AN URBAN PLANNING METHOD FOR MODELLING ENERGY USE WITH APPLICATION TO SELECTED CANADIAN CITIES

A DISSERTATION SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE
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ABSTRACT

This study demonstrates a method of organizing, processing and modelling data for urban residential energy use and applies it to Canadian Plains cities. The method offers explicit control of factors such as housing mix, dwelling age and condition, residential density, travel distance, and climate. These factors are obscured in methods of urban energy analysis, which depend on extrapolation of data from national or regional sources, or data from prototypical dwellings.

The method disaggregates residential data by urban tracts, compares areal residential energy use in alternative prospectives and investigates residential energy consumption, travel distance from the urban centre, and areal residential density. Aggregated census and public utility data and systematic development of estimated data are used in a procedure which involves: (1) establishment of an urban laboratory of three large Plains cities; (2) determination of residential energy consumption from real and estimated data; (3) simulation of time-related energy objectives using scenarios in a three-dimensional matrix; (4) selection of data for comparison of residential transport energy and internal residential consumption; and (5) generation of three-dimensional representations of areal residential energy use for each selected city.

An illustrative application of the method for three real cities shows that: (1) as areal residential density increases, energy consumption increases but less linearly; (2) areal residential energy use decreases with distance from the urban centre, at least initially, it may increase later due to concentrations of multiple units in the outer suburbs; (3) specific residential areas are identifiable from their energy use; (4) as residential energy efficiency increases, differences in residential energy use between older and newer areas diminish; and (5) areal residential transport energy use decreases with residential distance from the urban centre. The method offers an analytical and monitoring technique for urban planning which can be periodically reiterated using systematic time-series data to present three-dimensional change in urban energy use. It can also provide a first approximation of expected energy use characteristics for other selected cities and can identify where energy waste may be occurring.

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CHAPTER I - INTRODUCTION

Energy in renewable forms has always been essential in human settlements. However, the complex environments which comprise large industrialized cities consume substantial quantities of renewable and non-renewable energy, and an important determinant of growth and economic well-being of such cities is their ability to use all available forms of energy efficiently. This capability is particularly important in climatically-stressed cities where energy for environmental conditioning, mobility systems and other purposes is required to maintain residential lifestyles under seasonally adverse conditions. Consequently, in such energy-sensitive urban regions, the continued availability of energy choices over the long term, the efficiency of their use and the ability of cities and their residential areas to shift to alternative forms of energy, when necessary, are important considerations of long term urban energy security. Conversely, residential quality of life in cities, and concomitantly, the disposal incomes of urban households, increasingly depend on energy efficient means to satisfy residential energy needs.

With more residential consumers able to exercise informed choices about residential fuels, energy systems, dwelling types, transport modes and residential locations in relation to journey-to-work, it is important to develop effective methods to assess such choices in terms of residential energy consumption and energy system efficiency. This dissertation considers an alternative method of modelling of residential energy consumption which is under either direct or indirect control of residential consumers.

In this chapter, background is provided on aspects of urban residential energy consumption and efficiency in a context of selected large plains cities; the urban and regional environment of three laboratory cities is described; the central problem of this dissertation is defined; and some important questions for policy consideration are outlined.

1.1 BACKGROUND

Although energy and in particular urban energy and efficiency considerations are important in all industrial economies, they are essential in northern countries. A special response to severe climatic conditions and energy demands is required to maintain urban lifestyles. In Canada, efficient use of energy is critical to its ability to compete with the economies of other northern countries. Because it has some of the least favourable economic and energy efficiency indicators among developed economies and because urban energy consumption is an important factor in such indicators, the relationship between urban energy consumption and urban development is an important consideration to Canada's future competitiveness with respect to energy.

To appreciate the significance of urban energy consumption as a component of national and regional energy performance, it is useful to consider some indicators of energy and national economic behavior. These include: (1) energy investment as a component of national investment; (2) per capita consumption as an indicator of national energy performance; (3) energy consumption and end-use efficiency as factors in economic performance; (4) some characteristics of Canadian energy performance and its urban and regional implications; and finally (5) some dimensions of urban energy consumption in the Canadian Plains.

1.1.1 Energy Investment as a Component of National Capital Investment

During the 1970's, energy, historically an essential component of capital investment and economic performance in industrial nations, became an increasingly important indicator to economists, planners and other policy makers, as world energy markets were impacted by the actions of an international cartel, and fuel prices increased rapidly. Concern became acute in climatically stressed urban regions, where non-renewable energy supplies were imperative to economic well-being, and where historically low energy prices had resulted in complacency about projections of longer term limits for non-renewable fossil fuels (Hubbert 1969).

In considering the relationship between energy production and consumption and national or regional economic performance in industrial economies, energy investment as a proportion of total capital investment is an important indicator. Taking the example of Western Europe in the years prior to 1973, the original six common market countries spent in order of 25 percent of their total capital investment on energy. Similarly, between 1970-73, 24 percent of investment capital in the U.S. economy went into energy production (Commoner 1977). In the early 1970's the proportion of Canada's capital investment in the energy sector was approximately 23 percent (Gander and Belaire 1978). In part, this level of national investment in energy reflected Canada's historic role as a net producer and exporter of energy and energy-intensive raw materials to major trading partners. It also indicated the importance of energy to the Canadian economy, and in particular, to regions in which energy production was a major component of the economic base.

1.1.2 Per Capita Consumption as an Indicator of Energy Performance

In addition to energy investment as a percentage of capital investment, another useful indicator is per capita consumption of energy and the ratio of energy consumption to gross domestic product (GDP). For example, in 1979, among the industrialized countries Canada had the highest per capita consumption of energy at 9.3 Mtoe* (OECD/IEA 1980). This was followed by the U.S. at 8.5 Mtoe, and Sweden at 6.2 Mtoe (Table 1). Although, per capita consumption is useful as a comparable indicator of energy consumption, it is not sufficient alone. Consequently, the notion of comparing economic growth with per capita energy consumption is sometimes used.

In the 1970's, some analysts used a ratio of per capita energy consumption to gross national product (Cook 1976) For example, daily per capital energy consumption in kilocalories was sometimes compared with per capita gross national product (Figure 1). With all countries placed on a common graph, a median line of best-fit established a shallow curve of energy use which provided a crude indicator of relative efficiency of energy use. The increasing slope of the curve represented increased per capita energy consumption with increased gross national product. Nations which were more energy efficient reflected ratios which placed them below the line of the best fit, and those which were less efficient were above it. On this scale, Canada was not only the second highest per capita energy consumer, but also had the highest ratio of energy consumption per capita in relation to gross national product per capita. Although this indicator suggested that of all the nations analysed, Canada was least efficient in its use of energy, like many other countries, not all of its energy was consumed internally, at least 30 per cent was exported. The value of comparing per capita energy consumption with per capita GNP (or GDP) has been questioned on the grounds that structural differences and efficiency differences are not adequately accounted for (Fowler, 1984). It has also been suggested that in the long run, "there are no firm rules relating energy use to gross national product" (Schipper and Darmstadter 1978).

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* 1 Million Tonnes of Oil Equivalent (Mtoe) is equivalent to 28.8 gigajoules.

TABLE 1

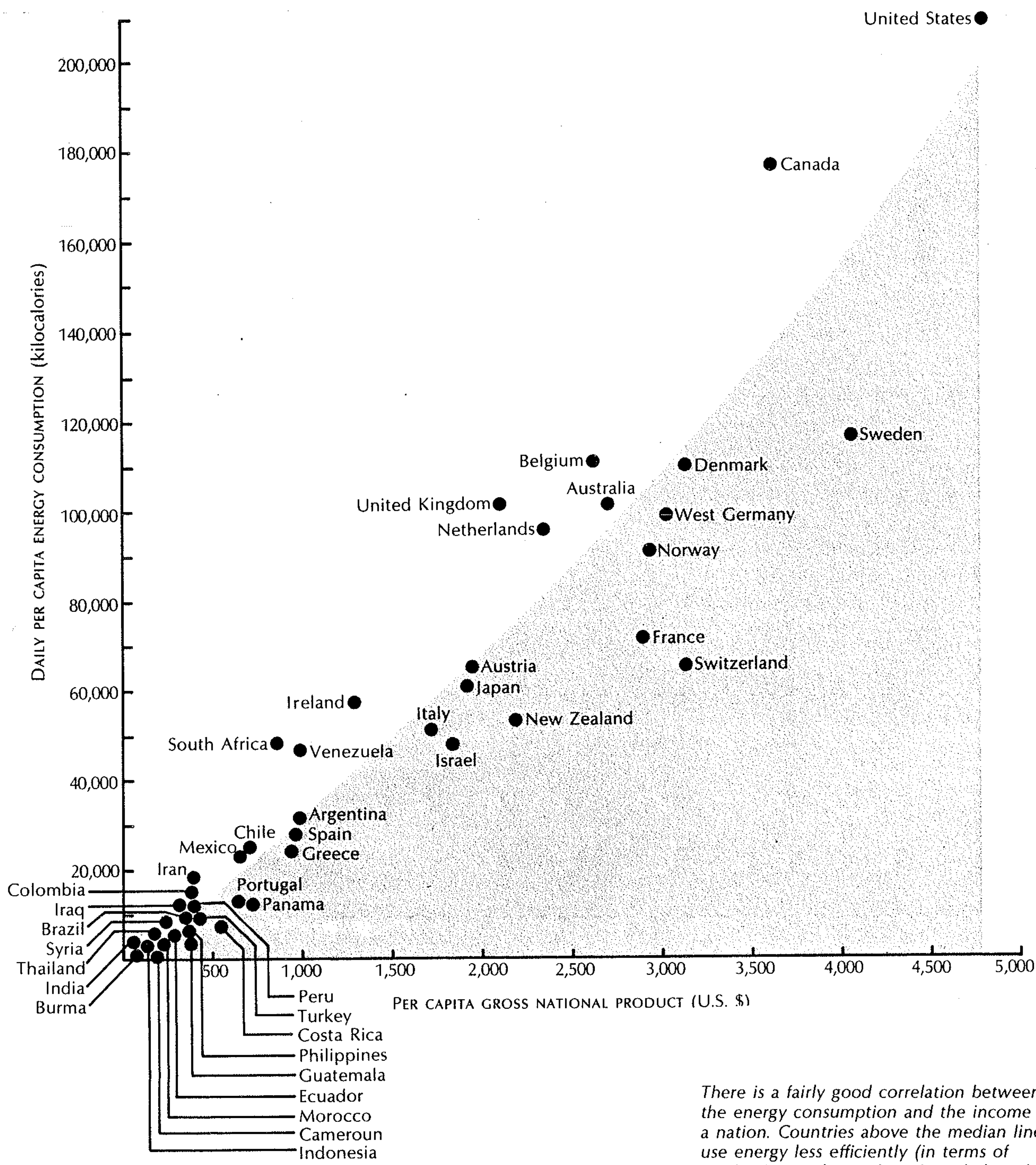
A COMPARISON OF ENERGY CONSUMPTION AND ECONOMIC PERFORMANCE FOR SELECTED OECD COUNTRIES.

Country	Energy Production TPE* / Economic Growth GDP (1979)	Energy Consumption Per Capita (1979) TPE in Mtoe per capita
CANADA	1.17	9.3
UNITED STATES	1.04	8.5
SWEDEN	0.70	6.1
NETHERLANDS	0.74	4.9
WEST GERMANY	0.58	4.7
UNITED KINGDOM	0.88	4.0
DENMARK	0.48	4.0
JAPAN	0.59	3.2

* TPE: Total Primary Energy

Source: OECD/IEA 1980: 109 - 297

FIGURE 1: A COMPARISON OF RATIOS OF DAILY PER CAPITA ENERGY CONSUMPTION TO PER CAPITA GROSS NATIONAL PRODUCT FOR SELECTED U.N. COUNTRIES



There is a fairly good correlation between the energy consumption and the income of a nation. Countries above the median line use energy less efficiently (in terms of production, at least) than those below the line.

Data are for 1970; for per capita GNP, from Statistical Abstract of the United States - 1972; for energy consumption from United Nations, World Energy Supplies 1969-72. Statistical Paper J.17 .

SOURCE: Earl Cook. 1976. Man Energy and Society. San Francisco: W.H. Freeman and Co.: 192.

1.1.3 Energy Consumption and Efficiency as Factors in Economic Performance

Levels of energy consumption and efficiency of energy use are also significant factors in the comparative economic performance of national economies. For example, it is not coincidental that while Canada had the highest ratio of primary energy consumption to gross domestic product among selected OECD countries in 1980 (Table 1), it also had high per capita energy consumption relative to gross national product among U.N. countries in the early 1970's (Figure 1). Commoner has argued that poor economic performance by industrial economies is linked to high levels of energy consumption, inefficient use of energy, and inappropriate capital investment in energy related technologies (Commoner 1977).

Since the Second World War and particularly over the past several decades, Canada's poor economic performance with respect to energy consumption and efficiency has been underscored by the superior performance of many industrial economies with which it competes in world markets. For example, by the late 1970's, industrial economies which had at one time trailed Canada and the United States had either caught up with or surpassed both countries in many economic indicators (Table 1) related to standard of living and quality of life (Schipper and Lichtenberg 1976). This has occurred despite heavy dependence on fossil fuels, which most OECD countries do not have but which Canada and the United States both have in relative abundance, and the necessity of costly major post-war reconstruction in many OECD countries, which neither Canada or the U.S. experienced directly. Although some evidence indicates that better economic performance by some industrial economies has been, in part, a consequence of greater emphasis on more efficient use of technology and capital (Stobaugh and Yergin 1983), there are also other reasons. Colcord (1979) has argued that in some countries it is due to greater social benefits of long range, large scale planning. Conversely, it has also been suggested that energy shortcomings in the

United States, one of the most advanced industrial economies, are due to failures of its short term market economy to envisage and respond to long term energy problems (Goldstein 1979).

1.1.4 Some Characteristics of Canada's Energy Performance and Its Urban and Regional Implications

Since 1945, Canada's economic performance and its high level of energy consumption have been in part attributable to structural economic conditions, such as dispersed patterns of growth, a need to service extensive remote and inhospitable regions, and dependence on a primary resource base of energy-intensive (extractive) industries located far from markets (Canada, ECE Secretariat 1977). However, it has also been due in part to the structure and development patterns of larger Canadian cities and in particular to the relative inefficiency with which such cities have been planned and use energy to condition space, heat water, power urban transport, and generate electricity.

As of 1976, total primary energy consumption in Canada totalled approximately 8.44 exajoules (Canada EMR 1981). By 1981, primary energy increased to approximately 9.98 exajoules. As indicated in the following table, approximately three quarters of this energy, or 7.39 exajoules, was classified as secondary energy:

TABLE 2 SECONDARY ENERGY CONSUMPTION IN CANADA - 1981

Classification	Percentage Total	Exajoules
Energy Supply Industries (including Pipelines)	6.9	.50
Domestic and Farm	19.6	1.44
Commercial	12.7	.98
Industrial	35.0	2.57
Transportation	24.8	1.83
Unaccounted	1.0	0.07
	100.0	7.39

Adapted from: Canada, EMR - Energy Update - April 1981: 28

To appreciate the magnitude of an exajoule (EJ), or 1.05×10^{18} joules, as a unit of residential energy, it is useful to consider the example of a typical household. In 1981, an average reasonably insulated household in Canada consumed in order of 250 GJ (gigajoules) per year, including approximately 100 GJ for space heat, 35 GJ for water heat, 15 GJ for appliances and 100 GJ for household transport. If, on the basis of the 1981 Census, there were approximately 8.0×10^6 of such "typical" households in Canada, then the total energy requirement of these households for these four purposes was approximately 2 exajoules. Consequently, total energy consumption for all households in Canada was slightly more than 2 exajoules. Although this figure is less than the aggregate for Domestic and Commercial in Table 2, the categories Domestic, Farm and Commercial include both residential and non-residential energy consuming land uses.

In 1981, more than 75 percent of Canada's population lived in cities and towns. In excess of 54 percent represented households in cities larger than 100,000 population (1981 Census of Canada). It has been estimated that in 1981, household energy consumed for urban and related purposes approached 60 percent of total residential consumption. On the basis of 1981 figures (Table 2), this represented in the order of 4.4 exajoules of secondary energy consumed in larger urban centres. If at least 27 percent of this energy was consumed for domestic purposes, including space heat, water heat, and transport energy for journey-to-work, then 1.19 exajoules were consumed by households in large urban centres. Since much of this energy was consumed for low temperature purposes, and at low system efficiencies, and was based on consumption of depleting resources, the impact on the national economy of using non-renewable resources for such purposes was significant. A breakdown of sources of this energy and an estimate of its capital cost to the national economy has been summarized as follows:

> Of total energy consumed in Canada including biomass, 43 percent was accounted for by oil, 23 percent by hydro-electricity, 18 percent by natural gas, 9 percent by

coal, 4 percent by nuclear generation and 3 percent by biomass. Our energy needs cost the economy $22 billion in 1979 or about 10 percent of the Gross National Product (Canada, EMR 1979: 18).

At over $2 billion per exajoule (1979) to the Canadian economy (annually), and assuming at least 2 exajoules for urban household consumption, dollar savings to the national economy could have been substantial if large quantities of urban domestic energy had been provided from energy conservation. Although not all energy for urban and related purposes can be used more efficiently through institutional change or technical innovation, it is suspected that more efficient production, processing, and distribution of energy for residential and other purposes could result in a significant improvement in national and regional energy performance in Canada. For example, evidence which has compared Sweden and the United States has suggested that comprehensive measures to improve urban energy performance in Sweden have resulted in estimated energy efficiency increases in the order of 24 per cent (Schipper and Lichtenberg 1976). If a similar percentage improvement in energy efficiency had been in place in Canada in 1981, economic savings could have represented in the order of $3.6 billion per annum. If a particular urban region within such a national energy perspective is considered, some regional dimensions of urban energy conservation can be defined.

1.1.5 Some Dimensions of Urban Energy Conservation in the Canadian Plains Region

To establish a range of empirical limits for energy consumption in the Plains region to the year 2025, it is necessary to consider several assumptions: (1) the prairie provinces will continue to represent approximately 17 per cent of total Canadian population to at least the year 2025 (Foot 1981); (2) at a high rate of national energy consumption, total (primary) energy consumption will increase from 9.5 exajoules per annum in 1980, to approximately 21 exajoules per annum in

2025 (Gander and Belaire 1978); and (3) on a proportional regional basis, per capita energy demand for the Canadian Plains region will grow at a high rate, from approximately 1.6 exajoules per annum in 1980 to 3.6 exajoules per annum in 2025; (3) At a low rate of energy growth, energy demand will decline to the year 2025. It is assumed however, that future total national primary energy consumption will not decline below 8.4 exajoules and on that basis, the proportion of future energy consumption for the region will be at least 1.5 exajoules.

The difference between a low of 1.5 exajoules and a high of 3.6 exajoules suggests a range of potential annual regional energy savings to the year 2025 of approximately 2.1 exajoules per year. If it is also assumed that, on a per capita basis, at least 60 percent of regional energy is consumed in larger urban centres, and that within such centres 30 percent of urban energy consumption, conservatively, represents residential energy, then potential energy savings for urban households are in the range of $0.57 - $1.36 billion. However, the significance of these numbers is less their precision than their usefulness as an indicator of magnitude of residential energy conservation potential for large cities in a climatically-stressed region of Canada.

1.2 THE REGIONAL ENVIRONMENT

The implications of potential per capita residential energy savings are significant. However, to consider residential energy consumption and efficiency on a regional basis, it is important to define more precisely the urban and regional environment in which urban residential energy consumption and efficiency are considered. This subsection considers two aspects of this environment: (1) the Interior Plains as a habitable region, which provides a context for the environmental conditions and characteristics of selected climatically-stressed cities within a similar physiographic region; and (2) the selected cities as an urban laboratory in which specific urban energy characteristics of large cities can be considered.

1.2.1 The Interior Plains as a Habitable Region

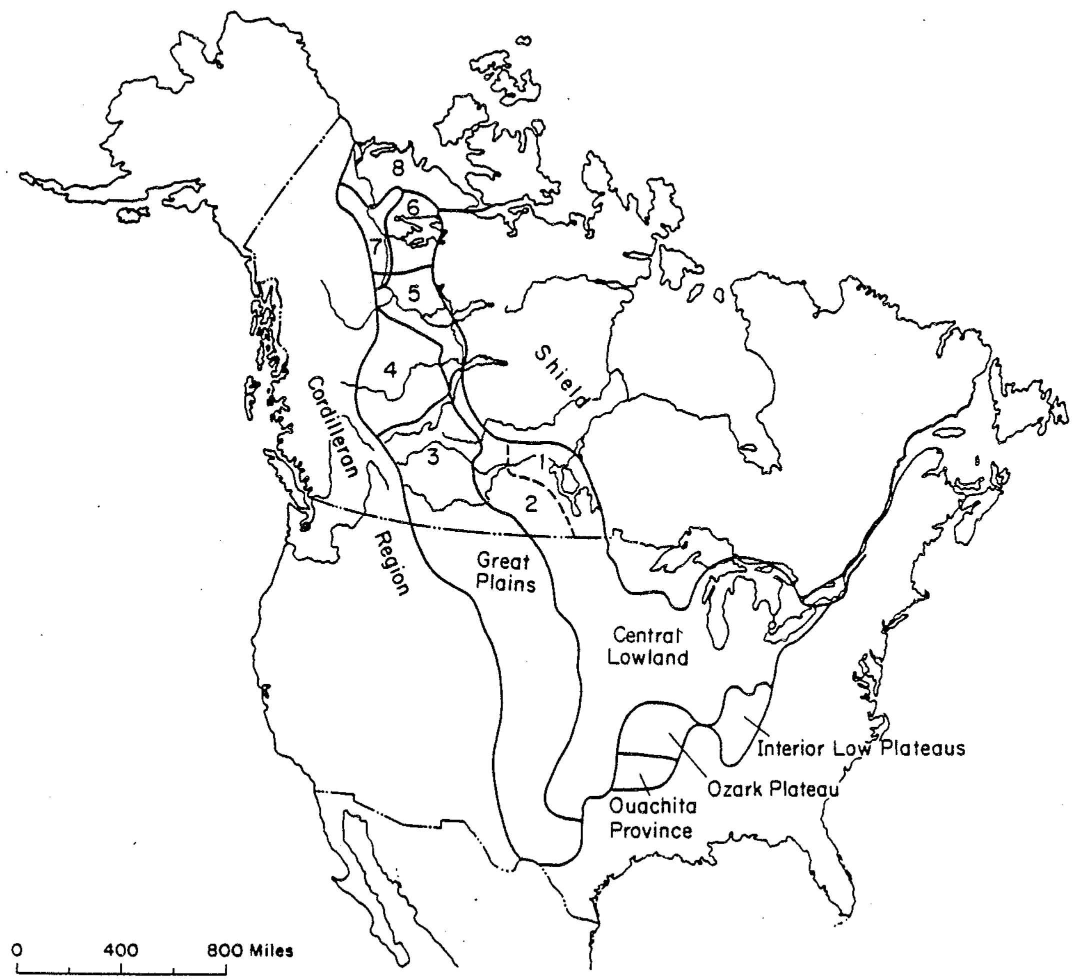
An important consideration of sound planning for a habitable urban region is not only the regions ability to support its population, but also, to consume resources efficiently so that there can be surplus for trade with other regions. Physiography is the term used to describe the intrinsic physical conditions which influence the habitability of regions. For example, de Blij (1980) has suggested that:

> physiography involves more than just the landscape and land forms it is made of. It relates ... to all natural features on the earth's surface including not only the land forms but also the climate, soils, vegetation hydrography and whatever else may be relevant to changes in the overall natural landscape. (p.63)

In physiographic terms, Canada is composed of at least 10 major sub-divisions or regions, in which only limited areas enjoy environmental conditions satisfactory to support urban populations of a significant size (Figure 2). One of these major divisions, the Interior Plains, extends from the eastern slope of the Rockies to the to the Laurentian Shield and from the Arctic Circle to the United States border (Figure 2). In southern Canada, the Interior Plains region is a large continental depression of low relief stretching from the Rockies to the Canadian Shield (Figure 3). Formed over 500 million years ago, the bedrock underlying the region's surface contains substantial oil, gas and coal, and in some areas, uranium. In the the Canadian Interior Plains, primarily between the Saskatchewan - Manitoba border and the Canadian Rockies, fossil fuel energy resources are particularly abundant. With most of Canada's fossil fuel resources located in this region, its large cities are particularly well situated to accessible, but depleting supplies of fossil fuel energy.

Of the three Canadian provinces in the Interior Plains region, Alberta and Saskatchewan are both heavily dependent on fossil fuels for thermoelectric power and other energy needs. Manitoba has long ago

FIGURE 2: INTERIOR PLAINS AND PLATEAUS IN CANADA



CENTRAL LOWLAND

1. *Manitoba Plain:* southern part is bed of Lake Aggasiz. Underlain by Paleozoic and some Jurassic. Ends eastward against the Shield; ends westward at foot of the Manitoba Escarpment formed by Cretaceous formations. Altitude of the plain is about 800 feet.
2. *Saskatchewan Plain:* Underlain by Cretaceous formations. Ends eastward at rim of Manitoba Escarpment; westward at Missouri Coteau, the edge of the Tertiary formations. Lower and smoother than plains to west (Alberta Plains). Altitudes 1,500 to 2,600 feet. Streams entrenched about 300 feet in open valleys.

GREAT PLAINS

3. *Alberta Plains:* Underlain mostly by Cretaceous formations. Eocene near the foot of the mountains. Rougher than Saskatchewan Plain. Altitudes around 2,500 feet; Cypress Hills reach 4,700 feet and probably were not glaciated. Valleys entrenched 200 to 400 feet.
4. *Alberta Plateau:* Between Athabasca and Liard Rivers. Cretaceous formations in plateaus separated by broad valleys. Plateaus 2,500 to 3,200 feet in altitude. Lowlands along the Athabasca and Liard Rivers 1,000 to 1,500 feet lower. Near foot of Rocky Mountains altitudes are about 4,300 feet on the plateaus.

GREAT SLAVE AND GREAT BEAR PLAINS

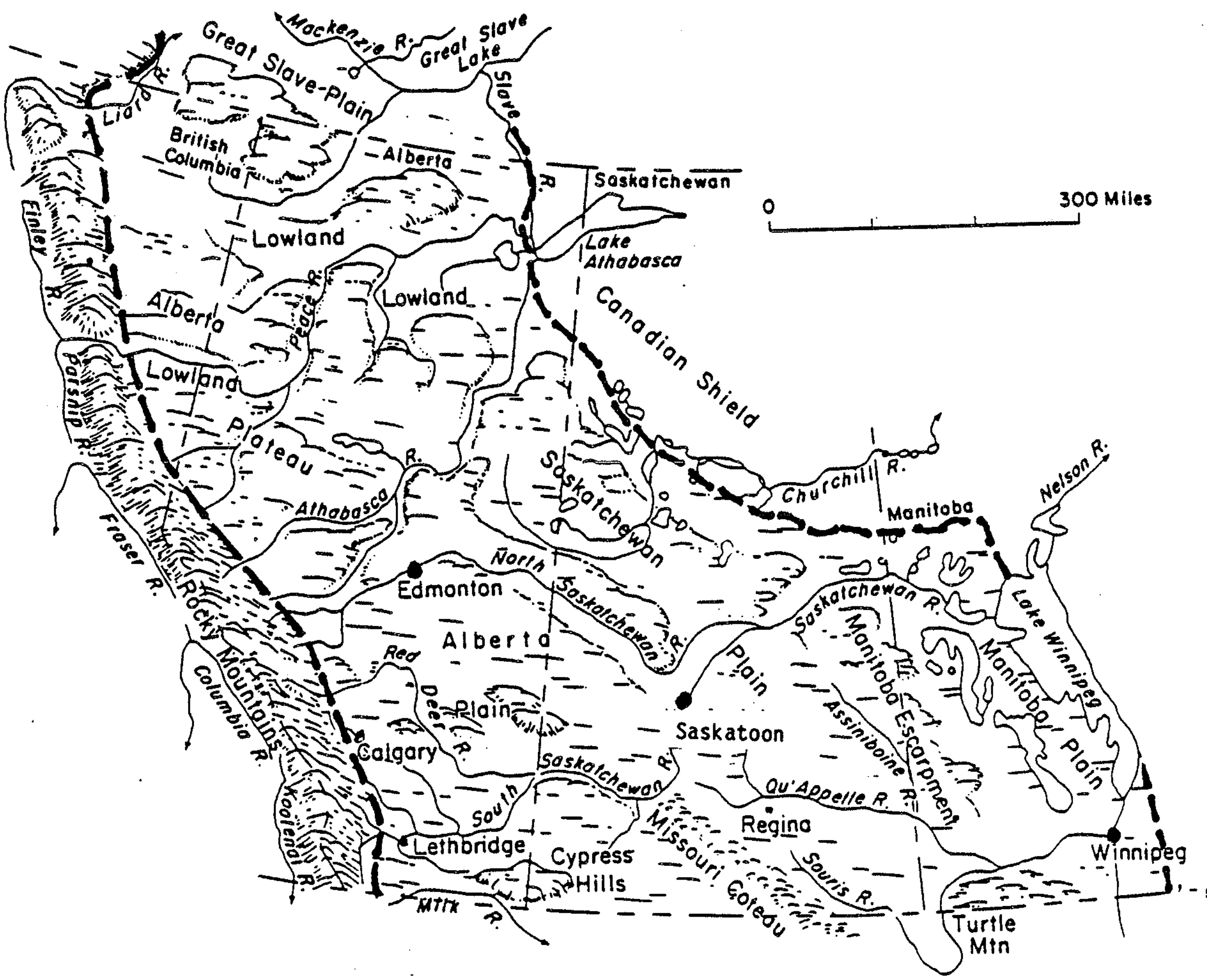
5. *Great Slave Plain:* Underlain by Paleozoic formations. Altitude about 1,000 feet; little relief.
6. *Great Bear Plain:* Underlain by Mesozoic formations. Rolling surface generally lower than 1,000 feet altitude; a few hills up to 500 feet high. Ends at south-facing escarpment overlooking Great Slave Plain.

NORTHERN PROVINCES

7. *MacKenzie Plain, Franklin Mountains, and Colville Hills:* Altitudes near sea level along the MacKenzie River and more than 2,000 feet in the mountains which are ridges of Paleozoic formations.
8. *Arctic Slope, including the MacKenzie Delta:* Slope north from 2,000 feet to sea level. Western part largely covered by glacial drift and slightly lower than eastern part. Streams entrenched increasingly toward the south to about 400 feet.

SOURCE: Charles B. Hunt. 1973. Natural Regions of the United States and Canada. San Francisco: W.H. Freeman and Co.: Figure 13.2 p.328.

FIGURE 3: ALBERTA, SASKATCHEWAN AND MANITOBA PLAINS



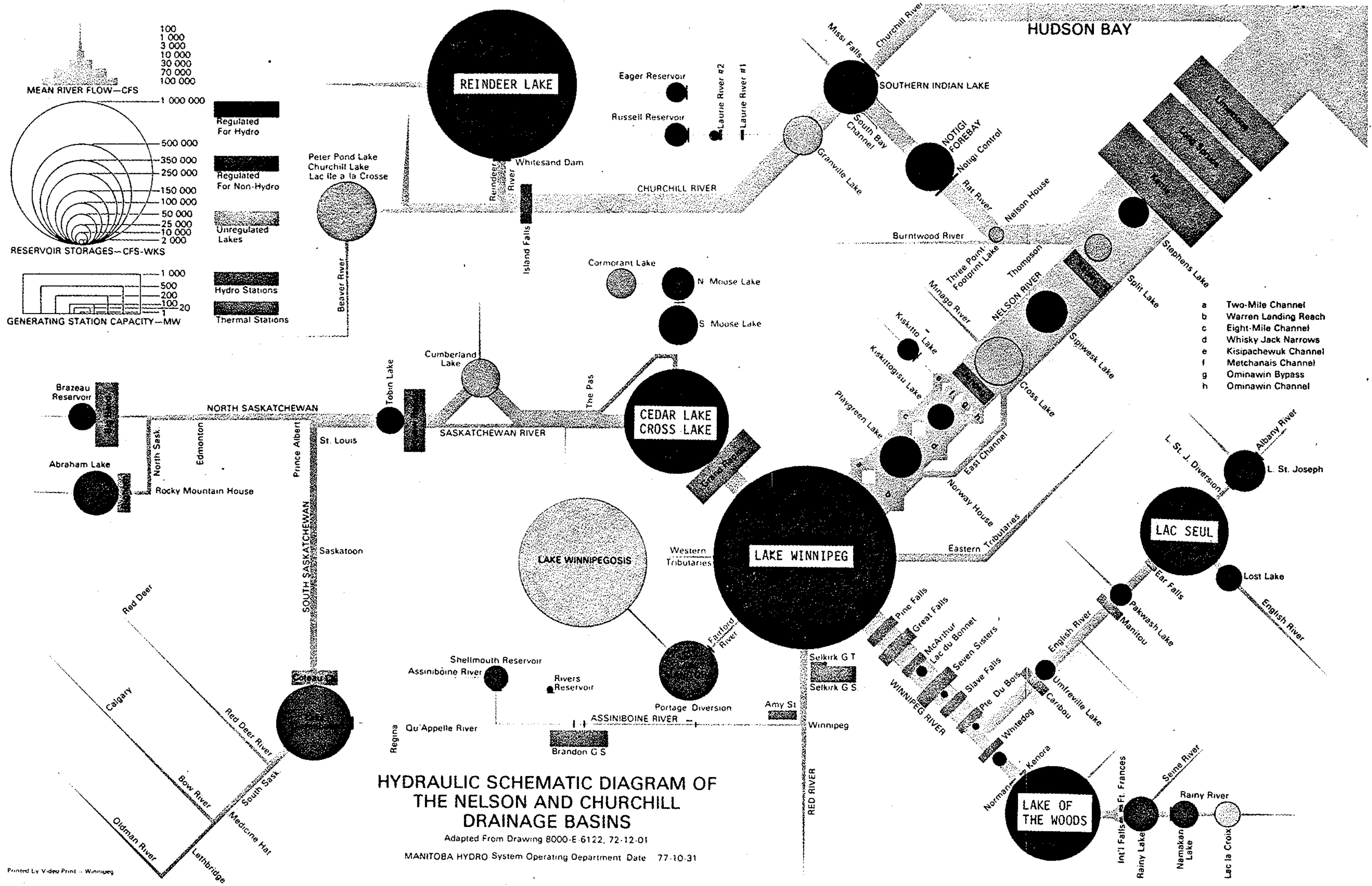
SOURCE: Charles B. Hunt. 1973. Natural Regions of the United States and Canada. San Francisco: W.H. Freeman and Co.: Figure 1.3 p.329.

exhausted what little coal it had, and compared to its two western neighbours has relatively little remaining gas or oil. With large coal deposits close to the surface from west of Edmonton to the foothills of the Rockies, as well as in the southwestern region of the province, most of Alberta's electrical energy needs are provided from thermoelectric plants situated near extensive strip mines. In southern Saskatchewan similar sub-surface coal deposits are used for development of electric power. Both provinces use available waterbodies as once-through condenser cooling for thermoelectric power plants with little use of waste heat.

With respect to renewable energy, although Alberta and Saskatchewan are both served by a number of major north-east and east flowing rivers, watersheds in their upstream regions either have little or uneven potential for hydroelectric generation, or are situated within protected national parks which restrict hydroelectric development. For example, with some exceptions, such as The Big Bend and Big Horn dams in Alberta, and the Squaw Rapids, Island Falls, and Gardiner dams in Saskatchewan, not until these east-flowing watersheds are well east of Lake Winnipeg in Manitoba, do they possess sufficient flows to generate large hydroelectric potentials. Consequently, the eastern and western portions of the Canadian plains region are a study in contrasts with respect to energy potentials such as hydroelectricity (Figure 4).

Although the portion of the Interior Plains which comprises the three prairie provinces includes only 17 per cent of the Canada's population, it contains approximately 77 per cent of all arable land (Canada DBS 1966). With essentially flat relief and fertile soils, the Canadian Interior Plains, despite climatic limitations in growing season, is ideal for agriculture, including grain, livestock, dairying, and market gardening. Therefore, in addition to energy production, the region's economic base provides, through grain (and livestock) production, another important "renewable" and exportable resource for

FIGURE 4: HYDRAULIC SCHEMATIC DIAGRAM OF THE NELSON AND CHURCHILL DRAINAGE BASINS



SOURCE: Manitoba Hydro: Research and Planning Department. Winnipeg, Manitoba.

the Canadian economy. Correspondingly, the large cities in this region are essential to effectively service this component of the economic base, and economically sustainable energy is important to enable these cities to fulfill their service role.

In Canada, the Interior Plains compromises eight sub-regions or areas (Figure 2, p.13). These areas include most of the Prairie provinces and the Northwest Territories. However, only the most southerly of these sub-regions, specifically areas one, two and three, are climatically habitable for large populations. Consequently, these areas contain more than 60 per cent of the urban populations of Alberta, Saskatchewan and Manitoba. Two of the areas in Manitoba and Saskatchewan are sub-divisions of the Central Lowlands, and the third is part of the Great Plains. These three sub-regions of the Interior Plains are selected as a regional context in which to analyse energy and urban development because they contain large cities which seasonally experience severe climatic stress and as such require large energy investments to overcome this stress. Also, because they represent a range of cities with housing of different age and condition, they provide an opportunity to consider urban energy consumption in relation to characteristics, such as age, urban compactness and the use of available residential energy.

It is indeed a paradox of energy and environment that although the Canadian Interior Plains is one of world's two coldest urbanized regions, it is also rich in indigenous energy resources. However, given the export potential of many of these energy resources to other less well-endowed regions or nations, improving urban energy efficiency within the Canadian Plains has important economic and quality-of-life implications for Canada, for the region, and for its urban areas. For example, effective urban energy conservation can enable the region to extend the life expectancy of its depleting energy resources, allowing it to continue longer as a net exporter of energy.

1.2.2 Characteristics Of The Selected Cities

Of the three Interior Plains cities selected for analysis within sub-regions (1)-(3) in Figure 2, Winnipeg is situated in sub-region 1, Saskatoon is in sub-region 2, and Edmonton is in sub-region 3. These cities are selected for analysis because they are representative of their respective provinces in size, latitude and climate. For example, within their provinces they are: (1) among the largest cities, with populations in the range of 100,000 to 600,000; and (2) the most northerly and coldest large cities. They are also among the five coldest large cities in Canada. Therefore, among large Canadian cities, they represent those most in need of large quantities of energy for space heat and urban transport. Also, given their locations in provinces with different degrees of dependence on non-renewable energy, the cities reflect different degrees of long term vulnerability with respect to depletion of energy resources. For example, Edmonton and Saskatoon are heavily dependent on strip-mined coal for electricity generation, while Winnipeg with its greater access to hydroelectricity can depend more on renewable energy*.

1.3 THE URBAN CONTEXT FOR ENERGY INVESTIGATION

Although placed in a broad national and regional framework, the context of this dissertation is urban and its focus is on energy use in

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* Although Figure 4 schematically illustrates the large hydroelectric potentials available in the Churchill and Nelson Drainage Basins and the smaller hydraulic potentials of other rivers in the Canadian Interior Plains which feed these basins, it does not include all power production plants within the region. For example, it does not include thermal power stations in Alberta, Saskatchewan and Northwestern Ontario, or hydraulic potentials from the Peace and Slave River systems of northern Alberta and the Northwest Territories. Notwithstanding these limitations however, it illustrates the importance of hydroelectric potentials in Manitoba relative to other provinces in the late 1970's.

specific residential tracts in large cities. This sub-section considers some aspects of this urban energy context including: (1) a brief history of urban growth and energy development; (2) the impact of climate on urban energy consumption; (3) some relevant dimensions of urban energy; and (4) some limitations in evaluating urban energy in specific urban tracts.

1.3.1 History of Urban Growth and Energy Development

In modern industrial economies net internal population increase normally represents little more than one per cent per annum. More rapid urban growth is usually a result of substantial net inter-regional migration, which occurs when the labour force available within a region cannot satisfy local needs. For example, in the fifteen years preceding World War I, and during the third quarter of the twentieth century, many large Canadian Plains cities experienced rapid growth and substantial increases in population through immigration (Artibise 1981). In 1945, all but Winnipeg of the five largest Plains cities had less than 100,000 population. However, in the subsequent 35 year period, Edmonton and Calgary grew rapidly in population from 100,000 to 500,000, or from approximately 40,000 to 200,000 dwellings. Their growth rates sometimes exceeded five per cent per year (Robinson 1981). Saskatoon and Regina also experienced significant, although less dramatic, growth increasing by a factor of three.

Rapid urban growth after 1945 had a number of underlying causes, including a post-depression and post-war baby boom, an increase in capital intensive agriculture, which propelled many rural people into cities, and an expansion of cultural, education and health care programs and facilities in major urban centres. However, for larger cities, such as Edmonton and Saskatoon, an important growth impulse was the rapid increase in energy resource development activity in Alberta and Saskatchewan.

Historically, urban development in the Interior Plains was closely linked with development of available energy. For more than a century, the transformation of energy to power machines and to generate heat and electricity has depended on fossil fueled engines. Initially, such engines powered steam boats, locomotives, and tractors. Subsequently, steam powered automobiles and stationary engines in thermal or thermoelectric power plants were common. Eventually, power systems shifted to lighter and cheaper fuels such as gasoline or diesel oil, and more recently, to propane for some systems.

During the first half of the twentieth century, a number of Canadian cities depended on coal-fired plants to generate steam for industrial processes, electric power and to provide space heat and hot water in central areas. Major institutions and commercial establishments, including public buildings, factories, warehouses, retail outlets, as well as apartments, depended on such systems. Up to the 1960's, the local coal yard supplied household fuel to many residential areas in Plains cities. In Winnipeg, as recently as 1966, some residential neighbourhoods even enjoyed the benefits of district heat supplied from central or community based coal-fired steam plants (Carvalho 1976). However, in the past three decades, dependence on oil and gas, particularly in Alberta and Saskatchewan, has become almost complete, as most fixed and mobile urban systems shifted to these fuels. With the onset of a world energy crisis in the 1970's a shift back to coal for thermoelectric power production began. However, within this same period, Winnipeg, with a larger renewable energy resource base, increased its dependence on hydroelectricity.

Unlike Edmonton and Saskatoon, which were situated in regions with limited hydraulic potential, Winnipeg developed an early strategic advantage in hydroelectric energy. Although it led in development of coal-fired steam plant technology early in the twentieth century, it also developed hydroelectricity transmitted from the Winnipeg River system to power its extensive street railway and municipal lighting networks (Artibise 1975). Winnipeg's unique energy systems, diverse economic base, gravity location for serving prairie grain production and transport, as well as the continued dependence of Western Canada on railways for long haul heavy freight transport, helped to ensure its strategic advantage as a regional transport centre up to the 1960's. However, after 1950, rapid growth in long-range jet air travel, dieselization of railways, and development of major oil and gas discoveries in Alberta and western Saskatchewan, were reflected by a slowing of growth in Winnipeg, and a shift in investment to newer Plains cities, such as Edmonton, Saskatoon, and Calgary.

Rapid development of fossil fuels, including oil, gas, and coal, in the Western Plains after 1945, coincided with decentralizing urban and regional forces in many industrial countries. For example, burgeoning low density subdivisions and single family residential areas in many older large cities were becoming increasingly dependent on automobiles rather than on fixed line electric street cars and trolley buses which had served denser residential configurations in previous decades (Schaeffer and Sklar 1975; Warner 1962 and 1970). By the 1970's dependence on fossil fuels for transportation and other urban purposes in Plains cities was virtually complete (Edwards 1978). In Alberta and Saskatchewan, dependence on non-renewables, particularly gas and oil, for urban energy exceeded 90 percent, with Manitoba close behind (Statistics Canada 1976). Consequently, for more than three decades, to the mid 1970's, urban areas of the Interior Plains, like cities elsewhere in North America, developed in form, pattern, and extent, independent of considerations such as energy and resource limitations (Yeates and Garner 1976).

With a possibility of substantial depletion of liquid fossil fuels within present lifetimes (Willson 1980), underscored by a world energy supply crisis, which is currently mitigated by a period of temporary oversupply, some cities in the Interior Plains not only must consider costly replacement of their urban infrastructure over the longer term, but must also consider how to develop urban growth policies which can respond more effectively and efficiently to future energy resource realities. The prospect of a failure to respond to such longer term conditions has been outlined by Foley and Nassim (1976):

> If there is going to be an increase in energy production sufficient to maintain present living standards, let alone increase them, the world is indeed, facing a difficult time. The indiscriminate growth patterns of the past decades will not be sustained; in many cases they will be reversed. There will be consequent unemployment and economic disruption. Because they no longer control, through the agencies of the international oil companies, the sources of their energy supplies many of the affluent countries will find their ambitions curbed and their aspirations unfulfilled. Inevitably for some, their power and influence will decline as the balance shifts away from them towards countries better endowed with resources. With some 30 percent of their energy spent on "non-productive" domestic energy consumption, most of it on space-heating, the industrial countries of the northern latitudes are heavily handicapped in competition with countries with more equable climates. In these circumstances eliminating waste becomes a matter of paramount importance for everyone. (p.328)

1.3.2 The Impact of Climate on Urban Energy Consumption

Seasonally, the continental climate of Canada's Interior Plains fluctuates widely. Winters are cold and are accompanied by frequent blizzards while summers are hot and are subject to severe storms including tornadoes. Despite intense sunlight and long summer days, the growing season is relatively short. In southern Manitoba the average frost free season is between 110 - 120 days with Winnipeg close to 118 days. Frost free periods in Saskatoon and Edmonton are even shorter.

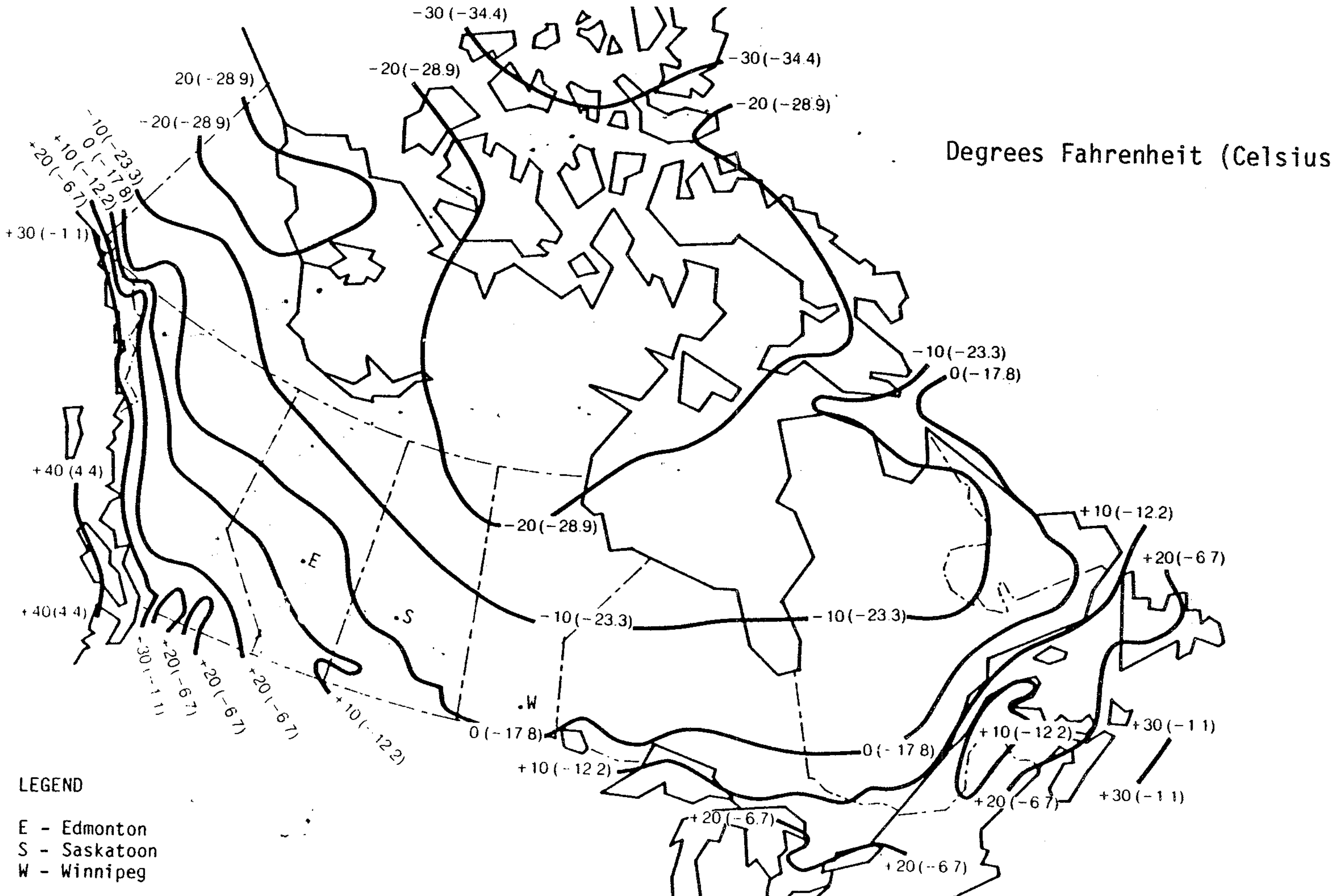
As indicated in Figure 5, all major cities of the Interior Plains are within mean January isotherms of -6.7° to -23.3° Celsius. The three most northerly large cities in their respective provinces approach 6000 degree days (Figure 6). These three selected cities also experience more than 500 hours per year of temperatures below 20°C, and in excess of 125 days per year with more than one inch of snow cover. At the same time they experience relatively few days with no sunshine and receive bright sunshine for a large number of hours. Of the three cities, Saskatoon and Winnipeg experience temperatures greater than 30°C for a relatively large number of hours (Table 3).

For energy for space heating, Figures 6 and 7 indicate that all three cities experience annual heating characteristics of 5450 to 5995 degree days and are in the range of January design temperatures for dwellings of -31.7° to -34.4° Celsius. This means that although households, particularly in low density subdivisions, are capable of absorbing and storing significant quantities of passive solar energy even during cooler seasons, over longer winters they must also expend 20-30 per cent more for space heat than similar housing in more equable climates. In addition, because motor vehicles in colder urban regions consume greater quantities of fuel for warm-up, starting and stopping requirements (Carrier 1974; Drolet et al 1977), urban transportation consumes significantly more energy in the largest and coldest Plains cities.

1.3.3 Some Relevant Dimensions of Urban Energy

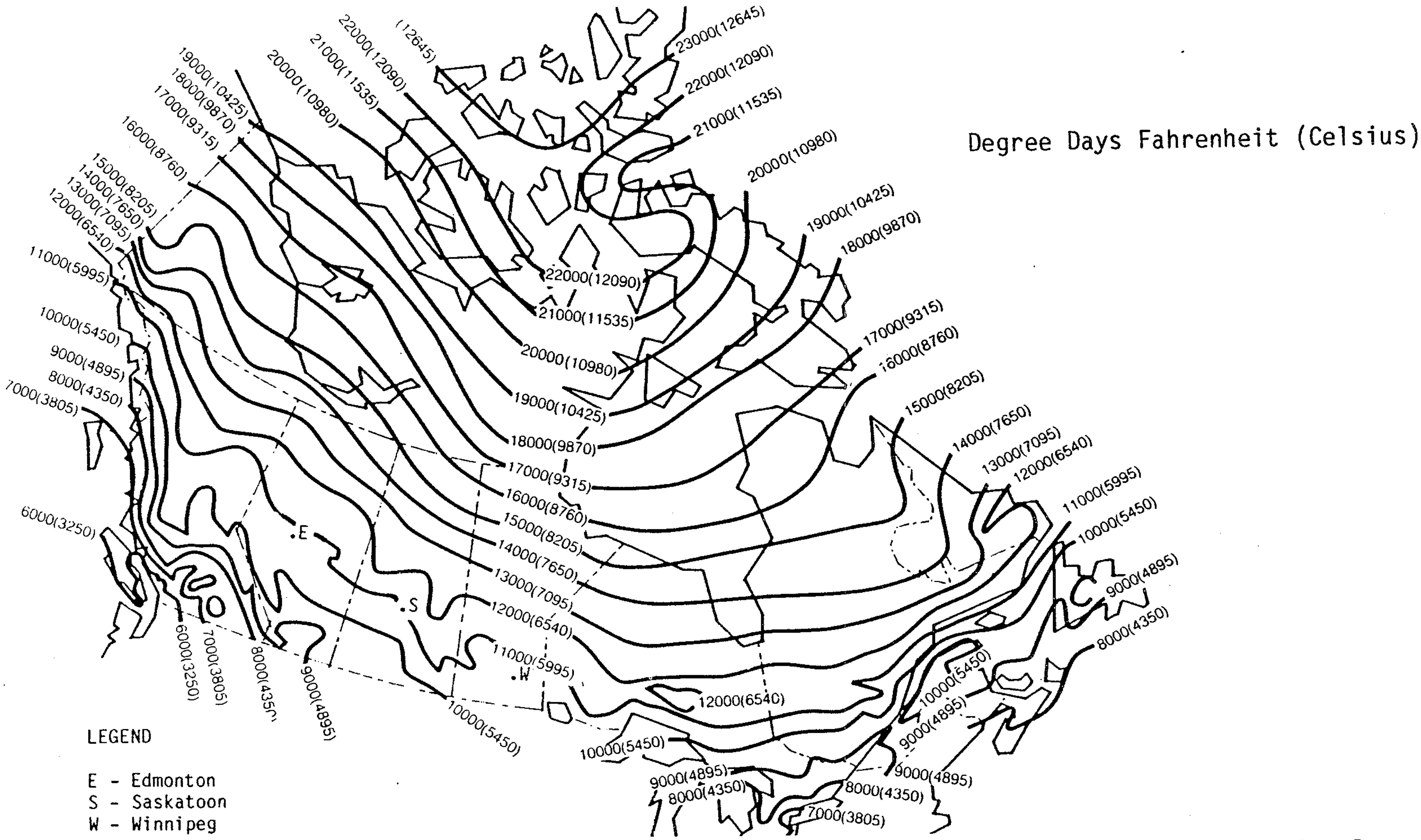
By the mid 1970's, the dependence of Canadian cities on energy was substantial. Nationally, transportation represented 25 percent of total energy consumption, residential 20 percent, commercial 14 percent, industry 27 percent, and energy supply industries and losses and non-energy uses represented 15 percent (Statistics Canada 1976). For large urban centres, energy consumption figures were grouped closer together, with values of 12.5, 12, 10, 15 and 10 percent respectively,

FIGURE 5: MEAN JANUARY TEMPERATURES IN CANADA



SOURCE: Climatological Atlas. Ottawa: National Research Council of Canada and Department of Transport 1953. From CMHC. 1977. The Conservation of Energy in Housing. Ottawa: 3.

