COMMUNITY ENERGY SYSTEMS

Executive Summary

This report examines a broad range of issues relating to the implementation of cogeneration in low-rise residential applications. Cogeneration technology is outlined in general terms, and the specific aspects of reciprocating engine cogeneration plants are presented in greater technical detail. A design concept is developed for the application of a reciprocating engine-based cogeneration system to a generic single dwelling unit,operating with a supplementary boiler in a thermal load following mode. A second concept is developed for a generic multiple unit low-rise dwelling which incorporates district heating infrastructure. Both concepts are outlined in some detail in text and schematic drawing format.

As an aid to conducting a preliminary assessment of a site for cogeneration feasibility, a comprehensive summary of site evaluation considerations is included. While each potential site is different, many criteria such as fuel pricing, electricity price, capital cost and operating cost are common to the evaluation of every project. A simplified economic model is presented which allows a developer to quickly estimate the economic viability of a potential project. Certain parameters such as fuel cost, electricity savings, capital cost and operating and maintenance cost are inserted into the model, which then produces a payback period. A series of graphs have been plotted, based on this model, as a set of sensitivity analyses and as a visual means of quickly identifying economic performance.

Regulatory, economic and social factors combine to either support or erode the case for cogeneration. This report includes a background section on the current status of cogeneration in Canada, focussing particularly on Ontario which has witnessed the most the activity during the past five years. Included are recommendations which would ease the implementation of cogeneration in today's environment which ranges from neutral to hostile.

The implementation of cogeneration in multi unit low rise housing development can offer substantial environmental and operating cost savings benefits but also poses some challenges. The technology required to implement cogeneration is well proven. Numerous cogeneration projects have been implemented in recent years in the residential, commercial and institutional load displacement market. They range in size from 15 kW to multiple units of 800 kW. Of note , the majority of the smaller projects were implemented as part of demonstration projects with marginal economic performance. The larger projects offer very attractive operating cost savings and attractive rate of returns.

The main difficulties identified in this report for the implementation of cogeneration in multiple unit low rise housing development are as follows:

- In order to attain a reasonable cogeneration plant size, a relatively large number of dwellings must be combined via a district heating infrastructure to common the space heating, domestic hot water and potentially space cooling loads. The cost of this infrastructure is quite significant compared to the conventional energy supply option and makes the rate of return on the overall proposition relatively unattractive by conventional investment standards.

- The routing of electrical power from the cogeneration plant to the housing units could be

achieved in a number of ways. Using the utility distribution system is the only cost effective approach for a large number of units. Parallel generation is a well proven concept. The difficulties that arise here are regulatory in nature. Ownership of the plant and wheeling and power purchasing options must be carefully reviewed in light of the prevailing regulations. In the end the value of the electricity produced must remain high enough relative to the fuel used to offer acceptable operating cost savings.

The main difficulty identified in implementing cogeneration in a single housing unit is as follows:

- There is no small cogeneration package (5 kW +/-) available in the Canadian marketplace suitable for this application.
- The thermal and electrical loads are inherently "mismatched" on an instantaneous basis due to the poor diversity factor of a single dwelling. Thermal storage combined with the use of the electrical grid as an "electrical bank" is required to operate the cogeneration at optimum efficiency.
- A small generator in this size range has a high installed cost per unit of power output. The need for thermal storage and backup heat supply also increases the cost of the overall project.
- Natural gas price at the residential level tend to be higher then the gas price of larger loads.
- Preliminary costing and economic performance analysis indicate this option to be relatively unattractive from an economic point of view.

Five sites were studied in this report for potential application of cogeneration. The design of the cogeneration systems and district heating infrastructures were conceptual in nature and costing on a preliminary basis. None of the sites offer an application which "stands out" as a potential champion based on conventional investment criteria. However the following remarks are made:

- The Bain Cooperative shows the most promise. The facility has high housing density. District heating infrastructure is existing, but must be reviewed in detail to determine the actual cost to retrofit from steam to hot water.
- The option of using a steam engine at the Ouje Bougoumou site should be reviewed.

