOTAL ENERGY: } 179.5 \times 10^8 \text{ BTU/yr.}$$

SUMMARY:

$$\text{Office } 90,310 \times 10^8 \text{ BTU/yr.} \quad 90,310 \times 10^8 \text{ BTU/yr.}$$

$$\text{Light Retail } 1578 \times 10^8 \text{ BTU/yr.} \quad 12.07 \times 10^8 \quad 1590 \times 10^8 \text{ BTU/yr.}$$

$$\text{Food Stores } 4101 \times 10^8 \text{ BTU/yr.} \quad 4101 \times 10^8 \text{ BTU/yr.}$$

$$\text{Restaurants } 599.4 \times 10^8 \text{ BTU/yr.} \quad 599.4 \times 10^8 \text{ BTU/yr.}$$

$$\text{Banks } 179.5 \times 10^8 \text{ BTU/yr} \quad 179.5 \times 10^8 \text{ BTU/yr.}$$

$$96,770 \times 10^8 \text{ BTU/yr} \quad 12.07 \times 10^8 \quad 96,780 \times 10^8 \text{ BTU/yr.}$$

Operating

Embodied

Total