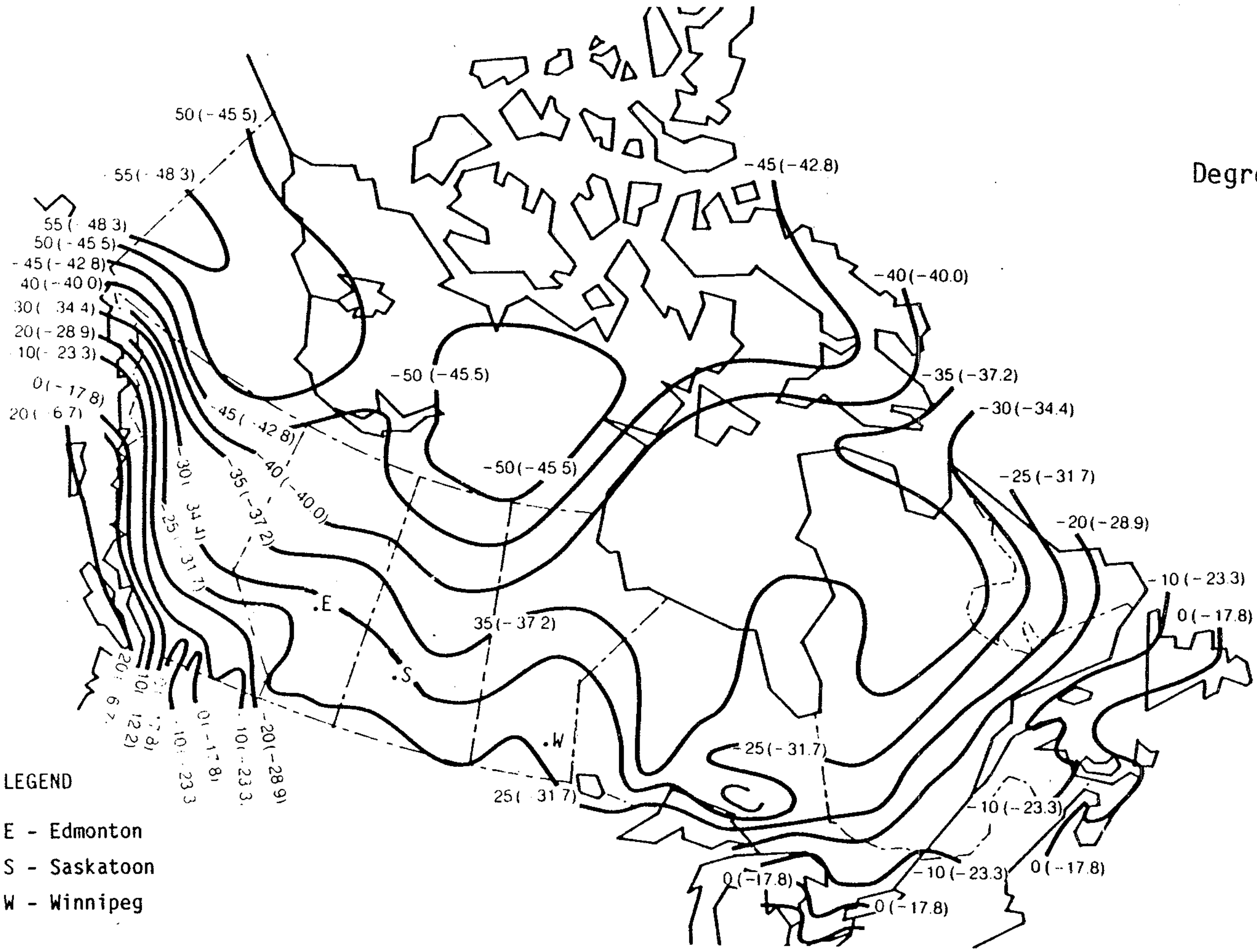
FIGURE 6: ANNUAL DEGREE DAYS IN CANADA



SOURCE: Climatological Information for Building Designs in Canada 1975 - Supplement to The National Building Code of Canada 1970. Ottawa: National Research Council of Canada. From CMHC. 1977. The Conservation of Energy in Housing. Ottawa: 7.

FIGURE 7: JANUARY DESIGN TEMPERATURES FOR DWELLINGS IN CANADA

Degrees Fahrenheit (Celsius)



SOURCE: Climatological Information for Building Designs in Canada 1975 - Supplement to the National Building Code of Canada 1970. Ottawa: National Research Council of Canada. From CMHC. 1977. The Conservation of Energy in Housing. Ottawa: 6.

TABLE 3: CLIMATE FOR 23 LARGE CANADIAN CITIES

	Hours of bright sunshine	Days with no sunshine	Days with measurable precipitation	Days with measurable snowfall	Days with freezing precipitation	Days with snow cover of 1 or more inches	Mean daily minimum temperature in January	Mean daily maximum temperature in July	Days with minimum temperature below 0°C	Hours with temperature greater than 30°C[9]	Hours with temperature below −20°C[9]
			annual average				degrees Celsius			annual average[9]	
Toronto	2,046	65[3]	134	45	10	62	−10.5	27.0	154	72.8	32.1
Montreal	1,959	67[3]	163	60	14	116	−14.3	26.3	153	30.5	130.2
Vancouver	1,931	76[3]	161	12	1	7	−0.4	22.2	57	1.3	0
Ottawa	1,995	69[3]	152	60	16	116	−15.6	26.4	166	48.8	190.1
Winnipeg	2,232	48	121	58	11	126	−23.2	25.9	195	56.2[10]	884.0[10]
Edmonton (municipal airport)	2,246	44[3,4]	121	60	6	121	−19.4	23.4	192	15.1[7]	517.3[7]
Quebec	1,827	81[5]	164	67	16	139	−16.2	25.1	177	16.6	233.0
Hamilton (Royal Botanical Gardens)	2,035	62[6]	125	38	12[8]	..	−8.6	27.2	134	..	..
Calgary	2,207	41	113	61	3	99	−16.7	23.5	201	17.0	415.0
Kitchener	1,950[2]	..	113	31	..	..	−9.9	26.9	154	..	..
London	1,929	69	165	66	12	..	−9.9	26.4	152	35.0	31.7
Halifax (Shearwater)	1,945	77	142	36	17[4]	60	−7.8	21.9	142	2.0	7.8
Windsor	..	..	137	42	8	43	−7.8	27.8	135	80.5	7.7
Victoria (Gonzales Heights)	2,183	51	142	9	<1	5	+1.9	20.8	18	1.3	0
Sudbury	..	..	155	73	19	139	−18.4	24.8	183	15.9	396.0
Regina	2,278	45	114	58	12	130	−22.6	26.2	207	91.4	744.0
St. John's	1,458	108	210	85	36	120	−7.0	20.1	177	0	2.1
Oshawa (Pickering)	..	..	122[7]	32	..	..	−10.9	25.7	..	..	..
Saskatoon	2,402	44	103	54	9	130	−23.9	25.9	206	64.8	845.9
Saint John	1,819	88	164	58	11	82	−12.6	22.3	175	1.9	92.0
Sherbrooke	1,901	72	170	63	9	..	−17.8	24.6	161	12.9	292.7
Trois-Rivières	..	..	152	53	7	..	−17.4	26.2	177	..	..
Kingston	2,113	51	130	39	..	..	−11.6	25.0	148	..	..

[1]Data based on records for 20 or 30 years, except where indicated.
[2]Figure is for Guelph, Ont.
[3]Figure based on records for past 7 years.
[4]Figure is for the international airport.
[5]Figure based on records for past 16 years.
[6]Figure based on records for past 9 years.
[7]Figure based on records for past 15 years.
[8]Figure is for the airport.
[9]Data based on records for 10 years, except where indicated.
[10]Figure based on records for past 20 years.

SOURCE: Atmospheric Environment Service, Environment Canada, Downsview, Ontario.

for the sectoral categories listed. Thus urban energy represented in the order of 60 percent of total national consumption.

The breakdown of fossil fuel energy demand was also significant. In 1976, over 80 percent of Canada's domestic energy demand was derived from gas and oil. Of the remaining 20 percent, approximately 16 percent was provided by electricity (Adler and Brusegard 1980, 260). With at least half of total electrical demand produced from fossil fueled thermoelectric systems (i.e. coal, gas, oil and nuclear), more than 85 percent of total energy demand, including domestic demand, derived from non-renewables. Assuming that more than 60 percent of this demand represented urban consumption, then at least 50 percent of total energy consumption was urban demand dependent on fossil fuels. In the transportation sector, however, the proportion of demand served by fossil fuels was closer to 99 percent with most from rapidly depleting liquid fossil fuels. An analysis of the transport sector indicated that 50.3 percent of energy was consumed by automobiles, 25.2 percent by other ground transport (primarily trucking), 5.7 percent by railways, 10.8 percent by aircraft, and 7.3 percent by marine transport (Knelman 1975).

For specific Plains cities, little comprehensive data have been available to provide detailed breakdowns of urban energy consumption. The primary means of deriving such data has been to extrapolate by sectors from aggregate national or regional energy accounts (Gander and Belaire 1978). For example, analysis of residential and commercial sectors which represent the portion of residential energy demand internal to households, results in approximately 85-90 percent of this demand being consumed for space heat and hot water (Hirst and Moyers 1973). The remaining 10-15 percent comprises primarily electricity to power small appliances, lighting and household machinery.

For the transport component of household energy consumption, the automobile offers the largest potential for discretionary energy consumption by residential consumers, particularly for journey-to-work. For example, in 1975, of the total automobile transportation distance for all CMA's in Canada, approximately 27 percent represented journey-to-work travel (Transport Canada 1979). Of total journey-to-work trips, 74 percent were by automobile (Transport Canada 1979). For Winnipeg and Edmonton, the figures were 73 percent and 78 percent respectively, and approximately 27-29 percent of total automobile travel distance represented journey-to-work travel in those cities. With automobiles consuming in the order 50 percent of total transport energy and passenger transport using 85 percent of auto energy (Knelman 1975), journey-to-work by automobile in Winnipeg and Edmonton represented in the range of 11.5-12.3 percent of the total transport energy sector for those cities.

With core based journey-to-work trips representing approximately 20 percent of total urban travel (Transport Canada 1979), the proportion of travel, and consequently energy, for journey-to-work into the core in the selected cities has been estimated to be in the order of 2 percent of transport energy. However, when increased energy consumption and urban congestion for short trips (i.e. less than 4.8 km) are accounted for, this figure increases in excess of 3 percent of total transport energy. With 1980 transport energy representing approximately 25 percent of Canadian consumption of total secondary energy (Canada EMR 1981, 28), energy for average journey-to-work commuting to the central cores of urban areas by auto represents less than 1 percent of total national energy consumption.

Although household energy consumption for journey-to-work transport is slightly higher when public transport energy is added, total journey-to-work energy consumption is relatively small, when compared with total energy consumption for conventional residential/commercial development. For example, residential/commercial consumption represents in the order of 36 percent of total national consumption (Gander and Belaire 1978). Energy for space conditioning and hot water alone represents approximately 88 percent of this total. Consequently, approximately 32 percent of total national consumption represents (low temperature) residential/commercial energy needs. With 44 percent of this energy comprising urban residential consumption and with a residential transport component for journey-to-work to the core added to this figure, total consumption of low temperature residential heat, and transport energy, approaches 16 percent of total national energy consumption. However, with apartments, classified as commercial, comprising at least 60 percent of this sector, total residential/commercial consumption is closer to 27 percent of total national energy consumption.

In the Plains region urban households consume approximately 5 per cent of national residential energy demand. At the same time, many Plains cities depend on fossil fuels for more than 90 percent of their heating needs (CMHC 1977), alternatives which can significantly reduce this component of national consumption require serious consideration. For example, if a large proportion of urban residential energy demands can be satisfied by substitution of less valuable (lower quality) energy sources to satisfy residential needs which might otherwise use high quality fuels, and if energy demands can be more closely matched with available thermal energy potentials, the net result can be a significant improvement in energy productivity (Fowler 1984).

However, as a prerequisite to consideration of such changes in energy policy, it is important to develop a method of measuring residential energy performance on a scale which is larger than either an individual household or a specific residential project. For this purpose, standard census tracts are seen as appropriate areal units for urban energy analysis and the method of areal energy modelling developed in this dissertation depends on the application of such areal data units.

1.3.4 Some Limitations in Evaluating Urban Energy in Specific Urban Areas

Identification of energy consumption by groups of urban households poses several data problems. These range from inadequacies in energy and related data for specific residential tracts to a lack of objective energy efficiency indicators for residential transport. The first problem reflects a deficiency of area specific data on residential energy demand and on urban residential energy production and consumption while the second problem reflects a lack of area specific data on residential transport energy, including inadequate data retrieval on motor vehicle ownership, the use of vehicles for urban transport, and their system efficiency in transforming fuel into useful energy.

In analysing urban energy, these limitations in data, which for component aspects such as dwellings are provided by census and other systematic national information sources, are only overcome by the use of certain assumptions and devices which are discussed in Chapters III, IV and V. However, identification of these data limitations at this point helps to set the stage for definition of the central problem considered in this dissertation, which is to illustrate a method of organizing, processing and modelling urban residential energy use and related data and consider its implications as an urban policy tool.

1.4 THE PROBLEM

The application of present methods of urban energy modelling offer limited means to evaluate and present change in urban energy relative to urban development over time. A planning method is needed which can facilitate application of a model of such change. This is particularly important in residential areas of large cities where (1) residential energy represents a large component of urban energy, (2) there is a need for communities and their residents to be able to comprehend dimensions of urban energy change over time and (3) there is an increasing need for practical policies for urban energy conservation in larger residential areas such as subdivisions, communities and neighbourhoods.

This sub-section identifies a perceived need for an illustrative urban planning tool which can demonstrate in a new way application of a method of organizing, processing and modelling urban residential and energy related data. This method uses a range of techniques of data assembly and builds on real data as far as possible. It also introduces a variety of devices to overcome limitations in real data and other constraints. The three components of this sub-section are: (1) definition of the problem, (2) statement of objectives and (3) conditions and relationships for demonstration of the method.

1.4.1 Definition of the Problem

Energy consumption for urban residential areas is usually determined in one of three ways: (1) by extrapolating regional aggregations of data on residential energy supply and demand from national accounts (Brooks and Casey 1979); (2) by extrapolation of empirical data for energy consumption by prototypical units such as dwellings or vehicles (CMHC 1977). For example, in the residential sector, a common method of energy analysis establishes consumption for typical household and extrapolates this energy unit to a larger residential area; and (3) by interpretation from aerial survey material such as infrared photographs of urban areas.

Although on a global basis the first two are useful methods to analyse national or regional energy consumption by cities, at a more detailed areal level they obscure variations in urban energy consumption and energy system efficiency among residential units and tracts within cities. They also mask factors such as microclimate, housing mix, housing age or condition, and variations in residential density. Conventional methods of modelling energy also disassociate "internal" residential energy conditions from "external" conditions such as transport energy (Dole 1975). For example, energy for automobile pre-warming in colder climates may not be accounted for as transport energy and/or may not be accounted for as space heating or environmental conditioning under internal residential energy. Also, residential location and/or dwelling type decisions by consumers intended to optimize residential transport energy in relation to other costs may not be accounted for (Eichen and Tukel 1982). Although the third technique for determining residential energy consumption reflects significant advancement in land survey technology, it is still in its infancy, and can result in misinterpretation of data particularly for high density or mixed land uses.

To influence residential energy consumption and efficiency in urban areas, it is essential to be able to model residential energy use in relation to urban development within and between different cities. For this purpose it is useful to apply a method of modelling residential energy use and urban development which can use real energy data and can take account of parameters such as density, travel distance and time. In demonstrating a method of organizing and processing real data and notionally applying it to a model of residential energy use, this research can contribute to provide at least a first approximation of residential energy use and can help to identify waste in relation to urban residential energy.

1.4.2 Statement of Objectives

The dissertation has three objectives:

(1) to develop a practical method of disaggregating residential energy consumption and other characteristics of residential land use by areas or tracts;

(2) to estimate and compare residential/commercial energy consumption for selected urban residential tracts under alternative energy futures and to identify factors which influence residential energy consumption within them; and

(3) to consider urban policies which can sustain a better balance between urban and regional energy production and consumption and thus increase energy system efficiency.

1.4.3 Conditions and Relationships to be Investigated

In illustrating a method of organizing data and applying a model of urban residential energy for large cities, a number of urban conditions and relationships are investigated. For three selected cities, areal residential energy consumption and system efficiency of residential energy are considered in relation to

(1) urban size and compactness; where urban size refers to the population which is contained within the boundaries of a city and compactness refers to the ratio of the total dwellings or households to the area of a city or urban area;

(2) areal residential density; the expression "residential density" is sometimes interpreted as meaning either population or dwelling density. It can also refer to the number of dwellings within a building or within an area, in effect areal residential density. In this dissertation, unless otherwise indicated, the expression areal residential density is denoted by residential density. Similarly, the expression "areal residential energy consumption" is denoted by residential energy consumption;

(3) age and condition of urban residential areas; although clearly not synonymous, these two conditions exhibit characteristics with sufficient similarities to suggest further investigation;

(4) the system efficiency with which urban energy is available in residential areas; refers to the sum of the efficiencies of the individual components in an urban residential energy system.

1.5 KEY QUESTIONS

In investigating areal residential energy in three selected cities, the dissertation considers a number of parameters, which are important in influencing residential energy consumption and efficiency, and consequently urban form. These parameters are related to questions about the impact on residential energy consumption of (1) city size and urban compactness; (2) residential density and journey-to-work to the core; (3) age and condition of residential stock; and (4) the ability of residential/commercial tracts in large cities to use available energy efficiently. These questions are considered in sub-sections 1.5.1-1.5.4.

1.5.1 The Affect of Urban Size and Compactness on Residential Energy Consumption

Selection of a limited number of large cities within a common physiographic region provides an urban laboratory in which to consider residential energy consumption and energy efficiency in relation to urban size and compactness. Specifically, this investigation addresses (1) variations in residential density, distance to the central core, and residential energy consumption for tracts in larger and smaller cities; (2) changes in residential energy consumption which result from differences in urban size or compactness; and (3) the effect of residential density on residential energy consumption under three alternative scenarios.

1.5.2 The Impact of Residential Density and Distance to the Urban Core on Residential Energy Consumption

In considering the relationship of residential density, journey-to-work to the core, and residential energy consumption, the following questions arise:

(1) How do changes in residential density in urban tracts affect residential energy density and household energy consumption?

(2) How are changes in residential energy consumption reflected in the form of urban areas? For example, how do changes in residential density and energy consumption alter the dependency of residential areas on automobiles for journey-to-work and on single detached dwellings as a predominant urban form? The form of an urban area includes architectural indicators such as shape, size and position and also urban design considerations such as urban movement systems and the infrastructure required to service urban areas. To the extent that urban movement systems both require and carry energy they can influence urban form and urban energy efficiency.

1.5.3 The Effect of Age and/or Residential Building Conditions on Residential Energy Consumption

Within this issue the following questions are addressed:

(1) How do age and/or building conditions in the selected cities or their residential tracts affect residential energy consumption and consequently, the efficiency with which residential areas are able to use available energy?

(2) How do residential energy consumption, residential density and distance from residential tracts to the urban core vary with the

age and building conditions of the selected city or with the location of its respective residential tracts?

1.5.4 Urban Energy System Efficiencies in Selected Large Cities and Tracts and Their Use of Available Energy

An energy system refers to a regular or orderly way of producing and/or distributing energy to a network of customers. For example, these may be in dwellings or vehicles. Urban energy systems are energy production and distribution systems usually in or near urban areas or cities. Some important questions with respect to such systems are:

(1) What energy resources are available or potential for residential/commercial and other purposes in selected cities and tracts?

(2) What are the existing system efficiencies of residential energy use in selected cities?

(3) Do residential densities and other characteristics of selected large cities provide potential alternatives for environmental conditioning and other energy consumptive purposes? For example, could residential/commercial tracts use centrally produced thermal energy directly rather than depending on combustion of fossil fuels within individual residential buildings?

(4) What are some possible density limits for distribution of thermal energy in residential/commercial areas of selected cities?

CHAPTER II - LITERATURE REVIEW

In this dissertation, the literature review provides an opportunity to seek out and examine both general and specific material which offers background, precedents, comparable experience and other useful information on the subject of the research. Essentially, it represents a searching process which ranges from broader concerns, such as the importance of energy consumption and efficiency to Canada's competitive economic position, to more detailed considerations of urban residential energy.

In its three parts, this chapter provides a review of:

(1) literature on energy conservation and related issues available in the English language, from northwestern Europe and from North America in the years since 1960;

(2) relevant literature on urban models and energy perspectives including consideration of some difficulties involved in large-scale urban modelling; and

(3) literature of particular relevance to specific aspects of the research design.

2.1 AN OVERVIEW OF THE LITERATURE ON ENERGY CONSERVATION AND RELATED URBAN POLICY SINCE 1960

The efficient use of energy is closely related to its relative scarcity in the world economy and energy consumption conditions and policies within the economies of energy-dependent industrial countries. In the years following the Second World War, most European countries were obliged by necessity to use non-renewable energy resources prudently. Consequently, in this period, energy was used more efficiently than in North America. It is not surprising therefore, to find that European literature on energy conservation from academe and industry is more developed than in North America. For example, in Sweden, Denmark and West Germany, where improved energy efficiency and conservation are closely linked to national urban and industrial policies, the literature not only includes academic and government publications, but also includes material on urban energy systems developed by or for export-oriented industries (Muir 1976; Larson 1977).

2.1.1 Selected European Literature on Energy Conservation

By the early 1970's many European municipalities and their energy industries had developed sophisticated hardware systems for energy conservation, including thermal heat power stations (Rieber 1977; Muir 1976), insulated thermal pipeline systems (Mikkelsen 1977) and advanced thermal energy distribution technology designed to serve entire communities or cities (Karlberg 1977; Wahlman 1977). They had also produced "software" in the form of publications on energy conservation and related planning principles and problems, as well as empirical analyses dealing with the economics and technical aspects of energy efficient urban development (Danish Board of District Heating 1977).

Although Great Britain has not been a leader among the industrial countries in the technology of urban energy conservation, it has produced some important technical literature (Turpin 1966; Diamant 1970; Dryden 1975). For example, during the late 1960's Diamant wrote several books on total energy systems, energy conservation and district heating. These included: Space And District Heating (Diamant and McGarry 1968), which reviewed technical developments in the U.K. and elsewhere in Europe, and provided useful parameters on the design and performance characteristics of thermal power plants and on urban and regional limits for thermal energy distribution systems; and Total Energy, (Diamant 1970), which explored a wide range of substantial technical issues, including co-generation, and applications of total energy systems in building complexes and urban areas of large cities. North American examples were also cited.

With a similar profligacy in energy use and inefficiency in energy systems design in Canada and the United States, and given the close links between the economies of the two countries, it is useful to consider North American examples of research in urban energy conservation. Of particular interest is research into the related questions of residential density, urban travel distance, and household energy consumption in both countries, immediately before and after the 1973 energy crisis.

2.1.2 Urban Energy Conservation in North America Prior to 1973

In North America, energy conservation and its application to urban policy have been recent developments. For example, a 1979 computer search of Ph.D dissertation abstracts on the subject of energy conservation and related urban policy issues from the early 1930's to the late 1970's revealed that during that interval, little research had been undertaken on empirical problems of urban energy conservation. From 1934, only a few dissertations were relevant to this subject. None had been undertaken in Canada.

Two relevant dissertations in U.S. universities were "Thermodynamic Evaluation of Energy and Waste Heat Utilization" (Bashiere 1973) and "Energy Conservation Through Urban Transportation Planning" (Carrier 1974). The former considered technical engineering (thermodynamic) aspects of the use of waste heat from nuclear powered thermal plants and potential applications of such thermal energy for urban purposes. The latter reviewed relationships between transportation and urban energy consumption in the United States, with a particular emphasis on the energy consumption characteristics of urban passenger transport. Carrier's dissertation also presented a systems approach for evaluating thirty-seven techniques for conserving passenger transport energy. These included changes in vehicle design and operating characteristics, mode shifts, fuel economy improvements; and reductions in vehicle miles of travel.

At a philosophical level, a 1973 dissertation entitled "Prologue to a Political Theory of the Steady State" provided a seminal ecological perspective on resource utilization which ultimately resulted in a book on the same subject (Ophuls 1977). Arguing for an end to "... endless technological growth", Ophuls suggested that a valid alternative technology must be based on ecological and thermodynamic premises that are compatible with the coexistence of man and nature over the longer term; as a consequence it must necessarily avoid merely quantitative progress, and strive instead to maximize amenity and general human welfare at minimum material cost.

Given the complex interdisciplinary nature of energy conservation and its relationship to urban policy, and specifically problems of physical planning, the dearth of academic research (at the Ph.D. level), for most of the century is not surprising, since historically such research focussed within well-defined established academic and professional disciplines. However, in North America, the existence of a longer term problem in regard to non-renewable energy depletion and energy efficiency was not widely recognized until the late 1970's.

A review of the professional literature, including technical journals, government publications and published books on energy conservation and urban policy, in both Canada and the U.S., further confirmed limited interest in the subject area until the mid 1970's.

Exceptions included a small number of well established researchers and scholars whose writings on resource efficiency and the environment from the 1950's to the 1970's foreshadowed some of the climactic events in world energy of the early 1970's. For example, Kenneth Boulding (1969) and Nicholas Georgescu-Roegen (1971) in political economy, Earl Cook (1971), and M. King Hubbert (1969) in geology and geophysics, Farrington Daniels (1964) and John Holdren (1971) in physics, and Raymond F. Dasmann, John P. Milton and Peter H. Freeman (1973) in ecology, all shared, either explicitly or implicitly, a common perception. This perception assumed that scarce natural resources, and in particular non-renewable energy resources, are finite, and their efficient use is essential if a sustainable satisfactory environment and quality of life for man is to be achieved, at acceptable cost, into the 21st Century and beyond. The following examples are illustrative.

Georgescu-Roegen in The Entropy Law and the Economic Process (1971) argued for refraining from consuming energy "stock" in the form of non-renewable resources and shifting instead to the use of, or dependence on energy "flows" (i.e. solar energy or its by-products: wind, tides, and hydraulics). He also argued for policies which would use thermal energy in forms appropriate to the requirements of demand.

Cook (1971), analysing man's use of energy in industrial societies, observed that:

> While the U.S. contains 6% of the world's population it uses 35% of the worlds energy. In the long run, the limited factor in high levels of energy consumption will be disposal of waste heat.(p.83)

To overcome this anticipated problem, he concluded that:

> Major changes in power technology will be required to reduce pollution and manage wastes, to improve efficiency of the system and to remove the resource availability constraint. Making the changes will call for hard political decisions. Energy needs will have to

be weighed against environmental and social costs; ..... Democratic societies are not noted for taking the long review in making decision. Yet indefinite growth in energy consumption ..... is simply not possible. (p.91)

Hubbert (1969, 1971), while finding that the epoch of fossil fuels is quite brief in human history (only 200 - 300 years), projected that over 80 per cent of the world's liquid fossil fuels would be consumed in a 65 year period from approximately 1970 - 2035. He also observed that while other non-renewable fuels have a longer time frame (e.g. coal), like oil, they too must inevitably deplete. He concluded that, not withstanding substantial technical progress in energy power plant systems and related efficiencies, the world cannot continue along past courses in future energy policies.

> It is true of power plants or automobiles as it is of biological populations that the earth cannot sustain any physical growth for more than a few tens of successive doublings. Because of this impossibility, the exponential rates of industrial and population growth that have prevailed during the past century and a half must cease.
>
> ..... the forthcoming period ..... can hardly fail to face a major revision in those aspects of our thinking ..... that stem from the assumption that growth rates that have characterized this temporary period can somehow be made permanent (Hubbert 1971, 40).

Farrington Daniels (1964), who identified potentials and possibilities of solar energy and its applications for urban and related purposes, concluded that:

> "..... the years [after 1964] will see the utilization of solar energy in many sun rich fuel poor areas of the world" and the ground will be laid for general advances well before the inevitable decrease in our fuel resources requires alternative sources of energy.(p.260)

Holdren and Herrera (1971) put forward two propositions on the general question of the energy crisis:

> First, as economists have known all along, a crisis in supply and demand can be met by moderating demand as well as increasing supply; second, as biologists have known all along, on this finite planet, we must moderate demand eventually.(p.23)

One of the most important ways which they suggested for moderating demand, or "whittling down needless demand" was to reduce wasteful uses of energy through development of "a rational energy budget".

> The list of wasteful uses of energy ..... should be enough to suggest that energy consumption per capita could be substantially reduced without a corresponding reduction in true standard of living. Space heating and transportation alone probably use twice as much energy as is reasonable or necessary, so that making appropriate changes in these sectors could reduce per capita consumption by 15 percent. (p.134)

Despite the observations of these and other analysts up to 1973, the institutional and professional energy policy literature in North America was heavily preoccupied with maintaining supplies of non-renewable energy to fuel an assumed continuation of unbridled economic growth. Less attention was given to the nature of such growth and its relationship to energy consumption and efficiency. In response to sharp increases in OPEC prices in 1973, achieving national self-sufficiency, primarily through substantially increased energy supplies, and moving to world energy prices became the important public energy policy objectives in North America to the early 1980's. For example, in 1973, following a two-year inquiry into fuel and energy policies, a U.S. Senate Interior Committee report recommended measures to "..... drastically tilt the scales in favor self-sufficiency for the

United States," and in addition "..... to reduce reliance on foreign fuels" (U.S. Senate Interior Committee 1973).

In the fall of 1973, the U.S. Administration response to the OPEC crisis, entitled Project Independence, consisted of measures to increase domestic energy production by providing new incentives and opportunities for (oil and gas) exploration and development. Although these recommendations also included some "demand management" measures designed to restrict the use of energy, such as "reduced auto speeds, lower thermostats, cold water detergent, mandatory auto tune-ups and increased car pooling," they provided little which might otherwise be defined as energy conservation (U.S. Federal Energy Administration 1974).

Up to 1974, Canadian public policy also offered little with respect to energy conservation. Nor was there, as yet, much public initiative to reconsider national or provincial energy growth projections. By the mid-1970's these were running at 4.4 to 5.6 percent per year. However, despite a lack of comprehensive long-range planning for energy policy in North America, and in particular, planning for energy conservation on a large scale, a number of valuable studies and other efforts in empirical research were beginning to emerge.

2.1.3 The Influence of the Environmental Movement on North American Energy Conservation and Related Policies

In the late 1960's and early 1970's, some of the U.S. literature dealing with energy policy and energy conservation revealed the emergence of considerable countervailing pressures between the energy supply lobby and the influence of the environmental movement. For example, Borrelli (1971), while suggesting that:

> Lawmakers and regulatory bodies are stymied by the simultaneous clamor for more [electric] power and a better environment, noted that their unresponsiveness ... to the dynamics of social forces ... has resulted in legions of informed citizens creating new forums,

> forcing others to become more responsive and [rediscovering] a wide array of democratic weaponry. (p.11)

Holdren and Herrera (1971) suggested more dispassionately that:

> thoughtful observers on both sides worry about the costs of bringing pollution and depletion, realistically, into the balance sheets, and how the resulting increase in the cost of energy will effect the poor at home and abroad.(p.23)

Concern with environmental issues was also intensifying in regard to the environmental pollution and hazard implications of fossil fuel and nuclear energy. These hazards included sulfur dioxide, nitrogen oxide, acid rain, trace elements, carbon dioxide and radioactive fission products. For example, in coal production, Horwitch (1982, 113) argued that "serious problems exist at practically every part of the coal system." In the area of nuclear energy, while acknowledging the "inflammatory" issue of reactor safety arising after Three Mile Island, Bupp (1982), reviewing the history of nuclear development in the U.S., suggested that:

> the unresolved problem of spent fuel from reactors ..... stands in the way of new orders and threatens the operation of both plants already in the pipeline, or under construction.(p.137)

Referring to "a large gap in scientific knowledge about long term radioactive waste disposal" Bupp (1983) also acknowledged that "... the [premature] building of a number of nuclear power systems proved very costly for everyone involved." He argued further that the failure of governments to deal honestly with the concerns of environmentalists and others in the 1960's continues to impede progress in the development of nuclear energy. As a result, he concluded that:

> In the United States, there is simply no reasonable possibility for "massive contributions" from nuclear power for at least the rest of the twentieth century.(p.171)

Given that most U.S. electrical energy and a large proportion of electrical energy in Canada derive from thermal generation, including nuclear and coal, and that thermodynamic laws result in only one unit of usable electricity (out of the generator) for every two units of heat produced (at the turbine), a growing concern with environmental planning problems and related effects of thermal pollution emerged in North America in the 1960's. For example, in 1968, a Vanderbilt University research team undertook a study of thermal pollution impacts of power production and other sources. Their report, entitled Thermal Pollution - Status of the Art Report, concluded that, if no policy intervention occurred, on the basis of power plant and other major thermal energy systems then projected, under construction, or completed, over 50 percent of the water in U.S. river systems would be required for cooling purposes by the late 1990's (Parker and Krenkel 1969). However, a literature review by Mandell (1974), which analysed research and practical projects on both sides of the Atlantic, demonstrated how large quantities of otherwise wasted thermal energy could be constructively used if appropriate policies were introduced to link agricultural, urban, and industrial developments with energy production systems.

In Canada, studies similar to Mandell's had been undertaken with the objective of exploring positive alternatives to the thermal waste problem. For example, a 1972 study prepared for the National Research Council of Canada demonstrated the benefits of using waste heat from large thermal plants for district heating (Brown 1972). In the same year, a study for Environment Canada reviewed techniques for reducing thermal pollution by productively utilizing waste heat, and highlighted opportunities and potentials for increased energy efficiency from comprehensive approaches to urban development, energy development, and power production (Cook and Biswas 1972).

2.1.4 Canadian Energy Policy After 1973 - The Emergence of Energy Conservation Considerations

In 1973, Canadian energy policy focussed primarily on supply-oriented measures. However, 1974 marked the beginning of more substantive energy policy initiatives in energy conservation. For example, in that year, an Office of Energy Conservation was established within the Ministry of Energy, Mines and Resources - Canada "... to develop and recommend a program of energy conservation and to play a coordinating role in that policy area" (Canada EMR 1973).

At about the same time, the Science Council of Canada commissioned F.K. Knelman to prepare a major background paper. The paper, entitled Energy Conservation, represented one of a number of efforts by the Science Council to assist in developing a national perspective on energy policy issues, including energy conservation. Patterning his analysis on data and methodologies developed in similar U.S. studies, Knelman developed a comprehensive picture of Canadian energy consumption within the four sectors of transport, residential-commercial, industry and electric utilities. Using short-term, mid-term and long-term time frames extending over a 20 year period, a series of projections from 1975-1995 was presented. The major innovation of the study was described as:

> ... an attempt to trace out the rate and path of implementation of conservation measures in a plausible and realistic manner over each of the time periods (Knelman 1975, 27).

Approaching conservation "via enhanced efficiency and only to a lesser degree demand management," Knelman argued that substantial energy consumption and efficiency improvements could be achieved in each sector over a 20 year trial period. These included improvements of 29 percent for transport, 31 percent for residential and commercial, 30 percent for industry, and 9 percent for electrical utilities.

In 1976, the Science Council of Canada commissioned Amory Lovins to review long range forecasts of Canada's energy consumption. Considering a 50 year time frame of 1975-2025, Lovins suggested that Canada could achieve acceptable growth objectives without significant increases in effective energy demand. This could be done, he argued, through more vigorous pursuit of conservation objectives. Primary energy in the year 2025 could be as low as 9.9 exajoules, less than half of the energy demands then projected by Energy Mines and Resources Canada for similar (or close to 2 percent) levels of growth (Lovins 1976). Lovins also suggested that even lower energy demand objectives were possible. In 1977, Lovins argument was given further confirmation at York University by a team of researchers, who concluded that a Canadian energy consumption objective of less than 5.3 exajoules per annum was achievable (Robinson et al 1977).

In 1977, a technical background paper prepared for the LEAP report for Energy Mines and Resources Canada (section 2.3.5) projected upper limit primary energy consumption scenarios based on economic growth projections of 1.1 percent from 1975 to 2000 and 2.3 percent from 2000 to 2005 as 16.8 exajoules and 21 exajoules respectively (Gander and Belaire 1978). While the substantial reduction in Canadian energy consumption envisaged by non-governmental analysts such as Knelman, Lovins, Robinson et al, appeared in the short run to have little influence on Federal government energy policies which were based on more conventional assumptions, in the late 1970's and early 1980's energy conservation potentials suggested by these analysts gave rise to a new generation of non-governmental energy analyses in Canada. This new approach began to focus on achieving sustainable energy consumption futures within each (provincial) region based on "soft-energy path" analysis techniques (Alternatives 1979, 1980). Several of these regional energy analyses are discussed in section 2.3.5.

As a result of the impact of the 1973 energy crisis, urban energy policy in the mid 1970's began to receive serious consideration in all northern industrial countries. For example, in October 1977, in response to a recommendation of the UN Economic Commission for Europe (ECE), and following on Canada's successful efforts in hosting the UN Habitat Conference in Vancouver in 1976, the Government of Canada offered to host a UN sponsored seminar in Ottawa entitled "The Impact of Energy Considerations in the Planning of Human Settlements." Comprising countries from both Eastern and Western Europe, the seminar focussed on energy policy issues of physical planning, urban and regional planning, new and existing buildings, and methodologies. With each participating nation, and its respective non-governmental organizations, contributing topic and response papers on these subjects, the seminar provided a unique opportunity for Canadian representatives and non-governmental organizations to become familiar with state-of-the art developments in urban energy conservation policies in other ECE countries. The seminar also helped to identify for Canadian policy makers some of the technical, institutional and economic problems which must be resolved in order to keep pace with other northern industrial countries in matters of energy policy, and to increase energy efficiency and urban energy conservation. Some relevant seminar submissions included papers on district-vs-decentralized heating systems, and on methods and techniques for taking energy considerations into account when preparing community plans and development (ECE Energy Seminar 1977).

Seminar papers also confirmed that, in recent decades, there has been an increasing recognition that it is important to take advantage of urban design potentials to achieve more efficient use of available urban energy. Regardless of fuel consumed in power plants, or whether they are centralized or decentralized, an essential consideration in urban energy conservation is matching the quality of available energy (e.g. temperature) with the basic energy tasks required in urban areas. Consequently, it is necessary to be able to predict the extent to which cities and their urban tracts require energy for different sectoral needs and to be able to efficiently match these needs with appropriate resources. Such energy matching is a prerequisite, for example, to the establishment of centralized thermal energy distribution in urban areas.

Also of relevance to reduced residential energy consumption, and increased end-use efficiency and urban well-being, are multivariable studies of basic interrelationships which affect energy consumption for urban transportation and urban development. In 1977, the Canadian delegation to the ECE Energy Conference identified this as an important emerging issue (Canada ECE Secretariat 1977). In 1980, a Federal budget publication indicated that funding was available through 1978-80 to undertake such multivariable studies (Ledwell 1980). To date, however, no comprehensive studies of these relationships have been published in North America, and the need for such research continues if long term energy conservation policies are to be effective.

2.2 URBAN MODELS AND ENERGY PERSPECTIVES

Urban conditions in large cities, as in other complex systems, sometimes require the application of predictive and/or simulation models to abstract from reality, where real conditions are too complex to effectively analyse or predict. Such models range from description and prediction of the performance of urban facilities, services and growth (Mayer 1969) to measurement, evaluation, or prediction of the behaviour and preferences of consumers or other decision makers. Urban services which are commonly "modelled" include the movement of goods and people in urban transport systems (DMATS, 1955; CATS, 1957; MTARTS, 1966); the supply and consumption of water, electricity, gas, and communications; as well as the collection and treatment of urban effluents. More recently, urban energy has begun to be subjected to prospective modelling (Muir 1976).

2.2.1 Some Applications of Modelling of Complex Urban Systems

Urban gravity models with origins in the laws of physics emerged as a method of analysis of urban land use with the Law of Retail Gravitation (Reilly 1931). Using an empirical approach to analysis of retail trade areas in 132 U.S. urban areas, Reilly found that

> two cities attract retail trade from any intermediate city or town in the vicinity of the breaking point approximately in direct proportion to the population of the two cities and in inverse proportion to the square of the distances from these two cities to the intermediate town. (p.9)

In addition to population size and distance, Reilly noted other factors which might result in variations in retail trade area, including transport facilities, lines of communication, business services, social, recreational and cultural facilities, parking, and business leadership.

Mitchell and Rapkin (1954) identified and classified the nature of urban traffic in relation to all urban land uses. They suggested that much of the pattern of urban development can be explained by the movement requirements of business establishments and other institutions in urban areas, particularly with respect to locations in or near the urban centre.

> Specialization of urban activities ... [results in] ... a pervasive tendency for establishments to make accessibility a major locational consideration... For some this means access to the largest number of persons, firms or households - a central location; for others it means convenience in regard to an inexpensive channel of goods-movement; and in still other cases it means actual proximity.(p.132)

In the 1950's and 1960's, urban land use and transportation models began to be used extensively as a method of analysing the use, availability and demand for urban land use and transportation within large metropolitan areas (Detroit Metropolitan Area Traffic Study 1955;

Carroll and Bevis 1957; Chicago Area Transportation Study 1959). With the advent of the electronic digital computer and its application for urban research after 1946, an important analytical tool was developed for processing the complex data generated by urban models (Voorhees 1955). By the mid-1960's urban transportation and utilities modelling had evolved considerably with the development of such analytical tools (Metropolitan Toronto Area Region Transportation Study 1966).

In the subsequent twenty years, miniaturization of computer technology, increased processing speed and capacity, the development of the capability to analyse and describe multidimensional configurations and massive decentralization of computers with extensive pre-packaged software have opened up new possibilities for analysing and modelling three-dimensional time-related urban variables. It is now possible to adapt most urban information to analysis by computer, provided the data for such analyses can be readily accessed and provided that adequate software programs are available or can be developed.

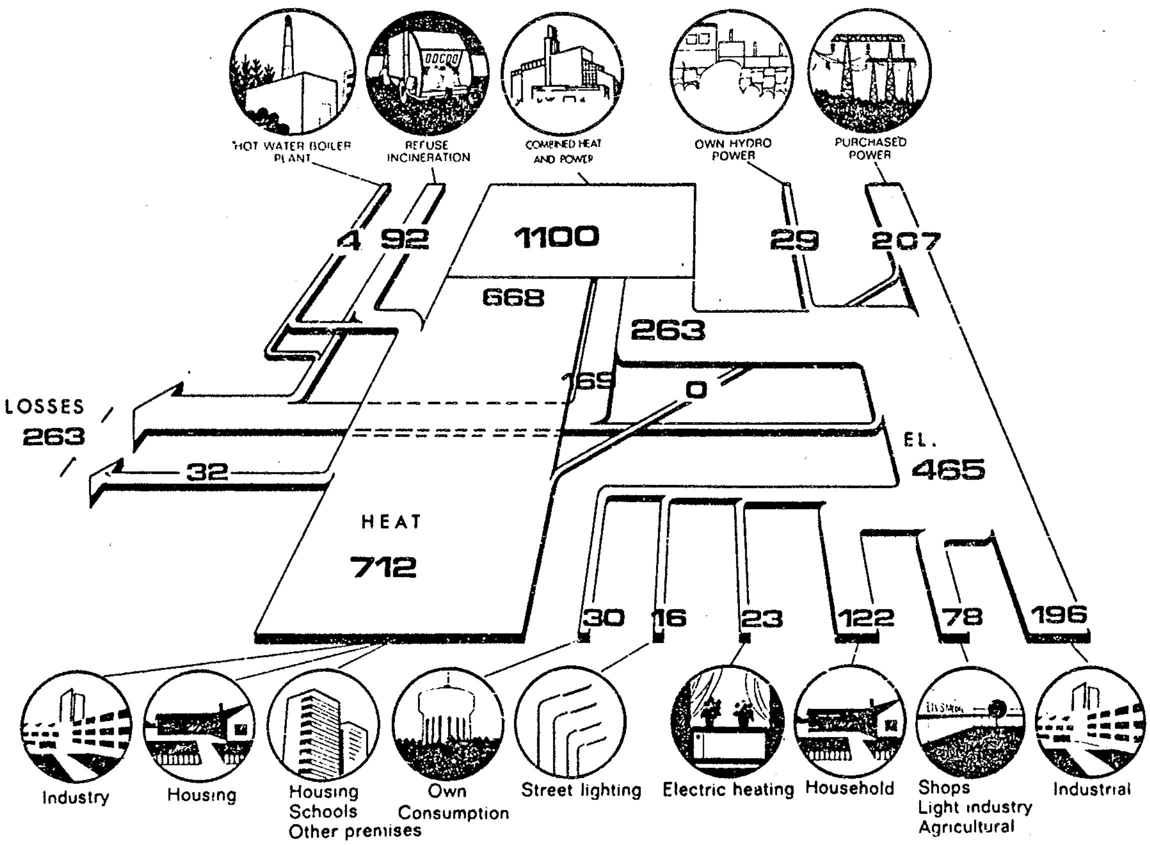
2.2.2 Modelling in Urban Energy Analysis

For almost a century, scientists and engineers have modelled and measured energy flows required to increase efficiency in energy production and consumption. In larger European cities, where thermal energy as well as electricity is often produced and distributed by municipalities, urban energy models of the input-output variety are an essential tool for public policy and planning (Figure 8). In fact, legislation under consideration in 1975 by Sweden's parliament called for federal and local authorities to establish a comprehensive review process for major energy investments. It was widely accepted that plans should be based on

FIGURE 8:

Energy balance sheet for Linköping power and heating company, 1974-75

Energy flows in millions of kWh



The figure shows the energy balance sheet for 1974-75 for Linkoping, Sweden, a city of over 100,000 population and with approximately 80 percent district heating coverage. The heat flows in the diagram are for district heating consumers only, while the electrical energy is for the city as a whole.

SOURCE: Neil Muir. 1976. Combined District Heating and Electricity Production in Sweden. Paper presented to a Symposium on Energy Production in the Built Environment, Garston, England. Finspong, Sweden: Stal-Laval Turbin AB: Figure 2. p.6.

> thorough study of actual consumption and supply patterns, a forecast of consumption of various kinds of energy, and a study of possible supply patterns taking into consideration economy financing, environmental and supply security (Karlberg 1977, 9-10).

In its 1977 national energy legislation, Denmark, in effect proposed similar requirements for municipalities in an effort to rationalize the production and distribution of electricity and thermal energy (Larson 1977).

In the development of comprehensive urban energy analyses, variables such as building density, building design characteristics, and spatial distribution of urban development are important considerations. Also important are questions of residential energy quantity and cost, not only for space conditioning, water heat, and power for appliances, but also for essential residential transportation needs, such as the journey-to-work.

2.2.3 Some Problems of Urban Energy Analysis in North American Cities

Although global or national energy perspectives on future energy supply and demand and related problems have been developed in North America, more often than not they have either been theoretical analyses based on: (1) projections of aggregated data, such as <u>An Energy Policy for Canada: Phase 1</u> (Canada EMR 1973), or the 1974 MIT Energy Laboratory policy study, <u>Energy Self-Sufficiency: An Economic Evaluation</u> (Adelman et al 1974); (2) aggregated data and gross assumptions (Knelman 1975); or (3) a cross section of opinions or judgements by informed international experts using delphi techniques or other methods (Smil 1974; O'Toole 1978; Staubough and Yergin 1983). Rarely have such perspectives been derived from an analysis of empirical data for specific urban or other energy consuming regions (Fels and Munson 1975). Consequently, the applicability of global or regional models to analyse energy in specific urban areas has been less useful than might have been the case if more specific and detailed evidence of urban energy had been systematically developed. Studies which were undertaken in urban areas, such as Trenton, New Jersey (Fels and Munson 1975), have been limited in their degree of comprehensiveness and in the precision of their energy data. Nevertheless, they represent important progress in urban energy analysis.

Gravity models of land use and transportation, and urban analyses of a more specific nature have been developed to address particular urban variables or constraints. Such variables have included modal split and journey-to-work distance, time savings, and related cost-benefit considerations. However, urban transport models have not related residential prototypes, transport systems or travel characteristics to household energy consumption -- a three variable approach. There are dangers in attempting to develop a comprehensive approach to urban energy analysis. For example, the soundness of "large scale" approaches to urban analysis and the need for care in predictive modelling in addressing fundamental urban questions have been identified as a matter of concern (Alonzo 1968; Lee 1973). Reliance on simpler more pragmatic approaches has also been suggested.

Lee evaluated successive efforts to construct and apply large scale models in a planning context. He suggested that such models were too complex, required excessive data, attempted to achieve too many purposes, required digital computers to process their data, and were too expensive for the results achieved. From an inspection and evaluation of previous large scale models and their results (which he did not document), he suggested the following guidelines:

(1) A balance should be obtained between theory, objectivity and intuition. Excessive concern for theory results in a loss of contact with the policy problem, but policy cannot be formulated well without a strong theoretical formation.

(2) Start with a particular policy problem that needs solving not a methodology that needs applying ... Work backward from the problem matching specific methods with specific purposes and obtaining just enough information to be able to provide adequate policy guidance ...

(3) Build only very simple models. The skill and discipline of the modeller is in figuring out what to disregard in building his model.

(4) Planning is in the unique position of being oriented around urban problems rather than around any discipline of science. The field can draw from others selecting only those theories and methods that will be most useful.(p. 175-176)

2.3 LITERATURE OF PARTICULAR RELEVANCE TO THE RESEARCH DESIGN

This sub-section focuses on aspects of the literature and related data which have direct application to specific components of the research design. These include: some implications of urban design on the energy characteristics of large cities, which is detailed in section 2.3.1; the relationship between energy and land use, which is reviewed in section 2.3.2; the relationship between energy and urban transport, reviewed in section 2.3.3; statistical data sources on energy and urban development, which are reviewed in section 2.3.4; and sources for analysis of two paradigms for hypothetical cities, which are covered in section 2.3.5. In section 2.3.6, literature on alternative energy futures under three scenarios is reviewed, and section 2.3.7 considers analyses of alternative energy futures for each of the three provinces of the Interior Plains.

2.3.1 Some Implications of Urban Design on the Energy Characteristics of Large Cities

In the early 1970's, in response to growing concerns about environmental costs and their urban impacts, the U.S. Council on Environmental Quality, the U.S. Department of Housing and Urban

Development (HUD) and the U.S. Environmental Protection Agency (EPA) jointly commissioned a study of the impacts of urban design on the overall costs of development (Real Estate Research). Although the study, entitled The Costs of Sprawl, took account of energy use as a factor in its evaluation, the depth of its energy analysis was limited, in part, because energy efficiency was not yet appreciated as the crucial variable it would become within a few years.