Résumé

Ce rapport traite d'un grand nombre de questions portant sur la mise en place de la cogénération pour de petits bâtiments résidentiels. La technologie de la cogénération est expliquée en termes généraux et les aspects techniques particuliers des centrales de cogénération à moteur alternatif sont expliqués en détail. Une étude conceptuelle est réalisées sur l'utilisation d'une installation de cogénération à moteur alternatif pour un logement individuel type utilisant une chaudière d'appoint en fonction de la charge thermique. Une seconde étude conceptuelle est menée pour de petits collectifs d'habitation types dotés d'une infrastructure de chauffage collectif. Les deux concepts sont expliqués au moyen de textes et de schémas.

Le rapport offre également un résumé complet des facteurs à envisager dans l'évaluation préliminaire visant à déterminer la faisabilité de la cogénération pour un emplacement donné. Bien que chaque emplacement envisagé soit différent, de nombreux critères comme le prix du combustible, le prix de l'électricité, les coûts en immobilisations et les coûts d'exploitation font partie de l'évaluation de chaque projet. Le rapport présente un modèle économique simplifié que le promoteur peut utiliser pour estimer rapidement la viabilité économique d'un projet. Certains paramètres comme le coût du combustible, les économies d'électricité, les coûts en immobilisations, les coûts d'exploitation et les coûts d'entretien sont introduits dans ce modèle et permettent ainsi de connaître le délai de récupération. Une série de graphiques sont tracés à partir du modèle. Ils tiennent lieu d'analyses de sensibilité et de support visuel favorisant la détermination rapide du rendement économique.

Mis ensemble, les facteurs réglementaires, économiques et sociaux servent à encourager ou à décourager la cogénération. Ce rapport comporte une section documentaire sur la situation actuelle de la cogénération au Canada, laquelle met l'accent sur l'Ontario, province où il y a eu le plus d'activité dans ce domaine ces cinq dernières années. On y trouve des recommandations destinées à faciliter la mise en place de la cogénération dans un milieu qui lui est actuellement indifférent, voire hostile.

La mise en place de la cogénération au sein d'un collectif d'habitation de faible hauteur offre d'importantes économies en matière d'environnement et de coûts d'exploitation, mais pose également certaines difficultés. Les techniques de mise en place de la cogénération sont éprouvées et de nombreux projets de cogénération ont été réalisés au cours des dernières années dans les marchés résidentiel, commercial et institutionnel du déplacement des charges. La puissance des installations varie entre 15 et 800 kW. À noter que la majorité des petites installations ont été mises sur pied dans le cadre de projets de démonstration n'offrant que de maigres performances énergétiques. Les grands ensembles permettent toutefois de réaliser de très importantes économies de coûts d'exploitation et procurent des taux de rendement très intéressants.

Le rapport relève les difficultés que soulève la mise en place de la cogénération pour les collectifs d'habitation de petite taille, dont voici les principales :

Pour que la centrale de cogénération ait une taille raisonnable, il faut réunir un assez grand nombre de logements au moyen d'un système de chauffage collectif permettant de mettre en commun les charges de chauffage des locaux, de chauffage de l'eau et, éventuellement, de climatisation. Le coût d'une telle infrastructure est très important comparativement aux modes traditionnels d'alimentation en énergie et rend le taux de rendement global relativement peu intéressant par rapport aux investissements habituels.

Le transport de l'énergie électrique entre la centrale de cogénération et les logements peut se faire de plusieurs manières. Mais l'utilisation du réseau de distribution des services publics est la seule façon économique de le faire pour les ensembles se composant de nombreux logements. La génération en parallèle a fait ses preuves, et les problèmes qui se posent dans ce cas sont plutôt de nature réglementaire. La propriété de la centrale et du service de transmission ainsi que les options d'achat d'énergie doivent être envisagées attentivement à la lumière des règlements en vigueur. Au bout du compte, la valeur de l'électricité produite doit être suffisamment élevée par rapport au combustible utilisé pour permettre des économies de frais d'exploitation acceptables.

Les principaux obstacles à la mise en place de la cogénération pour un logement individuel sont les suivants :

Au Canada, il n'existe pas de petites installations de cogénération (de ± 5 kW) pouvant convenir à ce genre d'application.