The study presented a series of hypothetical residential sub-division configurations which were assumed to be located close to a typical freeway interchange. Among other things, the study found that: (1) increased densities and planning practices such as integrated land uses and innovative subdivision planning could reduce urban energy use by as much as 44 percent; and (2) increased urban densities could result in as much as a 40 percent saving in energy (Real Estate Research 1974).

The study approach and its conclusions were also reviewed in the urban planning literature (Altschuler 1977). It was criticized, among other things, because it failed to account for differences in the floor area of its housing types. The same critic also suggested that real energy savings from high density were less than claimed and that energy efficient planning would achieve only a fourteen percent saving.

2.3.2 Energy and Land Use - Some Costs of Urban Policy

Urban spatial structure, energy studies, stimulation studies of alternative building types, studies of alternative urban structures, the relative effectiveness of a land use policy, and the costs of such a policy were examined in a paper entitled "Energy and Land Use - An Instrument of U.S. Conservation Policy" (Keyes 1976).

In analysing urban spatial structure, Keyes suggested that

> the overall relationship between patterns of land use (spatial structure of urban areas) and energy

> consumption, holding constant, the influence of climate, population characteristics, intensity of industrialization, end use efficiencies and the like derives from two intermediate relationships, one involving building types and the other travel behaviour. ... energy used in any city is ... a result of its three-dimensional structure.(p.225)

Keyes also found that disaggregated data on energy use in urban areas were unavailable and that descriptions of urban spatial structure depended on population density analysis. He suggested that "the use of data on building type rather than population density provide more insights" (p.227) and that multi-family buildings are not less thermally efficient than single family detached dwellings.

On land use and transportation, Keyes concluded that:

> Although comparison of findings from the various transportation studies is inhibited by the lack of commensurate units of analysis, the following can be stated as general findings:
>
> As population density increases, the number of non-pedestrian trips decreases. This appears to be true for both generally high and generally low density urban areas (the Hong Kong syndrome).
>
> As both population and employment density increase within urban areas, the percentage of trips taken by automobile decreases.
>
> As distance from the central business district (core) increases in British cities (a surrogate for decreasing population density), the average speed of traffic increases.
>
> Average metropolitan trip length has not shown to vary consistently with average population density, although some differences between central city and suburban trip lengths have been observed (Keyes 1976, 227).

In terms of relative effectiveness of a land use policy as a tool in energy conservation, Keyes observed that:

> in the case of energy conservation strategies available evidence will only allow us to reduce the degree of speculation about the effectiveness of each ... [and facilitate attempts] ... to estimate the savings that could reasonably be expected to obtain from control of new development patterns and to place these in the context of savings potentially achievable.(p.232)

He also noted that ... [over a decade] the likely savings from more efficient land development patterns are significant but not dramatic.(p.234)

Keyes suggested the following policy prescriptions as a means to reduce the need for regulatory land use control tools, and to encourage energy efficient urban development:

> sharp increases in price of fuels may work to encourage more efficient development patterns in the absence of increased land use regulation. Likewise, technological improvements in end use efficiencies and increased thermal efficiency standards may reduce the need for additional regulation by reducing the energy differential between efficient and inefficient development patterns.(p.235)

Local governments it was suggested should be encouraged" ... to explore a range of options" before supporting energy efficient land use and "... greater manipulation of development patterns" (p.235). Finally he argued that:

> the development and management of urban areas involves difficult trade-offs among multiple objectives. The most thermally efficient just may prove to be the deadliest from an air pollution perspective. (p.236)

2.3.3 Energy and Urban Transport

An urban transportation and energy analysis model which was particularly relevant to issues of transportation and urban energy in this dissertation was entitled "Energy Thrift in Urban Transportation - Options for the Future" (Fels and Munson 1975). This study, undertaken in the Trenton, New Jersey Census Metropolitan Area, examined patterns of urban transport energy consumption "... which are conceivable for the last quarter of this century."(p.7)

The working laboratory selected for the study was Mercer County, N.J., which at 304,000, by definition, represented medium size cities in the population range of 100,000 to 500,000. Using this urban laboratory and existing metropolitan transportation data, the study explored factors which influence the demand for transportation in an urbanized area under an assumption of increasingly scarce fossil fuels.

The study defined a spectrum of possibilities or "options" for improved transport energy performance over time. Energy consumption which resulted from policy preferences and living patterns assumed under each option were estimated, and no option was viewed as more likely than any other. Because as many as 70 travel estimates defined each option, and many varied among options, it was observed that "no particular energy result could be attributed to any causal effect but only to a combination of them."(p.8)

In their results, Fels and Munson calculated that by the years 1985 to 2000, differences in per capita consumption of energy of four times and ten times, respectively are possible. These proportions represented the difference between "a luxury car option", which assumed an affluent population living in dispersed urban arrangements and driving less energy efficient autos, and an "energy conscious option" under which fewer and shorter trips would be taken by more modest-income households who would live closer to one another and to their work. Under this latter option, travel would also be by more energy efficient modes. Between these two extremes, a range of intermediate options was assumed, including innovative forms of urban transportation, fuel price increases, modified automobiles, and various combinations of these variables.

Options which represented substantial changes in urban structure were also explored by Fels and Munson. Although not all of the analysis of their research was documented, the following were indicated:

(1) In a dispersed option

- households continued to live in low density arrangements but located or relocated to shorten their journey-to-work;
- employers responded by clustering in a few large employment centres throughout the metropolitan area;
- low density residential villages developed around major work centres significantly reducing journey-to-work distance (and energy) for average households;
- non-work trips were largely unaffected, however, where commercial activities were also clustered in larger centres, trips were slightly longer;
- savings of 20 percent and 35 percent were estimated for the most energy consuming option by 1985 and 2000, respectively. However, several technological and energy price changes were incorporated into the developmental characteristics of this option.

(2) In a more compact option,

- higher density living was emphasized, but more dispersed non-contiguous patterns of employment and development were assumed.

. non-work travel was greatly reduced while average work trips were lengthened. However, the former outweighed the latter, resulting in approximately 25 and 30 percent savings in consumption for the least efficient energy consumption patterns by 1985 and 2000 respectively.

2.3.4 Statistical Data Sources

Two statistical data sources for this dissertation are Perspectives Canada III and data summaries from the 1981 Census of Canada. As a third volume in a series of selected social statistics, which is brought together within a covering theme, Perspectives Canada III offers

> ... a set of descriptive essays which rely primarily on statistics to provide a variety of perspectives on the social and economic features of Canadian life... (Adler and Brusegard eds. 1980, V).

The study comprises fifteen chapters on topics such as Population, Health, Education, Work, and Justice. Chapter 11, Urban Profiles, (Mitchell and Bond 1980) and Chapter 13, the Use of Energy (Leyes, Fitzgerald and Mitchell 1980) are of relevance in this investigation. For example, Chapter 11 explored

> ... some aspects of the multiformity of 23 large urban areas in Canada. This can be viewed from three perspectives ... differences and similarities between any two cities* ... between different areas in the same city, ... or between similar districts of different cities.(p.185)

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* These cities contain (1976) census metropolitan areas (CMA's) with populations in excess of 100,000 and a main labour market in an urbanized core or built up area.

Chapter 11 is divided into two parts: (A) The Urban Residents, which deals with characteristics such as population growth and change, immigration, education, and socio-economic profiles; and (B) the Urban Environment, which deals with economic activity, the natural environment, the man-made environment and the social environment. The three selected cities in this dissertation are among the twenty-three cities analysed by Mitchell and Bond (1980). The three zones in the three cities from which tracts in this analysis are selected correspond closely with the zones identified by Mitchell and Bond, namely: Central Area, Mature Suburbs and the New Suburbs and Fringe.

Chapter 13 provides aggregate energy consumption for all types of energy sources for domestic and other purposes. While no energy consumption breakdown is provided between rural and urban areas or within urban areas of the twenty-three large cities, the chapter is useful in providing time-series data on energy consumption in Canada over many decades.

2.3.5 Polycentric Urban Models or Centralized Urban Megastructures - Two Paradigms for Hypothetical Cities

During the 1960's, at least two different views of resource efficient urban form emerged. The first, articulated by some geographers and urban planners, suggested that conservation of time and other resources could best be achieved by urban decentralization. For example, Gutkind (1962) argued that this would encourage decentralized urban patterns greater reliance on freeways and automobiles, depopulation of the central city, and increased dependance on telecommunications. Gottman and Harper (1967) argued that application of technology would make it possible to strengthen urban and regional patterns without sprawl. At the other end of the urban spectrum was a view suggested by architects and urban designers such as Erskine

(1961), Lynch (1961) and Tange (Boyd 1962), who suggested compact core cities or megastructures not unlike space stations or beehives. These were to be designed to provide efficient life support systems for large groups or whole communities on a sustained basis. Under adverse environmental conditions, most urban functions would be under one roof.

Despite the extreme differences in their urban form these different views about compact-vs-decentralized cities provide a useful scale for evaluating implications of conventional empirical urban development in a future of increasing resource constraints. On any scale of urban design values, most large cities fall between these notions of compactness or dispersal. In the 1970's, Golanyi (1976), Goodman (1977) and Dantzig and Saaty (1973) explored implications of such alternatives for energy resources, transportation, and urban form. The first two were particularly relevant to decentralized urban form, and the third illustrated a compact city.

2.3.5.1 Decentralized Urban Form - Golanyi undertook a survey of technical innovations which could facilitate decentralized urban development. Goodman presented a theoretical paradigm for urban decentralization based on a comprehensive view of its social and economic implications in a future of increasingly scarce non-renewable energy resources.

In an extensive survey of innovative urban design and related alternative technology, entitled <u>Innovations for Future Cities</u>, Golanyi reviewed potential advances in the application of telecommunications and other technologies, which influence urban design and development. Among other things, he examined the effect of teleconferencing on urban transportation; the possible role of satellite centres, neighbourhood centres, and the home, as work places; and the possible impact of telecommunications on rapid rail transit. He also considered commuting time and distance, capital and operating costs, and energy. In this research, he premised that:

> ... improvements in telecommunications may substitute for interoffice business trips thus reducing the need for clustering office activities in the central business district in order to facilitate face to face contact. (p.26)

Drawing upon a number of studies of larger metropolitan centres, including work by Harkness (1973), Golanyi also showed how a relatively small amount of "teleconferencing" could have a disproportionately large impact on urban land use and transportation. Considering three different types of decentralized offices, satellite centres, neighbourhood centres, and "work-at-home" arrangements, he showed how commuting patterns shift when firms relocate to the suburbs. He also found that a satellite urban centre accelerates in importance through advances in telecommunications in a manner quite different from a neighbourhood urban centre:

> The neighbourhood centre is fundamentally different from the satellite centre concept in that it fragments organizations instead of relocating them completely. [Nevertheless, he noted] ... the neighbourhood office concept is far less radical than the work at-home scheme ... with an elaborate (computer) terminal for each worker with no chance of the sharing that would be possible in [office] centres.(p.43)

With respect to urban transport, Golyani concluded that:

> ... unless office employment grows in central business districts, new rapid rail transit systems are not needed. In short, office decentralization supported by increased telecommunications is a potential alternative to multibillion dollar rail systems.(p.45)

> ... dispersing office jobs to suburban satellite centres can reduce commuting by about half, while dispersing them to neighbourhood centres can reduce commuting to any desired level.(p.45)

In a decentralized growth pattern of four satellite centres, which are automobile and/or personal rapid transit oriented, substantial transportation efficiencies over auto-rail based systems are possible to the CBD (Harkness 1973). For example, more than one half billion dollars each have been estimated as possible savings for more than twelve large U.S. cities that were considering improved or new auto-rail alternatives in the mid 1970's (Golanyi 1976, 47). On the question of energy efficiency, however, it was found that CBD oriented auto-rail concepts benefit to a greater degree from increased efficiency of rail over other modes.

A second book which made a strong case for decentralized urban settlements was The Double E by Percival Goodman. This was an effort to update (to the mid-1970's) utopian social and economic planning theories advocated in an earlier book entitled Communitas (Goodman and Goodman 1947). In his introduction to the 1977 update, Goodman provided the following explanation of the need for a rethinking of notions in Communitas.

> It was ... feasible to recommend many possibilities [in Communitas] since for the first time in history ... we [had] in the U.S. a surplus technology ... that [allowed] for the most widely various community arrangements and ways of life.
>
> The presumption was correct but who could have guessed how quickly our appetites would grow, our surplus would diminish and how badly we would choose ... Limits not free choice; scarcity not surplus, are now the facts that will condition our future.(p.4)

With this revised perspective, Goodman (1977) redefined a paradigm for decentralized urban and regional planning based on two interrelated concepts which were of particular concern in the industrialized world in the mid 1970's, "Economy (the management of expenses) and Ecology (the mutual relations between organism and environment)" (p.115). In practical terms, these concepts, designated by a Chinese symbol which resembled a double E, translated into providing "... the means by which all could produce a guaranteed subsistence earned through their own work" (p.174). As such, the planning concept which emerged resulted in highly rationalized living and working areas, a high degree of self sufficiency for most residents (e.g. 128,000 population), mixed land uses (except for nuisance industries), and a close integration of farming and food production with urban development through the inclusion of farms and kitchen gardens within the limits of smaller cities.

Goodman's paradigm housed 128,000 people within a 10.4 square kilometre area at a residential density of approximately 123 households per hectare. A hectare of garden space was allotted to every twenty-five inhabitants, and farm gardens or allotments were situated within a 1.6 kilometre ring surrounding the urbanized portion of the township. Along the ring roads on the outside of the town were specialized centres designed to service farms, gardens, and factories; along the towns outer edges were larger farms and what were called "basic economy production centres". Finally, around all of this was an open space green belt containing regional recreation, institutional, and major transport facilities. The area covered by this urban "township" was in the order of 260 square kilometres, at an average population density of 965 persons per square kilometre. (Further details of this paradigm are found in Chapters III and IV, and in Appendix 1, Plate 1).

2.3.5.2 Compact Urban Form - By the early 1940's, a need for improved productivity at the outset of the Second World War, among other things, stimulated considerable interest in archetypal relationships of (conventional) city size, travel time, modal split and urban efficiency. For example, a 1940 study which explored the potentials of more spatially efficient urban arrangements suggested:

> the average city of 10,000 will have a radius of one mile and a city of 100,000, a radius of 2.3 miles and the city of one-half million, 4.1 miles, in an idealized assumption of urban areas (Stewart 1947, 179-180).

A 1942 survey indicated that the average resident of cities over a half million lived 4.8 miles from work, and required 24 minutes to get there. In these cities 60 percent travelled by mass transit and 30 percent by automobile (Branch 1942). From the same year another survey suggested that

> ... in cities of 25,000 to 100,000, 80% of vehicle passengers arriving in the CBD travelled by auto versus 40% in cities over 1.2 million; the remainder travelled by some means of mass transport (Lee 1942, 311-325).

A concern with postwar population growth, and its general implications for urbanization in the 1950's, stimulated further interest in the relationship between population size, density and city size (e.g. radius). For example, Clark (1951) established a clear mathematical relationship between population density and city size with data from a large number of cities indicating an inverse variation of density with distance from the centre. Newling (1964, 1966, 1969) modified Clark's theory by using a second degree polynomial to identify a central area density crater. This in, in effect, accounts for population declines in or near the core in most cities.

By the 1960's extensive auto usage and the implications of its total cost was beginning to be of concern to urban planners and other urban policy makers, as auto dependency for journey-to-work increased sharply. For example, one estimate showed Chicago increasing to 60 percent auto dependency, with the remainder travelling by foot (10 percent), bus (10 percent), rail (10 percent) and taxis (10 percent). This study by The Kiplinger Magazine suggested that

> Converting two out of three car riders [commuters in the 60% group] back to bus and train travel ... would reduce Chicagoans' commuting bill by 25% and free $205,000,000 annually for other kinds of spending (Changing Times, May 1961, 88).

In the late 1960's, a number of planning and urban design concepts which had been articulated over that decade, began receiving greater attention in urban design and city planning literature. This interest reflected a number of universal concerns, including increased scarcity of land for urban development in some urban regions, the need to design buildings and cities in adverse climates, and an increased concern with problems of resource efficiency in urban development. Designers such as Tange (Boyd 1962) and Fuller (McHale 1962) suggested relatively compact, geometrically simple, urban prototypes. Others, including architects, planners, and urban designers, such as Aalto (Fleig 1963), Alexander (1971), Andrews (Jackson 1981), Erskine (1961; Egelius 1977), and McHarg (1971) indicated a concern with more complex environmentally responsive urban design. By the early 1970's, a number of simple paradigms of urban compactness had emerged. One of these, a simplistic hypothetical model (Dantzig and Saaty 1973) had origins which were closer to systems analysis, operations research, and industrial engineering than to more traditional approaches of architecture, city planning, and urban design.

Concerned with wasted environmental resources and time, Dantzig and Saaty (1973) illustrated their concept of <u>The Compact City</u> in a simple diagrammatic fashion. Using the Los Angeles conurbation as an example, they reduced 373 square kilometres of suburban California sprawl to 23 square kilometres of efficiently stacked three dimensional space. They considered density to be "a factor which could be used to estimate the availability of three dimensional space" (p.28). Therefore, density should be expressed not in persons per square kilometre, but in persons per cubic kilometre. In the extreme form in which they presented it, their compact city model began with the principle that:

> "... to keep population densities low, conserve land use, and avoid urban sprawl, man must move to effectively utilize the vertical dimension.(p.29)

Based on a population density in the order of 5400 persons per square kilometre for each layer, a household density in the order of 2100 dwellings per square kilometre represented more than 20 dwellings per hectare for each layer or "tray" of development. However, this density calculation was based on computing population and residential building density for only one layer of an eight layer city. Consequently, density calculations based on the number of households above a ground plane resulted in an effective residential density figure eight times the residential density for a single layer, or 43,200 persons per square kilometre (Dantzig and Saaty 1973).

The general plan for Dantzig and Saaty's compact city model assumed an initial population of 250,000 in a circle 5.7 square kilometres in base area, with a radius of 1348 metres, and ... a low flat silhouette (an upside down cake pan with sloped or battered sides)." It was also designed to grow to an area of 22.5 square kilometres, ultimately containing a population of two million (Appendix I).

Within its truncated cone shape, the compact city's eight platforms, 9.2 metres apart, rose to over 73 metres. Constructed on each of these trays were all of the required buildings and functions of a typical city with the exception of deleterious land uses, such as steel mills, foundries, refineries, and airports. These were to be located well outside the main urban volume. Atop the uppermost platform was "a landscaped central park plateau - a man-made mesa ... 73 metres above the surrounding countryside." One-half of all housing units were built on the outside periphery of this megastructure in the form of terraced apartments (with an outside view). Housing at the upper level, and just below the roof, received natural light through various deep light wells. An additional 80,000 highrise apartments were built in a ring surrounding the circular central roof top park. Various "lots" for offices, manufacturing plants, stores, schools, cinemas, auditoria, and a stadium were accommodated within the depths of the complex. The interior was envisaged as an all weather artificially lit space, much of it available 24 hours per day. Although access to the outdoors from the interior was not directly available to many interior units, it was assumed to require only a few minutes walk. Circulation in three dimensions was facilitated either by elevator, electric vehicle or on foot and minimum travel time and transport energy consumption were assumed. Thus, work trips into the core and to most urban destinations were by walking, cycling, electric cars, moving belts, elevators, escalators or other self-activated translational devices.

The radius of the city, approximately eighteen times its height, was selected to achieve minimum total travel time between the centre of the highest urban elevation or level and the greatest extremity at the base of the city circle, including both horizontal and vertical circulation. Most travel distances were relatively short because the diameter of this urban model was only slightly larger than 1.33 kilometres. (This compares with Winnipeg's diameter of 22.4 kilometres). Even at a hypothetical maximum population of two million, the urban radius of Dantzig and Saaty's compact city model was only 910 metres from the centre - a 15-20 minute walk (Appendix 1, Plate 2).

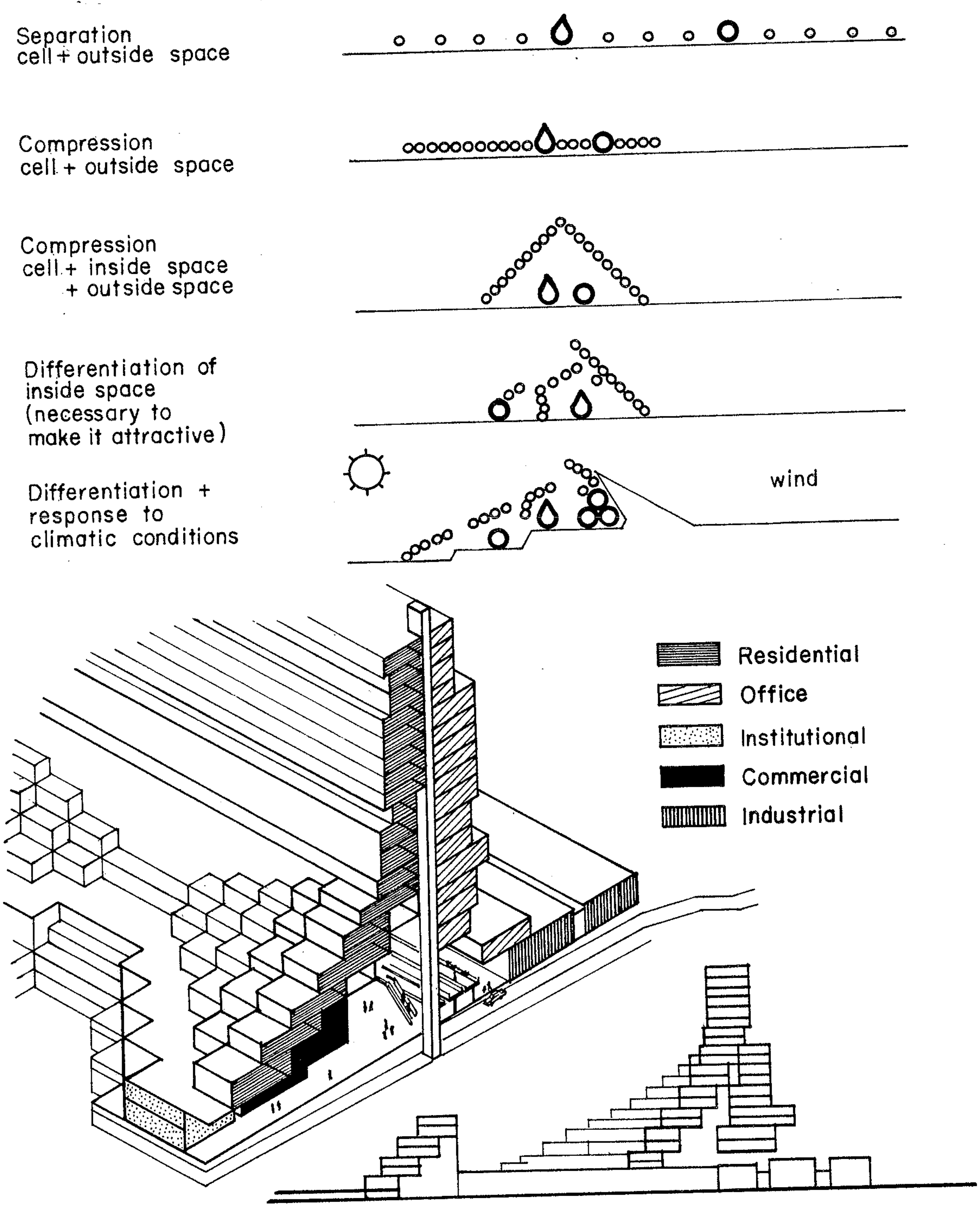
The Dantzig and Saaty model, which represented a hypothetical urban "megastructure" - a large scale built-form which was capable of expanding outward in successive rings, suggested a useful paradigm for a dense, compact city to accommodate a range of population from 250,000 to 2,000,000. However, it also reflected a number of intrinsic problems, including an inflexibility to change, particularly for areas of the city where interdependent structures and services presented problems in design and construction, and an assumption that more than 50 percent of an urban population would be willing to reside within a compact, totally enclosed, air-conditioned urban megastructure.

In 1968, as an elaboration of an earlier report known as The Canada North Development Corridor (Acres Research and Planning 1967) two members of the team which developed the initial design concept were asked to prepare illustrative urban design materials for a subsequent film entitled Leave This Not To Cain (Reason Associates 1968). Influenced by the work of architects such as Erskine (1961), Andrews (1964) and Pelli et al (1966), and by the potentials of condominium legislation, then being introduced in Canada, urban design concepts were evolved for a prototypical city which reflected large scale environmentally responsive urban development in a northern climate. The resultant sketch designs (Figure 9) and a three-dimensional model, shown in the film, highlighted some basic principles of city-building in such an environment.

The prototypical city concept comprised a series of continuous building clusters linked in an east-west direction. Along this major axis, concentrations of urban development radiated from points of major vertical and horizontal interchange. Residential units were located within and between these finger-like projections, as well as along the south-face of the major spine. Work activity functions and some institutions were located on the north side of the complex with retail commercial and major indoor spaces, such as arenas and auditoria, situated within the interior.

With corridor distances between major urban clusters relatively short (e.g. less than 0.5 km), internal transport (e.g. walking and cycling) was assumed to be augmentable by a variety of automated, electrically-powered mobility systems. Conventional transport modes were assumed to be required primarily to facilitate interurban and interregional transport. Deleterious, or nuisance producing, land uses were assumed to be situated some distance from the main urban structure. Initially designed to serve a modest population base (e.g. 25,000 dwellings), the complex was capable of addition, both horizontally and vertically, ultimately accommodating a population of excess of 100,000. This paradigm for a high density northern development (Figure 9) provided the basis for the modified compact city model discussed in sections 3.2.2 and 4.4.2, and illustrated in Appendix I, Plate 3.

FIGURE 9: A NOTIONAL LINEAR CITY PROTOTYPE FOR A NORTHERN REGION.



SOURCE: Sketches for a Reason Associates film, Leave This Not To Cain. Avrum Regenstreif and Hans D. Arends, Urban Designers, 1968.

2.3.6 Alternative Energy Futures - A Basis For Development Of Scenarios

As with most controversial areas of public policy, there are a number of different views about world energy futures, particularly with respect to energy alternatives in northern industrialized regions. These range from an absolute confidence and belief in man's ability to find technical solutions to all energy problems; to more cautious and less optimistic perspectives about future energy choices which assume imperfect or inadequate knowledge; finally, to more pessimistic views, which argue that energy and other resources are limited and must be used judiciously.

2.3.6.1 The Technological Approach - Implicit in this approach is a view that industrial man has technically achieved the means to obtain or produce, on a sustained basis, all of the energy requirements necessary to maintain a highly industrialized economic state. Invest enough resources into a problem area, with an unfailing belief in the ability of science and technology to produce results, and the necessary solutions will be forthcoming. Either the basic technology already exists (e.g. fission), or it can be developed, given enough time and resources (e.g. fusion).

One exponent of this confident view of future technological possibilities concluded that:

> The great options in matters of energy in the 21st century have been well delineated. Breeding and hydrogen will allow establishment of an "all nuclear" solution for the year 2000, that will satisfactorily solve resource and independence problems and deliver us from the yoke of fossil fuels. In case of a failure of delay, the long-term solutions such as solar energy, geothermal energy and especially nuclear fusion, should be ready to come to our rescue for an almost unlimited time if we make a sufficient effort (Gibrat 1976, 41).

However, Gibrat offered a caveat to his position, noting that "the difficulties that have to be overcome are not small."(p.41)

2.3.6.2 The Unpredictable Future Approach - A second view of energy futures is that it is extremely difficult to predict energy reserves or resources in a reliable way, consequently future energy prospects are uncertain and indefinite. In arriving at future policies, wide flexibility, diversity and greater complexity of choices of energy supplies and technologies are necessary. This view was reflected by Kenward (1976) who, after an extensive review of world energy technologies and forecasts, concluded that:

> The future shape of the world's energy system is anybody's guess - there are as many alternative projections of energy supply and demand as there are energy pundits... It is impossible to make really accurate forecasts that take in all of the variables - and no forecast can cope with the vagaries of human nature. All the sensible forecaster can do is produce broad bands within which the future energy curves will probably fall. Most forecasts confidently predict that energy consumption will continue its upward growth as economic growth continues; but few observers of the energy scene expect a return to the energy profligacy of the 1950's and 1960's. Even before the 1973/74 oil crisis, more perceptive observers of the energy business were warning that the situation would change for the worse.(p.215)

In reviewing research and development investment strategies in Great Britain, Kenward cautiously suggested that "flexibility" is "a desirable commodity" as is "diversity" through appropriate use of fuels and technology:

> We would be better off working under the assumption that things will be more complicated in the future. If nuclear fission of fusion or even solar energy proves to be the most versatile of energy sources with no limits on its application, then we can adapt to meet the situation. It will be infinitely harder if we put all our eggs in one basket only to discover that there is a hole in the bottom.(p.218)

2.3.6.3 The Modified Technological Solution - A third view is that there will be insufficient fossil fuels to meet demand in 20-30 years, assuming historic rates of consumption (Hubbert 1969; Canada NEB 1981; Willson 1981). Consequently, either a nuclear future, which includes fast breeder reactors or thorium cycles (Thirring 1968; Gibrat 1976; Smil 1974; Jovanovich 1986), or a non-nuclear future heavily dependent upon conservation and renewables is a possible alternative (Knelman 1975; MacNabb 1976; Staubaugh and Yergin 1983). Some advocates of these views have also suggested that it might be many years into the 21st Century before a hydrogen economy and/or fusion technology can be put in place (Gibrat 1976). Others have questioned whether alternatives such as nuclear futures should be implemented (Knelman 1976; Rifkin 1981). Still others have raised questions about the lead time requirements to introduce new energy technologies (Foley 1976; Bupp 1981). For example, Foley and Nassim (1976) pointed out that:

> The development of substitute energy resources is limited by the rate at which it is possible to introduce new technologies on a large scale. Science and technology can achieve spectacular results in a short time..., (but) solving the problem of building the prototype is only the first step. The Manhattan Project produced the Bomb, but thirty years work and billions of dollars and pounds have not resulted in a nuclear power industry capable of replacing more than a minute proportion of the energy supplied by fossil fuels.(p.255)

Analysts concerned with lead time have also suggested that until new technologies are in place, long lead times will be required, and other transitional technologies and strategies will have to be utilized. These include measures to reduce or otherwise constrain energy demand and to increase major investments in renewables, such as solar and energy conservation (Gander and Belaire 1978; Knelman 1976; Willson 1980; Stobaugh and Yergin 1983).

2.3.6.4 A Sustainable Energy Future - A fourth view argues that for many industrial states (including Canada) conventionally projected levels of energy consumption are simply unstable and unsustainable, given the nature of world energy resources (Thompson and Boerma 1979; Lovins 1981.) Consequently, in all economic sectors levels of energy consumption should be substantially reduced through increases in the end-use efficiency of energy (Georgescu-Roegen 1971; Berry and Fulton-Fels 1973; Commoner 1977).

Advocates of this view have argued that the allocation of energy resources should be brought about through the application of thermodynamic principles, rather than waiting for market response to the economics of short term pricing. For example, Berry and Fulton Fels have suggested that:

> If the economists in the market place were to determine their shortages by looking further into the future these estimates would come closer to the estimates made by their colleagues, the thermodynamicists ... For the ultimate long range planner, economic and thermodynamic analyses are equivalent.(p.60)

Georgescu-Roegen, arguing that conventional economics fails to capture the full cost of energy to both present and future generations, has suggested that conventional economics depends too heavily on limited non-renewable energy resources (capital stock) instead of natural energy flows (interest on capital). He has argued further that scarce resources such as non-renewable energy are in a concentrated, highly ordered, low state of entropy and the manner in which they are used in an energy-intensive economy results in overly rapid diffusion to a high state of entropy without taking advantage of much of their immediate potentials (e.g. energy cascading). This waste in energy use and production fundamentally constrains economic growth and contributes to prematurely rapid depletion of resources. Extending the argument further, Commoner has suggested an approximate dimension of this waste:

> ...about 85 percent of the work available in the energy presently consumed is not applied to the work-requiring tasks of the production system - it is wasted.(p.203)

Lovins (1979) has articulated the thermodynamic view in terms of practical policy prescriptions, arguing for "soft energy paths" as a basis for future approaches to energy use. For Canada, he has suggested such an energy future implies a much lower overall demand for energy by 2025, and the development of a number of intermediate "bridging technologies" to effect a transition between non-renewable and renewable energy futures.

Although there are clear differences of views with respect to future energy prospects, including policies tools, and appropriate technologies, most observers appear to agree that the era of dependence upon unlimited non-renewable resources, in particular fossil fuels, is rapidly drawing to a close and sustainable alternatives have to be found. These different views about alternative energy futures set the stage for the application of scenarios as a device to simulate time-sensitive urban energy conditions.

2.3.7 Some Relevant Scenarios in the Literature

In the last section of this chapter, literature sources representative of three distinctly different perspectives about energy supply and demand and energy sustainability are reviewed. Each perspective implies different assumptions about how energy might be supplied and consumed. With the exception of "soft energy path" analyses, which "backcast" from the future using regional data, most conventional perspectives depend on national aggregate data, adjusted and projected forward in time over a long period (e.g. 2025). Scenarios range from assumptions of modest changes in future energy policy to assumptions about more substantial interventions designed to influence future consumption and efficiency in the energy sector. Literature sources which correspond with these three scenarios include: (1) The

Historic Trends Scenario (Gander and Bellaire 1978); (2) The Modified Historic Trends Scenario (Willson 1980); and (3) The Soft Energy Path Scenario (Lovins 1979; Brooks and Casey 1979; Penning and McCall 1979; Ross 1979; Thompson and Boerma 1979).

2.3.7.1 Historic Trends - A Long Term Energy Assessment Program (LEAP), a 1978 study prepared by the Energy Mines and Resources Canada Energy Review Group, represented "a single view of an uncertain 50 year period (1975 - 2025)" and resulted in what the Federal Energy Minister at the time referred to as "a credible base case scenario" (Gander and Belaire 1978: v). Drawing upon a wide range of major Canadian and international energy research studies and analyses, the report arrived at a single composite view of energy potentials and policies which had developed to that time. Consequently, in a broad sense, LEAP represented an "historic trends" scenario, relying heavily on market forces and the private sector:

> ...Although government participation will increase, market forces ... will be relied upon in large part to alter patterns of demand, and to bring forward the requisite energy resources and allocate them according to the preferences of Canadians... At the same time, ... imaginative government intervention will be required (Gander and Belaire 1978, 21).

The LEAP study had four major components. The first part of the report dealt with transitions to a new era and meeting urgent long-term needs. The second dealt with magnitudes of change and included: world energy futures, Canada's internal energy relationship, energy requirements, energy availability, achieving a sustainable energy balance, and provincial energy balances in a national context. The third dealt with the adjustment process, including energy prices and pricing, finance, ownership and control, research development, demonstration and deployment and other adjustment factors. The fourth part provided conclusions and recommendations, placing major emphasis on interfuel substitution and indigenous supply. The study proposed to "... transform energy end uses to conform to the energy we can have from Canadian sources..." (p.261), and to achieve this through basic programs affecting space heating, transportation, industrial energy, consumer products and community design.

Notwithstanding the comprehensive approach which the study took in covering the entire sector from "a single perspective", it included limitations in the following areas:

(1) Although the LEAP report repeatedly mentioned the importance of improving energy efficiency, an important indicator of energy efficiency, the ratio of secondary to primary energy was projected to change very little between 1975 and 2025 (e.g. from a ratio of 5.3: 8.4 to a ratio of 13.1: 21, respectively). This suggested that under this base case scenario, energy conservation and energy efficiency would not receive significant attention, particularly with respect to energy production.

(2) LEAP's treatment of the question of oil supply and demand to the year 2000 and beyond, highlighted inconsistencies in projections and expectations within and between Federal agencies. For example, although LEAP suggested that:

> The principal supply objective is to reduce Canada's dependency on imported oil to negligible amounts by the year 2000, ... oil will continue to be perhaps the second largest component of Canada's energy supply at least until 2025.(p.56)

The study also suggested indicative supply targets which would:

> Increase by one-half by the year 2000, the production of oil in Canada, principally from heavy oils and oil sands, making appropriate use of additional supplies from new discoveries and enhanced recovery methods; to at least maintain that higher level of production to 2025.

> By 2000, reduce oil imports to not more than 10 or 15 percent of total oil requirements (less than 400,000 bbls per day compared with over 600,000 bbls per day in 1977); reduce oil imports further from the year 2000 to 2025.(p.107)

Although the LEAP report acknowledged that "achieving necessary levels of performance for each resource... rested on the fine edge of the barely possible" (p.109), National Energy Board reports, on which LEAP was based, in part, highlighted major differences in estimates among Federal agencies, for example:

> In NEB's estimate, imports could be called upon to supply more than 50 percent of Canada's oil requirements and perhaps as much as 85 percent by 1995. The domestic production of oil both conventional and from the heavy oil deposits and oil sands might be just over one million barrels per day in 1995 compared with a demand for oil at that time of nearly 2.5 million bbls/day. More than 50 percent of the oil production in 1995 would come from the oil sands and heavy oil deposits (Gander and Belaire 1978, 109-110).

On the question of oil self-sufficiency, without documenting how it proposed to achieve drastic reductions in oil consumption, LEAP's authors argued that:

> If Canadian production of oil in 2000 were to achieve the 2.5 million barrel per day (level) ... it would no longer meet the requirements even of Western Canada and Ontario unless significant substitutions away from oil are made. If oil constituted only 30 percent of total primary energy needs by 2000 (as called for in this [LEAP] assessment) instead of 46 percent as at present, Canadian oil production could serve the oil requirements of all regions.(p.178)

However, elsewhere the LEAP report raised a question about the realism of its position when it proposed to achieve its oil supply objectives for 2000-2025 by completing more oil sands surface mining projects (by the year 2000) than some environmental impact studies suggested could be realistically built within the environmental limitations of Alberta's tar sands. Gander and Belaire recognized the difficulty of this position as they noted that:

> These oil targets are extremely difficult to achieve even if agreement can be reached on their acceptance. For example, a new oil sands plant (surface or in-situ) would have to come into production every 18 months or 2 years compared with 5 or 6 years at present - roughly a 3 fold acceleration in preparation, financing and installation. Provincial acceptance, environmental impacts, financing, manpower, equipment, materials, infrastructure and service requirements should therefore be approached on that basis.(p.271)

In its analysis, the LEAP report did not specifically examine the levels of efficiency at which synthetic oil and/or other expensive non-renewables might be consumed, whether energy quality and quantity were closely matched to energy demands, nor did it consider long-term effects of substantial improvements in energy efficiency and increased energy conservation as a strategy in achieving a sustainable balance of energy from within Canada.

Despite these limitations, LEAP provided a useful base case for an "historic trends" scenario (or in energy conservation terms a status quo scenario) for at least one possible future energy alternative. As such, it provided:

(1) a possible upper limit for national energy demand by the year 2025 of approximately 21 exajoules;

(2) a basic set of numbers from which to extrapolate energy consumption to regional, or local levels; and

(3) a useful description of an energy context from which comparable numbers on regional energy might be generated.

2.3.7.2 A Modified Trends Approach - In a panoramic view of the energy crisis, entitled The Energy Squeeze -- Canadian Policies For Survival, Willson (1980) placed strong emphasis on the question of gas and oil supply over the period 1980-2025, while also examining Canada's position in regard to coal, hydro, nuclear, solar, and other renewables. This analysis drew upon many of the same data sources used in LEAP, and also made generous use of the same research, tables, and graphics. However, this energy policy critique, not only reviewed the LEAP alternative, and the sources upon which it was based, but also developed a substantive alternative to the National Energy Program.

Although, for purposes of analysis, Willson indicated that he was prepared to adopt LEAP energy demand projections from 1975-2025 as a base case (e.g. 8.4 exajoules primary in 1975 and 21 exajoules primary in 2025), he acknowledged that "Adoption does not necessarily mean advocacy." Consequently, he was prepared to accept a lower figure for primary energy based on substantial improvements in energy conservation and efficiency. Unlike LEAP, which identified and addressed a single future perspective, Willson identified several future alternatives, including some suggested by conserver society or soft energy path advocates who presented sharply divergent perspectives of total (national) energy demand for 2025. These included upper level maximums of 13.7 exajoules or a 1 percent growth rate assumed by Brooks et al (1977), and 5.4 exajoules by Lovins (1976), who concluded that "given a serious commitment to conservation in Canada, energy demand need not increase significantly at all" (Willson 1980, 18).

These different perspectives on Canada's total energy demand to 2025 also reflected significant differences in expectation of shifts in demand from non-renewables to renewables. For example, while Gander and Bellaire (p.274) assumed that only 2.1 exajoules or 10 percent of primary energy demand would be satisfied by renewables in 2025, Willson considered a range of figures from 2.1-12.6 exajoules (Table 4).

TABLE 4:

ESTIMATES OF ENERGY DEMAND FROM RENEWABLES BY 2025	%	EXAJOULES
LEAP	10	2.1
Science Council	20	4.7
Amory Lovins	25	5.3
Robinson et al (Work group on Energy Policy)	60	12.6

Source: Adapted from B.F. Willson. 1980. <u>The Energy Squeeze: Canadian Policies for Survival</u>. Toronto: Lorimer and Co.: 18.

Willson also differed from the LEAP analysis on the energy supply side. For example, with respect to LEAP assumptions and conclusions, he identified the following concerns:

(1) Conventional oil and gas would likely be depleted more rapidly than the LEAP report had acknowledged.

> Canada is dependent upon these fuels for nearly 2/3 of its energy supply ..."[but]"... the prospects for adequate gas and oil volumes are indeed gloomy ... Canada faces large shortages of oil and gas within a very few years and other energy forms are not unlimited ... the trends are all in the wrong direction to achieve a sufficient and sustainable supply ... life indices for oil and gas continue to decline, while prices and profits escalate.(p.68)

(2) At the level of consumption and fuel substitution assumed by LEAP, Willson suggested that indigenous Canadian coal supplies would also be rapidly depleted.

> Canada's recoverable coal reserves are modest particularly compared with those in the U.S. If known recoverable domestic reserves were developed and utilized to contribute 13 percent of the share of total forecast energy demand, they would be exhausted by 2025.(p.132)

(3) Nuclear fuel assumptions in LEAP were questionable since indigenous Canadian uranium supplies would be substantially depleted before 2025, and substantial additions to existing reserves were unlikely.

(4) Unlike LEAP, which acknowledged that only 2.1 exajoules would be recoverable from renewables (other than hydro) by 2025, Willson saw greater potential in energy conservation and increased energy efficiency. He also observed a wide range of possibilities for energy conservation:

> Estimating potential for renewables presents the same sort of problem as estimating potential for energy conservation. A wide range appears to be possible; within limits, the potential depends on what we want the potential to be. This not as true in the short to medium term where physical and other constraints of moving to a large renewable component are significant, as it is for the longer range. It appears we can choose to have a relatively low or relatively high contribution from renewables in the longer term ... he concluded that ... the role of renewables must be an integral part of a full assessment of how to achieve a sustainable energy future.(p.85)

With respect to energy conservation, he recommended that:

> Conservation should be encouraged and demand for scarce energy resources should be controlled by allocating them to priority uses and by equitable rationing.(p.134)

In addition, Willson's recommendations included the following points:

> Policies should be developed immediately to ensure adequate supplies of energy for Canadians in the medium term and to allow ... transition from dependence on non-renewable sources to renewables in the longer term.
>
> All energy resource planning and development should be placed under Federal jurisdiction. To this end, a National Energy Corporation or similar government authority ... should be constituted ... (through which) governments and the private sector could coordinate both the supply and demand for energy. Development and operating control would be delegated to provincial authorities; resource owners would receive appropriate royalties; and environmental and socio-economic concerns would accorded proper consideration.(p.134)

Rather than Gander and Bellaire's market oriented approach, Willson suggested:

> a cost based approach to energy pricing with costs to include reasonable royalties on the production of non-renewable resources and an appropriate return on investor-contributed capital.(p.106)

He also indicated that

> rationing of petroleum might seem to be the most satisfactory method of handling problems of high oil and gas demand in the period of transition to a sustainable energy base.(p.22)

Because both Gander and Belaire, and Willson considered Canadian energy problems essentially from a national level and dealt with energy data in aggregate, they provided neither regional nor local (municipal) energy analyses nor analysis of their implications. Nonetheless, they were useful perspectives from which to develop empirical urban scenarios (e.g. historic trends or modified trends).

2.3.7.3 Soft Energy Paths - The literature on soft-energy paths (SEPs) dealt with energy scenarios which assumed significant reductions in demand for new energy supplies through sectoral improvements in end-use energy efficiency, timely application of "transitional strategies", and thermodynamically (or qualitatively) matched energy sources. As such SEPs provided a different scale from which to consider anticipated improvements in urban energy performance because (1) they were closer to an empirical level of urban and regional policy and (2) they depended on "backcasting" from technically realistic future potentials (i.e. they worked backward in time from the future to the present), rather than depending on forecasting from present economic growth conditions and/or past expectations of growth in energy demand.

In October 1978, a Soft Energy Path workshop at Trent University brought together environmentalists and energy researchers from across Canada. The workshops objective was to organize soft energy path analyses in each of the Canadian provinces and the Northwest Territories. In the case of the Prairie provinces, the effort gave rise to a number of provincially based studies. These studies provide the literature sources in this sub-section.

Briefly recounting current energy conditions in Canada and the U.S., in a keynote presentation to the Trent workshop, entitled "Soft Paths versus Hard Paths", Lovins argued, until very recently all units of energy demanded were treated as essentially the same ... without considering the structure of energy demands or the quality of energy supplied. If more energy was required, energy producers (usually large centralized electricity authorities) simply built more, rarely considering if, or how, existing energy supplies might be used more effectively and efficiently. As conventional sources became depleted with supplies increasingly dependent on more expensive sources (frontier, synthetic and/or nuclear), costs rose sharply (by at least a factor of 10 in many cases). Such large capital demands for new energy supplies tended to starve other critical economic sectors often provoking crises:

> Putting billion dollar blocks of capital into projects that take about 10 years to build would tend to make inflation worse, unemployment worse because of capital stagnation, utility finance instable, and indeed, every big power station we build would probably lose the economy directly, or indirectly, in the order of four thousand net jobs, just by starving other sectors for the capital that they need (Lovins 1979, 5).

As an alternative, Lovins called for a soft energy path approach, which had three main technical components, these included:

(1) Making more efficient use of available energy to extend existing supplies. In this regard, Lovins (1979) estimated:

> we can roughly double efficiency by the turn of the century and roughly redouble (again) over the next quarter century ... and still have a ways to go.(p.6)

(2) Obtaining energy increasingly from "soft technologies." These were defined as having five specific properties:

> (i) First of all, they are diverse. There are dozens of kinds, each used to do what it does best.
>
> (ii) They are renewable, they run on sun, wind, water, farm, and forestry wastes - not on depletable fuels.
>
> (iii) They are relatively simple and understandable from the users point of view, but they can still be technically very sophisticated ...
>
> (iv) They supply energy in the right scale and the right quality for our range of end-use needs ...
>
> (v) And, in the U.S. the end use structure is 58% heat of which 35% is heat below 100°C and most of the rest not far above. In fact half of all the end use is heat below 600°C and within the

present convenient solar range (...distribution in Canada is essentially the same). There is another 34% in the U.S., and 32% ... in Canada which is portable liquid fuels for transport and the premium end-uses that need electricity ... are only about 8%. This might be, as much as 10% in Canada (Lovins 1979, 7).

(3) Intelligently using fossil fuels for transitional technologies and increasing the efficiency of energy generation. As an example of this last point, Lovins cited the case of commercial development of fluidized bed converters in Swedish power plants which were fired by a wide range of fuels, and a district heating grid connected to such plants, which was also designed to be eventually converted to accommodate seasonal storage of solar energy (Lovins 1979, 8).

In their paper entitled, "A Guide to Soft Energy Studies", Brooks and Casey (1979) set out a basic guide to soft energy studies as an initial framework in setting out goals, principles, and methods for carrying out energy analyses on a province by province basis. The paper was divided into three chapters. The first described the nature of a soft energy path study; the second outlined methods used; and the third chapter provided a preliminary manual for SEP studies.

In Chapter 1, the authors defined an SEP study as:

> ... an analysis of the potential in a specific society, with explicit social and economic characteristics, for keeping energy demands within the bounds that can be supplied by renewable forms of energy (or at least by forms that are relatively benign from an environmental point of view, and relatively easily controlled from a political one). This means that a soft path must focus first on the services provided by energy; second, on the techniques for and costs of providing those services with less energy; and third on the techniques for the costs of using renewable sources to supply whatever energy is demanded. In addition, most soft path studies will consider the transition from our existing hard energy paths to the soft alternative.(p.10)

Brooks and Casey also emphasized the importance of matching energy quality in both supply and demand:

> The most important rule in getting onto a soft energy path is to use energy in ways that are suitable for the tasks at hand ... matching energy, quality and quantity to end-use requirements. ...engineering and economics, not ecology and political science [provide] ... the most immediate (though not ultimately the most important) support for soft energy paths over hard ones.(p.11)

One of the most important features of a soft energy path approach was the concept of working backwards from a technically feasible future state to the present, "to see which technologies have to be deployed, and when," (p.11) and in this way compare the implications of policies that would lead towards one or more soft energy futures from existing policies.

In Chapter 2, the importance of developing an organizing theme for an SEP study was emphasized

> ... as the base from which assumptions are derived, data arranged, methods chosen and analysis conducted ... (Also), it is more useful to policy makers if energy paths can be defined in terms of policy options which incorporate the goals that governments normally think of ... In this way the conclusions will flow not from a few arbitrarily assumed numbers and growth rates, but from the goals and criteria inherent in one view (or a set of views) of what a future society might be or should be.(p.11)

Some of the more common themes used in energy studies were also reviewed, including:

(i) Extrapolating the Past into the Future: This approach freezes the status quo (e.g. 1973 Federal Report, An Energy Policy for Canada Phase I).

(ii) Extension of Existing Relationships: Economic and policy variables are given explicit roles in determining results (e.g. 1976 Federal Report, An Energy Strategy for Canada).

(iii) What if Scenarios: e.g. What if Canada made a national commitment to reduce energy use? What if Canada decided to maximize energy exports? ... this one can suffer from being too independent of [the] past.

(iv) Maximum Efficiency: ... the problem with this scenario is that it (may) ignore the dollar and time costs of achieving greater physical efficiency. Still, ... it is useful to see where a trend to greater energy efficiency will lead.

(v) Energy Targets: ... postulated as a social goal for some future year ... researchers ... work backwards (backcast) to ascertain what is required (and when) to meet this target. (p.12)

These five scenarios, it was pointed out, were "pure types". In reality however, SEP studies combine elements from two or more scenarios, taking into account base case estimates as well as concerns with maximizing efficiency and achieving acceptable overall targets. The authors also suggested that the conserver society theme could provide a relevant alternative perspective, ... because it was based on "lower rates of material throughput in society":

> Regardless of organizing theme... it is essential that analysis begin at the point of end-use - the way in which energy is directly consumed to heat homes and offices, fuel automobiles, and trucks, power appliances and heat boilers.(p.12)

While they suggested categorizing energy consumption by sector and by temperature, they acknowledged that data and information state-of-the-art made this task difficult:

> Unfortunately ... thus far, governments have had little interest in how energy was used, so data for end-use breakdowns are typically scattered, incomplete, or just non-available. Also, many data are not available in terms of physical units of consumption, but only in terms of monetary expenditures ... In periods when

> prices are constant these can be converted to physical terms fairly easily, but in other cases great caution must be exercised.(p.13)

In their paper, Brooks and Casey also defined and reviewed end-use analysis, forecasting and backcasting, and special aspects of soft energy path studies, including: energy conservation, transitional technologies, renewable technologies, balance of trade in energy, as well as technology choice and timing. They also briefly considered: appropriate cost analysis, including economic efficiency criteria based on discounted cash flow-vs-life cycle costs; subsidies; externalities; and the importance of "conservatism" (i.e. bending over backwards to avoid overstating a case). Finally, they dealt with implications, providing a rough flow chart of the analytical process in SEP studies.

In the third chapter of their paper the authors expanded on their concepts. For example, they considered several SEP studies, including a national energy study by the Workgroup on Energy Policy (Robinson et al 1977). This study was notable for its development of an end-use energy consumption scenario which provided among the lowest, if not the lowest, estimate of energy demand projected for Canada to that date. Thus, the Brooks and Casey work and the sources it drew upon were useful in comparing sectoral energy demand which could form a basis for SEP scenarios for specific Canadian cities. In terms of supply options, the manual also provided other useful data sources and techniques for developing a realistic set of future energy supply options.

Following the 1978 Trent Conference on Soft Energy Paths, three technical analysis groups working independently within the Prairie provinces began the task of developing SEP analyses for their respective regions. Following the outline suggested by Brooks and Casey, these groups, which included Penning and McCall in Manitoba, Thompson and Boerma in Saskatchewan, and Ross in Alberta, adopted approximately similar approaches in identifying end-use energy supply and demand for all energy sectors in their respective provinces over the same time period (1975-2025). Different future energy scenarios were also assumed. Although, the studies provided a useful overview and a comparable interprovincial perspective on soft energy futures in their regions, there were significant differences among the three studies in the manner in which issues such as population data, growth rates, and future scenarios were dealt with. In particular, within each region, data sources, assumptions and, to an extent, analytical approaches, differed among the study teams. These differences complicated the task of developing clear comparisons of performance in end-use efficiency and energy conservation among the respective provincial regions.

The first difference was population. For example, although the Manitoba group used a single 1977 medium population picture (CMHC) as a growth projection assumption, the Saskatchewan team used high and low population scenarios in attempting to establish a range of limits for energy demand. On the other hand, the Alberta analyst selected a single high rate of population growth so that "... results would be readily compared with the Alberta Energy Resources Conservation Board (AERCB) forecast." (i.e. a comparable scenario within Alberta). However, Ross (1979) acknowledged that "in the Saskatchewan work, [the authors] selected a future more consistent with the values underlying a soft energy future.(p.19)

The second difference in these studies was the fact that all drew upon energy supply and related data from different energy information sources. For example, the Manitoba team depended heavily on available data from CMHC (1976-78), the Saskatchewan group used 1977 Saskatchewan Energy Flow Accounts, while the Alberta analysis depended on data from the Alberta Energy Resources Conservation Board (1978) and Calgary Power (1977).

A third basic area of difference in the prairie studies was scenarios. The Manitoba team introduced only two scenarios - namely: (I) A "Current Trends" approach based on high (energy) growth assumptions and (II) A "Conservative" approach:

> By conservative we mean that the application of an assumption will have any, or a combination of the following effects: (i) increase the demand for energy (ii) decrease the supply of renewable energy and/or (iii) decrease energy savings beyond levels of other accepted estimates (Penning and McCall 1979, 27).

Presentation of data by Penning and McCall indicated that while Scenario II was supposed to represent a more energy conserving option, their definition was inconsistent with their intent of achieving a soft energy path future for Manitoba.

Unlike the Manitoba team, Thompson and Boerma (1979) based their Saskatchewan study on three distinct scenarios about energy use patterns in 2025:

> Scenario I is a "business as usual" scenario, with no particular improvements in energy efficiency beyond what is common practice today. Growth in energy demand is based on published projections, current per capita consumption, or extrapolation of past trends.
>
> Scenario II is a "technical fix" scenario in which we apply only those energy technologies which are proven to be feasible today (although not necessarily economical today). This scenario does not assume significant changes in lifestyles, but rather, shows the extent to which we can improve the efficiency of our use of energy.
>
> Scenario III assumes the same technical improvements found in Scenario II, with the addition of some lifestyle changes. Changes in values are implied in this scenario. If Scenario II shows serious applications of conservation, then Scenario III is conservation applied with something approaching religious fervor. In this scenario, there may be some curtailment or "going without" although this is assumed to be voluntary and a result of changed values.(p.38)

The approach to alternative scenarios for Alberta by Ross (1979) was less clear. Although data were assembled to be comparable with AERCB's (high growth) scenario, the assumptions underlying AERCB projections were not made explicit. As a result, comparison between current trends and energy conserving alternatives was difficult. In retrospect, declines in Alberta's gross provincial product from 1981-85, call into question the high growth assumptions of the Ross analysis.

Because all of the SEP studies depended on aggregate (provincial) data and were not broken down by specific cities or urban sub-areas, data derived from these analyses had to be considered with care. Nevertheless, allowing for differences in data base, population growth assumptions, and scenarios, the energy performance of the three prairie provinces as represented in these limited studies provides a useful source for comparing implications of improvements in sectoral efficiency and energy conservation within provincial sub-regions of the Interior Plains.

2.4 SUMMARY

The three parts which comprised this chapter included: (1) a review of aspects of the literature on energy conservation in northeastern Europe and North America from about 1960 to the present; (2) a review of literature on urban models and energy perspectives; and (3) a review of literature of specific relevance to the components of the research design.

In this review energy conservation and related urban data sources prior to the 1973 energy crisis were considered, and it was observed that environmental and energy conservation concerns had some common origins. For example, thermodynamic views of energy had important links to both environmental concerns and to issues of energy efficiency.

In Europe interest in energy conservation was necessitated by a lack of indigenous non-renewable energy earlier in the 20th century. Consequently, energy conservation research and related techniques were well developed by the 1950's. By contrast, in North America prior to 1973, there was little interest in such research.

In the late 1960's and early 1970's, propelled in part by the environmental movement, interest in energy conservation in North America began to increase. In both Canada and the United States research into problems of thermal pollution from power production suggested ways to use energy more efficiently. However, after 1973 following the impact of the world oil crisis, interest in North America focussed more intensely on issues of energy efficiency and energy conservation. Research by "soft energy path" advocates began to indicate that increased energy growth was not inevitable and that other alternatives were possible.

To assist in establishing a practical model of urban residential energy conservation, literature on applications of urban modelling was reviewed. Some analysts cautioned that only modest expectations should be assumed from modelling processes. For example, one argued for careful development of simple models from available data and procedures.

A number of components in the application of the method were developed from literature of particular relevance to the research design. For example,

(1) empirical sources for statistical data in selected tracts in real cities were identified;

(2) literature on hypothetical cities which could provide prototypes for development of empirical urban energy limits was also identified;

(3) scenarios, similar to those postulated by some soft energy path analysts for Canadian provinces in the late 1970's, were identified as a useful means to develop time-related data for future energy consumption in selected Plains cities.

These data sources and analytical devices from the literature are considered further in the following chapters.

CHAPTER III - RESEARCH DESIGN AND ORGANIZATION OF DATA

This chapter describes a research design for a method of comparing several urban and energy related variables in selected cities to determine energy characteristics and identify discretionary residential energy. These variables include residential density, transport energy for journey-to-work to the core, and residential energy (internal to households). It is comprised of five subsections: (1) general description of the research design; (2) definition of residential energy environments in real cities; (3) determination of internal residential/commercial energy consumption for households and urban tracts using real and estimated data; (4) determination of energy consumption for journey-to-work to the core for selected residential tracts in the selected cities; and (5) identification of a base level of urban residential energy at the discretion of urban households.

3.1 GENERAL DESCRIPTION OF THE RESEARCH DESIGN

This sub-section describes a research design for analysing areal residential development and energy characteristics in selected large cities. The research design also makes it possible to consider urban residential energy implications under alternative future policies. In particular, the relationship between urban form and residential energy use is examined to discover how energy efficiency and other related urban characteristics can be improved.

The research design involves organization and modelling of real and estimated energy data for selected residential areas of real cities. These data are obtained or derived from (gas) utility agencies; from census data for tracts in the selected cities; and from empirical data on urban transport energy from a variety of published sources. The method involves the following steps:

(1) relevant urban environmental characteristics for selected cities are identified;

(2) urban census tract types are defined;

(3) residential data for urban tracts are described;

(4) internal energy requirements for households in the selected cities are estimated;

(5) travel distances for journey-to-work from residential tracts to the core and related energy consumption are computed from empirical data; and

(6) total residential energy for selected tracts in real cities is estimated and compared with real data obtained from urban utility records to establish a base level of residential energy consumption.

3.2 DEFINITION OF RESIDENTIAL ENERGY ENVIRONMENTS IN REAL CITIES

In distinguishing the characteristics of energy and related urban environments in real cities, three levels of information are important: (1) characteristics of selected cities; (2) characteristics of tracts within the cities; and (3) characteristics of residential energy within specific urban tracts. This subsection considers these three levels.

3.2.1 Characteristics of the Selected Cities

Within the southern Interior Plains region of Canada, Winnipeg, Saskatoon, and Edmonton are three climatically-stressed cities, which are selected as an urban laboratory. Although all of the cities are larger than 100,000 population, they vary in physical size, age, and dependence on fossil fuel energy. For example, Winnipeg, in the eastern portion of the Interior Plains, is well served by hydroelectricity. To the west, other Plains cities are progressively more dependent on fossil fuels for electricity production (Canada ECE Secretariat: 1977).

The three selected cities share other distinctive characteristics, including temperature, solar range, topography and urban form. There are also similarities in residential prototypes and residential planning and construction standards in the selected cities. These similarities are particularly apparent in newer residential areas where housing has been planned and built by the same developers to the same building standards. Common dwelling unit prototypes also reflect similar energy characteristics in newer residential areas.

Among large Canadian cities, these three cities experience among the largest number of days with sub-zero temperatures. They also experience a significant number of hours with temperatures greater than 30°C (Table 3). In major urban redevelopment tracts, such as those in downtown core edge areas, air-conditioning is required in many buildings during warmer months. In addition, hours of bright sunshine and relatively few days with no sunshine offer potentials for passive solar heat gain and for consideration of seasonal use of active solar energy systems.

Located in relatively flat plains with contiguous compact urban plans, the three cities are also comparable with respect to urban transport characteristics. Only the crossings of their riverine locations cause any significant impediments to traffic circulation.

Consequently travel distance from most outer suburbs to their respective central cores is relatively short and direct.

3.2.2 Characteristics of Residential Tracts within the Cities.

Data based on standard quinquennial census tracts are assembled to systematically compare urban energy characteristics in the selected cities. Statistics Canada outlines the following set of criteria for such tracts:

(1) boundaries must follow permanent and easily recognized lines on the ground;

(2) population must be between 2500 and 8000 (with a preferred average of 4000 persons), except for census tracts in the Central Business District, in major industrial zones, or in peripheral rural or urban areas, which may have either a lower or higher population;

(3) the area must be as homogenous as possible in terms of economic status and social living conditions; and

(4) shape must be as compact as possible (Mitchell and Bond 1980, 191).

Based on 1976 and 1981 data, three types of residential tracts are selected in each city. These are: (1) Inner Core Edge tracts, designated (I), usually the oldest in their respective cities and situated closest to the downtown core; (2) Mature Suburban Tracts, designated (M), often older suburbs developed after the Second World War; and (3) Outer Suburbs and Fringe Areas, designated (O), representative of more recent suburbs such as those developed from 1965-85.

In each of the selected cities, tracts are chosen which reflect successive phases of residential growth and urban development, and as such represent different distances from the central core. For each city, tracts are selected from three zones indicated in Figures 10, 11, and 12.

3.2.3 Derivation of Data for Selected Urban Tracts

For specific tracts in each of the selected cities, data are derived for residential density, travel distance and energy for journey-to-work to the core and residential energy consumption. The procedure is as follows:

(1) in each city, at least three tracts are selected in different urban zones, and consequently at different distances from the central core;

(2) from the 1981 Census, relevant data are extracted for selected residential tracts (e.g. residential densities in numbers of households per square kilometre);

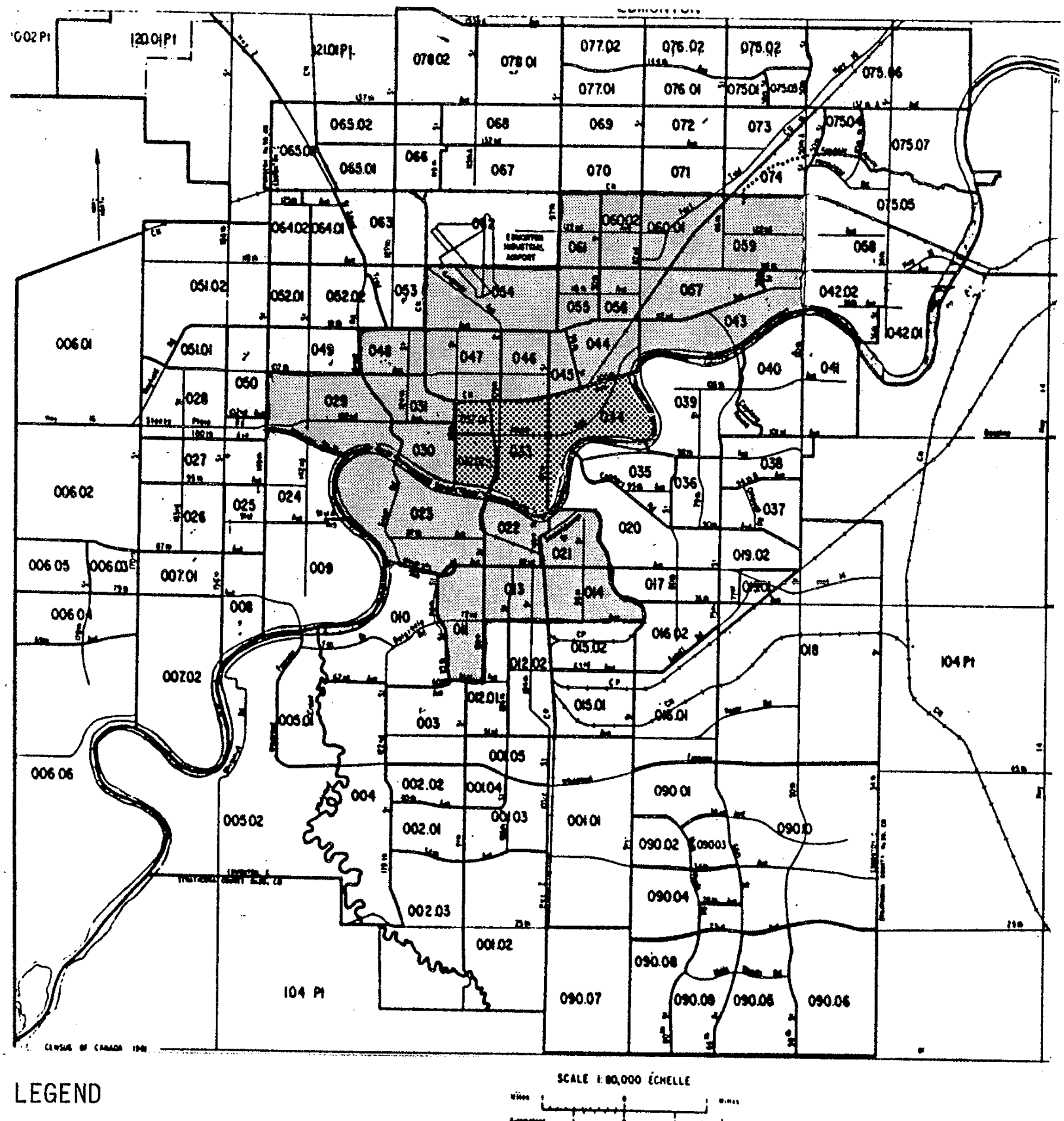
(3) travel distances from the centroid of each tract to the centroid of the core are computed;

(4) energy consumption data for each selected tract are obtained from energy utilities in the respective cities. (Examples of utility data are shown in Appendix 2, Plates 1-3 (p.230-232).

3.3 DETERMINATION OF INTERNAL RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION FOR HOUSEHOLDS AND URBAN TRACTS USING REAL AND ESTIMATED DATA

Three components of residential/commercial energy consumption are considered in deriving real or estimated residential energy consumption

FIGURE 10: EDMONTON TRACT TYPES



LEGEND

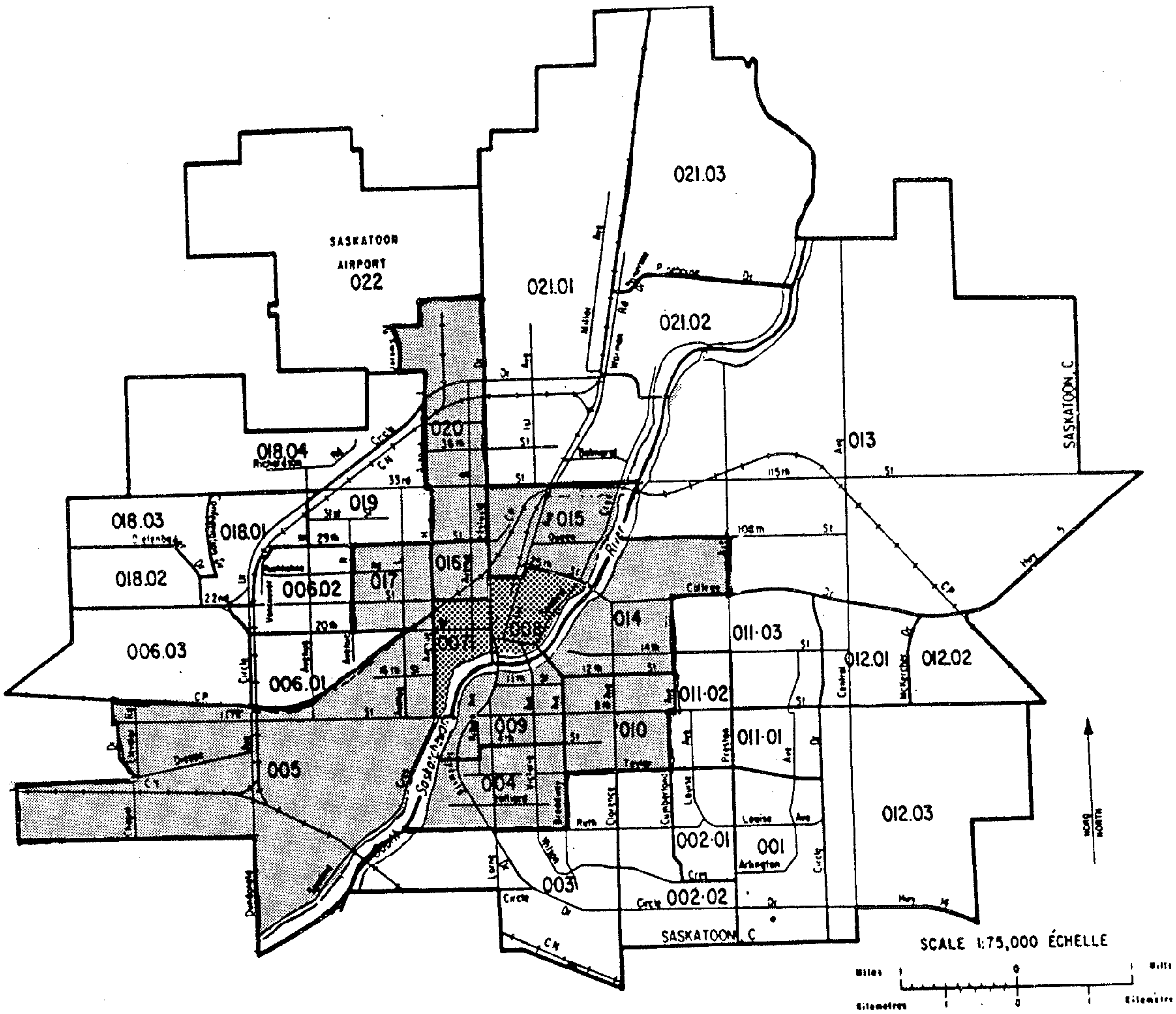
INNER CORE EDGE TRACT

MATURE SUBURBAN TRACT

OUTER SUBURBAN TRACT

SOURCE: Statistics Canada - Census of Canada 1981.

FIGURE 11: SASKATOON TRACT TYPES

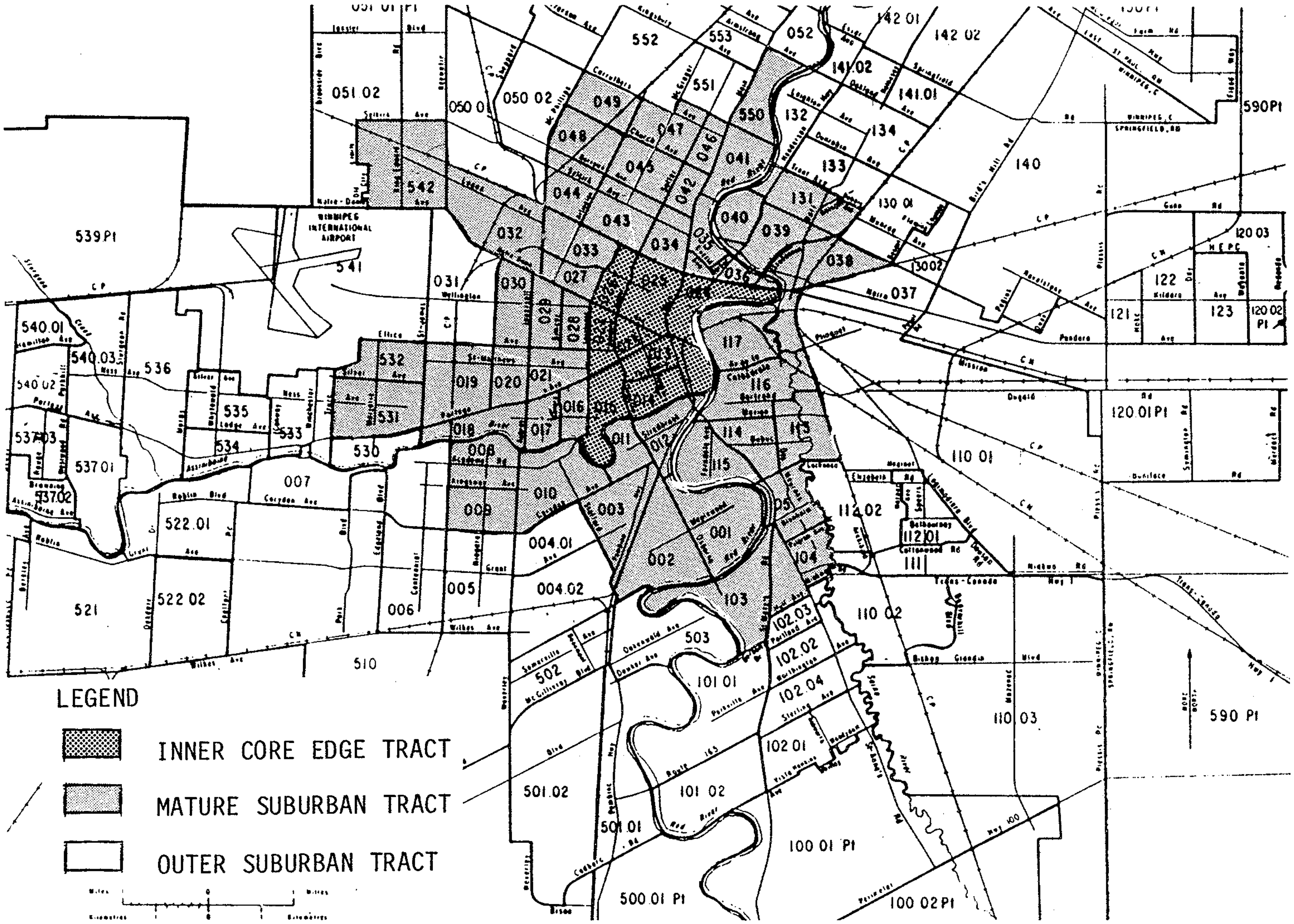


LEGEND

- INNER CORE EDGE TRACT
- MATURE SUBURBAN TRACT
- OUTER SUBURBAN TRACT

SOURCE: Statistics Canada: Census of Canada 1981

FIGURE 12: WINNIPEG TRACT TYPES



SOURCE: Statistics Canada. Census of Canada 1981.

within selected urban tracts: space heat, water heat, and transport energy for journey-to-work to the core. Real energy data are derived from utility records provided in aggregate form for areas of the selected cities (Appendix 2, p.231-233). Where real data are unavailable or insufficient, estimated data on residential energy are substituted. Such data are obtained from available technical research and publications (e.g. CMHC 1977; Fowler 1984).

For the three energy components identified in this subsection, the first two, space heat and water heat are internal (to residential units or households) and are developed in section 3.3. However, the third component, energy for journey-to-work to the core, is external to the residential unit. A method of deriving this transport energy component is described in subsection 3.4. (p.111)

Journey-to-work energy is considered to be a residential/ commercial energy component for two reasons:

(1) transport energy for journey-to-work is an integral part of residential location decisions, and as such is considered to be closely bound with household energy consumption by virtue of a consumer trade-off of distance to work from residential areas.

(2) urban households routinely make choices with respect to alternative modes and routes for journey-to-work as an intrinsic aspect of household budget and valuation of personal time.

3.3.1 Determination of Estimated Energy Requirements for Space Heat

A number of steps are required to determine space heat for selected urban tracts. These include:

(1) determination of the number and location of occupied dwelling types for particular tracts;

(2) determination of energy consumption for each dwelling type from estimated data sources;

(3) establishment of the proportion of dwelling unit types in a tract universe; and

(4) from the product of items (1), (2), and (3), determination of estimated energy consumption for space heat in each tract.

3.3.2 Determination of the Estimated Energy Requirements for Water Heat

Unlike space heat for which energy consumption can vary among urban residential areas in accordance with their period of construction and the thermal efficiency of their buildings (CMHC 1977), energy for water heat varies in a different way. Less dependent on the design and locational aspects of dwelling types, water heat is more dependent on household size and age of population. In this respect, changes in family size as well as in the age-mix and numbers of persons per household can significantly affect the proportion of household energy which is used for water heat, regardless of dwelling size or type. For example, an area with a large elderly population will normally use less water than an area of younger families with many children. However, since water heat only represents in the order of one third the proportion of energy for space heat or approximately twenty percent of total household energy (CMHC 1977, 121), it is proportionately less sensitive to variations in population characteristics.

Therefore, the method of determining energy consumption for water heat using estimated data is similar to the steps outlined for space heat in section 3.3.1. However, rather than tract characteristics, such as building age, more important dwelling energy indicators are age of inhabitants and number of persons per household.

3.3.3 Derivation of Internal Residential Energy Consumption from Real Data

In contrast with the method of determining internal energy consumption for typical urban households and selected tracts in sections 3.3.1 and 3.3.2, which used estimated data, an alternative method is devised for determining areal residential energy consumption. As illustrated in Table 5, column 12 and in Appendix 2, Plates 1-3, p.231-233, aggregated real residential/commercial energy consumption data are obtained through the cooperation of gas distribution utilities in each of the selected cities. This entails running data on residential gas consumption of utility customers in each tract using postal code addresses. A computer program is developed by cross-referencing (1976) postal code computer tapes for the selected cities with (1981) base year gas consumption records by postal code for each tract. Thus, partially aggregated real residential energy data are obtained for selected tracts.

Inadequacies in the postal code conversion software programs which were available for this research posed several problems in extracting urban related data. These problems included a lack of disaggregated data from which to analyse the characteristics of census tracts which had experienced rapid change during intercensal periods, and differences in the quality and consistency of census data retrieval programs which were available for postal codes in Edmonton, Saskatoon and Winnipeg. In future, urban energy research might be assisted by an urban data system which can anticipate, at least to a degree, changes in postal codes. For example, under such a system, postal code changes might be registered simultaneously with municipal construction permit approvals, so that updated postal code conversion programs of a consistent standard would be available for all large Canadian cities.

TABLE 5: DENSITY AND ENERGY CONSUMPTION CHARACTERISTICS FOR THREE SELECTED CANADIAN PLAINS CITIES

(1)		(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
CITY	TRACT	LOCATION AND CATEGORY		DENSITY POP. PER UNIT AREA (km^2)	NO. OF HSHLDS.	LAND AREA	AREAL RESID. DENSITY	1981 (INTERNAL) ENERGY CONSUMPTION PER HOUSEHOLD				1981 RESID. ENERGY CONS. PER UNIT AREA (km^2)	
								ESTIMATED[1]		REAL		ESTIMATED	REAL[2]
								SPACE HT.	HOT WATER	SPACE HT.	HOT WATER		
	NO.	-		PP km^2	DUS.	km^2	DUS/km^2	GJ/DU/Y	GJ/DU/Y	GJ/DU/Y	GJ/DU/Y	TJ/km^2/Y	TJ/km^2/Y
Winnipeg	.014	Core Edge	I	5821	2885	0.67	4306	107	31	104	31	520	581
	.017	Mature-Old	M	6350	1595	0.60	2658	154	31	151	45	494	521
	.535	Mature-New	M	3308	1595	1.37	1164	113	31	113	40	168	178
	.540.02	Out Suburb	O	3957	1455	1.09	1335	137	31	126	39	184	220
Saskatoon	.008	Core Edge	I	2198	1335	0.88	1517	82	31	123	38	171	244
	.015	Mature-Old	M	1915	2200	1.25[3]	1760	118	31	126	38	158	174
	.010	Mature-Old	M	2714	2570	2.07	1242	140	31	102	31	213	165
	.018.02	Out Suburb	O	3621	1275	1.29	988	N/A	N/A	N/A	N/A	N/A	N/A
Edmonton	.032.00	Core Edge	I	7289	4620	1.24	3726	91	31	66	20	455	320
	.048	Mature-Old	M	3427	1528	1.09	1402	131	31	103	31	249	205
	.025	Out Suburb	O	3204	1340	1.09	1229	110	31	90	28	205	145
	.006.05	Out Suburb	O	3413	1380	1.09	1266	N/A	N/A	N/A	N/A	N/A	N/A

Sources: (1) Central Mortgage and Housing Corporation. 1977 - The Conservation of Energy in Housing (1977).

(2) Greater Winnipeg Gas Company Ltd., Computer Services Division, Winnipeg, Manitoba, July 1983.
Saskatoon Power Corporation, Computer Services Division, Regina, Saskatchewan, December 1983.
Canadian Utilities Ltd., Management Information Systems, Edmonton, Alberta, June 1984.

(3) Effective tract area adjusted from 2.07 km^2 to 1.25 km^2 due to a large area of railway yards within the tract.

3.3.4 A Comparison of Internal Energy Consumption Using Real and Estimated Data Methods

Real and estimated data on "internal" household energy are compared. Although values obtained by a method which applies real data vary above or below average levels obtained by a method which uses estimated data, values obtained using both methods are sufficiently close to confirm the estimated data method as a practical approach. However, the real data method is used as far as possible in investigating internal residential energy.

3.4 DETERMINATION OF ENERGY CONSUMPTION FOR JOURNEY-TO-WORK TO THE CORE FOR SELECTED RESIDENTIAL TRACTS IN THE SELECTED CITIES

In estimating household energy consumption for urban transport, only the component of energy consumption for journey-to-work from residential tracts to the central core is considered. The two reasons for this limitation are: (1) such trips are regular, predictable and substitutable by alternative means of transport; and (2) mode substitutions and economies in energy consumption for journey-to-work to the core are discretionary to urban households.

In determining the household transport energy component for journey-to-work to the core, a multicolumn table is introduced (Table 6). Column 1 lists each city and its respective tracts; column 2 lists the number of households per tract; column 3 indicates the proportion of households with at least one person travelling to work by car; and column 4 indicates the number of households with at least one member working in the core.

TABLE 6: SELECTED CENSUS TRACTS IN THREE CANADIAN PLAINS CITIES: ENERGY CONSUMPTION FOR JOURNEY-TO-WORK TO THE CORE BY PUBLIC TRANSIT AND PRIVATE AUTOMOBILE - SCENARIO I DATA FORMAT

(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	(9)	(10)	(11)	(12)	(13)	(14)
CITY & TRACT NO.	NO. OF HSHLDS.	% HSHLDS. TO WORK IN CORE	NO. OF HSHLDS./KM² TO WORK IN CORE	AV. ST. LINE DISTANCE CENTROID TO CENTROID	ADJUSTED DISTANCE TO CORE FOR AUTO & TRANSIT	JOURNEY-TO-WORK TO CORE ANNUAL TOTAL DIST. KMS/ANNUM: TRANSIT TRAVEL	AUTO TRAVEL	ENERGY CONS./ UNIT DIST. (AUTO)	ANNUAL AUTO CONS. /HSHLD.	UNIT DIST. ENERGY CONS. TRANSIT /HSHLD.	ANNUAL TRANSIT CONSUMP. /HSHLD.	TOTAL ANNUAL TRANSPORT CONSUMPTION WORK/HSHLD.	TOTAL ANNUAL ENERGY CONSUMPTION PER TRACT TO WORK IN CORE ALL HSHLDS.
	dus/km²		dus/km²	kms	kms	kms/Y	kms/Y	MJ/km	GJ/du/Y	GJ/du/Y	GJ/du/Y	GJ/du/Y	TJ/km²/Y
									% AUTO (8)(9)		% TRANS (11)(7)	(10)+(12)	(4) (10+12)
		(Est.)		(Dc)	$L=4+1.52Dc_1$	$A_1=240x2LxM.S.$							
Winnipeg						(.27)	(.73)						
014	4036	.30	1292	0.5	4.8	622	1682	5.4	-	2.0	-	-	-
017	2658	.30	797	3.0	8.6	1115	3013	4.5	-	2.0	-	-	-
535	1164	.30	349	7.6	15.6	2022	5466	3.9	-	2.0	-	-	-
540.02	1335	.30	401	11.2	21.0	2722	7358	2.2	-	2.0	-	-	-
Saskatoon						(.20)	(.80)						
008	1517	.35	531	0.3	4.5	432	1728	5.8	-	2.0	-	-	-
015	1760	.35	616	0.8	5.2	499	1997	5.6	-	2.0	-	-	-
010	1242	.35	435	3.1	8.7	835	3341	3.5	-	2.0	-	-	-
018.02	988	.35	346	6.0	13.1	1258	5030	3.0	-	2.0	-	-	-
Edmonton						(.22)	(.78)						
032	3726	.30	1118	0.9	5.4	570	2022	5.0	-	2.0	-	-	-
048	1402	.30	421	3.0	8.6	908	3220	3.5	-	2.0	-	-	-
025	1229	.30	369	7.5	15.4	1626	5766	2.8	-	2.0	-	-	-
006.02	1266	.30	380	11.0	20.7	2186	7750	2.1[4]	-	2.0[3]	-	-	-

Sources: (1) Adapted from data from Strategic Planning Group - Transport Canada 1979:32 (Appendix 4A)
(2) Adapted from data from Strategic Planning Group - Ibid:26 (Table 4.3)
(3) Adapted from Carrier 1974:80
(4) Adapted from Shortreed 1977:16
(M.S.) = Modal Split

The next group of columns in the table indicates the shortest distance to the core in kilometres. This is designated by Dc*, the direct distance from the centroid of any residential tract to the centroid of the core or CBD (column 5). Adjusted travel distance to the core is denoted by L_c (Tables 6 and 7 - column 6). This "adjusted" distance allows for a tendency for automobiles to be used more frequently for longer and more dispersed trips to work than other modes, and for an underestimate of straight line distance of dwellings from the CMA centre (Transport Canada 1979, 32).

The next step is to break down the proportion of commuter population which travels to work by different modes. In Table 6 and 7 - columns 7 and 8, modal split percentages of households, using different forms of transport, are established. Energy consumption for private automobiles (Tables 6 and 7 - column 9) is derived from 1978 data (Canada EMR 1978). These data assume 1980-81 fleet car average fuel consumption is in the order of 11.7 litres per 100 kilometres, or a level of vehicle energy consumption of 2.08 megajoules per kilometre.**

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* Adjusted distance is given by the formula: L_c=4.0 + 1.5.2 Dc, where:

- 4.0 is a constant denoting a minimum positive value for average trip length
- 1.52 is a coefficient which allows for differences in routes and road conditions
- Dc is the average straight line distance of dwellings from a central business district in kilometres (Transport Canada 1979, 32)

** Other sources suggest that significant adjustment is required for short distance cold start conditions (Drolet et al 1977; Carrier 1974). On this basis an urban distance of 0.5 kilometres results in short trip energy consumption for a typical fleet car average of 5.4 megajoules per kilometre. This compares with 2.08 megajoules per kilometre for a more normative (longer) journey-to-work trip of 11 kilometres. Therefore, unit fuel consumption increases significantly for short trips.

TABLE 7: SELECTED CENSUS TRACTS IN THREE CANADIAN PLAINS CITIES: ENERGY CONSUMPTION FOR JOURNEY-TO-WORK TO THE CORE BY PUBLIC TRANSIT AND PRIVATE AUTOMOBILE - SCENARIO I DATA

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
CITY & TRACT NO.	NO. OF HSHLDS.	% HSHLDS. TO WORK IN CORE	NO. OF HSHLDS./KM^2 TO WORK IN CORE	AV. ST. LINE DISTANCE CENTROID TO CENTROID	ADJUSTED DISTANCE TO WORK FOR AUTO & TRANSIT	JOURNEY TO WORK ANNUAL TOTAL DIST. KMS/ANNUM TRANSIT TRAVEL	AUTO TRAVEL	ENERGY CONS./ UNIT DIST. (AUTO)	ANNUAL AUTO CONS. /HSHLD.	UNIT DIST. ENERGY CONS. TRANSIT /HSHLD.	ANNUAL TRANSIT CONSUMP. /HSHLD.	TOTAL ANNUAL TRANSPORT CONSUMPTION WORK/HSHLD.	TOTAL TRACT ANNUAL ENERGY CONSUMPTION TO WORK IN CORE ALL HSHLDS.
	dus/km^2		dus/km^2	kms	kms	kms/Y	kms/Y	MJ/km	GJ/du/Y	GJ/du/Y	GJ/du/Y	GJ/du/Y	TJ/km^2/Y
		(Est.)		(Dc)	$L=3+1.35Dc_1$	$A_1=240x2LxM.S.$			% AUTO (8)(9)		% TRANS (11)(7)	(10)+(12)	(4) (10+12)
Winnipeg						(.27)	(.73)						
014	4036	.30	1292	0.5	3.6	466	1261	5.4	6.8	2.0	1.0	7.8	10.1
017	2658	.30	797	3.0	7.1	914	2470	4.5	11.1	2.0	1.9	13.0	10.4
535	1164	.30	349	7.6	13.3	1719	4646	3.9	18.0	2.0	3.5	21.5	7.5
540.02	1335	.30	401	11.2	18.1	2348	6349	2.2	13.8	2.0	4.8	18.6	7.5
Saskatoon						(.20)	(.80)						
008	1517	.35	531	0.3	3.3	321	1283	5.8	7.4	2.0	.6	8.0	4.2
015	1760	.35	616	0.8	4.1	394	1574	5.6	8.1	2.0	.8	8.8	5.4
010	1242	.35	435	3.1	7.2	691	2765	3.5	8.3	2.0	1.4	9.7	4.2
018.02	988	.35	346	6.0	11.1	1066	4262	3.0	11.7	2.0	2.2	13.8	4.8
Edmonton						(.22)	(.78)						
032	3726	.30	1118	0.9	4.2	445	1576	5.0	7.9	2.0	.9	8.9	10.0
048	1402	.30	421	3.0	7.1	744	2640	3.5	9.2	2.0	1.5	10.8	4.5
025	1229	.30	369	7.5	13.1	1385	4912	2.8	13.5	2.0	2.8	16.3	6.0
006.02	1266	.30	380	11.0	17.9	1884	6683	2.1_4	13.9	2.0_3	3.8	17.7	6.7

Sources: (1) Strategic Planning Group - Transport Canada 1979:32 (Appendix 4A)
(2) Strategic Planning Group - Ibid:26 (Table 4.3)
(3) Adapted from Carrier 1974:80
(4) Adapted from Shortreed 1977:16
(M.S.) = Modal Split

Table 7 - column 10, which represents annual automobile consumption for journey-to-work per household, is derived by combining columns 8 and 9. Column 12, which represents annual transit energy consumption per household for journey-to-work, is derived by combining columns 7 and 11. It is the product of unit energy consumption for transit per household (column 11) and the modal split (27 per cent), annual journey-to-work distance to the core (column 7) as a proportion of transit travel.* Column 13, which represents the total annual energy consumption per household for journey-to-work to the core, is derived by adding columns 10 and 12. Column 14, which represents total transport energy consumption to work in the core for all households per tract, is derived by multiplying column 13 by column 4.

This method of analysing residential transport energy depends substantially on the use of empirical data from sources in the literature. Residential transport energy data must be estimated or derived from such sources because there are at present insufficient real data to derive transport energy consumption in a manner consistent with the method of establishing internal residential energy consumption from utility data for real cities.

In future, if greater methodological consistency and precision are desired, it will be necessary to analyse both internal and external residential energy using a consistent method. This may be achieved by transposing motor vehicle registration data into fleet car energy consumption figures for vehicle types registered in each postal code within a particular residential tract. In combination with origin and destination analyses for residential tracts in the selected cities, such real transport data sources, together with appropriate census question amendments or other questionnaires, could facilitate more precise

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* For transit buses, energy consumption is assumed not to vary with warm-up-time, since transit equipment is assumed to run at normal engine temperatures due to continuous operation through most of the day.

estimation of journey-to-work energy to the core from within each residential tract, and would also result in greater consistency in data for both internal and external residential energy consumption.

3.5 IDENTIFICATION OF A BASE LEVEL OF URBAN RESIDENTIAL ENERGY AT THE DISCRETION OF URBAN HOUSEHOLDS

For residential households, two aspects of energy comprise total residential energy consumption: (1) internal energy, which includes space heat, water heat, and energy for appliances; and (2) external energy, which includes residential related transport energy. The proportions of internal residential energy represent approximately 70 percent for space heat, 18 percent for water heat and approximately 12 percent for appliances (Canada ECE Secretariat 1977). Of these components of internal residential consumption, approximately 88 percent can be said to be discretionary, that is, household consumers can decide on the type of fuel to use and on the quantity of heat required from their residential energy system(s) for acceptable levels of comfort.

By comparison, appliance energy is less discretionary to the extent that electrical energy choices are not usually available to residential consumers, nor are consumers able to exercise much control over the quality or quantity of energy consumed by most appliances. The major choice available to them, aside from a decision of non-use of appliances, is to select appliances with higher energy efficiencies. For external residential energy, such as residential transport, although choices are usually available for the journey-to-work mode to the core in most large cities, for many other urban travel purposes, the automobile is the only realistic choice for residents of most lower density suburbs. Consequently, commuting energy, and in particular, energy for journey-to-work to the core, represents one of the few areas for significant modal discretion among residential energy consumers. Therefore, for this analysis, a base level of discretionary residential energy for urban households is assumed to comprise space heat, water heat, and energy for journey-to-work to the core.

A figure for base level of discretionary residential energy is obtained by adding values obtained for internal residential energy in section 3.3 to values obtained in section 3.4. Table 8 illustrates a format for comparison of such energy consumption characteristics for the selected real cities. In this table, the last row denotes total residential energy which results from a combination of internal residential energy and energy consumption for journey-to-work to the core.

3.6 SUMMARY

This chapter has described a research design for determining residential energy consumption in real cities. This included determination of residential energy conditions internal to households as well as external residential energy requirements, such as energy for journey-to-work. It also compared real and estimated data methods for deriving internal energy consumption, and identified a base level of residential energy under the discretionary control of urban households.

Given the inadequacy of real data available to determine characteristic residential energy limits and changes in urban residential energy consumption over time, and also, given a need to process and manipulate large quantities of energy data from a number of urban tracts in three cities, a variety of devices and related procedures were employed to originate data in this urban laboratory. These included a comparison of real city data with comparable data for hypothetical cities; the use of scenarios to provide a surrogate for time series data; and the application of a three-dimensional matrix to process and manipulate large quantities of real or estimated urban data. This urban laboratory, its devices and their application are outlined in Chapter IV.

TABLE 8: FORMAT FOR COMPARISON OF RESIDENTIAL ENERGY AND RELATED PARAMETERS FOR REAL CITIES

CITY			WINNIPEG				EDMONTON			SASKATOON		
TRACT NO.			014	017	535	540.02	032	048	025	008	015	010
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O
(1) TRACT AREA	km^2		0.67	0.60	1.37	1.09	1.24	1.09	1.09	.88	2.07	2.07
(2) GROSS RESIDENTIAL AREAL DENSITY	DUS/km^2	I										
(3) SPACE HEAT (S.H.) ENERGY/DU/Y	Gj/Y	I										
(4) WATER HEAT (W.H.) ENERGY/DU/Y	Gj/Y	I										
(5) SUB TOTALS	Gj/Y	I										
(6) TRAVEL DISTANCE	km											
(7) JOURNEY-TO-WORK ENERGY CONS./DU/Y	Gj/DU/Y	I										
(8) ENERGY/DU/INC. JOURNEY-TO-WORK ENGERY/DU/Y	Gj/DU/Y	I										
(9) ENERG. CONS/km^2/Y (SPACE HEAT AND WATER HEAT)	Tj/km^2/Y	I										
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	Tj/km^2/Y	I										
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H. AND J.-TO-WK. IN CORE	Tj/km^2/Y	I										

CHAPTER IV RESEARCH METHOD

This chapter focuses on a research method in an urban laboratory which comprises three real and two hypothetical cities. It identifies major devices used in this laboratory to overcome constraints in the method and its data base. Such constraints involve urban limits, changes in urban residential energy consumption over time, and the manipulation of information in a three-dimensional matrix.

4.1 THE URBAN LABORATORY -- ITS DEVICES, THEIR PURPOSE AND APPLICATION

Canada's 24 largest urban areas, that is census metropolitan areas of at least 100,000 population in 1981 (Census of Canada, 1981) can be divided into six regional groups with similar characteristics. These include: (1) the Pacific Coast cities, Vancouver and Victoria; (2) the Interior Plains cities, Calgary, Edmonton, Saskatoon, Regina and Winnipeg; (3) the Central Lowland and Great Lakes cities, Windsor, London, Hamilton, St. Catherines - Niagara, Kitchener, Toronto, and Oshawa; (4) the lower St. Lawrence and Ottawa Valley cities, Ottawa-Hull, Montreal, Trois-Rivieres, and Quebec City; (5) the Atlantic Coast cities, Saint John, Halifax and St. Johns and (6) the Canadian Shield cities, Chicoutimi-Jonquiere, Sudbury, and Thunder Bay. These six groups of large cities exhibit distinct regional similarities in physiographic characteristics which include climate, vegetation, land forms and resources. Some of these urban regions are also subject to greater environmental stress from adverse climate, and/or are more vulnerable to depletion of non-renewable (energy) resources.

Among the six groups of large Canadian cities, the Interior Plains which are subject to the most severe winter climate and to depletion of fossil fuels provide an ideal region in which to consider residential energy conservation and related urban policies. Consequently, Winnipeg, Saskatoon and Edmonton, the most northerly large cities in their respective provinces within the region, are three real cities selected as the urban laboratory for this research.

Within this urban laboratory, several devices are introduced to overcome methodological constraints. These include hypothetical cities, scenarios, and a three-dimensional matrix of urban energy data:

(1) Hypothetical Cities: these provide a benchmark to compare urban energy data in both real and hypothetical cities. Such urban models help to overcome limitations in data for real cities by providing a scale of practical limits of urban energy parameters. Within these limits, relevant conditions in real cities are compared.

(2) Scenarios: the application of alternative energy scenarios to data for real and hypothetical cities over comparable time periods assists in the establishment of prospective time limits or "lead time windows" within which sustainable urban energy conditions can be achieved.

(3) The Three-dimensional Matrix: the matrix format provides a method for organizing and presenting urban energy related data in three-dimensions. Its purpose is to help to visualize and predict change in urban residential energy parameters in response to changing energy policies over time.

4.2 THE USE OF HYPOTHETICAL CITIES TO ESTABLISH LIMITS FOR COMPARING URBAN ENERGY CHARACTERISTICS

In section 3.2, urban environments in Winnipeg, Saskatoon and Edmonton were defined in terms of real data for residential energy consumption and related conditions. For similar tracts in each of these cities, characteristic variables such as residential density, travel distance to the core, and residential energy consumption, are compared. However, because only three real cities are analysed, conclusions which can be derived from this small database are limited.

In order to mitigate the data constraints of a limited universe, and clarify perceived differences in urban parameters, a broader scale for comparison of urban data is required, within which urban characteristics such as, residential density, commuting distance, and residential energy consumption can be assessed. Therefore, in addition to consideration of parameters in real cities, comparable data are derived from two urban models at either end of a spectrum of residential density and commuting distance. This use of hypothetical cities provides a scale against which empirical evidence on energy consumption from real cities can be compared with postulated limits.

In the urban laboratory, an environmental context is defined for two hypothetical cities in a climatically-stressed region; characteristics of these cities and their respective tracts are compared; and limits from these urban models are used to simulate residential energy limits for areas of real cities.

4.2.1 An Urban Context for Hypothetical Cities

In establishing an urban context for hypothetical cities, a region similar to the southern Interior Plains of Canada is assumed as a surrogate for a prototypical climatically-stressed urban region. Within this region, large seasonal differences in temperature and extended heating seasons are assumed to be normative, and space heat is required for most of the year. Consequently, residential energy consumption and efficiency are important policy concerns. Because the designated region varies in physiographic characteristics and energy resources, its sub-regions and their major urban centres depend on different mixes of fossil fuel and hydroelectric energy, and reflect a range of potentials to achieve balanced sustainable energy.

In this context, two hypothetical cities are selected to simulate divergent characteristics of urban centralization and decentralization. As such, they reflect different assumptions about urban residential compactness or dispersal, residential density, commuting distance to the core, and energy consumption by urban households and urban areas. At one end of the scale is the assumption that urban resources are used most efficiently when urban residential development is intensive. This is the case, for example, in urban megastructures, or continuous urban building systems, which are able to contain entire cities or substantial portions thereof (Banham 1976, 8). Such a concept of concentrated intensive urban development is exemplified by a hypothetical compact city which takes the form of a ring of horseshoe-shaped urban clusters (Appendix 1, Plate 3, p.228). It is designed to ensure reasonable amenity for each household with respect to natural light, air, sun, and outdoor access, and, at the same time, minimize unnecessary urban energy consumption.

At the other end of the density scale is a hypothetical decentralized city. This model is based on the assumption that urban settlement patterns are most efficient where development is extensive and uncrowded. In this case, households may consume in the order of an acre of land each, including private outdoor recreation space and "kitchen gardens". For almost a century, this pattern of urbanization has been advanced by planning theorists and architects, such as Howard ([1902] 1960), Borsodi (1933), Wright (1935, 1953) Kaufman and Raeburn (1961), and Goodman and Goodman (1947). In this dissertation, it is illustrated by a decentralized urban model representing a highly structured regional configuration of urban settlements (Goodman 1977).

Although the two hypothetical cities reflect distinctly different concepts of urban form and structure, neither represents a model of extreme high or low residential density. However, both are sufficiently different in residential compactness and travel distance to the urban core to provide useful limits for comparison of energy and urban parameters in real cities.

4.2.2 The Application of Hypothetical Cities

Hypothetical cities are described and their tract characteristics are defined and compared to establish a scale against which real urban energy parameters can be assessed. This is outlined in the following steps:

(1) Two hypothetical cities are described. One is compact and centralized and the other is decentralized and dispersed.

(2) Sectors and tracts in the two hypothetical cities are defined. Areal units within hypothetical cities which can be compared with similar units in real cities are identified.

(3) Relevant data for both centralized and decentralized urban models are tabulated, analysed and compared with data for real cities. The format for tabulation and comparison of data is illustrated in Table 9. This aspect of the procedure includes:

- (i) establishment of gross residential/commercial densities for each tract;
- (ii) derivation of space and water heat requirements for each residential tract;

TABLE 9: FORMAT FOR COMPARISON OF RESIDENTIAL AND RELATED ENERGY PARAMETERS FOR REAL AND HYPOTHETICAL CITIES

CITY			WINNIPEG				EDMONTON			SASKATOON			COMPACT			DECENTRALIZED		
TRACT NO.			014	017	535	540.02	032	048	025	008	015	010	Spine	Inter	Web	T.C.	D.C.	R.C.
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O	I_{cm}	M_{cm}	O_{cm}	I_{dm}	M_{dm}	O_{dm}
(1) TRACT AREA	km^2		0.67	0.60	1.37	1.09	1.24	1.09	1.09	.88	2.07	2.07	1.00	1.00	1.00	1.00	1.00	1.00
(2) GROSS RESIDENTIAL DENSITY	DUS/km^2	I																
(3) SPACE HEAT (S.H.) ENERGY/DU/Y	GJ/Y	I																
(4) WATER HEAT (W.H.) ENERGY/DU/Y	GJ/Y	I																
(5) SUB TOTALS	GJ/Y	I																
(6) TRAVEL DISTANCE	km																	
(7) JOURNEY-TO-WORK ENERGY CONS./DU/Y	GJ/DU/Y	I																
(8) ENERGY/DU/INC. JOURNEY-TO-WORK ENERGY/DU/Y	GJ/DU/Y	I																
(9) ENERG. CONS/km^2/Y (SPACE HEAT AND WATER HEAT)	TJ/km^2/Y	I																
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	TJ/km^2/Y	I																
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H. AND J.-TO-WK. IN CORE	TJ/km^2/Y	I																

LEGEND

cm denotes compact model

dm denotes dispersed model

T.C denotes town centre

D.C denotes district centre

R.C denotes regional centre

(iii) estimation of travel distance to the central core and associated energy consumption for journey-to-work commuting to the core; and

(iv) estimation of aggregate energy consumption for residential/commercial tracts to facilitate identification of potential energy consumption savings through more efficient urban arrangements.