Les charges thermique et électrique sont foncièrement incompatibles puisque les besoins peu diversifiés des logements individuels varient à chaque instant. Le stockage de l'énergie thermique et le recours au réseau public d'électricité en tant que «réserve d'énergie électrique» sont nécessaires pour exploiter la cogénération de manière optimale.

Un petit générateur de cette capacité requiert un coût en place élevé par unité de puissance de sortie. La nécessité de recourir au stockage thermique et à une source de chaleur d'appoint augmentent aussi le coût global de l'opération.

Le prix du gaz naturel utilisé par les résidents a tendance à être plus élevé que pour les charges plus importantes.

Une analyse préliminaire des coûts et du rendement économique de la cogénération indique que cette solution serait relativement peu intéressante du point de vue économique.

Ce rapport fait état de cinq emplacements étudiés dans l'optique de l'application éventuelle de la cogénération. Les installations de cogénération et les infrastructures de chauffage collectif dont il est ici question sont de nature conceptuelle et les coûts établis sont préliminaires. Aucun des emplacements ne se démarque des autres sur la base des critères d'investissement traditionnels. Néanmoins, les auteurs font les remarques suivantes :

La Bain Cooperative est l'ensemble le plus prometteur. Il se caractérise par une forte densité d'habitation et le chauffage y est déjà collectif. Toutefois, il devra être étudié en détail afin de déterminer ce qu'il en coûterait réellement pour transformer cette installation à la vapeur en système à eau chaude.

L'utilisation possible d'une machine à vapeur à l'emplacement Ouje Bougoumou devrait être envisagée.

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1.0 Introduction

The Healthy Housing Concept

We are witnessing a paradigm shift toward healthy housing and environmental efficiency. CMHC's "Guide to Healthy Housing" states that the five key issues underpinning the concept of future Healthy Housing are occupant health, energy efficiency, resource efficiency, environmental responsibility and affordability. Relevant extracts from CMHC's guide reinforce the concept:

- Occupant health is determined by indoor air quality, water quality, light, sound and radiation levels.
- Energy efficiency includes not only the operating efficiency of installed equipment, but the embodied energy inputs in utility power production and transmission, material manufacturing, transportation, maintenance, recycling, replacement and demolition of all related equipment. Building design heat loss, HVAC requirements, electrical consumption and the use of renewables remain key design factors.
- Resource efficiency involves an examination of resource use not only on the construction site, but at all stages in the extraction, processing and disposal of the product. Water utilization (both indoor and outdoor) are examined. Buildings must be designed for durability, ease of retrofit and longevity.
- Environmental responsibility includes all local and non-local effects of the housing project, such as emissions, combustion by-products, waste water and sewage, hazardous material disposal, housing density, land use and landfill.
- Affordability examines the trade-offs between lot size, floor space, first time cost and operating costs.

The focus of this study relates to the energy supply options for low rise residential housing units. In certain instances conventional energy supply designs may not be the optimum environmental and efficient options for a given area. A fundamental review of the design options may reveal that cogeneration, for instance, could offer substantial environmental and economic benefits to a community.

The benefits of decentralization are becoming increasing attractive as the megaproject mentality for electrical energy supply has begun to lose its lustre. Local control of energy supply resulting in minimum waste and maximum efficiency also results in increased cost effectiveness and lower environmental impact. It is visionary to depart from conventional designs to minimize energy waste and reflect the uncertainty of future energy supply. Envelope, water, and electric systems efficiency upgrades are consistent with this goal by making the alternate energy supply solutions more manageable. Lower energy consumption profiles due to increased efficiencies and the potential use of small cogeneration systems are certainly a step in the right direction.

Cogeneration

The majority of this report centres around the use of cogeneration as an alternate means of energy supply to housing community. This method of electrical and thermal power production can offer substantial environmental and economic benefits over the conventional means of energy supply.