Following these steps, hypothetical cities are used to establish a scale of limits for parameters in real cities. These limits are illustrated in Figure 13.

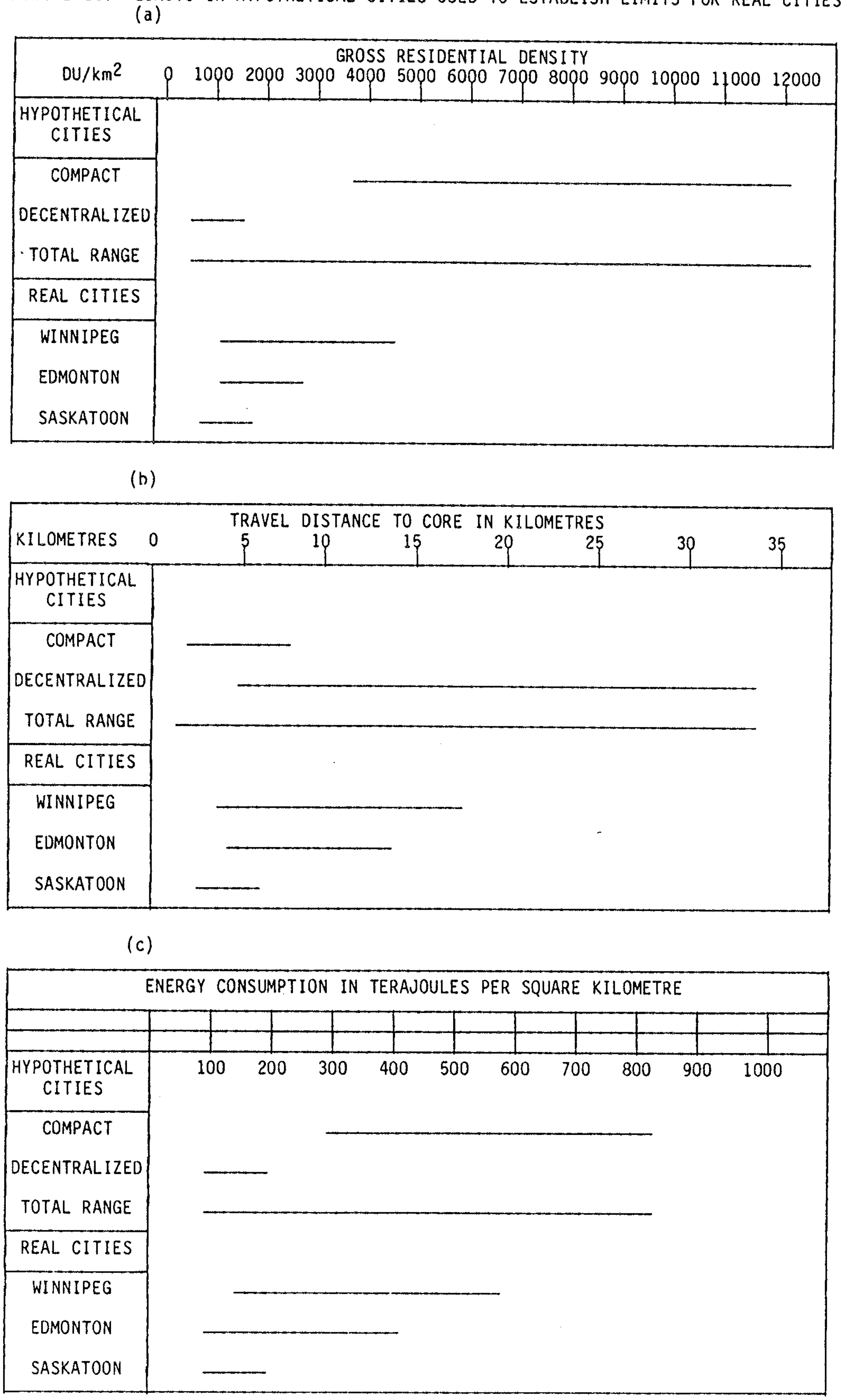
4.3 THE USE OF SCENARIOS TO COMPARE URBAN ENERGY CHARACTERISTICS ON A TIME SCALE

Uncertainties about future energy policies, and the limited time series data on residential energy consumption suggested the need for a method to compare residential energy behaviour in real and hypothetical cities on a long term time scale. For this purpose, scenarios offer imaginary pictures of alternative energy policy well into the future. In this respect, scenarios provide surrogates to simulate present and future urban energy parameters.

Scenarios have two functions in this method: (1) to provide an indicator of energy sustainability; and (2) to establish a prospective time frame.

(1) Indicator of energy sustainability. Given limitations of time, resource availability, and economic conditions, scenarios make it possible to project energy availability to a specific time period (e.g. 2021 or 2025). After this time, energy futures are less certain and dependence on non-renewable energy resources is less sustainable. However, some scenarios, which are dependent on renewables, are possible to sustain indefinitely.

FIGURE 13: LIMITS IN HYPOTHETICAL CITIES USED TO ESTABLISH LIMITS FOR REAL CITIES



(2) A prospective time frame. This is, in effect, a lead time window within which energy-related objectives can achieve a sustainable energy resource future for urban areas. To achieve such "steady-state" urban energy conditions, a strong commitment is required to initiate urban energy planning in a timely manner and to use lead time wisely for energy efficient urban investments.

In this section, three scenarios are defined; policy alternatives underlying these scenarios are described; alternative techniques for determining residential energy consumption are considered; a method of applying the scenarios to estimate changes in total residential energy consumption over time is described; and implications of residential energy consumption and efficiency are discussed for both real and hypothetical cities under each scenario.

4.3.1 The Definition and Characteristics of Scenarios

Scenarios provide a means of staging or simulating urban and related energy conditions over time. In this respect, they are an important device to overcome a lack of time-series data on urban and energy-related conditions for specific cities. They also facilitate consideration of the availability of future energy resources; the impact of urban growth and system efficiency on future energy; and implications of the lead time required to implement energy efficient urban policies.

Scenarios are arrived at in two ways: (1) extrapolating or "forecasting" from present real or assumed parameters into the future; and (2) "backcasting", or working backward in time from a future target level of energy consumption and system efficiency to urban parameters which must obtain at present to achieve future energy objectives. Such parameters include residential compactness, urban commuting distance, and urban residential energy consumption. These reflect particular levels of residential energy use and energy system-efficiency. Although each scenario is related to a particular energy perspective such as that suggested by Gander and Belaire (1978) or Lovins (1976), no scenario represents an absolute with respect to a particular level of urban energy consumption or system efficiency. However, each scenario is sufficiently distinct to facilitate differentiation in energy behaviour among selected urban residential tracts or cities.

Three policy alternatives are considered in establishing a range of scenarios:

(1) There is the confident view that an easy technical fix exists or can be developed to ensure future energy supplies. However, the essential optimism of this scenario may conceal an inherent complacency about rapid depletion of available fossil fuel energy. This has been characterized as a Fast Growth scenario (Rowland 1974), or as a Technical Fix or Historic Trends scenario (Willson 1981).

(2) At the other end of the scale from the fast growth alternative is the Zero Energy Growth or Soft Energy Path scenario (Lovins 1979). It is sometimes referred to as a Conserver Society scenario (Cordell 1979). This scenario adopts a thermodynamic view of economics and energy, stressing implications of the rapid depletion of non-renewable resources and the importance of using energy resources efficiently. Thus it seeks to buy time for future generations to ease the transition to a sustainable energy future. However, it also assumes modifications in urban lifestyles.

(3) The Economic Fix or Modified Historic Trends scenario (Brooks and Casey 1979) represents a pragmatic compromise. This approach is characterized by an assumption of modifications in present energy policy to respond gradually to depleting non-renewable resources and to a need to conserve energy over the longer term. This scenario is limited to dealing only with middle to long range policy alternatives, and assumes little fundamental change in urban lifestyle.

Characteristics of the three scenarios are summarized as follows:

(1) Fast Energy Growth or Historic Trends Scenario: under this scenario, over an extended period (e.g. 20-35 years) urban energy consumption increases, or at best stabilizes. It assumes either a modest increase in urban and economic growth, or stable growth conditions with little change in urban energy system efficiency. Conditions which influence present urban energy consumption and system efficiency parameters are assumed to continue into the future with little change in energy consumption per household or per areal unit.

(2) A Modified Trends Scenario: this scenario is assumed to reflect modest increases in residential density accompanied by significant decreases in areal residential energy consumption. In effect, it represents a compromise between the low energy system efficiency of Scenario I and the high energy system efficiency of Scenario III.

(3) A Soft Energy Path Scenario: under this scenario, a substantial decrease in residential energy consumption is assumed to occur. This reflects significant increases in residential density and substantial and rapid increases in urban energy system efficiency. For example, Scenario III assumes that, initially, stringent energy objectives are established which must ultimately be met at a future date (e.g. 2025). By postulating such a date and defining related conditions -- "backcasting" from the future to the present -- energy conditions are identified which are required in the present in order to achieve a sustainable energy future.

4.3.2 Alternative Methods of Determining Total Residential Energy Consumption under Different Scenarios

Two methods of determining residential energy under different scenarios are considered. The first involves apportioning (national) sectoral energy consumption to selected cities under each scenario on a household basis. Energy consumption for tracts within the cities is then apportioned from such globally derived data. The second method involves computing total household energy consumption on a unit basis from empirical sources. Unit consumption under each scenario is then multiplied by the number of households per tract to determine areal energy consumption.

(1) Method I - Extrapolation of Urban Energy Consumption from Global Data. In 1981, Winnipeg, with a census metropolitan area (CMA) population of 584,842 represented approximately 2.4 percent of Canada's 24,341,700 persons; Edmonton, with a CMA population of 657,057 represented 2.6 percent; and Saskatoon, with a CMA population of 154,210 represented approximately 0.6 percent. In 1980, total secondary energy consumption in Canada approached 7.14 exajoules (EJ) or 7140 petajoules (PJ) (EMR 1981: 26). In Winnipeg, Edmonton and Saskatoon, secondary energy consumption for all energy sectors on a household basis was in the order of 171, 185, and 43 petajoules, respectively. Of this urban energy, the total residential/commercial component represented in the order of 53, 57, and 13 petajoules respectively and the journey-to-work energy component represented approximately 4, 4, and 1 petajoules, respectively.

Because the residential/commercial sector included a significant non-residential energy component for shops, offices, and institutions, as well as a commercial-residential component for rental apartments, the residential energy component of this sector was reduced accordingly. Consequently, for Winnipeg, Edmonton and Saskatoon, internal residential/commercial energy was in the range of 31-53 petajoules, 33-57 petajoules and 8-13 petajoules, respectively. The ranges for total residential energy including residential transport were approximately 35-57 petajoules, 37-61 petajoules and 9-14 petajoules, respectively. Average values for residential consumption alone in these selected cities were in the order of 42, 45, and 11 petajoules, respectively.

Considering the case of Winnipeg, if in 1981, its total share of national energy consumption for residential purposes was 42 petajoules, then its 217,210 households each consumed in the order of 193 gigajoules for their total internal residential needs. These needs included energy for appliances, as well as for space conditioning, and water heat. Since these latter two purposes alone represented approximately 83 percent of the total residential energy for households in Winnipeg, 193 gigajoules resulted in 154 gigajoules for both space and water heat or approximately 158 gigajoules when a component for journey-to-work energy consumption was included. If 1981 household consumption levels were assumed to continue to a scenario target year 2021, then "internal" residential energy consumption in Winnipeg would remain close to 154 gigajoules, and parameters such as residential density and transport energy would remain relatively unchanged.

(2) Method II - Derivation of Internal Residential Energy Consumption from Real Data. Under this method, total residential energy data for specific cities and urban residential areas are derived from estimated values for residential transport energy and from available real data sources such as utility records for internal residential consumption (Table 5, p.110). Such records are used where real energy consumption data are available in aggregate form by postal code addresses, and a postal code conversion software program is available to correlate utility billing addresses with other Canada census data. This method has the potential to handle large quantities of urban and energy related data on a tract basis and is also responsive to the specific parameters considered in this analysis.

4.3.3 The Application of Scenarios to Compare Time-Related Changes in Urban Residential Energy

Urban and related energy parameters at a single point in time are insufficient to project change in urban energy. However, the application of a range of scenarios facilitates simulation of time-related change in urban and related energy parameters.

The three scenarios are simulated as follows:

(1) Fast Energy Growth or Historic Trends Scenario: under this scenario, urban energy parameters are established by assuming that existing conditions of areal residential density, travel distance to the core and areal energy consumption either continue at the same level or increase substantially in the future. Therefore, the scenario assumes continuation of existing or historic conditions as future trends and reflects little change in present levels of urban energy consumption and efficiency.

(2) A Modified Trends Scenario: this scenario represents a compromise which is close to a mid-range of values of urban energy defined for Scenarios I and III. Although the scenario results in little fundamental change in lifestyle, it assumes significant change in urban residential energy consumption and urban energy system efficiency.

(3) A Soft Energy Path Scenario: a long term objective of maximum urban energy system efficiency is assumed and areal residential energy consumption and other parameters are analysed with respect to their impact on selected urban tracts over an extended time period (e.g. 20-35 years). Projected values are "backcast" (i.e. projected backward in time) from an assumed future date to the present (e.g. 2021-1981). Scenario III indicates the magnitude of change required to present urban residential energy conditions in

order to achieve long term objectives of significantly increased residential energy efficiency and reduced residential energy consumption.

As indicated in Table 9 (p.124), residential energy characteristics are compared under all of the scenarios. This includes values for selected tracts in real cities, as well as values for compact hypothetical cities, designated CM and decentralized hypothetical cities, designated DM. Residential characteristics in the table incorporate a number of residential energy components at the discretion of households under each scenario. These include space and water heat as well as journey-to-work energy to the core.

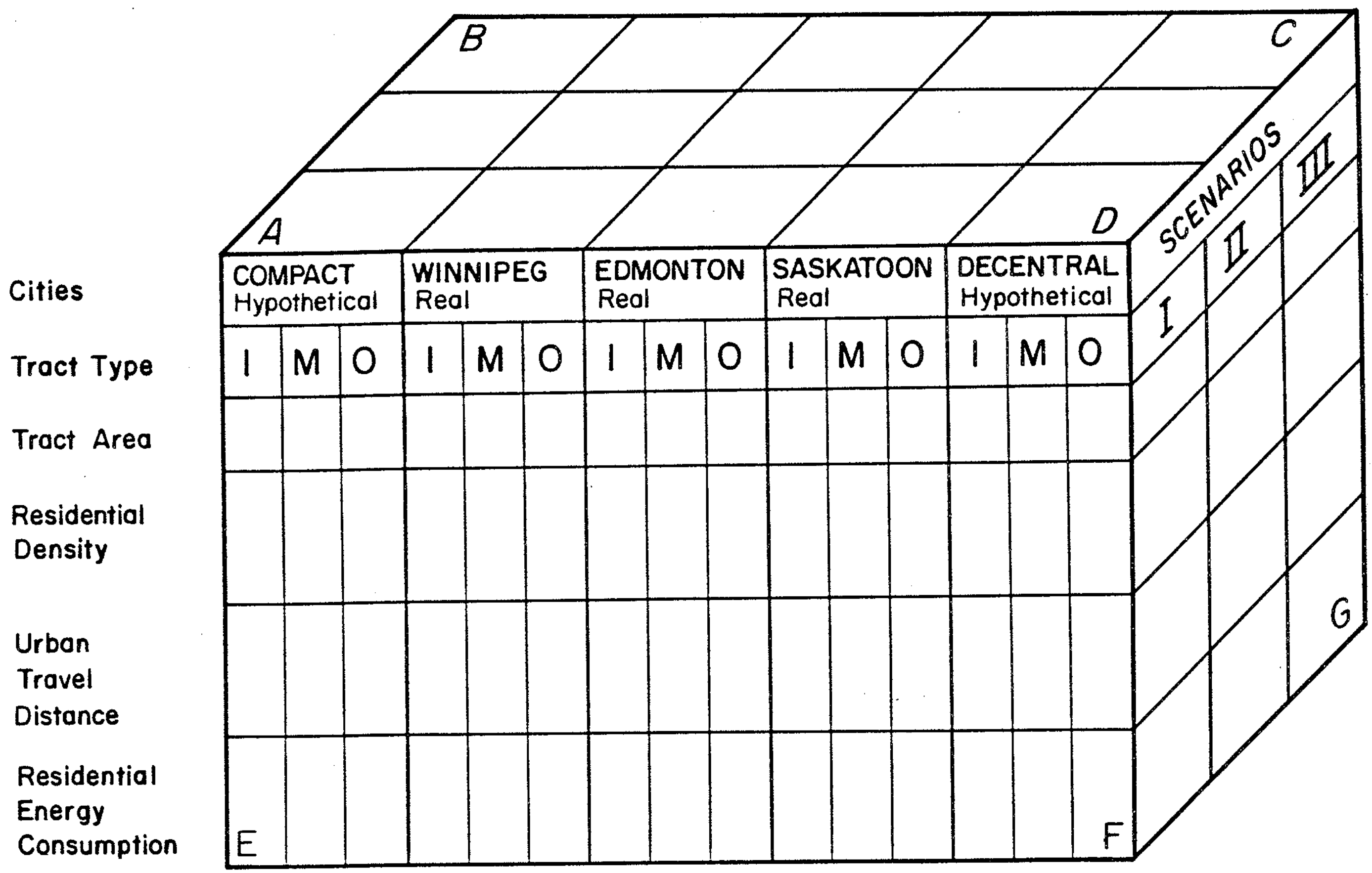
Urban characteristics are tabulated and potential residential energy consumption and related energy components are compared (Table 9). For example, at least ten possible urban characteristics are tabulated and levels of residential energy consumption are compared for sixteen different tracts or areas in real and hypothetical cities.

In the next section, analysis is done and results are presented for the three scenarios using a two- and three-dimensional format.

4.4 THE USE OF A THREE-DIMENSIONAL MATRIX TO COMPARE ENERGY CONDITIONS IN REAL CITIES WITH HYPOTHETICAL CITIES

Derived from mathematical modelling, the matrix format provides a three-dimensional framework of time-related data on selected urban areas in real and hypothetical cities. The format is used to compare data on characteristics such as residential densities, distances for journey-to-work to the core and residential energy consumption for selected urban areas. At the same time, these characteristics are considered in terms of scenarios which simulate alternative energy futures (Figure 14).

FIGURE 14: THE THREE-DIMENSIONAL MATRIX



Plane ABCD: Cities/Scenarios
Plane ADEF: Cities/Characteristics
Plane DCFG: Scenarios/Characteristics

This section describes the three-dimensional framework of the matrix, considers its function and purpose, and explains its application in the analysis of urban residential development and energy parameters.

4.4.1 Description of the Matrix and its Three-Dimensional Format

The three-dimensional matrix format provides an important means to graphically display and compare characteristic data for urban tracts under a variety of possible scenarios. The three-dimensional form of the matrix is notionally represented by a box with three adjacent planes, subdivided into columns and rows representing fifteen residential tracts, six urban characteristics and three energy future scenarios (Table 9 and Figure 14).

In the plane ADEF, selected real and hypothetical cities and their respective tracts are listed. Along the axis AD, the three types of tracts considered are Inner Core edge, designated I; Mature Suburb, designated M; and Outer Suburb or Fringe, designated O. Along the axis AE, characteristic parameters are tabulated. These include: residential density, urban travel distance, and residential energy consumption. In the plane ABCD, the matrix is divided into fifteen city sections and 45 tract sections. Along the axis DC, these divisions tabulate the three alternate energy futures or scenarios under which urban characteristics can be compared for each selected tract. In the plane DCFG, the matrix is divided into three columns or 45 subsections. This plane facilitates comparison of characteristics/parameters for any specific tract along the axis AE, under alternative scenarios along the axis DC.

Therefore, the three dimensions of the matrix facilitate simultaneous comparison of residential energy consumption and other characteristic parameters for each of the selected tracts under alternative scenarios and for both real and hypothetical cities.

4.4.2 The Purpose of the Matrix

By juxtaposing a range of characteristics from a number of urban residential tracts under varying conditions of energy consumption over time, the matrix facilitates investigation and comparison of characteristic urban energy parameters. These include residential density, external residential energy for journey-to-work to the core, and internal residential energy for space heat and hot water. Although the matrix framework potentially can facilitate processing of data from a large numbers of cities and their respective tracts, for demonstration purposes, the numbers of tracts and urban residential energy conditions considered in this urban laboratory of three cities has been intentionally limited.

In the context of alternative energy scenarios, the ability to describe a large number of urban conditions within a common framework is useful in considering policy implications of urban residential energy consumption and system efficiency for different cities. Also, the matrix approach, notionally, permits comparison of groups of households or areas which exhibit similar energy parameters among a large number of urban tracts for both real and hypothetical cities.

4.4.3 The Application of a Three-Dimensional Matrix Format

In applying the matrix format, the relative compactness or density of urban residential tracts or areas is compared on a scale of limits which is established from conditions in hypothetical cities (Figure 14). In addition, age and related building conditions in urban residential tracts are compared among cities of similar or different size, and representing significantly different periods of residential development. Comparison is also made between older and newer residential tracts within the cities. Age of residential areas becomes in part a surrogate for building condition, in particular, the thermal insulation. Age is also reflected in energy consumption of residential areas within cities, when areas are compared on a scale of distance to the central core from outer residential suburbs.

Finally, the matrix, in particular those characteristics which relate to the axis DC, facilitates comparison of time-related changes in residential energy parameters for urban tracts under different assumptions of future energy resources and energy system efficiencies.

4.5 SUMMARY

This chapter established conditions of the urban laboratory, its devices and their application. Specifically, it reviewed the use and application of three devices: (1) urban models to establish urban energy limits; (2) scenarios to compare urban energy parameters over time; and (3) a three-dimensional matrix to compare energy characteristics in real and hypothetical cities and assess the impact of change on residential energy.

The devices were applied to the method outlined in Chapter III in accordance with the following steps:

(1) relevant characteristics of real large cities, selected as an urban laboratory, were defined;

(2) hypothetical urban models and their related tracts were postulated, and real urban conditions of residential compactness and energy consumption were compared;

(3) three energy scenarios were postulated to simulate time-related changes in residential energy among selected cities;

(4) data for various characteristics were derived and assembled in a three-dimensional matrix format to compare urban energy conditions and relationships under alternate scenarios;

(5) using a matrix format, real and hypothetical data were compared for different cities and tracts. The results were then projected in terms of two- and three-dimensional relationships of residential density, commuting distance from residential tracts to the city centre, and residential energy consumption.

These steps and the data which they generated are applied in the method discussed in Chapter V.

CHAPTER V APPLICATION OF THE METHOD

In this chapter, data which are developed and organized in accordance with the steps outlined in Chapter III, Development and Organization of Data, are used to illustrate application of the method. Several devices introduced and described in Chapter IV, Research Method, are applied to provide a shorthand for consideration of limited urban residential energy data.

The first sub-section identifies evidence generated by the research and applies this real and estimated data to analysis of selected residential energy parameters in three large real cities. The second sub-section investigates limits of residential conditions in the real cities using limits derived from conditions for hypothetical cities. The third sub-section applies scenarios of alternative energy futures to an investigation of time-related changes in residential energy consumption. The fourth sub-section uses the device of a three dimensional matrix, which is described in Chapter IV, to consider changes in the parameters: internal residential energy consumption, residential density, and energy for journey-to-work to the central core. The three-dimensional matrix format is also used to facilitate comparison of residential energy characteristics among real cities and urban residential tracts, with characteristics of hypothetical cities.

5.1 CONSIDERATION OF SELECTED RESIDENTIAL ENERGY RELATED PARAMETERS IN REAL CITIES

Parameters of residential energy environments are investigated for a limited number of real cities. Data for this investigation derives from two cities in the population range of 550,000 - 600,000 and a third city with a population in excess of 150,000. For these large cities, the following residential energy related parameters are considered:

(1) residential density;

(2) age and condition of residential development;

(3) urban size and compactness; and

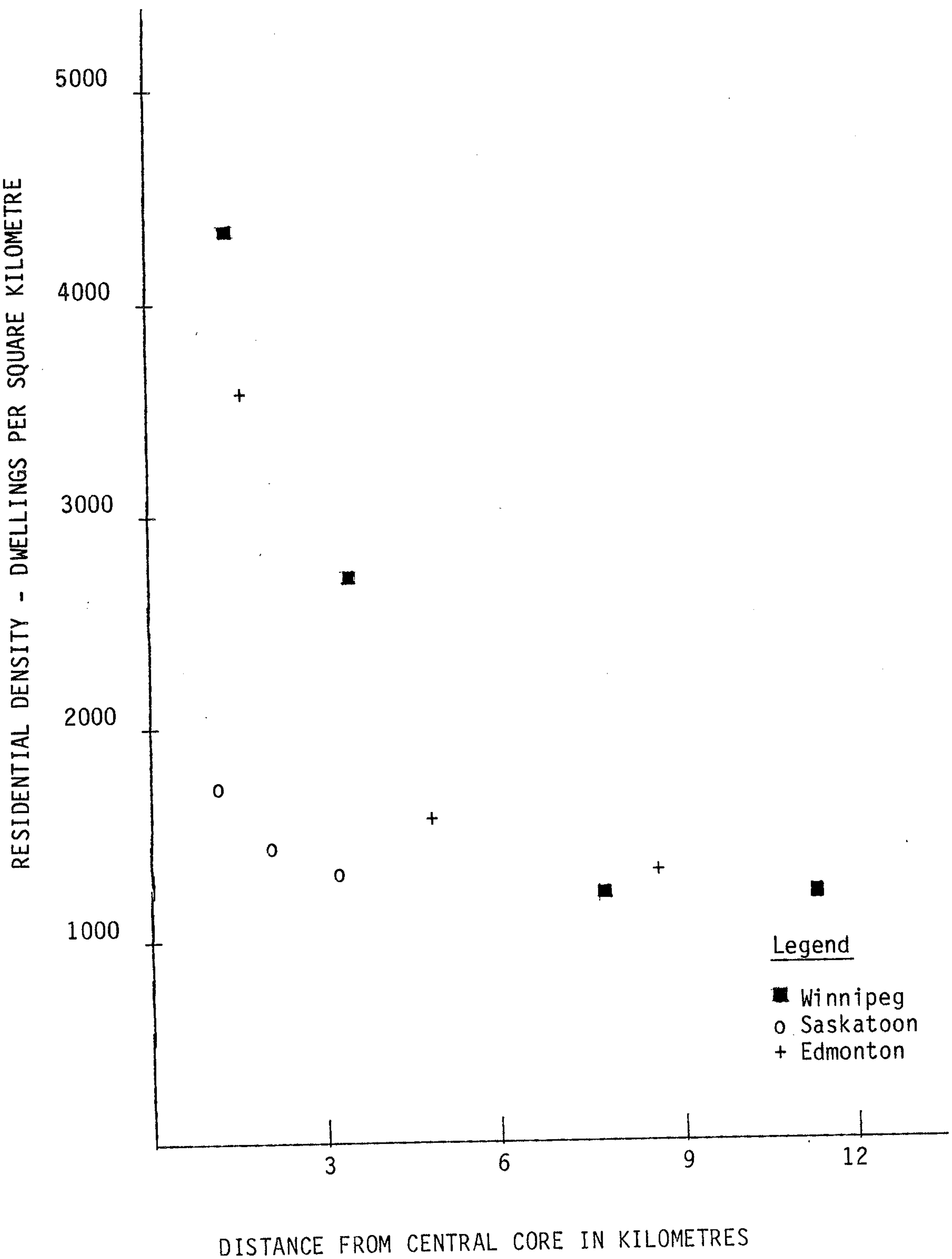
(4) residential energy consumption and energy system efficiency.

5.1.1 Residential Density

In an investigation of residential density for urban tracts in selected cities (Table 9, p.124), relationships focus on (1) changes in residential energy consumption with residential density, and (2) changes in residential density with travel distance from the central core to residential areas (Figure 13, p.126). In Table 9 residential density data are derived from the 1981 Census for each of the selected cities (Statistics Canada 1982), and from residential energy consumption data obtained from the energy utilities serving these cities (Appendix II). When these data are compared and modelled for comparable residential tracts in each city, including inner core edge tracts (I), mature suburban tracts (M), and outer suburban tracts (O), relationships of residential density and distance from the central core are indicated in Figure 15. From Figure 15 and Table 9, the following characteristics are observed for the selected tracts:

(1) Residential density decreases with distance from the core. Specifically, from selected inner core edge tracts to mature and outer suburbs, residential densities decrease with distance from the centre.

FIGURE 15: THE RELATIONSHIP BETWEEN RESIDENTIAL DENSITY AND DISTANCE FOR CHARACTERISTIC TRACTS



(2) In Winnipeg, outer suburban densities increase slightly from some older suburban tracts to newer tracts at the outer suburban fringe. This can be explained in part by a higher proportion of multiple dwelling types which are developed in newer growth areas near the outer urban fringe.

(3) Residential densities for inner core tracts in large cities are greater than residential densities for outer suburban tracts. This corresponds with findings of Clark (1951) and Newling (1969) on the relationship of urban population density to distance from the core in larger cities.

(4) In inner core edge and mature suburbs of Winnipeg and Edmonton, residential densities are higher than in corresponding tracts in Saskatoon. This is due, in part, to a greater mix of non-residential land uses and to less residential redevelopment in the selected inner core tract (008) in Saskatoon.

Further consideration of these characteristics also indicates a consistent difference between relative values of density for Winnipeg, Saskatoon, and Edmonton. This difference in residential density for the three cities is explained by

(i) a greater mix of older and less well-insulated multiple units and residential dwelling conversions in the selected older mature Winnipeg tract (017) than in similar tracts in newer cities, such as Edmonton tract (048) or Saskatoon tract (015); and

(ii) smaller and narrower lots in older mature Winnipeg tracts than in counterpart areas in the newer cities, reflected in part, in higher tract density in the older Winnipeg tract.

5.1.2 Age and Condition of Residential Development

In this application of a method of handling energy data, an important issue which is considered the relationship between age and condition of dwellings and residential energy density. In Table 10, data are presented which compare the parameters, percent of dwellings in need of repair (major and minor), and percent of dwellings over 40 years, with internal residential energy consumption for each tract. In Figure 16, the percent of dwellings in need of repair is compared with residential energy consumption, and data are plotted as a scattergram. In Figure 17, a similar comparison is made between age of dwellings in various tracts, and residential energy consumption, and a scattergram is also produced.

Although the evidence for the three cities is limited, in most instances data indicate high energy consumption for residential tracts which contain a large proportion of older single detached dwellings and/or apartments. Notwithstanding climatic differences among Winnipeg, Saskatoon and Edmonton (Table 3, p.27), which result in some variations in residential energy consumption among tracts in the various cities, parameters such as condition of dwelling and age of tracts are more important. For example, when data for selected residential tracts are plotted in a scattergram which correlates numbers of dwellings in need of repair with residential energy consumption (Figure 16), inner city tracts in Winnipeg not only contain a larger proportion of dwellings in need of repair, but also consume significantly greater residential energy. By comparison, Edmonton, a newer city, reflects lower residential energy consumption in its corresponding inner city tracts.

Because Edmonton is a warmer city than Winnipeg (Table 3) selected tracts in Edmonton can be expected to and do consume less residential energy than counterpart tracts in the colder Manitoba city (Table 13, p.158). However in comparing Edmonton with Saskatoon, which

TABLE 10: COMPARISON OF AGE AND CONDITION OF DWELLING UNITS AND ENERGY CONSUMPTION FOR SELECTED TRACTS

CITY	TRACT NO.	ZONE	BLDG. DENSITY	PERCENT DU's* >40 YRS	PERCENT DU's NEED REPAIR	ENERGY CONSUMPTION TJ/KM^2
WINNIPEG	.014	I	4306	26	20	581
	.017	M	2658	81	41	521
	.535	0	1164	6	26	178
	.540.02	0	1335	3	16	220
SASKATOON	.008	I	1517	26	16	244
	.015	M	1760	42	24	174
	.010	M	1242	25	31	165
	.018.02	0	988	NA:	7	NA:
EDMONTON	.032	I	3726	9	7	320
	.048	M	1402	32	22	205
	.025	0	1229	5	36	145
	.006.05	0	1266	NA:	NA:	NA:

Source: Census of Canada, 1981 and urban gas utility consumption data (1981).

* Dwelling Units are abbreviated DU's

FIGURE 16: THE RELATIONSHIP BETWEEN RESIDENTIAL ENERGY CONSUMPTION AND CONDITION OF DWELLINGS

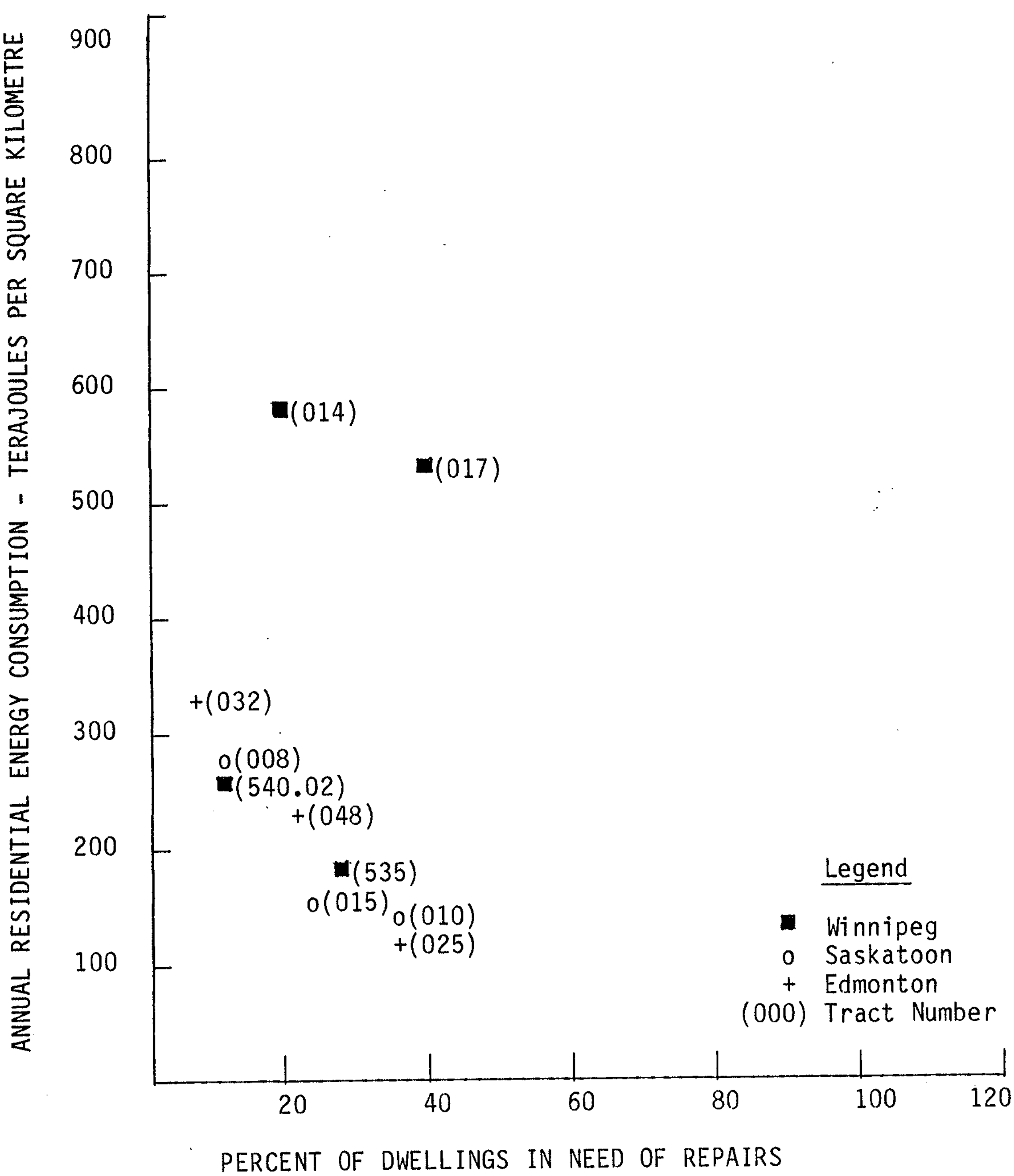
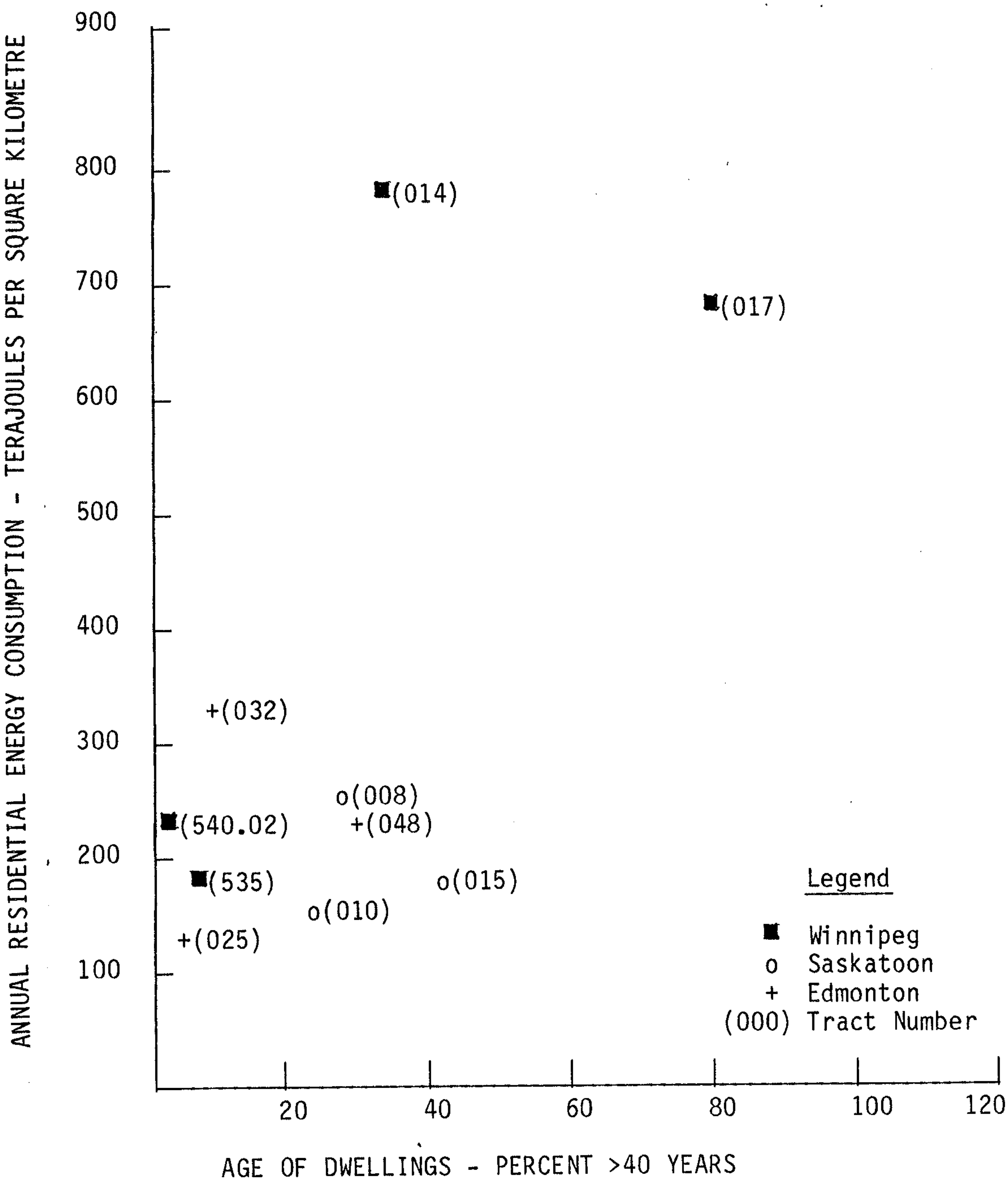


FIGURE 17: THE RELATIONSHIP BETWEEN RESIDENTIAL ENERGY CONSUMPTION AND AGE OF DWELLINGS



is also a colder city, the selected Edmonton tracts are consistently lower in energy consumption than counterpart tracts in Saskatoon. Therefore, climate is not consistent in its impact on residential energy consumption in the three selected cities. A possible explanation for this variation may be that climate is less important than other factors in influencing residential energy consumption. Another explanation may be variations in climatic conditions among the cities for a specific year (1981) compared to a multiyear period (Table 3, p.27).

In Figures 16 and 17, scattergrams indicate a correlation between the parameters age of residential area and residential energy consumption (Figure 17), and the parameters percent of dwellings in need of repair and residential energy consumption (Figure 16). For example, Winnipeg tracts indicate significantly higher residential densities than tracts in Edmonton and Saskatoon. Also, older areas in the newer cities, such as tracts 032, 048 and 008 in Edmonton and Saskatoon, are greater in terms of residential energy consumption and age of dwelling, than are newer residential areas such as tracts 015, 010 and 025, in the same two cities.

5.1.3 Urban Size and Compactness

Among the three cities, differences in urban size and residential density provide an opportunity to consider size and compactness as parameters of residential energy consumption. Data for tracts and residential densities are derived from census metropolitan areas (CMA's) in the 1981 Census (Statistics Canada 1982), and from 1981 municipal boundaries for the three selected cities (Table 11).

Using these data, size is plotted and compared with residential density and population density for each city (Figures 18 and 19). From these data, a relationship emerges between the parameters urban size and residential energy consumption for the three cities. It indicates that in 1981: (1) Saskatoon had the lowest gross residential density, and Edmonton the highest in absolute terms; (2) Winnipeg was less residentially compact than Edmonton (Figure 17) and; (3) available data on gross residential density and energy consumption were not sufficient to establish a definitive relationship between urban size and residential energy density for the areas of the three cities*.

TABLE 11: COMPARISON OF POPULATION AND RESIDENTIAL DENSITY IN THREE SELECTED CITIES

City	1981 Census Population (Municipal Limits)	Number Households	Area km^2	Population Density pp km^2**	Density dus/km^2
Winnipeg	544,949	205,420	411	1326	500
Saskatoon	154,210	57,340	122	1264	470
Edmonton	517,331	163,870	285	1815	544

** Persons per square kilometre and dwellings per square kilometre, respectively, are abbreviated pp km^2 and dus/km^2.

Higher average density for Edmonton compared with Winnipeg indicates, that Edmonton's greater compactness in 1981 was in part institutional; that is, it was due to man-made planning constraints designed to ensure compact urban growth and development***. Conversely, Winnipeg's lower population and densities relative to Edmonton reflect the large areas of undeveloped suburban land within the 1981 boundaries of the older and historically slower growth Manitoba city.

A significance of urban compactness for residential energy consumption is its effect on travel distance to the core. For example,

* Value for gross energy consumption for an entire city was only provided by Winnipeg's utility agency.

*** The annexation of large areas of rural land to the City of Edmonton by the Province of Alberta, effective January 1, 1982, significantly reduced the relative compactness of the City of Edmonton which had existed at the time of the 1981 Census.

FIGURE 18: URBAN POPULATION AND SIZE - THREE CITIES

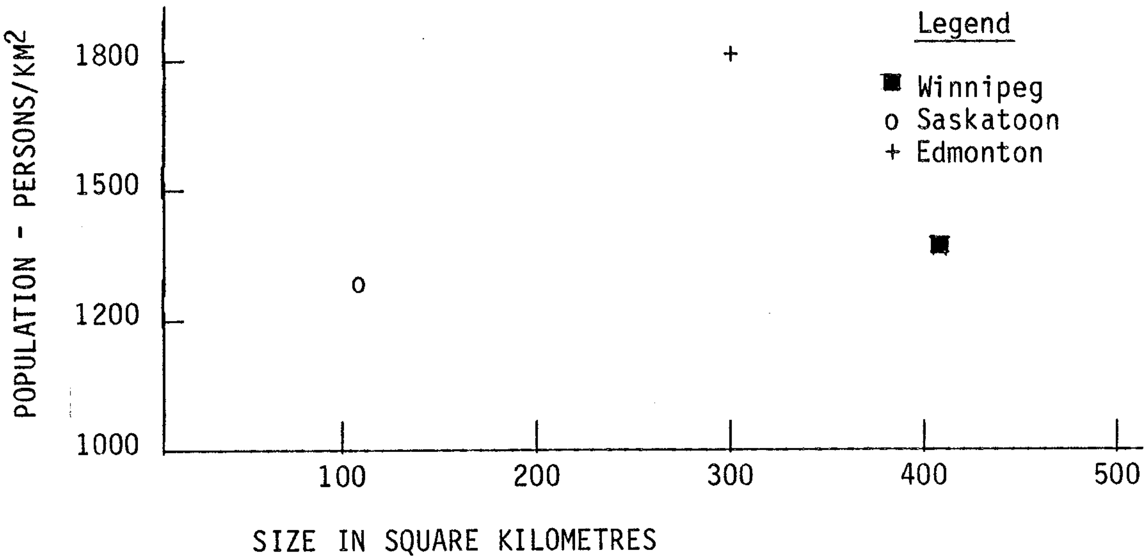
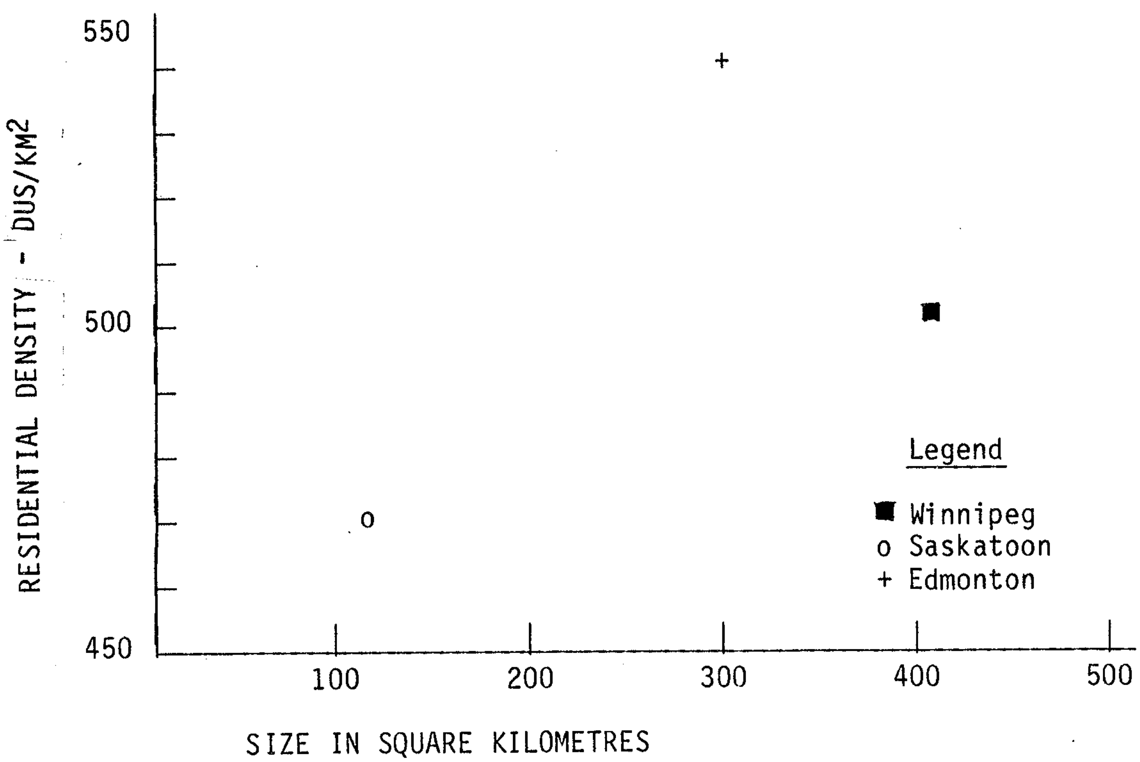


FIGURE 19: RESIDENTIAL DENSITY AND SIZE - THREE CITIES



if it is assumed that the selected cities are all circular, then for the areas given in Table 11, Winnipeg, Saskatoon, and Edmonton would have unadjusted radii (D_c) of 11.4, 6.2 and 9.5 kilometres, respectively, and adjusted radii of 21.3, 13.4 and 18.4 kilometres, respectively, where adjusted distance is $L_c = 4 + 1.52\ D_c$. Therefore, an average trip to the core from the outer fringe of Saskatoon represents 54 and 65 percent of the unadjusted trip distance from the outer fringe to the core for Winnipeg and Edmonton, respectively. Using adjusted distance values, Saskatoon's radial distance to the core represents 61 and 72 percent of the respective adjusted distances for Winnipeg and Edmonton. As will be shown in sections 5.2.1 and 5.3.5, Saskatoon's shorter radial distance to the core is ultimately reflected in lower energy consumption for shorter journey-to-work travel distance to the core.

5.1.4 Residential Energy Consumption and Energy System Efficiency

In this subsection, parameters of residential energy consumption and energy system efficiency are investigated. These include: (1) the proportion of energy consumed by each component of residential demand; (2) the system efficiency of specific components of residential energy; and (3) total energy system efficiency of urban households.

5.1.4.1 Components of Residential Energy Demand. In this investigation, urban residential energy involves two major components: (1) residential energy consumption internal to households; and (2) transport energy for residential purposes; that is, travel energy which is required to provide daily access to a workplace from a residence and return.

(1) More than 80 percent of internal residential energy represents space conditioning and water heat. Most of this household energy most is required for use at low temperatures. For example, space heat at less than 100°C comprises in excess of 60 percent of internal

residential energy, and water heat, most of which is used at little more than 40°C, comprises an additional 20 percent (CMHC 1977; Fowler 1984). The residual 20 percent of internal residential energy represents high temperature or high quality energy such as electricity for refrigeration, cooking, lighting and powering various appliances. To the extent that in fossil fuel dependent regions much of this is inefficiently produced thermoelectricity, electrical energy production and distribution suggests an important area in which to improve energy efficiency.

(2) When total energy demand is analysed by economic sectors, the residential-commercial sector component comprises approximately 36 percent and the transport sector approximately 25 percent of this total. The proportion of transport energy which reflects in part residential-commercial consumption is slightly over 50 percent of the total for all transport purposes or approximately 13 percent of all energy consumed. This includes both private automobile and transit energy. Of this total, residential energy for journey-to-work comprises 43 percent of all travel trips or approximately 6 percent of total transport energy (Transport Canada 1979). With work trips to the core representing approximately 35 percent of total journey-to-work travel, this aspect of residential transportation is in the order of 2 percent of total transport energy. When this "external" component is added to the internal residential/commercial components of space and water heat, or approximately 29 percent, total residential energy consumption represents in the order of 31 percent.

5.1.4.2 System Efficiencies of Residential Energy Components. The three components of residential/commercial energy in this investigation also represent different degrees of energy system efficiency. For example, considering that the system efficiency of automobiles and buses is in the range of 5-10 percent under dry road conditions, a conservative figure of 5 percent is used for transport system efficiency (Cook 1976).

In urban dwellings, residential heating plants (primarily gas furnaces), range in efficiency from 45-72 percent (Cook 1976; and Fowler 1983). Another source has suggested 63 percent as a reasonable figure (CMHC 1977). Also, within this range, system efficiency for gas fired water heat is in the order of 56 percent (Cook 1976).

5.1.4.3 System Efficiency of Urban Households. The total system efficiency of residential energy consumption by urban households is represented by the sum of the product of each residential energy component and its respective device efficiency. For example, if furnaces and automobile engines represent heating devices for specific components of residential energy, the following table illustrates a method of determining system efficiency of urban households:

Table 12: ENERGY SYSTEM EFFICIENCY OF URBAN HOUSEHOLDS

Energy Component	Proportion of Total Residential Energy	Approximate Device Efficiency	Residential System Efficiency
Space Heat	.60	.63	.38
Water Heat	.20	.56	.11
Journey-to-Work Energy to Core	.02	.05	.001
		Total	.49

Therefore, 49 percent represents a conservative base level for energy system efficiency in urban households. Table 12 indicates that although the three residential energy components are all substitutable by more efficient energy sources or systems, including changes in either the proportion of total residential energy consumed and/or the relative efficiency of energy conversion devices used for residential purposes (e.g. vehicle engines or furnaces), the transport energy component is not large enough under current (inefficient) conditions to appreciably affect residential system efficiency. However, if the relative proportions of energy for space conditioning and transport shift in favour of increased transport energy, and if device efficiencies increase substantially for residential transport alternatives, residential transport energy could influence residential system efficiency more significantly.

5.2 CONSIDERATION OF URBAN PARAMETERS IN REAL CITIES USING LIMITS FOR HYPOTHETICAL CITIES

In an investigation of energy consumption in residential areas of real cities, it is essential to establish practical limits for urban parameters. In this subsection, limits for hypothetical cities are used to identify, investigate and compare urban residential parameters in real cities.

5.2.1 Limiting Values of Real Urban Conditions

Under normal urban conditions in real cities, residential limits fall within certain values for the parameters residential density, travel distance for journey-to-work to the core and residential energy consumption for both compact and decentralized city tracts. This subsection considers these limits.

5.2.1.1 Limits of Residential Density. In large real cities there is a wide range of residential densities. At the upper end of the scale, some in southeast Asia may exceed 75,000 dwellings per square kilometre (Dantzig and Saaty 1973). In Chicago, mixed residential and commercial highrise developments with densities in excess of 71,000 dwellings per square kilometre were built in the late 1950's. In the central Manhattan area of New York City, luxury residential redevelopment projects on entire blocks resulted in residential densities in the order of 48,000 dwellings per square kilometre (Meyerson 1963). However, for the city as a whole, average residential densities are considerably lower, or in the order of 14,000 dwellings per square kilometre (Dantzig and Saaty 1973). This lower figure also allows for other non-residential land uses including streets, roads and public open space.

In colder places, such as Canadian cities, a number of high density mixed commercial/residential projects have been projected or developed in the past several decades. One of these, Project la Concorde, a 14.8 hectare redevelopment at the edge of the downtown core of Montreal, proposed in the mid 1960's, was to have in excess of 56,000 dwellings per square kilometre. Subsequently, it was implemented in a scaled down version at a reduced density. In Edmonton in 1980, a mixed commercial/residential redevelopment for the downtown core was approved in principle with a density exceeding 40,000 dwellings per square kilometre, including a large commercial retail component within the complex.

In this investigation, a much lower limit of maximum residential density is assumed. In part, this is because large urban areas usually support lower residential densities than are developed on individual sites. Another reason for assuming a more modest residential density is that energy consumption increases appreciably at higher residential densities (Keyes 1978). Consequently, at the upper limit of the residential density scale, conservative values are assumed for a compact hypothetical city.

At the low end of the density spectrum, potential limits are more constrained. In part, this reflects concerns with the diseconomies of servicing low density urban development and an increased understanding of the total costs of such services (Pearson 1967; Real Estate Research Corporation 1974). In Table 11 (p.148), the three selected cities had densities ranging from 470-544 dwellings per square kilometre. At an average density of 505 dwellings per square kilometre for the three cities, this low end limit was approximately 15 percent higher than the figure of 408 dwellings per square kilometre for a compact decentralized city proposed by Goodman (1977). Hypothetical cities with even lower residential densities have been suggested. In 1935, for example, Broadacres City, a decentralized low density urban model, was proposed. Situated within the plains region of the United States, this hypothetical city had a residential density in the order of 135 dwellings per square kilometre (Wright 1935; Ciucci et al 1983).

Summarizing density limits, a residential density spectrum in the range of 130-16,000 dwellings per square kilometre is assumed to be possible for hypothetical cities. However, for real cities under the three suggested scenarios, more conservative upper and lower limits of residential tract density in the range of 1000-10,000 dwellings per square kilometre are assumed. For example, under Scenario I, residential tract densities in the selected cities range from more than 1000 dwellings per square kilometre (e.g. 1063 dwellings per square kilometre) to less than 4500 dwellings per square kilometre (e.g. 4306 dus/km^2). Under Scenario III, residential tract densities are assumed to range from 1500 to 10,000 dwellings per square kilometre.

5.2.1.2 Limits of Travel Distance and Related Energy Consumption. Although straight line (unadjusted) travel distance from the outer suburban fringe to the downtown core for large western Canadian cities like Edmonton, Saskatoon and Winnipeg is within a range of 6-12 kilometres, for Edmonton and Winnipeg it is closer to the upper limit. From typical residential tracts to the central core for large Canadian cities, "adjusted" travel distance ranges from 3.6 kilometres to more than 18 kilometres for selected cities (Transport Canada 1979). For Winnipeg, Edmonton and Saskatoon, inner core edge tracts are located within a 0.5-2.5 kilometre zone of the core; mature suburbs are generally located within a 1.5-5.0 kilometre zone; and outer suburbs are in a zone of 3.0-12.0 kilometres.

For hypothetical cities, travel distance limits for journey-to-work to the central core are greater than distance limits for real cities. In effect, urban models are constrained only by practical limits of travel time and the technology requirements of possible mobility systems. For example, in a hypothetical compact city, unadjusted journey-to-work distance D_C is assumed to range from 0.8-1.6 kilometres (Appendix 1, Plate 3, p.228). Although for a hypothetical decentralized city, assumed in this investigation, unadjusted distance ranges from 9.8-19.9 kilometres (Goodman 1977), values as high as 64 kilometres have been suggested for commuting distances to maintain low density lifestyles (Wright 1954). A maximum adjusted commuting distance to the central core for a decentralized city is assumed to be in the range of 4.5-33.5 kilometres.

The significance of travel distance on residential energy consumption is its affect on household transport energy, in particular for journey-to-work or other regular travel to the central core. Since most journey-to-work trips are automobile-oriented, energy consumption limits for this transport mode are important. For typical North American automobiles, fleet average consumption has been projected to be in the order of 10 kilometres per liter for 1985 (Canada, EMR 1977). At 32.1 megajoules per liter of fuel this translates into approximately 3.2 megajoules per kilometre. It has also been indicated that much higher efficiencies for automobile fuel consumption would be feasible by 1982. For example, one analysis suggested energy level targets as low as 0.8 megajoules per kilometre (Harding et al 1982).

Although under the efficient urban energy conditions in hypothetical cities, high levels of transport efficiency are achievable, under Scenario III in this investigation, 26 kilometres per liter or approximately 1.2 megajoules per kilometre is assumed to be a practical consumption level for residential transport energy. Under Scenarios I and II, more conservative levels of transport consumption are assumed. For example, when account is taken of efficiency losses due to cold starts, longer idling for warmups and short driving distances for urban trips, limits for residential transport vehicule energy consumption are assumed to be in the range of 2.0-5.0 megajoules per kilometre under Scenario I; 1.4-3.4 megajoules per kilometre under Scenario II; and 0.8-1.4 megajoules per kilometre under Scenario III.

Although less significant in its impact on residential energy consumption than the automobile, urban transit plays an important secondary role in journey-to-work energy, in particular, for work trips to and from the central core. For urban transit energy, approximately 1.2 megajoules per kilometre is assumed to be a conservative, yet practical level. Consequently, transit energy consumption limits are narrower. For example, because transit vehicles operate continuously with engines at optimum temperatures, despite their start-stop movements, surface transit energy consumption is assumed to range from a high of 2.3 megajoules per kilometre under Scenario I, to a low of 1.0 megajoules per kilometre under Scenario III. However, notwithstanding the potential increases in energy efficiencies for urban transport systems which are possible under various scenarios, journey-to-work transit energy as a proportion of total residential energy is small.

5.2.1.3 Limits of Total Residential Energy Conservation. Although limits of total residential energy consumption reflect a combination of components for residential transport and internal residential energy, only the energy component for journey-to-work to the core is included in this investigation (Tables 13-15). For example, in Table 13, Rows 5, under Scenario I, internal residential energy for selected real cities ranges from a low of 89 to a high of 196 gigajoules per household per year. If an assumed value of 100 gigajoules per year is added to this range of values for internal residential energy for transport energy (Harding et al 1982), then the assumed limits for total residential

TABLE 13: 1981 DATA BASE IN THE PLANE ADEF FOR A THREE-DIMENSIONAL MATRIX - SCENARIO I

CATEGORY			REAL CITIES										HYPOTHETICAL CITIES					
CITY NAME OR CLASSIFICATION			WINNIPEG				EDMONTON			SASKATOON			COMPACT			DECENTRALIZED		
TRACT NUMBER OR DESCRIPTION			014	017	535	540.02	032	048	025	008	015	010				T.C.	D.C.	R.C.
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O	I_{eq}	M_{eq}	O_{eq}	I_{eq}	M_{eq}	O_{eq}
(1) TRACT AREA	km^2		0.67	0.60	1.37	1.09	1.24	1.09	1.09	.88	2.07	2.07	1.00	1.00	1.00	1.00	1.00	1.00
(2) GROSS RESIDENTIAL DENSITY	DUS/km^2	I	4306	2658	1164	1335	3726	1528	1229	1517	1063	1242	12025	9375	4142	1497	92	92
(3) SPACE HEAT (S.H.) ENERGY/DU/Y	GJ/Y	I	104	151	113	126	66	103	90	123	126	102	40	45	50	70	70	70
(4) WATER HEAT (W.H.) ENERGY/DU/Y	GJ/Y	I	31	45	40	39	20	31	28	38	38	31	25	25	20	30	30	30
(5) SUB TOTALS	GJ/Y	I	136	196	153	165	89	160	129	162	154	133	65	70	70	100	100	100
(6) TRAVEL DISTANCE	km		3.6	7.1	13.3	18.1	4.2	7.1	13.1	3.3	4.1	7.2	3.7	5.9	6.4	4.5	24.6	33.5
(7) JOURNEY-TO-WORK ENERGY CONS./DU/Y	GJ/DU/Y	I	7.8	13.0	21.5	18.6	8.9	10.8	16.3	8.0	8.8	9.7	5.1	6.8	9.7	12.4	25.2	34.4
(8) ENERGY/DU/INC. JOURNEY-TO-WORK/DU/Y	GJ/DU/Y	I	144	209	175	184	98	171	145	170	163	143	70	77	80	1124	125.2	134.4
(9) ENERG. CONS/km^2/Y (SPACE HEAT AND WATER HEAT)	TJ/km^2/Y	I	585	521	178	220	332	224	159	245	164	165	820	697	315	168	111	119
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	TJ/km^2/Y	I	10.1	10.4	7.5	7.5	10.0	4.5	6.0	4.2	5.4	4.2	21.5	22.3	14.1	1.7	.8	1.1
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H. AND J.-TO-WK. IN CORE		I	595	532	186	228	342	229	166	249	169	169	842	719	329	170	112	120

Legend
cm denotes compact model
dm denotes dispersed model
T.C. denotes town centre area
D.C. denotes district centre area
R.C. denotes regional centre area

TABLE 14: 1981 DATABASE IN THE PLANE ADEF FOR A THREE-DIMENSIONAL MATRIX - SCENARIO II

CATEGORY			REAL CITIES										HYPOTHETICAL CITIES					
CITY NAME OR CLASSIFICATION			WINNIPEG				EDMONTON			SASKATOON			COMPACT			DECENTRALIZED		
TRACT NUMBER OR DESCRIPTION			014	017	535	540.02	032	048	025	008	015	010	Spine	Inter	Web	T.C.	D.C.	R.C.
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O	I_{cm}	M_{cm}	O_{cm}	I_{dm}	M_{dm}	O_{dm}
(1) TRACT AREA	km^2		0.7	0.6	1.4	1.1	1.2	1.1	1.1	.9	2.1	2.1	1.0	1.0	1.0	1.0	1.0	1.0
(2) GROSS RESIDENTIAL DENSITY	DUS/km^2	III	10000	3000	1500	1500	10000	2000	1800	3000	2000	1500	16000	12000	6500	4942	303	303
(3) SPACE HEAT (S.H.) ENERGY/DU/Y	GJ/Y	III	46	76	57	63	32	52	45	62	63	51	20	20	20	25	25	25
(4) WATER HEAT (W.H.) ENERGY/DU/Y	GJ/Y	III	19	32	28	27	15	22	32	27	27	22	15	15	15	15	15	15
(5) SUB TOTAL ENERGY/DU/Y	GJ/Y	III	65	108	85	90	47	74	77	89	90	73	36	36	36	40	40	40
(6) TRAVEL DISTANCE TO CORE	km		3.6	7.1	13.3	18.1	4.2	7.1	13.1	3.3	4.1	7.2	3.7	5.9	6.4	4.5	24.6	33.5
(7) JOURNEY-TO-WORK ENERGY CONS./DU/Y	GJ/DU/Y	III	2.7	3.8	5.6	4.5	3.0	4.9	4.4	2.9	3.2	2.9	1.9	2.6	3.7	2.8	8.1	10.9
(8) ENERGY/DU/INC. JOURNEY-TO-WORK ENGERY/DU/Y	GJ/DU/Y	III	68	112	94	100	51	79	85	92	94	78	38	38	40	43	48	51
(9) ENERG. CONS/km^2/Y (SPACE HEAT AND WATER HEAT)	$TJ/km^2/Y$	III	650	324	128	135	470	148	139	267	180	110	611	472	267	242	185	209
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	$TJ/km^2/Y$	III	6.3	3.3	2.8	2.7	8.1	2.6	3.1	2.0	1.9	2.2	10.6	10.9	8.4	1.1	1.1	1.0
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H. AND J.-TO-WK. IN CORE	$TJ/km^2/Y$	III	656	327	131	138	478	151	142	264	182	112	622	483	275	243	187	210

LEGEND

Spine = major central zone or core area
Inter = intermediate zone or finger area
Web = outer zone or web area

T.C. = town centre area
D.C. = district centre area
R.C. = regional centre area

c m = compact model
d m = dispersed model

TABLE 15: 1981 DATABASE IN THE PLANE ADEF FOR A THREE-DIMENSIONAL MATRIX - SCENARIO III

CATEGORY			REAL CITIES										HYPOTHETICAL CITIES					
CITY NAME OR CLASSIFICATION			WINNIPEG				EDMONTON			SASKATOON			COMPACT			DECENTRALIZED		
TRACT NO. OR DESCRIPTION			014	017	535	540.02	032	048	025	008	015	010	Spine	Inter	Web	T.C.	D.C.	R.C.
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O	I_{cm}	M_{cm}	O_{cm}	I_{dm}	M_{dm}	O_{dm}
(1) TRACT AREA	km^2		0.7	0.6	1.4	1.1	1.2	1.1	1.1	.9	2.1	2.1	1.0	1.0	1.0	1.0	1.0	1.0
(2) GROSS RESIDENTIAL DENSITY	DUS/km^2	III	10000	3000	1500	1500	10000	2000	1800	3000	2000	1500	16000	12000	6500	4942	303	303
(3) SPACE HEAT (S.H.) ENERGY/DU/Y	GJ/Y	III	46	76	57	63	32	52	45	62	63	51	20	20	20	25	25	25
(4) WATER HEAT (W.H.) ENERGY/DU/Y	GJ/Y	III	19	32	28	27	15	22	32	27	27	22	15	15	15	15	15	15
(5) SUB TOTAL ENERGY/DU/Y	GJ/Y	III	65	108	85	90	47	74	77	89	90	73	36	36	36	40	40	40
(6) TRAVEL DISTANCE TO CORE	km		3.6	7.1	13.3	18.1	4.2	7.1	13.1	3.3	4.1	7.2	3.7	5.9	6.4	4.5	24.6	33.5
(7) JOURNEY-TO-WORK ENERGY CONS./DU/Y	GJ/DU/Y	III	2.7	3.8	5.6	4.5	3.0	4.9	4.4	2.9	3.2	2.9	1.9	2.6	3.7	2.8	8.1	10.9
(8) ENERGY/DU/INC. JOURNEY-TO-WORK ENGERY/DU/Y	GJ/DU/Y	III	68	112	94	100	51	79	85	92	94	78	38	38	40	43	48	51
(9) ENERG. CONS/km^2/Y (SPACE HEAT AND WATER HEAT)	TJ/km^2/Y	III	650	324	128	135	470	148	139	267	180	110	611	472	267	242	185	209
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	TJ/km^2/Y	III	6.3	3.3	2.8	2.7	8.1	2.6	3.1	2.0	1.9	2.2	10.6	10.9	8.4	1.1	1.1	1.0
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H. AND J.-TO-WK. IN CORE	TJ/km^2/Y	III	656	327	131	138	478	151	142	264	182	112	622	483	275	243	187	210

LEGEND

Spine = major central zone or core area
Inter = intermediate zone or finger area
Web = outer zone or web area

T.C. = town centre area
D.C. = district centre area
R.C. = regional centre area

c m = compact model
d m = dispersed model

energy for selected cities increase, from a range of 86-196 gigajoules to approximately 186-296 gigajoules per dwelling per year.

Energy for journey-to-work to the core represents only a small proportion of 100 gigajoules per dwelling per year assumed for all residential transport energy. In Section 5.1.4, it was established that core oriented residential work trips represented approximately 6 percent of total residential transport energy. Therefore, an assumed base figure of approximately 100 gigajoules per dwelling per year represents approximately 6 gigajoules per dwelling per year for energy consumption for journey-to-work for an average household.

From Table 13, under Scenario I, the limits of total residential energy consumption for selected real cities, including energy for journey-to-work to the core, represent a range of approximately 96-206 gigajoules per dwelling per year. By comparison, under Scenario III the range of internal residential energy is 47-108 gigajoules per dwelling per year for selected real cities, and 51-112 gigajoules per dwelling per year for total residential energy consumption.

Internal residential energy consumption can be reduced further. For example, a base figure of close to 36 gigajoules per dwelling per year for internal residential energy has been indicated to be achievable*. Consequently, if the minimum value for internal energy consumption is assumed to be 36 gigajoules per dwelling per year and the transport component is 6 gigajoules per dwelling per year, the minimum range of total residential energy consumption becomes 42-118 gigajoules per dwelling per year (Table 15).

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* In the late 1970's, the Saskatchewan Conservation House demonstrated that an internal residential consumption level as low as 36.2 gigajoules per household per year was achievable for a "laboratory" dwelling unit (Besant, Dumont and Schoenau 1982).

5.2.2 Comparison of Limits for Real and Hypothetical Cities

From limits for residential density, journey-to-work distance to the core and energy consumption, which are considered in section 5.2.1, a scale of expected real and hypothetical conditions is generated under alternative scenarios. From these data and from Figure 13, limiting values for residential areas in real cities fall within a narrower range than values for hypothetical cities. For example, while residential densities for hypothetical cities are assumed to range from approximately 100-16,000 dwellings per square kilometre, residential densities for real cities fall within a range of 1000-10,000 dwellings per square kilometre.

The purpose of such limits is to identify a range of densities within which residential energy efficiency can be significantly improved in large cities. For example, in fossil fuel dependent cities significant increases in residential energy efficiency can be achieved where densities are sufficient to economically distribute thermal energy. Therefore, in such cities density limits are useful in delineating realistic parameters for energy distribution systems. For example, in Edmonton and Saskatoon, which are heavily dependent on thermoelectric energy, and where thermal energy distribution is technically feasible for higher density areas (Shinyei 1978), approximately 1740 dwellings per square kilometre appears to be a practical minimum density for such thermal distribution (Danish Board of District Heating 1977).

For residential density, under less efficient conditions of Scenario I, residential consumption levels as low as 112 terajoules per square kilometre per year, and as high as 842 terajoules per square kilometre per year are possible for hypothetical cities. However, for real cities, values in the range of 150-660 terajoules per square kilometre provide practical limits for residential energy consumption under Scenarios I-III (Table 16).

TABLE 16: ASSUMED 40 YEAR DATA BASE IN THE PLANE ADEF FOR A THREE-DIMENSIONAL MATRIX - ALL SCENARIOS

CATEGORY			REAL CITIES										HYPOTHETICAL MODELS					
CITY NAME OR CLASSIFICATION			WINNIPEG				EDMONTON			SASKATOON			COMPACT			DECENTRALIZED		
TRACT NO. OR DESCRIPTION			014	017	535	540.02	032	048	025	008	015	010	Spine	Inter	Web	Town Cen.	Dist.Centre	Reg.Centre
TRACT TYPE	UNITS		I	M	O	O	I	M	O	I	M	O	I_{cm}	M_{cm}	O_{cm}	I_{dm}	M_{dm}	O_{dm}
(1) TRACT AREA	km^2		0.67	0.60	1.37	1.09	1.24	1.09	1.09	.88	2.07	2.07	1.00	1.00	1.00	1.00	1.00	1.00
(2) GROSS RESIDENTIAL DENSITY	DUS/km^2	I	4306	2658	1164	1335	3726	1528	1229	1517	1063	1242	12025	9375	4142	1497	92	92
		II	7153	2859	1332	1418	6863	1764	1515	2259	1532	1371	14000	10668	5321	2296	141	141
		III	10000	3000	1500	1500	10000	2000	1800	3000	2000	1500	16000	12000	6500	4942	303	303
(3) SPACE HEAT (S.H.) HSHLD. ENERGY/DU/Y	GJ/DU/Y	I	104	151	113	126	66	103	90	123	126	102	40	45	50	70	70	70
		II	61	100	76	84	44	69	60	82	84	68	30	35	40	45	45	45
		III	46	76	57	63	32	52	45	62	63	51	20	20	20	25	25	25
(4) WATER HEAT (W.H.) HSHLD. ENERGY/DU/Y	GJ/DU/Y	I	31	45	40	39	20	31	28	38	38	31	25	25	20	30	30	30
		II	23	39	34	33	17	27	30	33	33	27	23	23	23	25	25	25
		III	19	32	28	27	15	22	32	27	27	22	15	15	15	15	15	15
(5) SUB-TOTAL HSHLD. ENERGY/DU/Y	GJ/DU/Y	I	135	196	153	165	86	134	118	161	164	133	65	70	70	100	100	100
		II	84	139	110	117	61	96	90	115	117	95	50	53	53	70	70	70
		III	65	108	85	90	47	74	77	89	90	73	35	35	35	40	40	40
(6) TRAVEL DISTANCE TO CORE	km		3.6	7.1	13.3	18.1	4.2	7.1	13.1	3.3	4.1	7.2	3.7	5.9	6.4	4.5	24.6	33.5
(7) JOURNEY-TO-WORK ENERGY/CONS./DU/Y	GJ/DU/Y	I	7.8	13.0	21.5	18.6	8.9	10.8	16.3	8.0	8.8	9.7	5.1	6.8	9.7	12.4	25.2	34.4
		II	5.3	8.0	12.3	9.8	5.9	6.8	9.6	5.7	6.5	5.7	3.5	4.7	5.7	7.7	17.0	23.1
		III	2.7	3.8	5.6	4.5	3.0	4.9	4.4	2.9	3.2	2.9	1.9	2.6	3.7	2.8	8.1	10.9
(8) ENERGY/DU/INC. JOURNEY-TO-WORK/DU/Y	GJ/DU/Y	I	144	209	175	184	95	145	131	169	173	143	70	77	80	112	125	134
		II	89	147	122	127	67	103	97	121	124	101	54	58	60	78	87	93
		III	68	112	94	100	51	79	85	92	94	78	37	37	39	43	48	51
(9) ENERG. CONS/km^2/Y (S.H. & W.H.) RES. ENERGY CONSUMPTION (INTERNAL)	TJ/km^2/Y	I	581	521	178	220	320	205	145	244	174	165	781	656	290	168	111	119
		II	601	393	147	166	419	163	136	273	189	138	745	612	314	186	128	140
		III	650	324	128	135	470	148	139	267	180	110	611	472	267	242	185	209
(10) ENERGY CONSUMPTION/km^2/Y JOURNEY-TO-WORK TO THE CORE	TJ/km^2/Y	I	10.1	10.4	7.5	7.5	10.0	4.5	6.0	4.2	5.4	4.2	21.5	22.3	14.1	1.7	.8	1.1
		II	10.9	6.6	5.1	4.7	10.7	3.3	4.5	3.8	3.1	3.2	17.2	17.6	12.5	1.6	.8	1.1
		III	6.3	3.3	2.8	2.7	8.1	2.6	3.1	2.0	1.9	2.2	10.6	10.9	8.4	1.1	1.1	1.0
(11) TOTAL ENERGY CONSUMPTION/km^2/Y S.H., W.H., AND J. TO WK. IN CORE	TJ/km^2/Y	I	591	531	186	228	330	210	151	248	179	169	842	719	329	170	112	120
		II	612	400	152	171	430	166	141	277	192	141	762	630	327	188	129	141
		III	656	327	131	138	478	151	142	264	182	112	622	483	275	243	187	210

5.3 THE USE OF SCENARIOS TO CONSIDER LONG TERM CHANGE IN RESIDENTIAL ENERGY PARAMETERS

As described in Chapter IV, scenarios provide a means to compare change in residential energy for large cities based on alternative assumptions about accommodating future residential growth within new or existing urban areas. In the absence of extensive time-series data on energy consumption for real cities, scenarios provide an opportunity to consider alternative possibilities taking into account limits established for hypothetical cities.

For a 40 year time frame, three scenarios are assumed to compare changes in energy consumption and the effect of alternative urban development policies on such changes. The following subsections consider (1) derivation of data and application of three scenarios; (2) characteristics of real and hypothetical cities; and (3) two dimensional relationships of parameters in the three-dimensional matrix under the three scenarios.

5.3.1 Derivation of Data and Application of Three Scenarios

Data for the three scenarios are derived from a tabulation of residential density and related energy information described in Chapter III, Table 7 (p.114). In Table 17, a section through the three-dimensional matrix, which focuses on an inner core-edge Winnipeg tract, is used to exemplify characteristics of urban residential energy conditions under the three scenarios. Although normal population increase and related economic growth are assumed to occur under all of the scenarios, each of the scenarios illustrates the effect of accommodating such growth and change in a different way with respect to density and energy consumption.

TABLE 17: MATRIX SECTION PLANE DCFG - WINNIPEG TRACT 014 - ALL CHARACTERISTICS FOR THREE SCENARIOS 1981-2021

CHARACTERISTICS	UNITS	SCENARIO		
		I	II	III
CITY - WINNIPEG TRACT NO. (014) TRACT TYPE (I)				
1) TRACT AREA	km^2	0.7	0.7	0.7
2) GROSS RESIDENTIAL DENSITY	DUS/km^2	4306	7153	10000
3) HSHLD. ENERGY - SPACE HEAT	Gj/DU/Y	104	61	46
4) HSHLD. ENERGY - WATER HEAT	GJ/DU/Y	32	23	19
5) HSHLD. ENERGY - INTERNAL	GJ/DU/Y	136	84	65
6) TRAVEL DISTANCE	km	3.6	3.6	3.6
7) HSHLD. ENERGY - JOURNEY-TO-WORK	GJ/DU/Y	7.8	5.3	2.7
8) HSHLD. ENERGY (INCL. J.-TO-W.)	GJ/DU/Y	144	89	68
9) RES. ENERGY CONSUMPTION (INTERNAL)	$TJ/km^2/Y$	585	601	650
10) RES. ENERGY CONSUMPTION (TRANSPORT)	$TJ/km^2/Y$	10.1	10.9	6.3
11) RES. ENERGY CONSUMPTION (TOTAL)	$TJ/km^2/Y$	595	612	656

Scenario I, a low density residential alternative, assumes no significant change in either residential density or related residential energy consumption between 1981 and 2021. A figure of 3 percent growth in population and/or economic conditions is therefore assumed to be accommodated unchanged within the same urban areas. Under this scenario, by 2021, energy consumption on a per capita basis would grow to more than twice the 1981 consumption or by a factor of 2.3 over the 1981 base year. However, residential density is assumed to remain constant over the 40 year time period. Differences in residential energy demand, such as water heat for a larger population or other energy growth needs, are assumed to be accommodated from the same base of energy consumption through energy conservation and improved residential efficiencies over the interval.

Scenario II, a moderate growth alternative, assumes some increase in residential density and a significant decrease in unit energy consumption in response to a modest rate of growth in population and a per capita energy consumption level of more than 1.25 percent. Consequently, modest changes in lifestyle are assumed, including a shift to more energy efficient residential units arranged at higher densities. From Table 16, increased residential densities, from 4306 to 7153 dwellings per square kilometre for Scenario II, are accompanied by increases in residential energy consumption which are only marginally higher than for Scenario I, or from 595 to 612 terajoules per square kilometre per year.

Scenario III, a zero energy growth alternative assumes that growth in population and economic activity continue at historic rates (e.g. approximately three percent), with little growth in total and/or sectoral energy consumption in response to other growth factors within the period 1981-2021. Instead, energy growth to serve new population and other economic development is assumed to be derived entirely from energy savings from more efficient urban energy arrangements. For example, in the residential sector, increased energy demand would be satisfied entirely from energy savings from more energy efficient building and transport arrangements. Therefore, in this scenario very large residential density increases are assumed over the 40 year period. In Winnipeg's inner city tract 014, a density increase from 4306 dwellings per square kilometre to 10,000 dwellings per square kilometre occurs. Large density increases are also assumed for other residential tracts in Winnipeg and other cities under this scenario.

5.3.2 Two Dimensions of Data for Selected Real and Hypothetical Cities

Data from Table 16 (p.165) are plotted in two dimensions for tracts in three real and two hypothetical cities. When residential density is compared with residential energy consumption, non-linear relationships are established for the three scenarios.* These relationships, illustrated in Figures 20, 21 and 22, are investigated for the five cities as follows:

(1) Winnipeg. From Table 16, data are plotted for Winnipeg tracts and the non-linear relationships which result are illustrated in Figure 23. At the low density end of the scale, there is little difference between observations for residential tracts under each of the scenarios. Also, observations converge and energy differences are reduced as residential stock becomes more energy efficient with the development of newer suburbs. At the high density end of the scale, although significant increase occurs in residential density from Scenarios I-III, only a slight increase in residential energy consumption occurs for large increases in residential density.

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* Real data are insufficient to establish specific curves for these non-linear relationships.

FIGURE 20: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - ALL CITIES - SCENARIO I

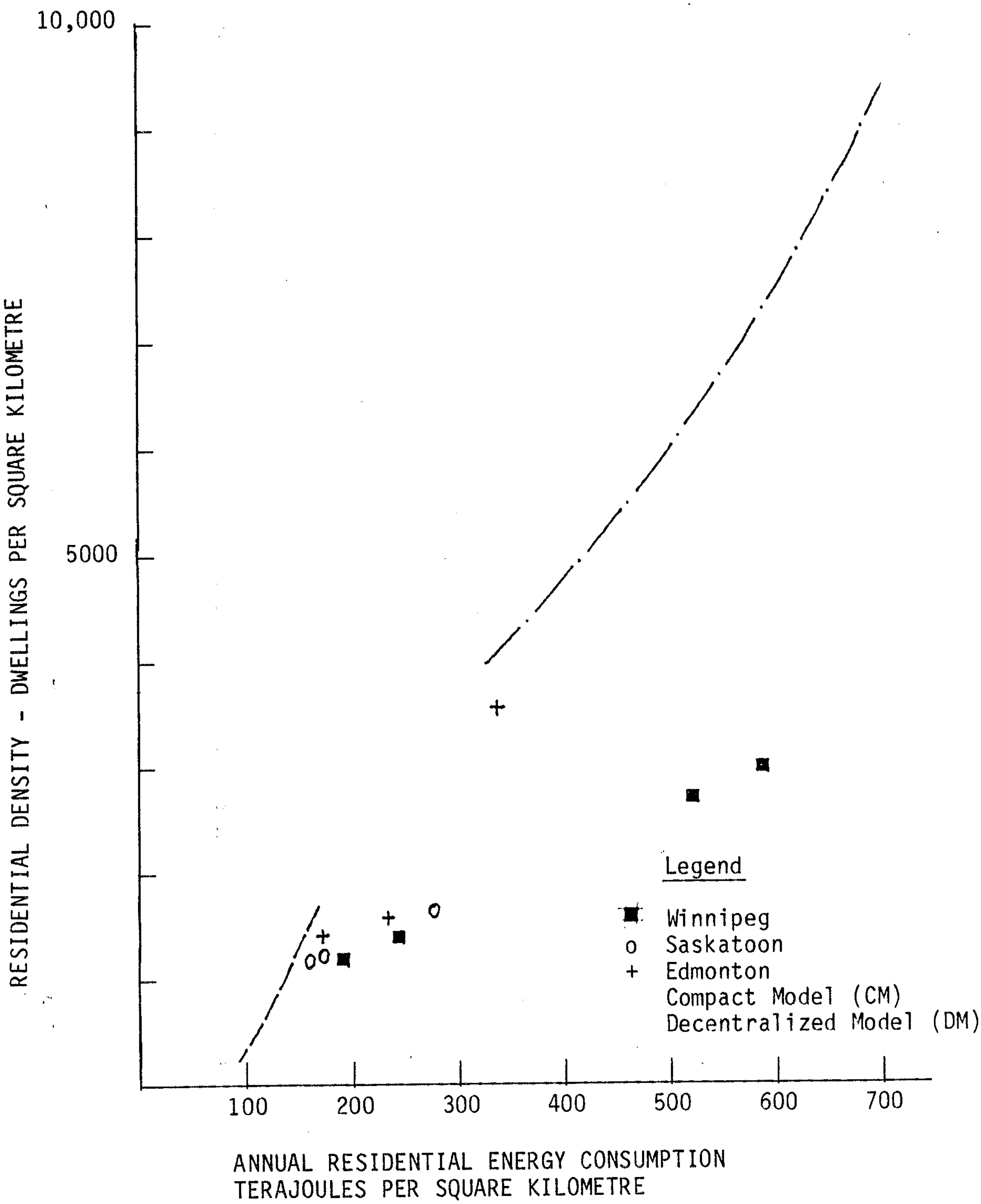


FIGURE 21: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - ALL CITIES - SCENARIO II

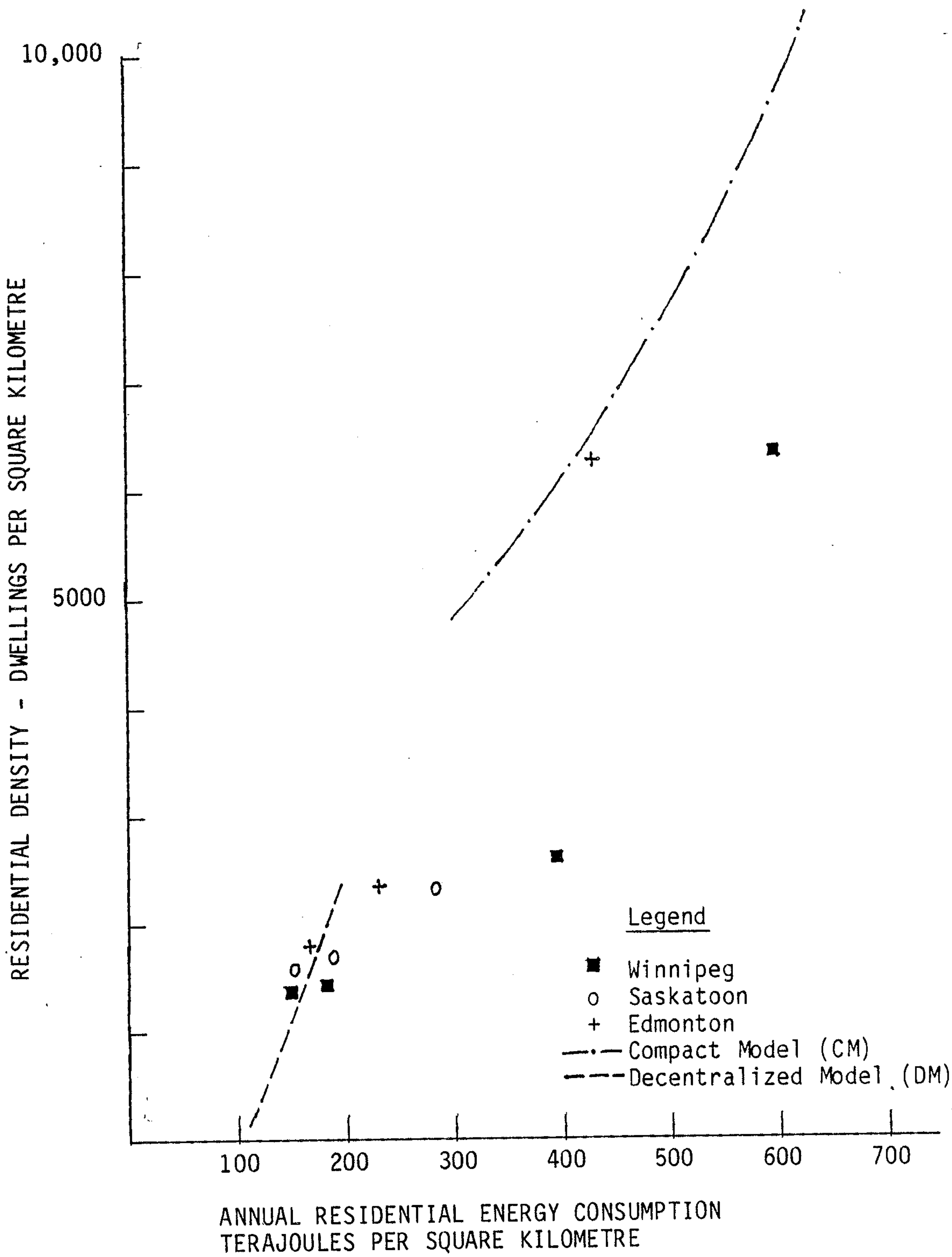


FIGURE 22: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - ALL CITIES - SCENARIO III

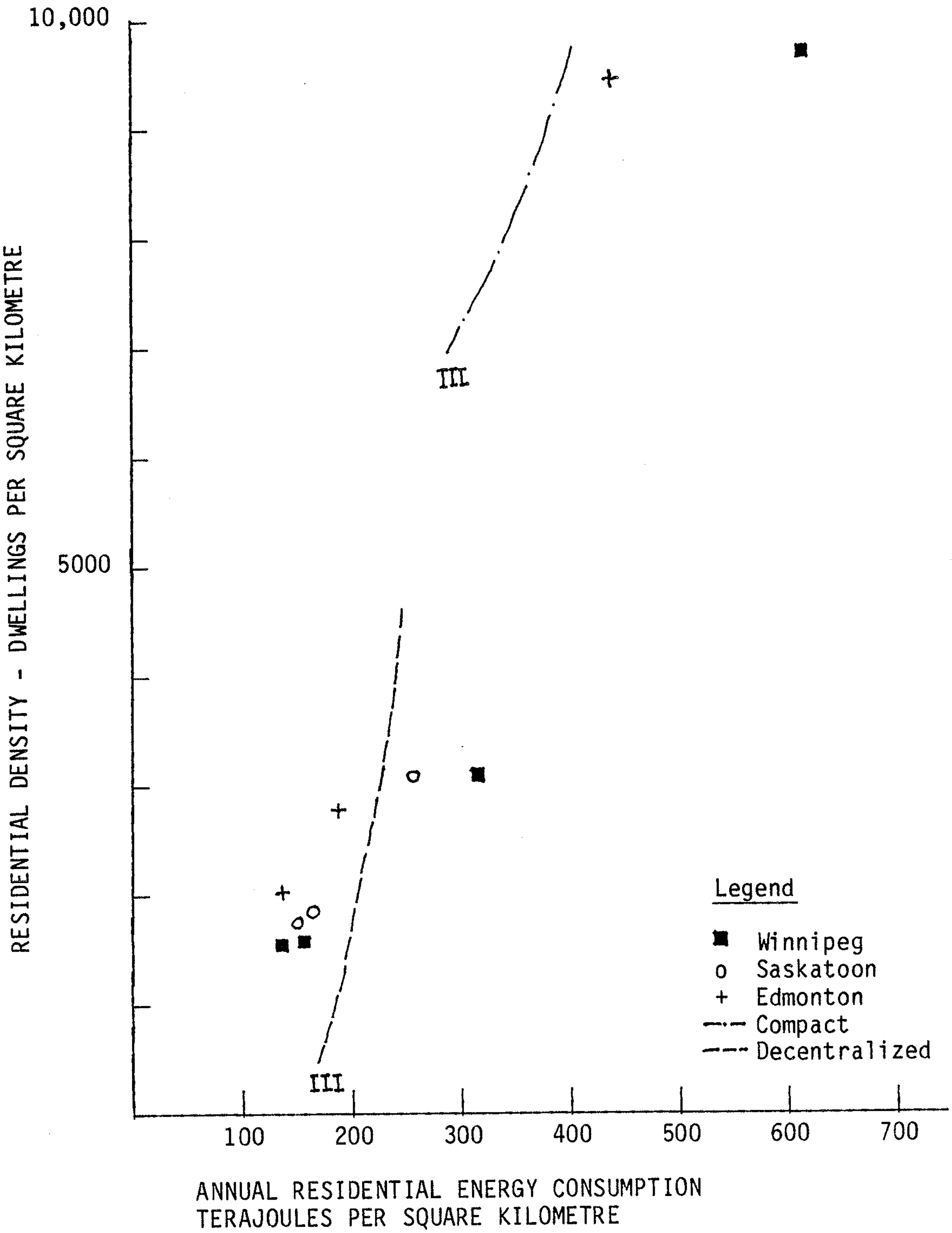
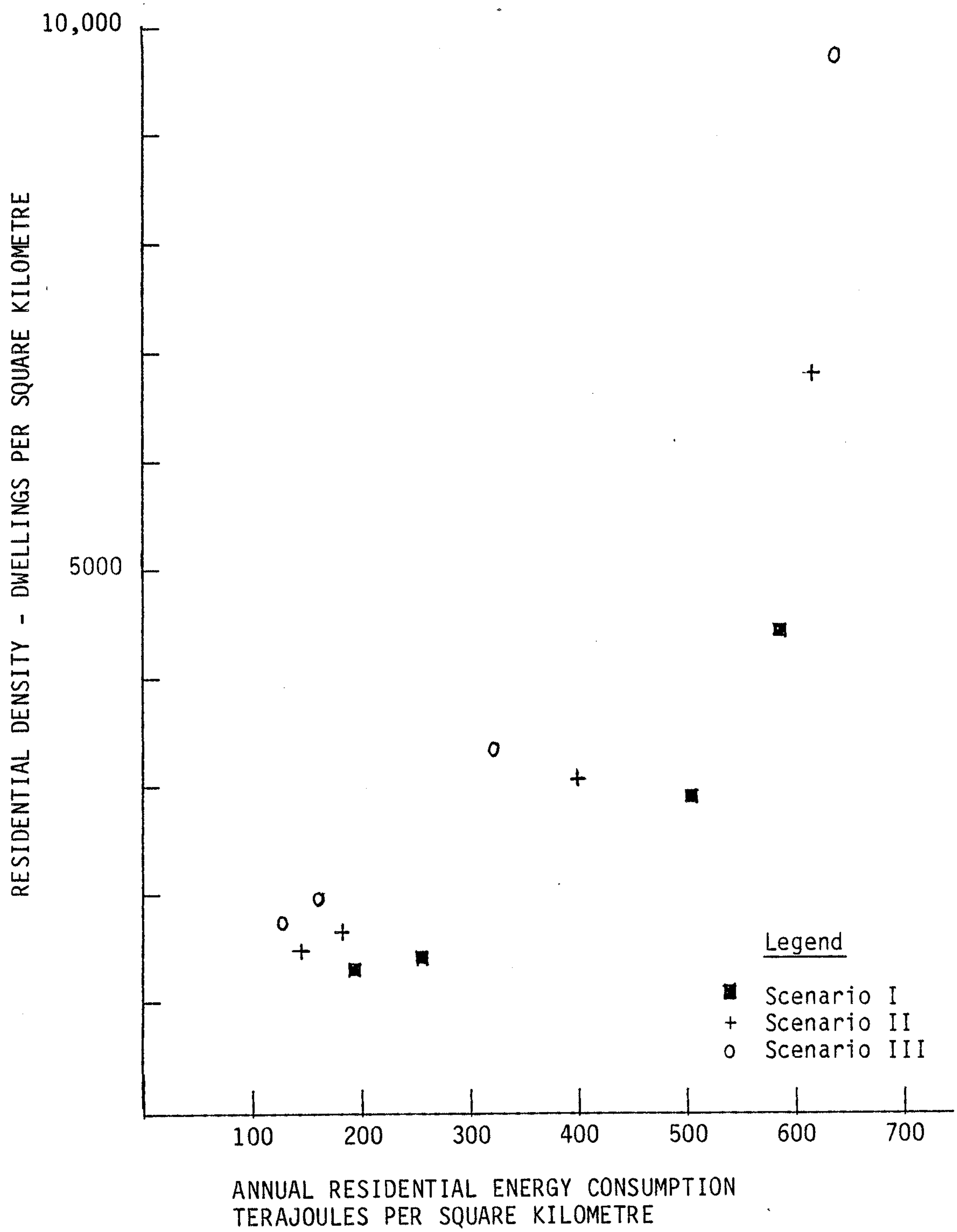


FIGURE 23: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - WINNIPEG - THREE SCENARIOS



(2) Saskatoon. When data from Table 16 are plotted for tracts in Saskatoon, the non-linear relationships which result are illustrated in Figure 24. At low residential density, there is little difference in values between the three scenarios. However, at higher residential densities, residential energy consumption is very close. This suggests that the increased residential density under alternative scenarios is compensated for by increased energy efficiency. However, because outer suburban tracts are not analysed for Saskatoon, and observations are limited only to inner city and mature tracts, observed non-linear relationships are limited accordingly.

(3) Edmonton. When observations for Edmonton tracts are plotted (Figure 25), regarding residential energy consumption as dependent upon residential density a series of non-linear relationships are established under each scenario. In the high range, there is a steady increase in residential density from Scenario I-III. However, for these scenarios, the rate of increase in residential density is reduced from 21 percent between Scenarios I and II to approximately 12 percent between Scenarios II and III. In the low range, as residential density grows at a reduced rate, residential energy consumption decreases slightly from scenario I-III. Thus, improved residential energy efficiency in the suburbs, in response to increased residential density, is reflected by a corresponding decrease in residential energy consumption.

5.3.2.4 Compact City Model (CM). When data from Table 16 are plotted for hypothetical cities, observations for tracts in the higher ranges of residential density and residential energy consumption reflect a series of limits for compact city models. In Figure 26, these observations are illustrated for the three scenarios as CM (I-III). Analysis of this figure also indicates that from Scenario I-III the ratio of residential density to residential energy consumption increases as the less than

FIGURE 24: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - SASKATOON - THREE SCENARIOS

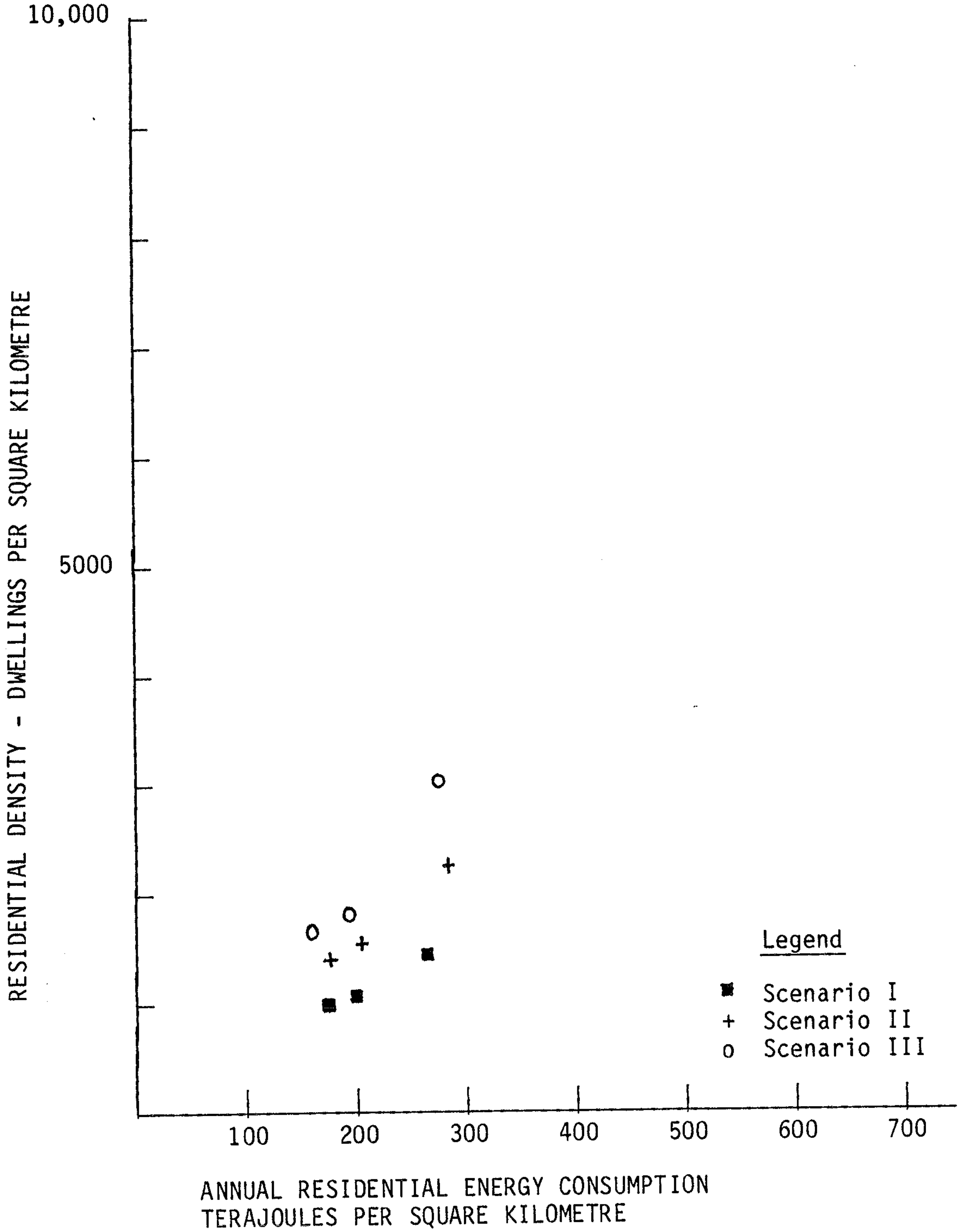


FIGURE 25: RESIDENTIAL DENSITY AND AREAL RESIDENTIAL ENERGY CONSUMPTION - EDMONTON - THREE SCENARIOS

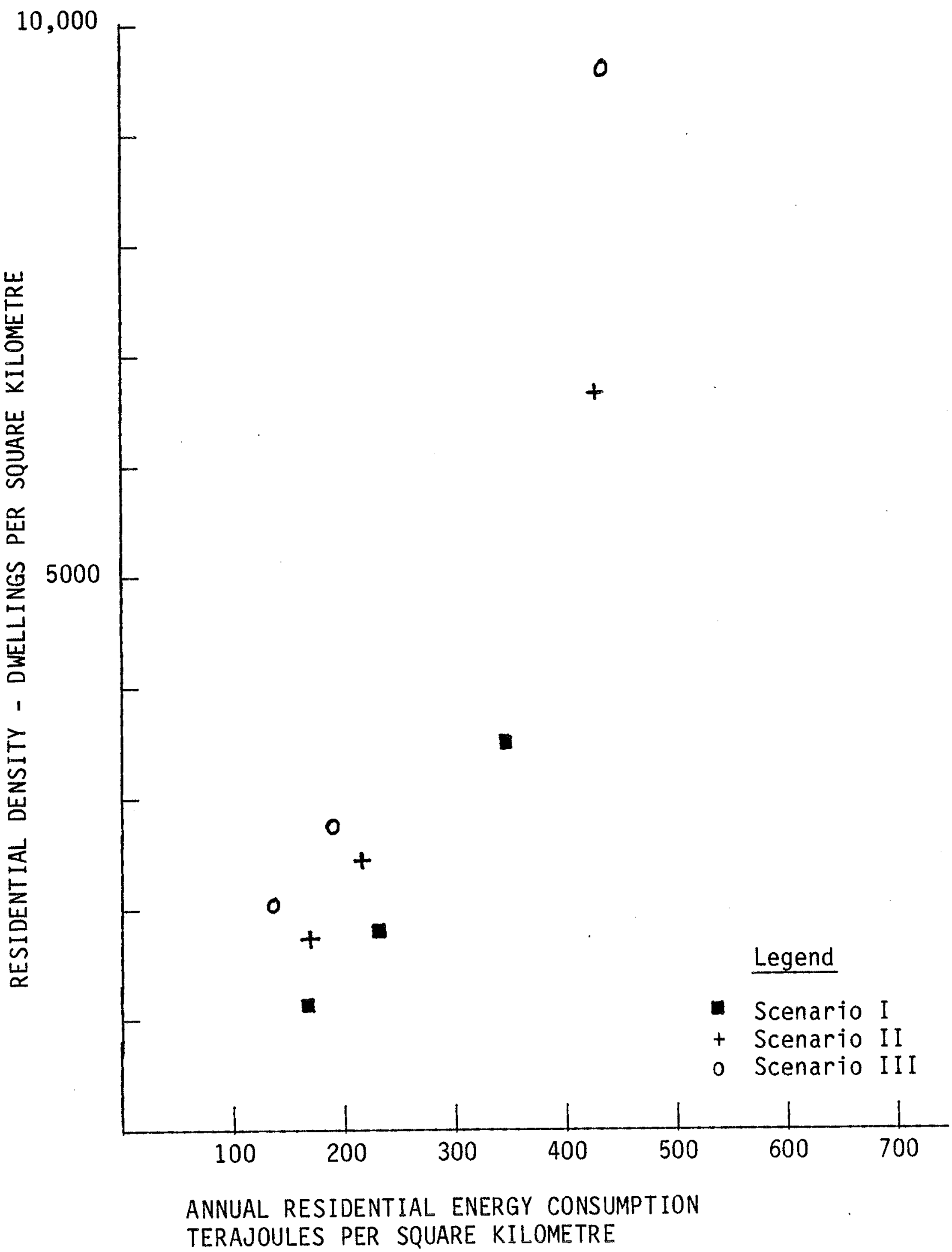
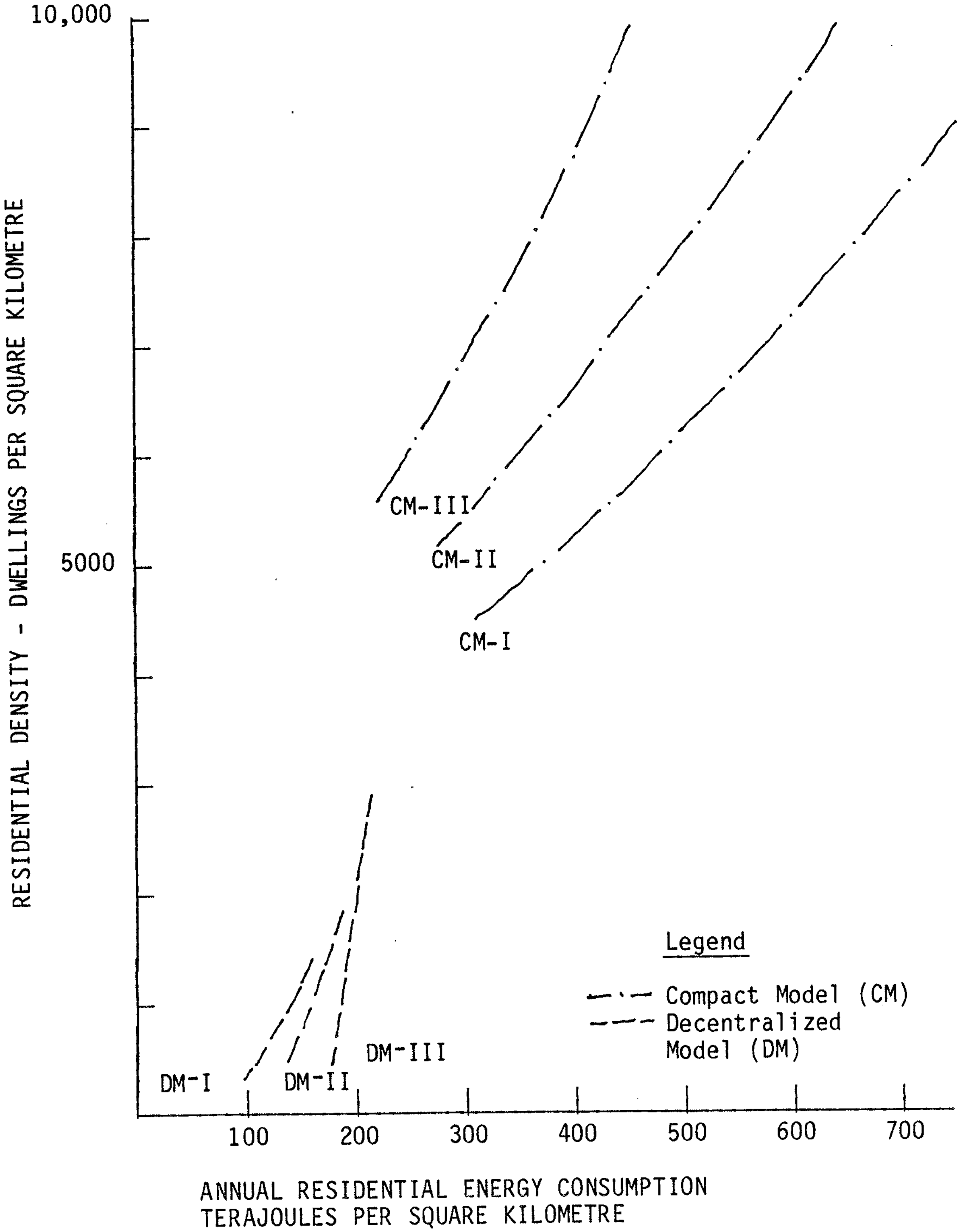


FIGURE 26: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION - HYPOTHETICAL CITIES - THREE SCENARIOS



linear relationship of the graphs of residential density to residential energy consumption approach a straight line.