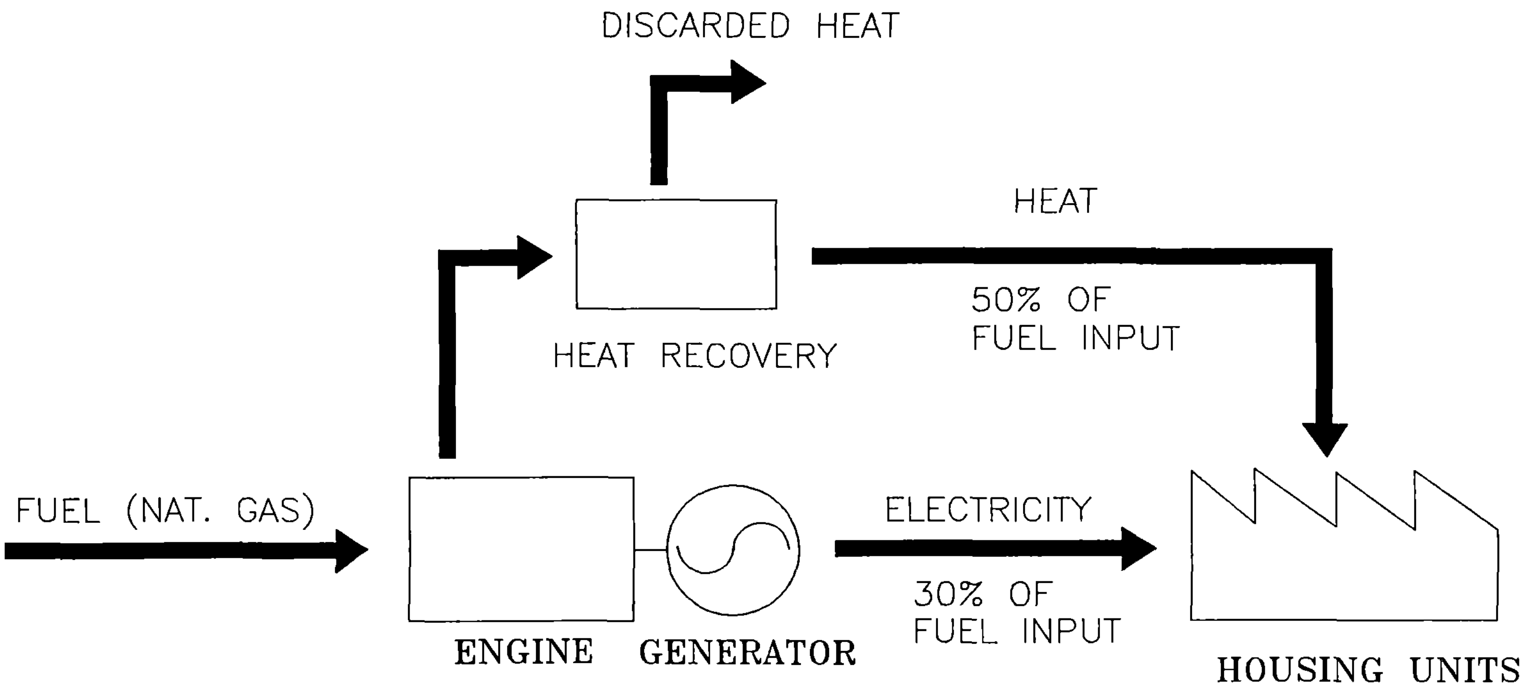
Simply defined, cogeneration is the simultaneous production of heat and electrical power from a single process and fuel source. A typical example is an engine driving a generator which produces electrical power. Heat normally discarded to the environment is recovered in a usable form such as hot water or steam (see Figure 1.1). Overall system efficiencies of 85% are achievable.

Cogeneration is an old concept. At the turn of the century, much of the nation's electrical power was produced on site in a cogeneration mode. However, with the development of reliable and cheap central power plants and distribution networks much of the electrical power generation was shifted to central utilities.

Cogeneration has again attracted much interest in recent years as a means of lowering a facility's utility costs. In regions of high electricity price relative to natural gas price, cogeneration presents a cost effective alternative to meeting both electrical and thermal loads. Under such scenarios, the value of the electricity produced and the heat recovered exceed the additional fuel and operating costs of the cogeneration plant which yield attractive bottom line savings.