Within the higher ranges of residential energy consumption, the compact model also provides a lower limit for selected real cities. In addition, from Scenarios II-III an increase in the gap between values for Edmonton and for the compact model suggests that hypothetical limits in the high density range are difficult to achieve for real cities.

5.3.2.5 Decentralized Model (DM). When data from Table 16 are plotted for a decentralized model in Figure 26, observations in the lower ranges of residential density and residential energy consumption suggest limits for a decentralized model. For the three scenarios, these are illustrated as DM (I-III).

5.3.3 Residential Density and Residential Energy Density

In Table 17 (p.165), a matrix section in the plane DCFG (p.134) lists selected characteristics for a single Winnipeg tract under all scenarios. Similarly, Tables 18 and 19 illustrate sections in the plane ABCD of the three-dimensional matrix. These compare data on specific characteristics such as residential density and residential energy consumption for all selected tracts and cities under the three scenarios. Table 19 illustrates a potential for using sections through the matrix to analyse threshold energy consumption limits for residential tract characteristics. For example, in the matrix section shown, a threshold of residential density which is sufficient to justify feasible distribution of thermal energy is illustrated.

A comparative analysis of data for residential density and residential energy consumption in tracts all cities under three scenarios (Figure 27) indicates that:

TABLE 18: MATRIX SECTION PLANE ABCD - ANNUAL RESIDENTIAL ENERGY CONSUMPTION - SELECTED TRACTS FOR ALL CITIES

CITY	TRACT	NO.	SCENARIO TERAJOULES PER SQUARE KILOMETRE		
(REAL)			I	II	III
WINNIPEG	I	014	595	612	656
	M	017	532	400	327
	M	535	186	152	131
	O	540.02	228	171	138
EDMONTON	I	032	342	430	478
	M	048	229	166	151
	O	025	166	141	142
SASKATOON	I	008	249	277	264
	M	015	169	192	182
	O	010	169	141	112
(HYPOTHETICAL)					
COMPACT CITY	I_{cm}	Spine	842	672	622
	M_{cm}	Inter.	719	630	483
	O_{cm}	Web.	329	327	275
DECENTRALIZED CITY	I_{dm}	T.C.	170	188	243
	M_{dm}	D.C.	112	129	187
	O_{dm}	R.C.	120	141	210

Legend

cm = compact model
dm = decentralized model
T.C. = town centre area
D.C. = district centre area
R.C. = regional centre area

Spine = major central zone or core area
Inter = intermediate zone or finger area
Web = outer zone or web area

TABLE 19 MATRIX SECTION PLANE ABCD - RESIDENTIAL DENSITY - ALL SCENARIOS

CITY	TRACT	NO.	SCENARIO		
(EMPIRICAL)			I	II	III
			DWELLINGS PER SQUARE KILOMETRE		
WINNIPEG	I	014	4306	7153	10000
	M	017	2658	2859	3000
	M	535	1164	1332	1500
	O	540.02	1335	1418	1500
EDMONTON	I	032	3726	6863	10000
	M	048	1528	1764	2000
	O	025	1229	1515	1800
SASKATOON	I	008	1517	2259	3000
	M	015	1063	1532	2000
	O	010	1242	1371	1500
(HYPOTHETICAL)					
COMPACT CITY	I_{cm}	Spine	12025	14000	10000
	M_{cm}	Inter.	9375	10668	12000
	O_{cm}	Web.	4142	5321	6500
DECENTRALIZED CITY	I_{dm}	T.C.	1497	2296	4942
	M_{dm}	D.C.	92	141	303
	O_{dm}	R.C.	92	141	303
		LEGEND: [shaded] INDICATES TRACTS WITH SUFFICIENT DENSITIES TO JUSTIFY FEASIBLE DISTRIBUTION OF THERMAL ENERGY.			

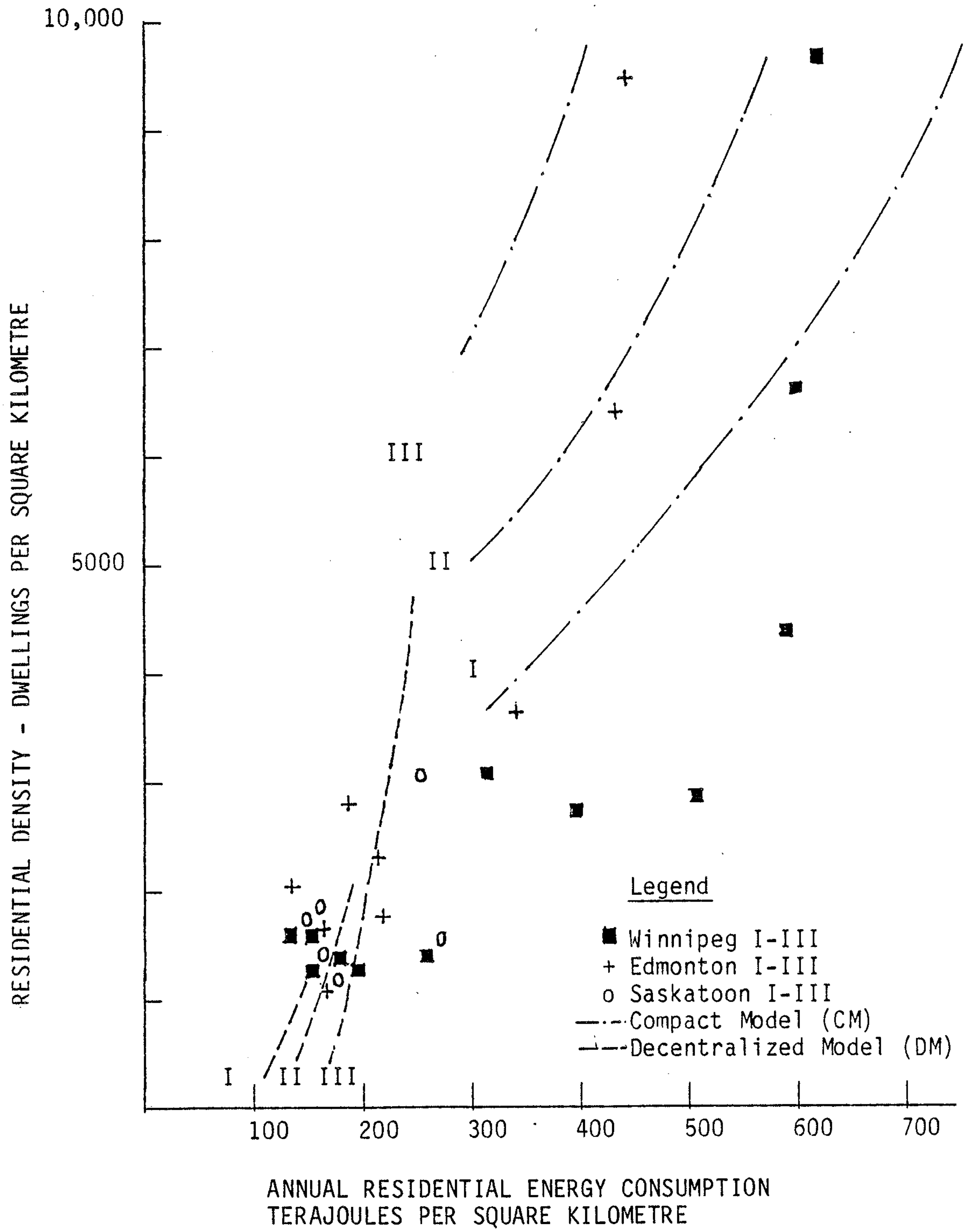
Shaded cells: Winnipeg 014 and 017 (I, II, III); Edmonton 032 (I, II, III), 048 (II, III), 025 (III); Saskatoon 008 (II, III), 015 (III); Compact City all; Decentralized City T.C. (II, III).

Legend

cm = compact model
dm = decentralized model
T.C. = town centre area
D.C. = district centre area
R.C. = regional centre area

Spine = major central zone or core area
Inter = intermediate zone or finger area
Web = outer zone or web area

FIGURE 27: RESIDENTIAL DENSITY AND RESIDENTIAL ENERGY CONSUMPTION -- ALL CITIES --THREE SCENARIOS



(1) Residential energy densities for selected inner city tracts in Winnipeg are greater than Edmonton and Saskatoon. This reflects consistently higher residential energy consumption in those areas of Winnipeg.

(2) Under Scenario I, ratios of residential density to residential energy consumption for outer suburban tracts in the real city are greater than the same ratios for tracts in the hypothetical decentralized city. However, under Scenarios II or III this relationship changes, and the ratios for real cities are less than the values for a decentralized city. This difference can be analysed in the following manner. In the hypothetical city, under Scenario I, residential densities are higher relative to residential energy consumption. This is intrinsic to the design of a decentralized city in which densities are controlled and energy consumption is minimized through urban design and land use policies (Goodman 1977). However, under Scenarios II and III, efficiency assumptions built into the hypothetical city at the outset are not sufficient to overcome transport and other efficiency increases which are intrinsic to more compact real cities.

(3) Considering the selected cities on a dwelling unit basis, internal residential energy consumption for households in a hypothetical decentralized city is, by design, lower than for households in selected real cities (Table 16, p.163). However, inclusion of an energy component for journey-to-work to the core reduces some of the efficiency advantage of a hypothetical decentralized city. For Scenarios II and III, indications from more energy efficient suburban tracts suggest that despite the small proportion of energy which is represented by journey-to-work to the core, it is a significant factor in residential energy efficiency.

(4) A comparison of tracts in a hypothetical compact city with real cities indicates that residential energy consumption is consistently lower in residential tracts in the former than in the latter. For example, observations from Table 16 and Figure 27, indicate that for Scenarios I and II values for high density tracts in Edmonton approach those for a hypothetical compact city. However, under Scenario III, the gap between observed values for Edmonton and those for high density residential tracts in the compact city increases significantly. This suggests that, despite increases in some Edmonton tract densities, and sharp increases in their ratios of residential density to residential energy consumption under this scenario, the selected compact city model is less energy consuming and more energy efficient.

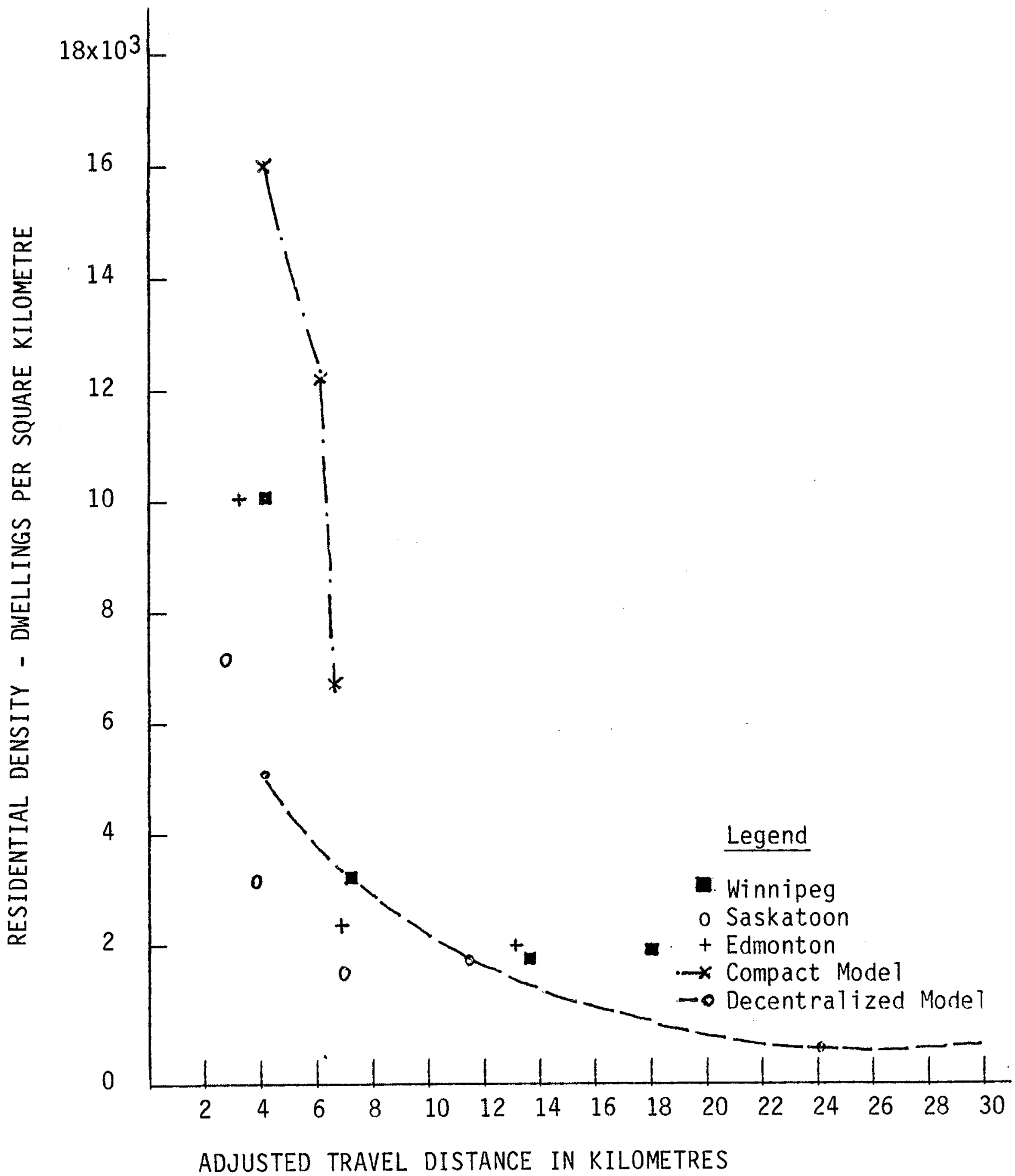
5.3.4 Residential Density and Travel Distance to the Central Core

From the format in Table 9, data for residential density are compared with travel distance to the central core for three selected real cities and two hypothetical models. When the ratios of the two variables are plotted in Figure 28, non-linear relationships are observed for selected tracts in the two largest cities. For Saskatoon, values are also reasonably close to observations for the larger cities. From limited data, the following conditions and relationships are noted:

(1) Observations of ratios of residential consumption to adjusted travel distance to the core, from various residential tracts in Winnipeg and Edmonton, are similar to one another. Also, for these tracts residential consumption decreases with adjusted travel distance from the centre except toward some outer suburbs (Figure 28).

(2) Toward the outer suburbs in some tracts in large real cities, areal residential consumption plateaus or increases with adjusted travel distance from the centre. This reflects higher residential

FIGURE 28: RESIDENTIAL DENSITY AND ADJUSTED TRAVEL DISTANCE TO THE CENTRAL CORE - ALL CITIES



densities and increased numbers of multiple dwellings in such areas.

(3) In comparison with values for residential tracts in real cities, hypothetical cities indicate continuous non-linear relationships with areal residential consumption decreasing with distance from the urban centre. For the decentralized model (DM), the non-linear relationship reflects a more gradual change in the ratio of areal residential consumption to adjusted travel distance from the consumption axis compared with ratios for real cities. For the compact city, the ratio of residential consumption to adjusted travel distance also decreases with distance from the consumption axis, but less sharply than values for real cities. These observations are consistent with earlier research on the inverse relationship between population density and urban distance (Clark 1951, Newling 1969).

5.3.5 Residential Energy Consumption and Travel Distance to the Central Core

In this sub-section, the relationship is investigated between the variables (i) residential energy consumption and travel distance to the central core in residential tracts. Data on these variables are derived from Table 16. For selected tracts in real and hypothetical cities, results are illustrated in Figures 23-25, regarding residential density as dependent upon residential energy consumption, a series of non-linear relationships are established. From these limited data, the following are indicated:

(1) For the selected residential tracts, residential energy consumption decreases with adjusted travel distance from the central core.

(2) Older residential tracts situated close to the central core edge and in mature suburbs consume more energy per unit area.

(3) In the older city of Winnipeg, the selected tracts are more energy consuming than similar tracts in the newer cities of Edmonton and Saskatoon.

(4) Significantly higher energy consumption in older tracts in Winnipeg reflects its larger stock of older housing. For example, most dwellings in the selected mature tract (017) in Winnipeg are 30-50 years older than dwellings in a comparable mature tract (048) in Edmonton.

(5) Higher energy consumption in older Winnipeg tracts is also due to higher residential densities in those tracts and reflects, in part, smaller residential lot sizes in many older areas.

(6) Differences in residential energy consumption with adjusted travel distance from the centre for the cities of Winnipeg, Saskatoon, and Edmonton are 521, 174, and 205 terajoules per square kilometre per year respectively under Scenario I (Table 16, p.163). For the same scenario and the same three cities, comparable values from estimated data are 494, 158, and 249 terajoules per square kilometre per year respectively. This appears to indicate a close correspondence between estimated and real data for selected residential tracts in the respective cities (Table 5, p. 110).

(7) Although distance to the central core is useful in investigating residential energy consumption, it is less important in considering transport energy, insofar as the transport component represents such a small proportion of residential energy.

(8) For hypothetical cities, data for a compact city model indicate that (i) travel distance to the core for a compact model represents only a small proportion of the distance to the core for real cities, with a maximum adjusted value of 6.4 kilometres, and (ii) residential energy consumption values fall only within the upper range of the residential energy consumption scale (Figure 30).

FIGURE 29: REAL AND ESTIMATED RESIDENTIAL ENERGY CONSUMPTION IN RELATION TO ADJUSTED TRAVEL DISTANCE - THREE SELECTED CITIES SCENARIO I

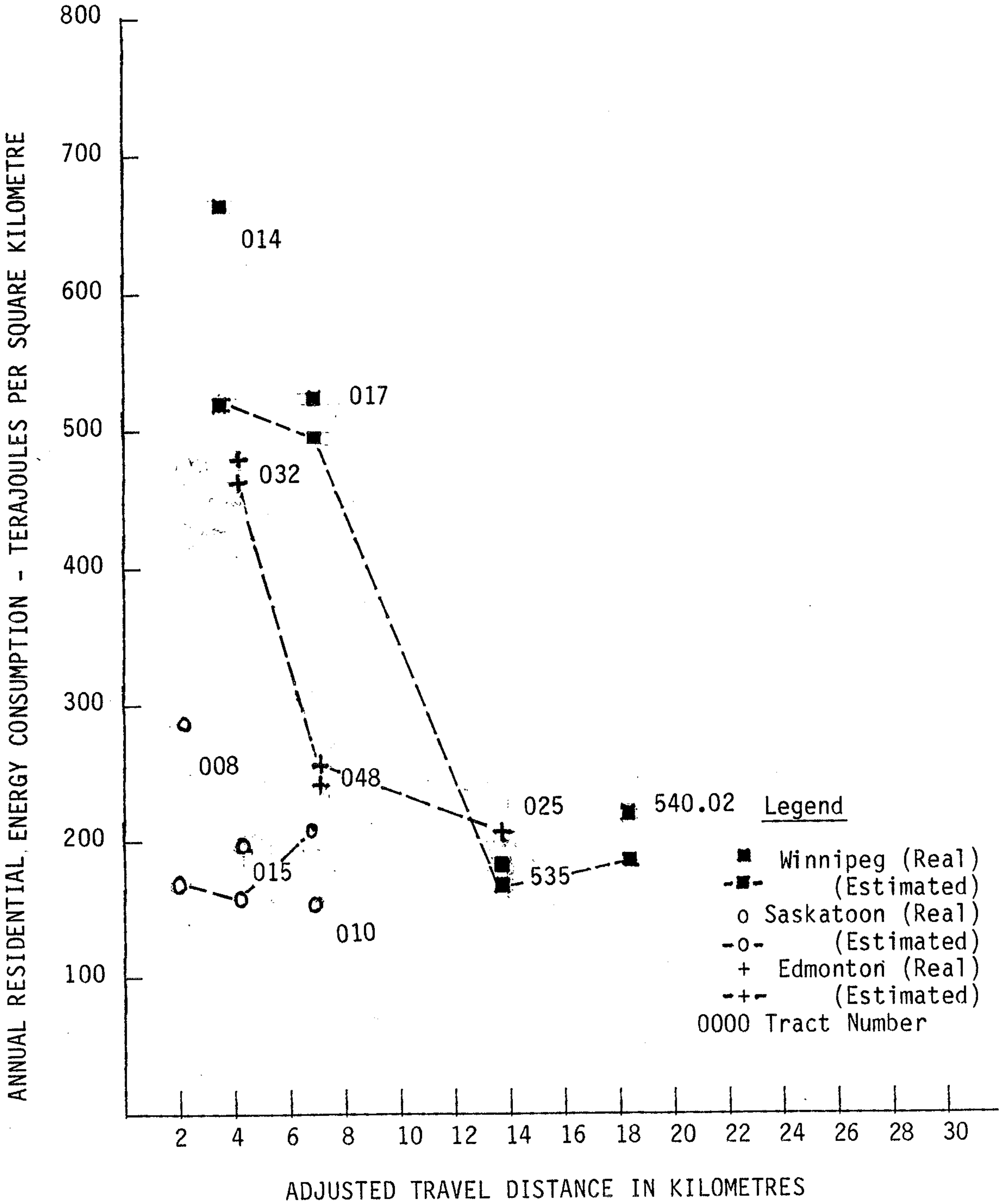
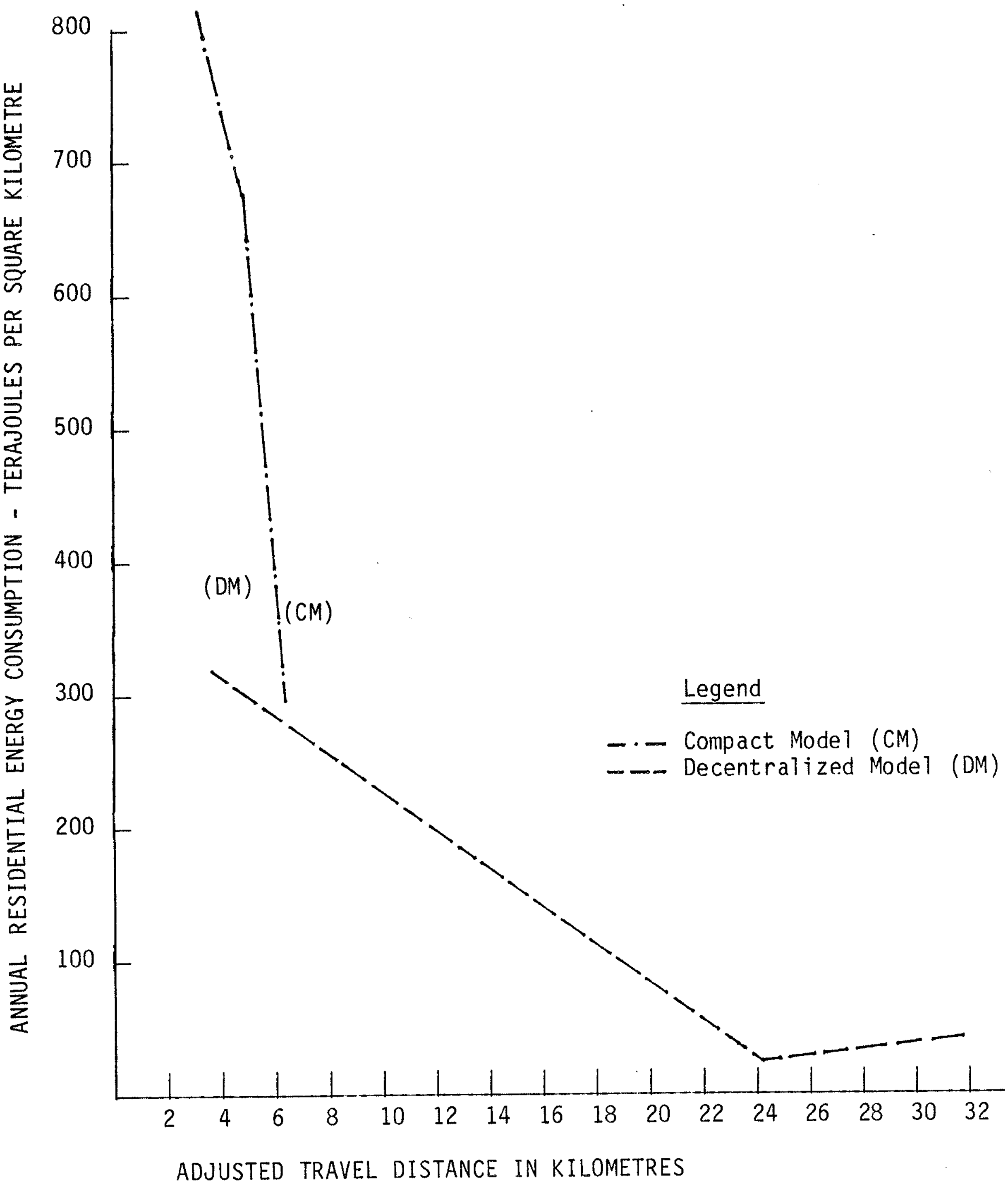


FIGURE 30: RESIDENTIAL ENERGY CONSUMPTION IN RELATION TO ADJUSTED TRAVEL DISTANCE - HYPOTHETICAL MODELS



For the decentralized city, values are reversed, with observations at the lower end of the scale of residential energy consumption and toward the maximum end of the scale of adjusted travel distance.

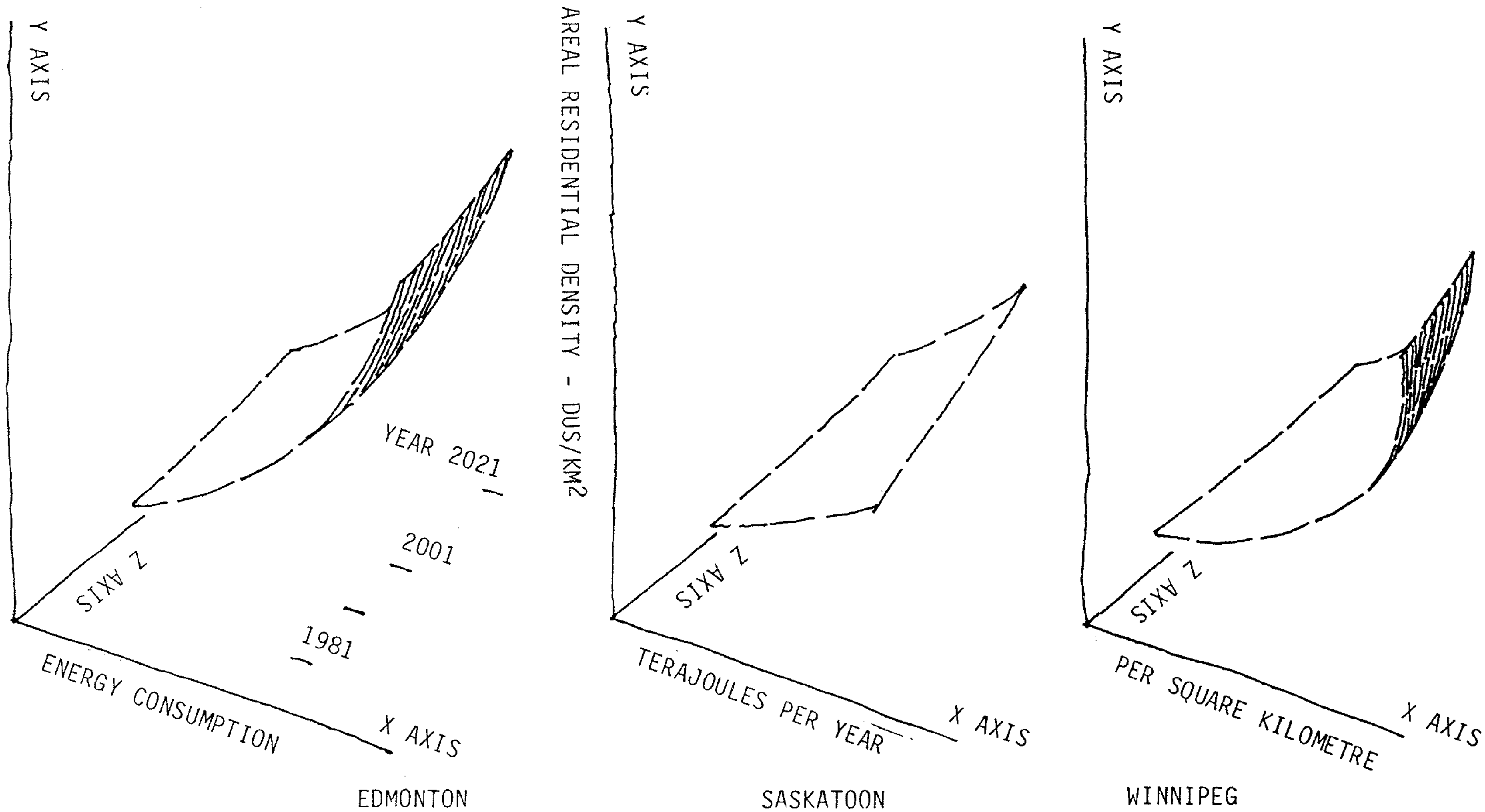
By combining observations for compact and decentralized city models, a composite hypothetical graph is established in which residential energy consumption decreases with distance from the core (Figure 30). A composite of observations that combines real values for the three cities under three scenarios with a composite of values for hypothetical models (Figure 30) indicates that values for Winnipeg and Edmonton under Scenarios I-III appear to approach the composite of values for the hypothetical cities (Figure 31).

5.4 THE USE OF THREE DIMENSIONS TO INVESTIGATE CHANGE IN RESIDENTIAL ENERGY CONSUMPTION IN REAL AND HYPOTHETICAL CITIES

In section 4.4, the three-dimensional matrix was described as a device to compare residential energy conditions. In section 5.3, two dimensional relationships of this matrix were investigated. This subsection, which focuses on three dimensional relationships, considers the variables residential density, residential energy consumption, and adjusted travel distance to the urban core. In particular, the implications of residential energy consumption for selected tracts and cities are considered under alternative scenarios. Time is used as a surrogate for scenarios, and notional circular cities are used as a means to simulate the effect of distance from the core for residential energy consumption in real cities.

Although the matrix is three-dimensional in form and in the arrangement of its data, its explanatory power is not intrinsic to the specific configuration of its three planes in Figure 14 (p.134). Rather, its three dimensional potential lies in the opportunities which its data offer to manipulate two dimensional relationships of variables

FIGURE 33: CHANGING RATIOS OF RESIDENTIAL DENSITY TO RESIDENTIAL ENERGY CONSUMPTION FOR THREE CITIES OVER TIME (NOTIONAL)



there was a plateau or slight increase in density between a tract in a mature inner suburb and one in a newer outer suburb. In part, this reflected an increase in multiple dwelling accommodation in the outer suburb of that city.

(2) For inner core edge tracts in the two larger selected cities, residential densities were higher than in the outer suburbs by a factor of two to three (Table 17, p.165). Also, in older mature and inner core edge residential tracts in the selected older city, higher residential densities, reflected in part, smaller lot sizes and more intensive residential development.

(3) Travel distance for journey-to-work to the core, alone, was insufficient as a parameter of residential transport energy. With different residential energy consumption levels at similar distances from the central core in both larger and smaller cities, other factors such as compactness or size of city had to be considered.

5.5.1.2 Age and Condition of Urban Residential Tracts. Parameters such as age and condition of urban residential tracts, when compared with values for residential energy consumption indicated from available data that (1) urban residential tracts with a high proportion of new dwellings exhibited lower residential energy consumption; and conversely, (2) an older city or tract with a large proportion of dwellings over 40 years exhibited higher residential energy consumption.

5.5.1.3 Urban Size and Compactness. Limited data from three real cities indicated the following characteristics with respect to urban size and compactness: (1) the two larger cities appeared more compact than the smallest city; and (2) the newer large city Edmonton was more compact than the older large city of Winnipeg.

5.5.1.4 Residential Energy Consumption and Efficiency. Investigation of the proportion of sectoral energy which comprised each component of residential energy, and consideration of the energy system efficiency of residential units indicated that residential energy system efficiency was less than 50 percent (Table 12, p.152). Investigation also indicated that considerable potential exists to increase residential energy efficiency, with the largest potential for efficiency increase in space and water heating.

5.5.2 Limits for Urban Residential Conditions

Limits for real urban conditions were derived by comparing limits for real cities with hypothetical cities. For compact and decentralized models limiting parameters were (1) residential density, (2) household or dwelling unit consumption and (3) the energy requirements of journey-to-work distance to the core.

5.5.2.1 Residential Density. Although empirical evidence indicated that high and low residential density limits were possible for real large cities, ranging from less than 150 dwellings per square kilometre to in excess of 70,000 dwellings per square kilometre, in this investigation, more conservative limits for residential density were selected. For example, under the three scenarios, selected cities ranged from 1000-10,000 dwellings per square kilometre.

5.5.2.2 Household and Residential Energy Consumption. When limits for total household energy consumption were derived by comparing consumption limits for dwellings in both hypothetical and real cities, under Scenario I, total residential energy ranged from 96-209 gigajoules per dwelling per year. Under Scenario III, residential energy ranged from 51-112 gigajoules per dwelling per year for the real cities, with low end limits of 37 gigajoules per dwelling per year for the hypothetical cities. Finally, with respect to total residential energy consumption, under Scenario I, 150 to approximately 600 terajoules per square kilometre provided a practical range of limits for real cities, with a low end limit of 112 terajoules per square kilometre for hypothetical cities.

5.5.2.3 Travel Distance to the Central Core. For distance to the central core, conservative limits were also selected. For example, although adjusted one-way commuting distances to the central core in excess of 64 kilometres were possible, adjusted journey-to-work limits for different residential zones in the selected cities were in the range of 3.6-18 kilometres. These limits, combined with empirical data on energy consumption for conventional vehicles, resulted in private auto energy limits of 2.5-5.0 megajoules per kilometre under Scenario I, 1.4-3.4 megajoules per kilometre under Scenario II, and 0.8-1.4 megajoules per kilometre under Scenario III. Transit energy was assumed to range from a high of 2.3 to a low of 1.0 megajoule per kilometre for Scenarios I-III.

5.5.3 The Use of Scenarios to Investigate Long Term Change in Residential Energy

An investigation of residential density and residential energy density for urban tracts in selected real and hypothetical cities under three scenarios indicated:

(1) residential energy consumption in selected older inner city tracts in Winnipeg was greater than in comparable areas of Edmonton and Saskatoon (Figure 16, p.163).

(2) in new outer suburban areas in the selected cities, residential energy consumption values were relatively close (Figures 29 and 31). However, toward the urban centre, residential energy consumption varied significantly among the cities.

(3) energy for journey-to-work to the core represented a small factor in total residential energy consumption under Scenario I, and was an even less significant factor under Scenario III (Table 17, p.165).

(4) Under Scenario I, the ratios of residential density to residential energy consumption for a selected hypothetical compact city surpassed ratios for Edmonton core edge tracts (Figure 27, p.179). However, under more efficient conditions for Scenarios II or III, the ratios for the compact city model did not exceed ratios for Edmonton, and the gap between the real and the hypothetical city increased. This suggested that for mature and inner core edge tracts, energy consumption in the real city did not match more energy efficient conditions in the hypothetical city.

5.5.4 Change in Residential Energy Consumption in Response to Dimensions of Time and Distance

To investigate change in residential energy and distance with time, a third dimension was introduced. This additional dimension made it possible to consider: (1) change in residential energy consumption with distance from the urban centre; and (2) time related changes in ratios of residential density to residential energy consumption.

5.5.4.1 Change in Residential Energy Consumption with Distance from the Urban Centre. A series of three-dimensional surfaces was generated by rotating each of the graphs of energy consumption against distance (Figure 31) through 360° about the energy consumption axis. Each configuration represented a particular scenario for an assumed circular city at a given point in time. Differences in the volumes of space enclosed by these configurations reflected magnitudes of potential energy conservation for notional cities which were assumed to be similar to selected real cities. Energy consumption in the notional circular cities was described under alternative scenarios (Figure 32). This three-dimensional representation of change in urban residential energy consumption was a central development of this dissertation. Results suggest that with sufficient data and appropriate computer technology, it can be adapted to model areal energy consumption in other large cities.

5.5.4.2 Changing Ratios of Residential Density to Residential Energy Consumption over Time. Changing ratios of residential density to residential energy consumption were compared over time for selected cities. Consideration of the resulting non-planar surfaces also suggested a way of predicting ratios of residential density to residential energy consumption for particular time periods within the limits of specific scenarios (Figure 33).

Chapter VI summarizes the dissertation, and considers some conclusions and policy implications which arise from this investigation.

CHAPTER VI - SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

This chapter comprises four sections. The first provides an overview of the study. It contains a description of the research method; an outline of the urban laboratory in which the research is conducted, including its devices, their purposes and applications; and a discussion of the selected parameters, limits, and scenarios that are used to analyse long-term change in urban energy. The second section identifies areas for further research that are required to transform the illustrative method into an operational planning tool applicable to large cities. The third section discusses research conclusions about questions which relate urban and energy characteristics in the context of three selected cities. The fourth section discusses some policy implications of the research.

6.1 OVERVIEW OF THE THESIS

This overview of the thesis recapitulates the five chapters: (I) Introduction; (II) Literature Review; (III) Research Design and Organization of Data; (IV) Research Method; and (V) Application of the Method

6.1.1 Chapter I - Introduction

This initial chapter, provided a background to the thesis, described its regional environment and the urban context for energy investigation. It also defined the problem, outlined research objectives and established conditions and relationships for application of a method of investigating urban residential energy. The three objectives of the dissertation were to:

(1) develop a practical method of systematically disaggregating energy consumption and other characteristics of residential land use by area;

(2) apply the method to investigate energy consumption in selected urban residential tracts under different assumptions about future energy; and

(3) consider the method in relation to urban energy policies which could help to achieve a balance between energy production and urban residential energy consumption and increase system efficiency of total urban residential energy consumption.

In considering these objectives, a number of conditions and relationships were investigated and a notional model of urban residential energy was applied to three large cities. Some relationships which were considered included (1) size of city (population) and compactness for three cities; (2) residential density of selected tracts; (3) age and condition of selected residential tracts; and (4) the system efficiency with which available urban and regional energy is available in two larger cities.

A focus for this analysis of relationships was a series of questions which are discussed in section 6.3.

6.1.2 Chapter II - Literature Review

The second chapter provided (1) an overview of relevant literature on energy conservation prior to 1973-74; (2) a review of some problems of modelling of complex urban systems; and (3) a review of literature of relevance to specific aspects of the research design. These aspects included some limits of urban design in relation to urban and related energy data and defined laboratory conditions in selected large cities and urban tracts. Relevant literature which was reviewed included several paradigms for compact and decentralized cities

-- urban configurations which reflected alternative scenarios for future energy. Scenarios ranged from a continuation of current urban energy conditions to an assumption of substantial present and future change in response to prospective limits in future energy.

6.1.3 Chapter III - Research Design and Organization of Data

The third chapter described a means of analysing the parameters: residential density, commuting distance to the central core, and residential energy consumption for selected tracts in three large cities. It comprised five steps:

(1) a research method was described;

(2) residential environments for the research design were defined;

(3) an alternative method of determining internal residential/commercial energy consumption for households and urban areas was developed using real and estimated data;

(4) a means of establishing energy consumption for journey-to-work to the core was developed for residential tracts in successive zones of the selected cities; and

(5) from data in (3) and (4), a base level of residential energy consumption at the discretion of urban households was defined.

This method derived and investigated real energy data obtained for the cities of Winnipeg, Saskatoon and Edmonton, and compared it with estimated data for typical dwellings extrapolated for residential tracts in these cities. In this way, real and estimated data were compared, and a method was applied which used real energy data to illustrate a practical approach to residential energy analysis.

6.1.4 Chapter IV - Research Method

In Chapter Four, a selection of three large cities in a region of adverse climate was identified to establish an appropriate context in which the proposed method could be applied. This regional setting, with its selected cities, provided an urban laboratory in which urban energy parameters for three real cities could be investigated.

To overcome limitations, such as a lack of time-series data on residential energy, a number of devices were introduced. These included: (1) postulating hypothetical cities to establish limits for real urban parameters; (2) using scenarios to simulate time-dependent changes in residential energy for real cities; and (3) developing a three-dimensional matrix format for processing urban energy data to facilitate analysis of parameters for a potentially large number of tracts in both real and hypothetical cities.

6.1.5 Chapter V - Application of the Method

This chapter investigated urban energy data developed in accordance with the Research Design and Organization of Data and the Method described in Chapters Three and Four respectively. This application of the method comprised five steps:

(1) residential density, distance to the core and residential energy consumption parameters for three types of urban residential tracts were defined for three selected large cities;

(2) practical limits for real urban tracts were established by comparing parameters for postulated hypothetical cities;

(3) scenarios were used to compare time-related changes in residential energy consumption and other parameters under alternative assumptions of future energy;

(4) residential energy consumption was considered as a function of residential density and of residential transport energy associated with journey-to-work distance to the central core for urban households; and finally

(5) a three-dimensional matrix format was used to compare residential energy parameters for real cities with limits derived from urban models.

6.2 AREAS FOR FURTHER RESEARCH

This dissertation has demonstrated the application of a method of organizing and modelling urban residential energy data in a new way. However, development of this method into operational tool which is generally applicable to large cities requires further research. This includes (1) expansion in the scope of the research design, (2) improvements in analytical procedures and (3) expansion and refinement of the database from which further investigation can be undertaken.

6.2.1 Scope of Research

In terms of the scope of the research, greater consistency and robustness in results require expanded terms of reference. This includes consideration of additional cities in different energy resource regions as well as additional residential tracts in each city. Although only the most northerly large cities in three Provinces were investigated in this research, in future, urban energy data need not be limited only to a single region. For example, at least six other large Canadian cities, also in relatively cold climate regions, merit similar investigation (Table 3).

In each of the three selected cities only three or four tracts were selected from each of three urban zones in order to simplify data processing, and to be able to easily obtain and manipulate utility data to demonstrate the application of the method. However, the small number of tracts considered did not provide a sufficient sample size or database for proper hypothesis testing. In future investigations, data from a larger number of cities and tracts in each city should provide sufficient statistical reliability for this purpose and would facilitate more precise modelling of changes in parameters among residential areas. In addition, more time-series data for additional tracts in each city would permit more effective comparison of residential energy consumption and other related urban parameters.

6.2.2 Analytical Procedures

With respect to improvements in analytical procedures, two areas for further research are: (1) clarification of components within the residential density parameter; and (2) improvements in accounting of urban residential energy consumption.

(1) In the first instance, although residential density significantly affects residential energy consumption, some relevant factors which are not explicit may be concealed within the variable residential density. For example, information on land use mix or condition of buildings can be obscured within (census) aggregations of residential data or land uses which are classified as commercial (rental apartments) but are functionally residential. Therefore, a more effective system of classification of urban land and residential energy consumption is required. Such a system would incorporate not only postal code conversion programs and energy utility data as employed in this dissertation, but would also include more precise land use and zoning information which is becoming increasingly available in larger municipalities.

(2) In the second instance, improvements in accounting of residential energy would consider all factors which affect energy

consumption for this sector. For example, space conditioning and water heat represent more than 80 percent of internal residential energy and much of the remaining 18-20 percent comprises energy for appliances. However, a large proportion of appliance energy, as well as beneficial heat losses by building occupants, supplements internal energy consumption for environmental conditioning through "energy cascading". It has been estimated that such beneficial losses from human occupants in dwellings and from major appliances can range from 8-16 percent of (internal) residential energy (CMHC 1977: 14). However, real data on energy consumption in residential areas from utilities often do not account for such beneficial heat losses. Consequently, real consumption data can result in an underestimate of residential energy consumption. To ensure a more complete picture of total residential consumption, future energy analyses should account for such thermal energy.

6.3 CONCLUSIONS

In this section conclusions are considered with respect to (1) the method and its application in organizing processing and modelling real urban energy data and (2) questions and relationships which were investigated in applying the method to three cities.

6.3.1 The Method and its Application

The dissertation has demonstrated the practical application of a method for systematically disaggregating, analysing and modelling urban energy and related characteristics for selected residential tracts for the Canadian Plains cities, Winnipeg, Saskatoon and Edmonton.

The method has been demonstrated using estimated data as a substitute where insufficient real data were available. However, sufficient real data were derived and investigated for each of the selected cities to indicate that the method can be useful to organize, process and model a range of energy and related urban characteristics. For example the method could be applied on a larger scale to process and model energy data in the same or different cities. This can also be done periodically, using a variety of systematic data such as census and geocode revisions, and mandated changes in municipal plans, to provide a basis for comparison of time-related change in urban energy use.

Application of the method can also provide a first approximation of residential energy use characteristics that might be expected for other cities with similar climatic conditions (e.g. Calgary and Regina). When notionally applied to selected cities, the method also demonstrates the potential to project real energy data in multidimensional formats and to generate three-dimensional presentations of urban energy use for cities and urban tracts with comparable characteristics. In this way, the method could be used to monitor change in energy use, to identify where energy waste may be occurring and to suggest where change in public policy needs to be directed.

6.3.2 Questions and Relationships Investigated

In applying the method to limited data from three cities, a number of questions and relationships of energy use which were identified in subsections 1.4 and 1.5 (pp. 31 and 35) have been investigated. Observations which arise from these questions relate to (1) the effect of urban size and compactness on residential energy consumption; (2) the impact of residential density and distance to the central urban core on residential energy consumption; (3) the effect of age and/or residential building condition on residential energy consumption within selected urban areas; and (4) urban energy system efficiencies in selected large cities and residential tracts, and their use of available energy.

6.3.2.1 The Effect of Urban Size and Compactness on Residential Energy Consumption. In this subsection observations and conclusions focus on three aspects of the relationship between urban size and compactness and residential energy consumption (1) urban size in relation to residential density, (2) urban size and compactness in relation to travel distance to the central core and (3) urban size and its effect on residential energy consumption.

(1) Urban Size in Relation to Residential Density. From data in Table 11 and Subsection 5.1.3 aspects of the relationship between urban size and residential density which are important for the selected cities include, the comparative size and densities of the cities and among the cities.

In 1981, Saskatoon, the smallest of the three cities investigated, had only 30 percent of the population of Edmonton, and 35 percent of its households. It also had 70 percent of the population density of Edmonton and 86 percent of its residential density, or and average of 470 dwellings per square kilometre for Saskatoon compared with Edmonton's 544 dwellings per square kilometre (Table 11). Population, dwelling and areal density figures for Saskatoon and Winnipeg also varied, although the difference in residential densities was less pronounced. For example, while Saskatoon contained only 28 percent of the population of Winnipeg, and 28 percent of its occupied dwellings, its residential density was approximately 94 percent of Winnipeg. Therefore, Saskatoon, although much smaller in size than either Edmonton or Winnipeg, approached the residential density of the two larger cities.

(2) The Relationship between Urban Size, Areal Compactness and Urban Travel Distance. The application of the method appears to confirm

that residential building density decreases with distance from the centre (Figure 28) in a similar way to population density (Clark 1951; Newling 1969). However, this relationship not only affects the distance parameter, but also residential transport energy to the core. Although transport energy data were limited in this investigation, sub-sections 5.2.1 and 5.3.5, and Table 13, (p.156) indicate that for the selected cities, short travel distances between the central core and mature suburban or inner core edge tracts require less areal residential transport energy than transport from more remote residential tracts. However, considering that the average energy consumption per trip is greater for short trips (sub-section 5.2.1.2), and that short trip distances are more common in a smaller city, average residential energy consumption per unit distance to the central core which is proportionately higher in the smallest city can be explained.

(3) The Effect of Urban Size on Residential Energy Consumption. In an investigation of the relationship between urban size and residential energy consumption for the selected cities, an important consideration is the effect of variations in urban size and compactness on residential energy use. From data in Table 11 (p.148), the following are observed:

(i) The smallest and newest city of Saskatoon*, with a high average residential density relative to its population (Table 11 p.148), has lower residential energy consumption than either the large new city of Edmonton or the large old city of Winnipeg. Although this may indicate higher energy efficiency in the smaller city, further data are required.

* Winnipeg was incorporated as a city in 1873, Edmonton was incorporated in 1904, and Saskatoon in 1906, and their populations in 1906 were 98,558, 11,167 and 3001 respectively (Artibise 1981, Tables A1-A3).