Benefits are not limited to the host site. For example, a properly designed cogeneration plant can contribute to global carbon dioxide, nitrous oxide and sulphur oxide emission reductions when compared to the conventional approach of utility power generation and on site thermal generation. This is due to the overall increase in fuel utilization efficiency and resulting net fuel consumption reduction produced by cogeneration. In addition, absorption chillers can be used to produce chilled water using heat as a driving force. These chillers operate on a lithium bromide solution and do not use CFC-based refrigerants, thus mitigating the effects on upper atmospheric ozone levels. The reader is referred to Section 3.4 for further details associated with environmental benefits offered by cogeneration.

The economic feasibility of cogeneration is largely determined by a few key factors such as fuel cost, electricity cost and plant capital cost. Larger cogeneration plants will benefit from economies of scale and will tend to have lower installed cost per unit of power output (ie $/kW) or capacity cost. Smaller cogeneration plants tend to have higher capacity cost which often is an economic barrier to their implementation. However, a holistic approach to our housing needs, under the emerging concept of "Healthy Housing" demands a closer look at the environmental and social factors of energy demand and supply. Externalities and longer-term thinking can very well justify a



Project	Drawing Title	Drawing No.
CHMC Community Energy Systems	COGENERATION ENERGY SUPPLY	Fig. 1.1
ALCO Engineers Inc.		

cogeneration project which does not meet simpler economic criteria.

Scope of This Study

This study examines the technical, economic and social merits of cogeneration including alternative means of improving energy efficiency. The existing load profiles of generic low-rise housing are presented, and the effects of potential improvements on energy efficiency are outlined. The viability of cogeneration is examined in light of the resulting load profiles. This approach supports the philosophy that any energy wasted should be minimized prior to the implementation of cogeneration technology.

The second broad area of study comprises a number of cogeneration conceptual designs using new or renovated housing sites which exhibit suitable characteristics for a cogeneration application.

In summary, this study includes the following:

- a characterization of typical low rise housing projects including population density, housing category, and energy loading;
- an examination of energy efficiency retrofits to lower present energy consumption;
- typical design concepts for cogeneration installations for existing and new low-rise housing including the interface with existing heating and electrical systems;
- a discussion of the economic merits of cogeneration for generic sites, i.e. typical capital costs for equipment supply, installation, engineering and the associated savings in energy costs;
- a checklist of economic and technical guidelines for use in determining the suitability of cogeneration installations in existing or planned housing projects;
- five case studies of existing low rise housing facilities in Canada where cogeneration could be applied as a demonstration project

Generic low rise applications may include cooperatives, government-sponsored housing and senior citizens' residences. The generic low rise residential housing applications examined include not only suburban and urban areas, but also rural locations where oil is the only fuel option. It has been our experience that cogeneration projects are only competitive against utility-purchased power when natural gas fuel is available. Nevertheless, in remote areas, where no utility power is available, oil-fired cogeneration may be economically feasible.

2.0 Low Rise Housing Energy Characteristics

2.1 Introduction

The purpose of this chapter is to define the electrical and thermal energy consumption profiles for typical low-rise housing applications. Once existing loads have been defined, further study can be conducted to determine firstly, how consumption may be reduced by means of energy efficiency enhancement measures, and secondly, how much energy could be displaced through the installation of a suitably-sized cogeneration system.

2.2 Generic Configurations

Three generic housing configurations have been defined for the purposes of this study:

Single Unit Dwelling
Low Density Dwelling
High Density Dwelling

Table 2.1 outlines several key characteristics of each configuration. At Appendix A-1 is a more detailed description of the building envelope characteristics.

2.3 Typical Energy Load Profiles

Four energy load types have been quantified in this study:

Thermal (Space Heating)
Thermal (Domestic Hot Water)
Electrical (Lights and Appliances)
Electrical (Space Cooling)

Energy loads have been modelled on both a monthly and an hourly basis for the three generic housing configurations based upon the National Building Code. This provides a seasonal indication of average, maximum and minimum requirements for sizing a cogeneration plant, as well as a daily indication useful in determining the operating cycle of cogeneration system. The hourly profiles were developed for both a typical winter day and a typical summer day.