(ii) with less residential transport energy required to travel shorter distances, average residential transport energy in the small compact city of Saskatoon is less than in the larger cities of Winnipeg or Edmonton (Table 13).

(iii) in Saskatoon, the smallest city, (population) high average residential density together with low residential transport energy results in lower average residential energy consumption (Table 13 and Figure 20). Comparing residential compactness in the three cities as reflected by energy parameters for their respective residential tracts low density tracts in new suburban areas have values for energy consumption which are clustered close together (Table 13). However, for higher density residential tracts in inner core edge and mature suburbs, residential energy consumption, and compactness varies among the cities. This variation of residential consumption and compactness appears to reflect different stages of urban development and redevelopment in older, mature and inner core edge suburbs in the three cities. For example, Winnipeg, has higher levels of energy consumption and higher residential densities for older housing tracts than similar tracts in the newer cities of Edmonton and Saskatoon because it has more older housing.

Therefore, summarizing the conclusions for sub-section 6.3.2.1:

(1) city size (i.e. total population or households) as such does not appear significant with respect to average residential density, but does appear to be significant with respect to residential energy consumption. From limited data available for energy consumption,

the smaller and newer city of Saskatoon appears to exhibit lower average residential energy consumption than either of two larger (old and new) cities of Winnipeg and Edmonton.

(2) from limited data for the three cities, residential energy consumption decreases with distance from the urban centre, however, the central density crater identified for population by Newling (1969) will likely not occur if energy consumption for residential is replaced by energy consumption by other land use functions in the central core area (i.e. not by parking lots);

(3) residential energy consumption varies among the three older and newer cities with higher consumption in older areas of Winnipeg. To the extent that Winnipeg continues to have more older buildings in its mature and inner core edge tracts, it will likely continue to reflect higher areal residential energy consumption than in the newer cities.

6.3.2.2 The Effect of Residential Density and Distance to the Central Core on Residential Energy Consumption. The second question focuses on how changes in residential density and urban travel distance affect residential energy consumption in selected urban tracts. This question involves two sub-issues: (1) how does change in residential density affect residential energy consumption for selected tracts? and; (2) how does travel distance to the urban core from the respective tracts affect residential energy consumption?

(1) The Effect of Residential Density on Residential Energy Consumption. From investigation of data for three large cities and their respective tracts, the following are observed:

(i) Changes in the ratios of residential density to residential energy consumption for tracts in real cities indicate less than linear relationships, with density increasing more rapidly than energy consumption (Figures 23-25, p. 171-174). In a city such as Edmonton, with energy efficient newer residential tracts, as residential density increases in relation to residential energy consumption (Figure 27, p.179), the ratios of these variables are similar, and the resulting less than linear relationships approach a straight line. However, in Winnipeg, which ha lower residential energy system efficiencies in its selected higher density inner city areas, lower ratios of residential density to residential energy consumption indicate a more rapid rate of change in less than linear relationships (Figure 27).

(ii) At higher residential densities, areal residential energy consumption appears to increase but less rapidly in the selected cities. At the same time, in moving from outer suburbs to inner core edge tracts, the rate of change of ratios of residential density to residential energy consumption is more rapid for Winnipeg than Edmonton (Figure 27).

(iii) For hypothetical models, cities in which, by definition, conditions of high energy system efficiency are assumed, ratios of residential density to residential energy consumption are slightly higher for energy efficient decentralized models than for compact city models (Figure 27). This is explained in part by increased energy consumption to power movement systems in compact cities. At the same time, from outer suburban tracts to inner core edge areas, under energy efficient conditions, changing ratios of residential density to residential energy consumption result in steep slopes which approach straight line relationships.

(2) Variations in Residential Energy with Travel Distance to the Central Core from Selected Residential Tracts. The second sub-issue which is addressed is "how does change in travel distance to the urban core affect residential energy consumption?"

Observations relate to older and newer residential areas, and also to variations in residential energy consumption with distance from the centre for both new and older suburbs.

Based on estimated data for a limited number of residential tracts in Winnipeg, Edmonton, and Saskatoon, residential energy consumption decreases with distance from the central core (Figures 29 and 31). However, energy consumption does not change with distance in a consistent way for all cities and tracts. For example, although values for residential energy consumption in outer suburbs are close for the three cities, for selected inner core edge and mature suburban tracts, sharp divergences occur in residential energy consumption. This is explained in part, by variations in age and condition of dwellings, with distance from the centre. For example, in new suburban areas in the three cities housing is relatively energy efficient while among older areas there is considerable variation in consumption and efficiency.

From this evidence and from section 3.3.5, observations can be summarized:

(1) selected older residential tracts in Winnipeg consume more energy, and consequently such areas in that city are less energy efficient than comparable residential areas in Edmonton or Saskatoon; and

(2) residential energy consumption in the selected cities decreases with distance from the urban centre, except toward the edges of some outer suburbs (e.g. Winnipeg). In such tracts, increases in areal residential energy consumption are explained by higher residential densities (Figure 9, p.75).

6.3.2.3 The Effect of Age and Residential Building Conditions on Residential Energy Consumption. From residential tract data in Edmonton and Winnipeg which are approximately similar in size but different in age and building conditions, three observations emerge about residential energy consumption with distance from the centre:

(1) residential energy system efficiency appears to be greater for residential tracts in the newer city of Edmonton than in similar tracts in the older city of Winnipeg (Figures 31 and 32);

(2) conversely, in the older city of Winnipeg, the increase in residential energy consumption for selected older residential tracts close to the central core is greater than for comparable residential tracts toward the centre of the newer city of Edmonton (Figure 31); and

(3) for selected older residential tracts in the older city of Winnipeg, residential energy consumption increases more gradually from a selected mature suburb to an inner core edge suburb than is the case for a newer city, such as Edmonton (Figure 32).

6.3.2.4 Urban Energy Efficiencies in Selected Cities and Residential Tracts and Their Use of Available Energy. An objective of this dissertation considered urban residential energy policies which could help to achieve a balance between energy production and useful urban consumption and as a consequence could result in increased urban energy system efficiency. The following observations about energy consumption in residential tracts consider this balance.

(1) Internal Residential Energy. For the components of residential energy consumption internal to dwelling units in the selected residential tracts, under Scenarios I-III (Figure 17, p.146), significant opportunities exist to reduce energy use. For example, as energy policies change from Scenario I - III, and as energy conservation is increased, a reduction of residential energy consumption of approximately 30 percent is possible under Scenario II, and in excess of 50 percent under Scenario III.

From Scenarios I-III, substantial improvements in residential energy system efficiency occur. For individual dwelling, large improvements in residential efficiency are possible for space conditioning and water heat. From Table 16 (p.163), reductions in consumption of up to 46 percent may be achievable. However, in absolute terms, such improvements in residential systems efficiency are not large, considering that systems efficiencies for internal residential energy are in the order of 16 percent of total energy in the U.S. (Fowler 1984) and between 12 and 13 percent of total energy in Canada. This assumes that total system efficiency for conventional domestic fuel systems is in the order of 45 percent and that 27 percent represents the proportion of internal residential energy.

In both new and retrofitted older houses, the system efficiency for typical residential fuel systems (e.g. 45 per cent) can be substantially increased with more energy efficient furnaces. The energy efficiency of dwelling design and construction can also be improved. For example, in energy efficient dwellings like the Saskatchewan conservation house (Besant and Schoenau 1978) internal residential system efficiency is in the order of 22 percent of total energy compared with 12 percent for conventional urban housing. This difference of 10 percent in internal residential energy efficiency represents a substantial increase in urban energy conservation.

(2) External Energy for Residential Transport. Urban residential transport energy for journey-to-work is a component of residential energy which is external to dwellings but within discretionary control of residents. Under Scenario I reductions in transport energy consumption of more than 40 percent are possible, with reductions in the order of 20 percent under Scenario II, and an additional 20 percent under Scenario III. The combined effect of internal and external efficiencies results in reductions in residential energy consumption by 30-35 percent under Scenario II, and an additional 30-35 percent under Scenario III.

Most urban residential transport depends on private automobiles with energy system efficiencies of 5-10 percent (Cook 1974; Fowler 1984). Gray (1980) has argued that energy efficient designs can result in automobile energy system efficiencies which are at least double conventional figures. Therefore, a figure in the order of 15 percent appears realistic. Although public transport vehicles represent a smaller component of urban transport energy they are more energy efficient. For example, diesel buses have system efficiencies of 18 percent (Fowler 1984), trolley buses powered by thermoelectricity have system efficiencies of 20 percent while those powered by hydroelectricity have system efficiencies of 60-80 percent (Cook 1974; Fowler 1984). Therefore urban transit with high system efficiencies can substantially affect urban transport energy efficiencies if they are widely introduced. However, most urban transit vehicles and private automobiles depend on internal combustion engines with much lower energy system efficiencies. Consequently, external residential energy for journey-to-work and for most other urban travel, reflects energy system efficiencies for private automobiles. If transport energy for all urban purposes is in the order of 12.5 percent of total energy and if transport system efficiency improvements of 5-15 percent are possible for private urban transport, then the effect on total energy consumption of such increases in energy system efficiency is in a range of 0.6 to 1.9 percent. With energy system efficiency for public transport vehicles in the order of 65 percent, the effect on total energy efficiency would be in the range of 0.6 to 7.5 percent.

Therefore, on the consumption side, the largest potential factor for improving total energy efficiency is internal residential energy use with potential increases in energy efficiency of up to 10 percent or in a range from 12 to 22 percent. Increases in transport energy efficiency are estimated to increase total residential energy efficiency approximately an additional 6 percent.

(3) Energy Production. Available urban energy potentials, particularly fossil fuel energy vary considerably among urban regions. Some cities are almost totally dependent on fossil fuels for energy supplies while others have greater access to hydroelectricity. Cities which are the most dependent on fossil fuels have considerable potentials for fuel substitution. Although experimental data on the supply side of total urban energy are not developed in this investigation, data from the literature on the comparative efficiencies of energy systems are useful in indicating conditions for achieving a balance between energy production and consumption for thermoelectrically dependent cities.

Thermoelectric systems which generate only electricity represent system efficiencies of 14 and 35 percent, respectively, for nuclear and coal fired power plants (Cook 1974; Fowler 1984). Additional system losses in power transmission further reduce efficiency to approximately 11 and 31 percent, respectively. However a central urban energy production system which efficiently generates heat and electricity has a system efficiency in the range of 45-75 percent. By comparison, a typical 1970's residential gas furnace had a system efficiency in the order of 45 percent (Cook 1976) and more recent domestic furnaces are in the order of 63 percent. By comparison, in hydroelectrically served regions, system efficiency for electricity used for electric heat was in the order of 83 percent (Cook 1976).

A comparison of system efficiency of energy production in regions which are dependent on hydroelectric energy with regions dependent on fossil fuels indicates significant differences. These efficiency differences can be in the range of 38-69 percent where no heat component from thermoelectricity production is used to a difference of between 8 and 23 percent when both heat and electricity are optimally used. A comparison of system efficiency for residential gas heat with hydroelectric resistance heat indicates a system efficiency difference in favour of resistance heating which ranges from 20 percent for an efficient gas furnace to 33 percent for a conventional domestic unit. Clearly, significant increases in system efficiency are possible for residential energy systems in which use is closely matched with supply.

Energy production represents approximately 15 percent of total energy consumption in Canada. If for selected cities the minimum system efficiency for a thermoelectricity is in the order of 30 percent then the proportion of total energy represented by useful energy production is only about 4.5 percent. However, if both the thermal and electrical components of thermoelectricity are optimized (assuming conventional fossil fuels), the proportion of useful energy can be increased to approximately 13 percent of total energy. Therefore, an increase in efficiency of up to 8.5 percent would be possible for energy production. However, this magnitude of increase in system efficiency for energy production is only possible in cities such as Saskatoon or Edmonton. For Winnipeg, which is hydroelectrically dependent and for which energy system efficiency for electricity production already exceeds 90 percent at the power plant (Cook 1974), there is less potential for a large increase in system efficiency of energy production.

A combination of data from sub-sections 6.3.2.1 to 6.3.2.4 suggests a range of increase for total energy system efficiency as a result of matching internal residential energy, external residential energy, and energy production. Therefore, if total residential energy efficiency increases for consumption are approximately 16 percent, and with 9 percent added for increased efficiency in energy production, the increase in total energy efficiency through a balance of residential system potentials is in the order of 25 percent.

Edmonton illustrates the potential for matching of supply and production in a large city. If, during the years 1981-2021, electrical consumption in Edmonton is within a range of 12.9-15.9 PJ/Y (Ross 1979), and the potential thermal energy available from this quantity of thermoelectricity is within a range of 20-24 PJ/Y, then 13-16 PJ/Y is the range of usable thermal energy which might be available for residential purposes, or 55-60 percent of energy production. However, with urban residential energy needs alone in a range of 10-16 PJ/Y, a close correspondence could be achieved between potentially available thermal energy from power production (e.g. 13-16 PJ/Y)) and urban residential needs.

This example suggests that if residential densities in a fossil fuel-dependent city, such as Edmonton, can be increased to levels which are sufficient to feasibly distribute thermal energy (e.g. in excess of 1740 dwellings per square kilometre), and if thermal energy can be distributed from thermoelectric plants, then total residential energy system efficiency can be substantially increased and a closer balance can be achieved between useful urban energy production and consumption.

6.4 POLICY IMPLICATIONS

The final section of this chapter outlines policy implications of the method and its application for urban energy planning. It also considers implications of questions and relationships about which observations and conclusions were presented in section 6.3.

6.4.1 The Method as a Tool for Urban Planning

This method of organizing and modelling urban energy data can be a useful tool for planning agencies which periodically require in-depth analysis of urban energy consumption and system efficiency, and use available time-series data. The method can be applied to any number of cities and/or tracts within cities under a variety of land use conditions. Real data available from utilities, statistics agencies and municipal planning bodies can be used together with estimated data avoiding the necessity of specialized surveys. The method can also be systematically reiterated to monitor and maintain time-series data in a consistent way. In this respect it can be useful in policy formulation to present time-related energy change in cities which results from public intervention, changing energy prices or urban growth. The method can also be useful in monitoring incremental changes in energy use in cities which are heavily dependent on fossil fuels.

6.4.2 Some implications of the Questions and Relationships Investigated

Analysis of the observations in Section 6.3 suggests some possible implications for future urban policy with respect to (1) urban size and compactness; (2) areal residential density and travel distance; (3) age and condition of residential areas; and (4) the efficient use of energy potentials in urban residential areas.

6.4.2.1 Urban Size and Compactness. Although further research data are required to establish optimum conditions of city size and compactness relative to urban residential energy consumption and efficiency, from available data and the conclusions in sub-section 6.4.1 the following policy implications are suggested:

(1) In large thermally dependent cities, residential tracts should be more compact (e.g. denser than approximately 1740 dwellings per square kilometre) so that thermal energy can be economically distributed for residential purposes. Conversely, new low density residential developments should be discouraged at the outer fringes of thermally-dependent large cities, unless such residential areas are designed to operate with a minimum requirement for depleting energy resources, such as natural gas or oil.

(2) In thermoelectrically dependent cities, development densities should be planned to make it feasible to optimize production and consumption of both electricity and thermal energy. Also, increased use of electricity for efficient urban transport to serve high and medium density residential areas should be encouraged.

(3) With respect to transport energy and urban compactness, dense polycentric residential configurations with well spaced compact urban cores or nodes, are more energy efficient than large concentric cities with low density inner city tracts and central core edge areas, and dispersed low density suburbs.

6.4.2.2 Residential Density and Travel Distance. Although further investigation of the extent and energy characteristics of residential-related urban trips in the selected large cities is required, from the limited data in this investigation, the following policy implications are suggested with respect to residential density and travel distance to the central core:

(1) Urban policies that are intended to improve energy characteristics of journey-to-work to the core should seek to achieve multiple benefits from energy conservation. For example, transport sector energy benefits should seek to improve the economics of distribution of alternative energy (e.g. thermal) as well as to reduce in total household consumption.

(2) Energy efficient large cities imply dense and compact residential arrangements with short travel distances to work. Although further investigation is required to determine more precise residential density and travel distance parameters for optimum residential energy efficiency in large cities, indications from these observations are that average adjusted travel distances to the core should be less than 5 kilometres. This will likely result in average residential densities considerably excess of 3000 dwellings per square kilometre (Table 17) with some residential density maxima in excess of 10,000 dwellings per square kilometre (Figure 31).

(3) Many inner core edge and mature residential tracts which are located close to central cores in the selected cities contain

residential densities which appear to be adequate to distribute thermal energy economically. In fossil fuel-dependent cities, such as Edmonton and Saskatoon, where thermal energy from nearby power plants is available and economic to distribute (Shinyei 1978), continued monitoring and analysis of energy system alternatives is required to confirm the feasibility of urban energy alternatives such as district heating. For example, in residential areas in which energy conservation programs are introduced to improve energy efficiency for individual dwellings, urban energy conservation programs should also consider the future potential for such areas to become heat sinks for economic distribution of thermal energy.

(4) Some older urban residential tracts in the selected cities may require restructuring and selective redevelopment to achieve more compact energy efficient yet socially acceptable urban arrangements. In addition, increased mixes of land use will be required in residential areas in order to reduce effective travel distances, not only for work trips, but also for shopping, personal business and other frequent urban travel.

(5) More energy efficient urban transport implies increased vehicle occupancies, shifts to more energy efficient vehicles, and reduced use of private automobiles for short urban trips (Carrier 1974). A shift to more energy efficient transport modes is also required for large cities. Subject to the urban design of cities, this may include electric powered horizontal and vertical movement systems, with capacities in the range of 1000 - 12,000 passengers per lane per hour (Government of Belgium 1986). At low areal densities, car and van pools, and telephone assisted transit services can also reduce urban energy consumption.

6.4.2.3 Age and Condition of Residential Areas. In areas of urban residential redevelopment or residential rehabilitation, older (poorly insulated) housing consumes substantially more internal residential energy (Table 5), and uses this energy less efficiently than new or retrofitted older housing (CMHC 1977). This has the following implications for residential energy policy:

(1) Universal programs that provide energy conservation assistance for both new and older dwellings, might be reconsidered in favour of programs targetted to least energy efficient residential tracts, or to pockets of energy inefficient dwellings within such tracts. This is particularly important to reduce differentials in residential energy efficiency between areas of old and new housing.

(2) District heating using hot water as a thermal medium can be a realistic and increasingly feasible technology for compact urban development (Danish Board of District Heating 1977). This is particularly important in new high and medium density residential areas, and in older residential areas, which are subject to redevelopment (Morofsky 1980).

(3) To identify and priorize older cities, and urban residential tracts that would benefit from increased residential energy conservation, application of the method outlined in this dissertation can be useful to simulate change in energy characteristics.

6.4.2.4 Urban Residential Energy System Efficiencies in Selected Large Cities and Residential Tracts, and Their Use of Available Energy. In thermally dependent cities three aspects of energy need to be optimized for most efficient residential energy conditions:(1) internal residential needs for thermal energy, such as space conditioning and water heat; (2) external residential transport energy use, such as energy consumption for urban travel; and (3) balanced production and distribution of heat and electricity for residential and other urban purposes. Optimized, these three aspects of urban energy can result in total energy system efficiency increases in the range of 28-38 percent.

Electricity produced from either hydropower or thermoelectric systems which co-generate heat and electricity can power urban transport more efficiently, on a systems basis, than fossil fuels. However, for this to occur, both the heat and electricity components of energy production must be balanced. Although this is difficult, with both heat and electricity demand fluctuating daily, weekly and annually (Diamant 1970), maximum residential energy efficiency can only occur when transport, housing and energy policies are effectively coordinated to balance energy production and use (Figure 8). However, resolving the institutional problems in such coordination is no small challenge (Smith Auld and Associates 1976).

The interrelationship of transport, housing and energy policies has the following quantitative implications for increases urban energy efficiency:

(1) Residential/commercial land uses represent the largest sectoral area of energy demand or almost 40 percent (Fowler 1984). The internal residential energy components of space and water conditioning representing more than 80 percent of this demand. Most is required at temperatures of less than 100°C, and is used at system efficiencies of less than 15 percent (Ford et al 1975).

(2) Although substantial increases in residential energy efficiency are possible in urban areas and within individual residential dwelling units, beyond certain limits, fundamental changes in building arrangements and residential areas are required. For example, economic distribution of thermal energy in urban areas requires a minimum residential density in the order of 1740 dwellings per square kilometre (Danish Board of District Heating 1977).

(3) Internal residential energy system efficiency for space conditioning and water heat can be increased up to 50 percent, to at least 22 percent.

(4) For the external or transport component of residential energy system efficiency increases of 7 percent are achievable.

(5) For energy production, system efficiency increases varies from less than 14 percent at the power plant (for nuclear electric systems without use of thermal energy) to as high as 92 percent for hydroelectric systems.However, with energy production only about 15 percent of total national energy, even at 85 percent efficiency under ideal conditions, the energy production component cannot exceed 13 percent. Therefore energy savings for this component are within a range of 2-13 percent of total national energy.

(6) Total system efficiency increases which are possible through a combination of efficiency improvements in energy production, residential transport energy, and internal residential energy, are in the range of 16-27 percent.

In conclusion, it is argued that the urban planning method for modelling energy use which is developed in this thesis offers an analytical and monitoring technique which can be periodically reiterated using systematic time series data to present three-dimensional change in energy use. It can also provide a first approximation of energy characteristics that may be expected for other large cities and can help to identify where significant energy waste may be occurring in urban areas.

APPENDICES

APPENDIX 1 - ALTERNATIVE URBAN MODELS: DECENTRALIZED AND COMPACT HYPOTHETICAL CITIES IN A NORTH AMERICAN CONTEXT

Plate 1: Diagrams of a Hypothetical Decentralized City.

Plate 2: Diagrams of a Hypothetical Compact City.

Plate 3: Project for Hypothetical Northern Compact City - Schematic Plan and Site Plan.

Plate 4: Typical Section through Central Spine.

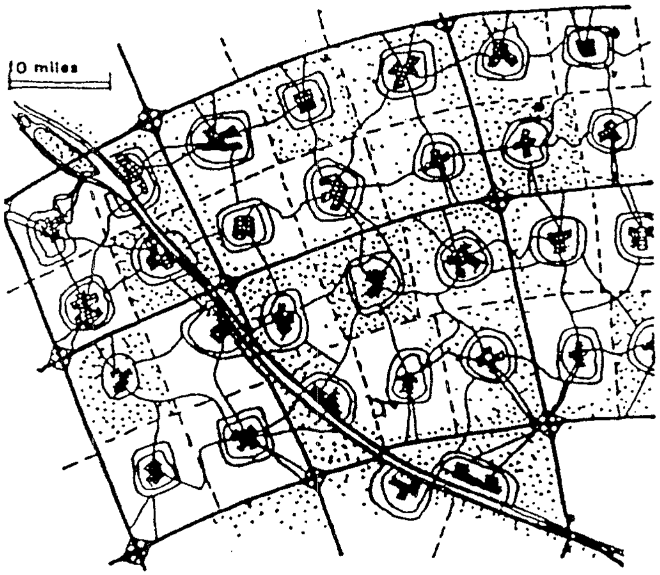
APPENDIX 2 - COMPUTER DATA FOR ENERGY CONSUMPTION IN RESIDENTIAL TRACTS FOR THE SELECTED CITIES: WINNIPEG, EDMONTON AND SASKATOON.

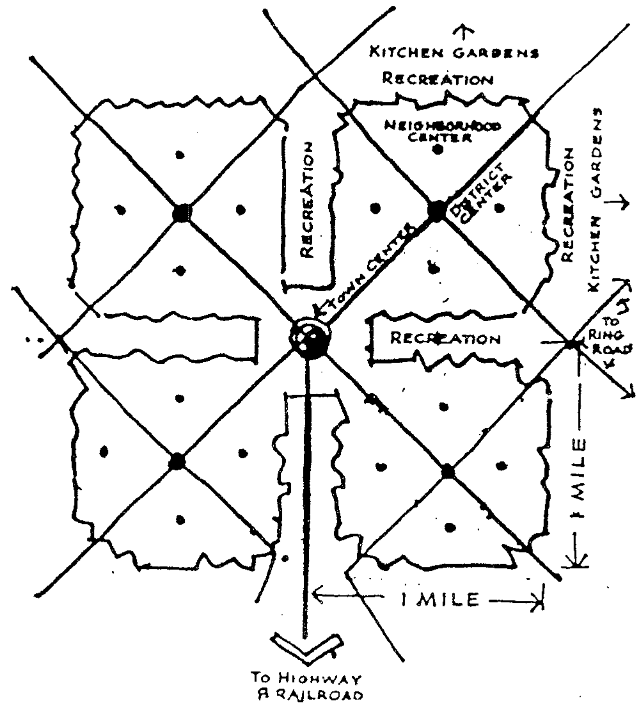
Plate 1: Computer Data, Winnipeg: Annual Consumption Per Postal Code Area for the Data Year 1981 - 82, Census Tract 017, residential, commercial and industrial consumption of natural gas in Total MCF per customer.

Plate 2: Computer Data, Edmonton: Energy Consumption for Selected Tracts for the Year 1981. Tracts 032, 048, and 025, inclusive, residential and commercial consumption in gigajoules.

Plate 3: Computer Data, Saskatoon: Annual Consumption Per Postal Code Area for 1981. Census Tract 008. Residential and Commercial Consumption of Natural Gas in Cubic Metres (M^3).

APPENDIX 1 - PLATE 1: DIAGRAMS OF A HYPOTHETICAL DECENTRALIZED CITY





SOURCE: Percival Goodman. 1977. The Double E. New York: Anchor Books: 160.

APPENDIX 1 - PLATE 2: DIAGRAMS OF A HYPOTHETICAL COMPACT CITY

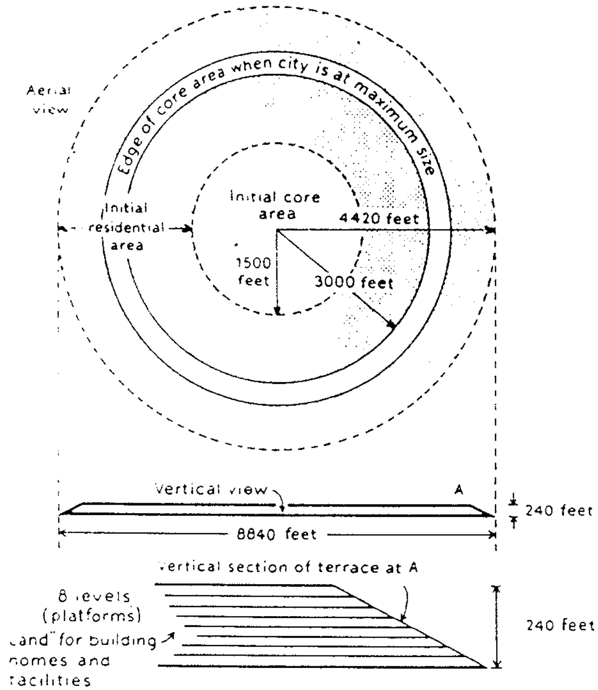
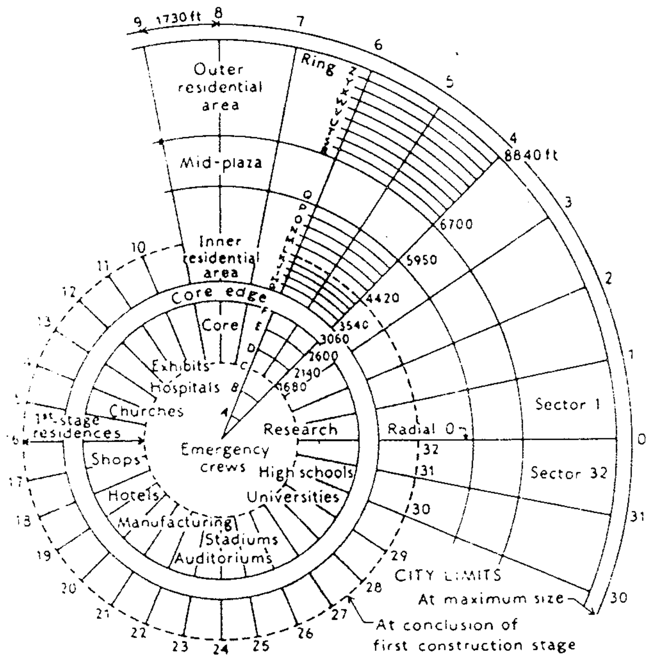


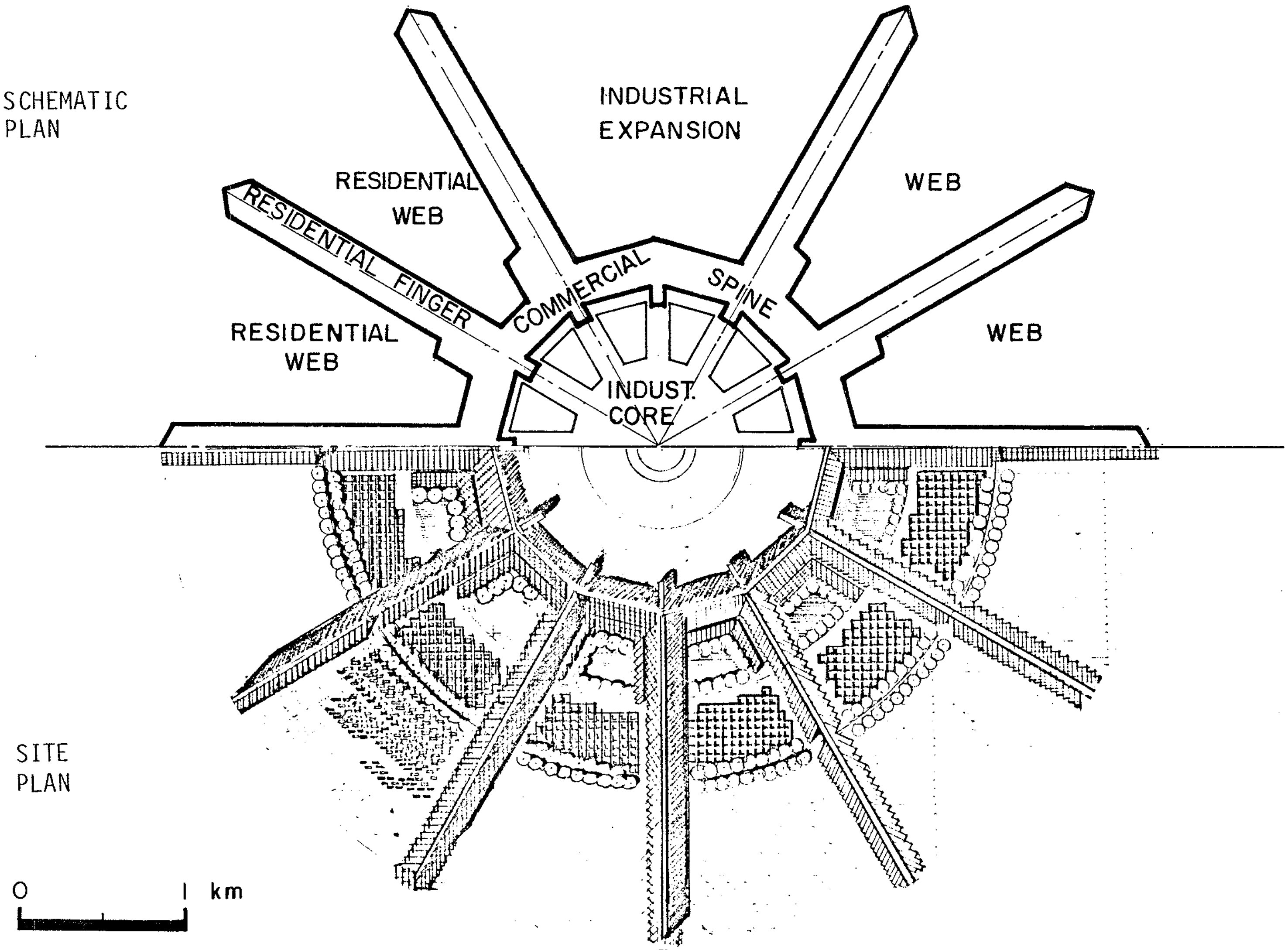
Figure 3-1 TOP AND SIDE VIEW OF COMPACT CITY
Population: 250,000. Base area, 2.2 square miles. As the city grows to 2 million people, its height and diameter are expanded to dimensions double those shown.



A TYPICAL PLAN FOR ONE LEVEL IN COMPACT CITY

SOURCE: G.B. Dantzig and T.L. Saaty. 1973. The Compact City. San Francisco: W.H. Freeman and Co.: Fig. 3-1.

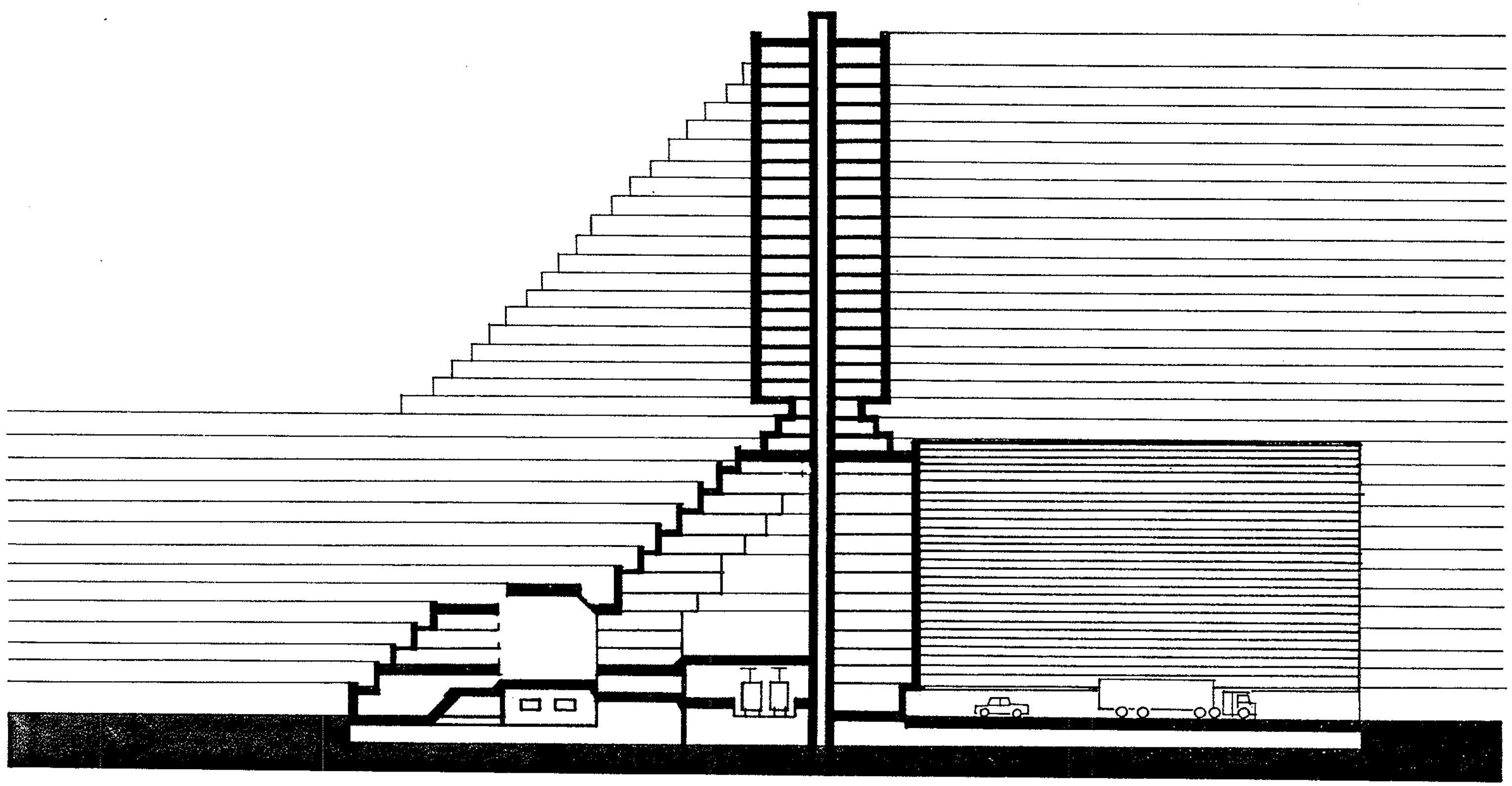
APPENDIX 1 - PLATE 3: PROJECT FOR A HYPOTHETICAL NORTHERN COMPACT CITY



APPENDIX 1 - PLATE 4:

PROJECT FOR A HYPOTHETICAL NORTHERN CITY.

TYPICAL SECTION THROUGH CENTRAL SPINE.



MEDIUM DENSITY RESIDENTIAL

RESIDENTIAL COMMERCIAL

HIGH DENSITY INNER RING

CORE AREA INDUSTRIAL OFFICE ZONE

APPENDIX 2 - PLATE 1: COMPUTER DATA - WINNIPEG ANNUAL ENERGY CONSUMPTION PER POSTAL CODE AREA FOR THE DATA YEAR 1981-82. CENSUS TRACT 017, RESIDENTIAL, COMMERCIAL AND INDUSTRIAL CONSUMPTION OF NATURAL GAS IN TOTAL MCF PER CUSTOMER

RUN DATE: 11/07/83 TIME: 21 32 28 GREATER WINNIPEG GAS COMPANY PROGRAM: MAPOST PAGE 41

MARKETING YEARLY CONSUMPTION PER POSTAL CODE AREA FOR 1982

POSTAL CODE	CENSUS TRACT	RANGE	RESIDENTIAL GENERAL	RESIDENTIAL SPACE HEAT	RESIDENTIAL SPACE HEAT & OTHER	COMMERCIAL GENERAL	COMMERCIAL SPACE HEAT	COMMERCIAL SPACE HEAT & OTHER	INDUSTRIAL	TOTALS
R3G 2J3	01700	< 125	0	1	8	0	0	0	0	9
		125 - 140	0	2	2	0	0	0	0	4
		141 - 160	0	1	3	0	0	0	0	4
		> 160	0	0	17	0	0	0	0	17
			0	4	30	0	0	0	0	34
		CONSUMPTION (MCF)	0	513	4,213	0	0	0	0	5,726
		AVERAGE (MCF/CUSTOMER)	0	128	173	0	0	0	0	168
R3G 3K9	01700	< 125	0	0	1	0	0	0	0	1
		125 - 140	0	0	0	0	0	0	0	0
		141 - 160	0	0	0	0	0	0	0	0
		> 160	0	0	0	0	0	1	0	1
			0	0	1	0	0	1	0	2
		CONSUMPTION (MCF)	0	0	101	0	0	5,161	0	5,262
		AVERAGE (MCF/CUSTOMER)	0	0	101	0	0	5,161	0	2,631
TOTALS	01700	< 125	6	72	122	2	12	2	0	216
		125 - 140	0	29	54	0	3	0	0	86
		141 - 160	0	27	86	0	2	1	0	116
		> 160	0	103	615	0	14	46	0	778
			6	231	877	2	31	49	0	1,196
		CONSUMPTION (MCF)	17	37,307	175,205	102	16,148	77,065	0	305,914
		AVERAGE (MCF/CUSTOMER)	14	161	199	51	520	1,572	0	255

SOURCE: Computer Services Department. Greater Winnipeg Gas Company, Winnipeg, Manitoba.

APPENDIX 2 - PLATE 2: COMPUTER DATA - EDMONTON ANNUAL ENERGY CONSUMPTION FOR SELECTED CENSUS TRACTS FOR THE YEAR 1981. TRACTS 032, 048 and 025, INCLUSIVE, RESIDENTIAL AND COMMERCIAL CONSUMPTION IN GIGAJOULES

ENERGY CONSUMPTION FOR SELECTED TRACTS 08/17/84
*** CITY OF EDMONTON ***
FOR THE YEAR 1981
MEASURED IN GJ
(RESIDENTIAL AND COMMERCIAL)

INNER TRACT (032.00)

--- RESIDENTIAL --- ENERGY CONSUMPTION	--- COMMERCIAL --- ENERGY CONSUMPTION
49,720.50	453,335.62

MATURE TRACT (048.00)

--- RESIDENTIAL --- ENERGY CONSUMPTION	--- COMMERCIAL --- ENERGY CONSUMPTION
200,617.69	53,848.03

OUTER TRACT (025.00)

--- RESIDENTIAL --- ENERGY CONSUMPTION	--- COMMERCIAL --- ENERGY CONSUMPTION
146,112.56	34,233.72

SOURCE: Computer Services Division, Northwestern Utilities Limited, Edmonton, Alberta.

APPENDIX 2 - PLATE 3: COMPUTER DATA - SASKATOON ANNUAL CONSUMPTION PER POSTAL CODE AREA FOR 1981. CENSUS TRACT 008. RESIDENTIAL AND CONSUMPTION OF NATURAL GAS IN CUBIC METRES (M^3)

REPORT NO. 02 ANNUAL CONSUMPTION PER POSTAL CODE AREA FOR 1981 12/13/83

POSTAL CODE	CENSUS TRACT	RESIDENTIAL	COMMERCIAL
S7K 4H9	00800		1,020,263
27K 4K3	00800		195,485
S7K 4K5	00800	219,618	1,232,755
S7K 4K7	00800	4,707	
S7K 5E5	00800	1,989	
S7K 5H5	00800	17,381	407,096
S7K 5T6	00800		1,142,139
S7K 5X2	00800	5,427	499,603
S7K 5Z8	00800	25,817	54,149
S7K 6A5	00800	41,490	17,461
S7K 6C2	00800		
S7L 0Y7	00800		40,501
S7L 0Y9	00800		26,681
S7M 1L5	00800		263,272
TOTAL	00800	1,194,681	44,690,150

SOURCE: Saskatchewan Power Corporation Data Centre, Regina.

GLOSSARY

AERCB. Alberta Energy Resources Conservation Board.

AREAL. Pertaining to an area.

AREAL DENSITY. Density of an area larger than the area of a building site (e.g. census tract).

BIOMASS. All matter of plant and animal origin, excluding fossil fuels.

CENSUS. A periodic counting of national population and other socio-economic characteristics.

CENSUS METROPOLITAN AREA (CMA). The major labour market area of an urbanized core (or continuously built-up area) having 100,000 or more population.

CENSUS TRACT. A permanent small census geostatistical area established in large urban communities with the assistance of local specialists in urban and social science research.

CITY. A large important community; in Canada, a municipality of the highest rank.

CLIMATICALLY-STRESSED. Subject to extreme variation in temperature and related environmental conditions. In northern environments, this refers to seasonal extremes of cold temperature.

CMHC. Canada Mortgage and Housing Corporation.

COGENERATION. The production of two useful forms of energy from the same process. In an urban area, hot water for residential space heating is first run through turbines to generate electricity (see also district heating).

CONCENTRIC CITY. A city with its urban concentration and growth around a common centre.

CONSERVATION. In a strictly economic sense, it is the redistribution of use rates of resources towards the future. In a more general way, conservation may be thought of as reducing the consumption of a resource in the near future so as to have more of it available in the more distant future. Also the prevention of waste or losses.

DECENTRALIZED CITY. A city in which urban growth and development is distributed away from one central point to many nodes or growth points (see also POLYCENTRIC CITY).

DEPLETION. The opposite of conservation, it is the redistribution of use rates toward the present.

DEVICE OR MACHINE EFFICIENCY. $\text{Efficiency} = \frac{\text{useful energy or work out}}{\text{total energy or work in}}$.
The ratio can never be greater than one. This is first law efficiency or device efficiency in which the device is a heat engine such as an automobile or a home furnace.

DIRECT CONTROL OF ENERGY. The ability of consumers to have control over the type of fuel and the technology which is used in heating their homes (e.g. furnace or heating device). Such control also includes decision making or choice with respect to the efficiency with which residential energy is used.

DISTRICT HEATING. The supply of heat in the form of steam or hot water to a group of buildings from a central source such as a dedicated thermal plant or from co-production, cogeneration, recycled or reject heat sources.

DWELLING OR DWELLING UNIT. A house or apartment that is a residence. The words are usually synonymous. It is abbreviated DU. (See also residence).

EFFICIENCY. Efficiency of a machine, or more generally, of any process in which some energy or work is put in and some combination of work or energy comes out, is the ratio of the desired output (work or energy) to the input.

EMR. Ministry of Energy, Mines and Resources (Canada).

END-USE ENERGY EFFICIENCY. The efficiency of energy for any task which is ultimately responsible for energy consumed and the efficiency of its consumption.

ENERGY CONSERVATION. The prevention of waste or unnecessary loss in energy potential as it changes from a state of low entropy to high entropy.

ENTROPY. A measure of the amount of energy no longer capable of conversion into work. An index of energetic usefulness. Every time energy is transformed from one state to another, a penalty is exacted in a loss in the amount of available energy to perform useful work in the future.

EXAJOULE. In SI units a unit of energy which represents 10^{18} joules. It is abbreviated EJ.

FLUIDIZED BED COMBUSTION. A process in which combustible materials are introduced into a greater volume of hot inert particles contained in a chamber and maintained in a state of turbulence by a stream of gas (air) from below. During their thermal conversion, the process can be pressurized.

FOSSIL FUELS. Fuels such as coal, crude oil, natural gas, oil shales, and oil sands, formed from remains of plants.

FUEL. Any combustible materials which give off heat; also materials which can be fissionized in a chain reaction to produce heat (e.g., nuclear energy).

GIGAJOULE. In SI units a unit of energy which represents 10^9 joules or one billion joules. It is abbreviated GJ.

GROSS NATIONAL PRODUCT (GNP). A measure of the total flow of goods and services produced by an economy over a particular time period, normally a year. It is obtained by valuing outputs of goods and services at market prices and then aggregating.

HEAT. The transfer of energy from one body to another as the result of a difference in temperature. As such it is the ability to raise the temperature or change the phase state of a colder substance.

HEAT EXCHANGER. A device in which heat from a hot fluid is transferred to a cold fluid.

HEAT SINK. An environment either natural or man-made in which heat is transferred from a hot body (e.g. thermoelectric plant) to a cold body (e.g. a cooling pond or an urban heat distribution network).

HIGH-GRADE (OR HIGH-TEMPERATURE) HEAT. Heat which exceeds a temperature of 100°C.

HOUSEHOLD. A group of persons living together; pertaining to a home. (See also RESIDENCE).

HYDROELECTRIC. The use of a head of water (e.g. from a lake or river) passed through a turbine to generate electricity.

HYPOTHETICAL. Based on an assumed or supposed hypotheses.

IEA. International Energy Agency.

INTERCENSAL. Between census counts.

INTERNAL RESIDENTIAL ENERGY. The total energy consumed within a dwelling (e.g. space heat, water heat, and appliance energy).

JOULE. A unit of work or energy equal to 10,000,000 ergs or .24 calories. Electrically, it represents the energy expended in one second by a current of one ampere at a potential of one volt; abbreviated J. It is the standard unit of energy in the SI or Systeme International.

JOURNEY-TO-WORK. Commuting travel to employment, usually daily return trips from a residence to a work place.

KILOWATT HOUR. In SI units 1 Kilowatt hour, abbreviated kWh, is a power unit equal to 3.6 x 10^6 joules or 3.6 megajoules.

LOW GRADE (OR LOW TEMPERATURE) HEAT. Heat which does not exceed a temperature of 100°C.

MATRIX. A rectangular array of quantities or other symbols convenient for representing relations between each pair of an aggregate. Strictly speaking, such an array can be called a matrix only if it itself can be treated as a generalized quantity subject to certain rules of calculation.

MCF. Abbreviation for one million cubic feet of (natural) gas. It is equivalent to approximately 0.028 x 10^6 cubic metres (M^3) or 1090 gigajoules.

MEGAJOULE. In SI units, a unit of energy which represents 10^6 joules or one million joules. It is abbreviated MJ.

MODEL. A theoretical system of relationships which attempts to capture the essential elements in a real world situation.

MTOE. Million tonnes of oil equivalent. One Mtoe represents approximately 28.8 gigajoules.

NEB. National Energy Board (Canada).

NON-LINEAR RELATIONSHIP. A relationship between a set of variables in which at least one of the variables is non-linear.

NON-RENEWABLE ENERGY. An energy resource is non-renewable if its rate of formation is so slow as to be meaningless in terms of human life spans. Energy resources which are derived from capital stock (or principal on capital). Coal, petroleum and natural gas are non-renewable, as are natural concentrations of radioactive minerals such as uranium and thorium.

OECD. Organization for Economic Cooperation and Development.

PARAMETER. Constant term in an algebraic equation (e.g., in the relationship y = ax+b, the numbers a and b are parameters).

PETAJOULE. In SI units a unit of energy which represents 10^{15} joules or a quadrillion joules. It is abbreviated PJ.

POLYCENTRIC CITY. A city which is decentralized and concentrated around a number of interrelated urban centres or nodes.

PRIMARY ENERGY. The energy commodity at the point of production, (e.g. crude oil, raw natural gas, coal, and hydroelectricity).

PRIVATE TRANSPORT. Privately owned means of conveying individuals or groups of people (e.g. private automobiles).

PUBLIC TRANSPORT OR PUBLIC TRANSIT. A publicly owned means of conveying members of the public or their goods, often in large cities and towns.

REAL. actual or true.

RENEWABLE ENERGY. Energy sources which are perpetual or replenishable; have life spans comparable to that of the solar system. Solar, biomass, geothermal, wind, and hydraulic - river, ocean tides and waves -- are examples. Renewables may also be defined as energy resources derived from income (interest on capital).

RESIDENCE. The place where one lives.

RESIDENTIAL. Adjective for residence. In urban economic sector classifications, it refers to land use in which dwellings are owner occupied.

RESIDENTIAL/COMMERCIAL. Land use in which dwellings are both owner and renter-occupied. In this analysis the term is taken to be synonymous with residential.

RESOURCE. All potential energy-producing natural phenomena and accumulations of naturally occurring substances which are known or inferred to exist (e.g., oil, natural gas, oil, coal, uranium hydraulic sources, peat and forest biomass).

RETROFIT. In residential development it pertains to restoring and renovating older housing to bring it up to current standards of technical performance (e.g. insulation and air circulation).

SCARCITY. In economic terms, a condition where there is less of something than people would like to have if it cost nothing to buy.

SCENARIO. Outline simulation or synopsis of a particular set of future conditions (e.g., future energy conditions).

SECONDARY ENERGY. End-use energy or the energy available for useful purposes after all of the energy consumed in conversions, transmissions or transportation is accounted for.

STEADY-STATE SOCIETY. A society that has achieved a basic long term balance between the demands of its population and the environment that supplies its wants. In the field of energy this implies careful husbanding of energy resources.

SUSTAINABLE ENERGY. Energy sources which are virtually infinite in terms of their utilization in the foreseeable future or which are replenishable. It may include renewables, nuclear reactors, and coal, where the supply is very large.

SYSTEM EFFICIENCY. The ratio of total work done in propelling a vehicle or heating an environment to the energy content of the fuel as it originally existed in the ground. It is computed by multiplying the efficiency of a particular component in a system with the cumulative efficiency of all previous steps.

SYSTEME INTERNATIONAL. This international system of units abbreviated SI, uses the joule as a basic energy unit, and the watt as a basic power unit.

THERMAL DEPENDENT. Dependent on energy resources which require combustion of fossil fuels or fission to generate useful heat for electricity and other purposes.

THERMODYNAMICS. The study of the motive power of heat; that is, the capability of energy bodies to produce useful work.

THERMODYNAMIC LAWS. The laws of thermodynamics in combination state that the total energy content of the universe is constant and the total entropy is continually increasing. The first law states that energy can never be created or destroyed, it can only be changed in form. The second law states that every time energy is transformed from one state to another there is a loss in the amount of available energy to perform work of some kind in the future.

THERMAL EFFICIENCY OF A COMBUSTION ENGINE. The ratio of the amount of work produced in the pistons by expanding gas in the cylinders, to the potential internal energy of combustion in the gasoline used as a fuel.

THERMAL ENERGY. Useful energy in the form of heat. (See also HEAT).

THERMOELECTRIC. The combustion of any fuel which produces steam for turbines and generates electricity (and heat).

TOTAL PRIMARY ENERGY. Abbreviated TPE, it is the total energy potential available at the point of production. (See also PRIMARY ENERGY).

TRANSPORT. A means of conveying people or goods, a conveyance. (See also public transport and private transport).

URBAN MODEL. A hypothetical city or a system of urban relationships which attempts to capture the essential elements in a real city.

UTILITY. A company or institution which exists to provide specific services via contractual arrangements (e.g., municipal gas supply and distribution).

VARIABLE. A quantity that may have a number of values.

WATT. SI unit of power is the watt, which is equal to 1 joule per second.

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