In addition, reduced energy load profiles have been developed for the above cases based upon an assessment of what may be achieved through the use of efficiency enhancement measures other than cogeneration (Energy Upgrade option). These measures are discussed further in Chapter 4 of this study.

Ottawa was selected as a base case location. Factors have been developed to adjust the base case to other Canadian sites. These are outlined in Appendix A-2. In summary, the following 18 base case profiles have been developed:

- Typical Monthly Energy Consumption
  - Single Unit Dwelling
    - National Building Code — Figure 2.1
    - Energy Upgrade — Figure 2.2
  - Low Density Dwelling
    - National Building Code — Figure 2.3
    - Energy Upgrade — Figure 2.4
  - High Density Dwelling
    - National Building Code — Figure 2.5
    - Energy Upgrade — Figure 2.6

- Typical Hourly Energy Consumption in Summer
  - Single Unit Dwelling
    - National Building Code — Figure 2.7
    - Energy Upgrade — Figure 2.8
  - Low Density Dwelling
    - National Building Code — Figure 2.9
    - Energy Upgrade — Figure 2.10
  - High Density Dwelling
    - without Energy Upgrade — Figure 2.11
    - Energy Upgrade — Figure 2.12

- Typical Hourly Energy Consumption in Winter
  - Single Unit Dwelling
    - National Building Code — Figure 2.13
    - Energy Upgrade — Figure 2.14
  - Low Density Dwelling
    - National Building Code — Figure 2.15
    - Energy Upgrade — Figure 2.16
  - High Density Dwelling
    - National Building Code — Figure 2.17
    - Energy Upgrade — Figure 2.18

In the following section, the approach taken to develop these graphs are explained in greater detail

2.3.1 Thermal (Space Heating)

2.3.1.1 Monthly

The monthly space heating energy for the Single Unit Dwelling and the High Density Dwelling were modelled on the Enerpass hour-by-hour building energy simulation tool. The Low Density Dwelling values were interpolated for use in developing the space heating profile.

The Enerpass program allows the simulation of the energy consumption requirements for space heating, cooling and domestic hot water within a wide range of operating conditions and building types provided they can be modelled in a maximum of four zones. Modelling criteria include building data, thermal capacity data, ventilation supply data, water vapour data, heating system data, fuel type data, as well as costing. Calculations are made on an hourly basis from measured data rather than relying upon monthly averaging equations.

Enerpass will display monthly, as well as, hour by hour totals of solar, internal and lighting heat gain, energy required to heat and cool the building, and energy to heat domestic hot water.

Table 2.2 presents the Space Heating Load and the Annual Energy Consumption for each dwelling type in the base case location of Ottawa. At Appendix A-2 are multiplication factors to be applied to the figures in Table 2.2 to determine the corresponding figures for dwellings located in other Canadian cities. The values for Ottawa, Winnipeg, Vancouver and Toronto were modelled on Enerpass. The remaining cities were modelled on Hot2000 and were correlated with the cities run on Enerpass.

2.3.1.2 Hourly

The formula used to quantify hourly space heating load was as follows:

$$S = L - G_i - NG_s$$

$S =$ Space Heating Load
$L =$ Building Gross Heating Load
$G_i =$ Internal Gains
$NG_s =$ Net Usable Solar Gains

The average monthly figures as developed on the Enerpass Energy Modelling program were used as the basis to choose typical days (i.e. days which had space heating load requirements similar to those for the average monthly value) from which typical hourly load figures were gathered. Curve fitting was employed to model the effect of solar and internal gains loading throughout the day.

2.3.2 Thermal (Domestic Hot Water)

2.3.2.1 Monthly

Table 2.3 describes the annual average domestic hot water load for each building type and profile option. The difference in domestic hot water loads between each dwelling type arises from family population variations.

In the case of the Energy Upgrade option, water-saving taps and showers consistent with water conservation practices were assumed. Field experience and references (CMHC Healthy House Competition Guide and Technical Requirements) suggest that at least 1/3 of the power consumption can be reduced with such careful fixture selections. As such, the Energy Upgrade option was considered to consume only 2/3 of the National Building Code standard dwelling for domestic hot water consumption.

The values given in Table 2.3 are annual averages. The monthly average consumptions are higher in winter and lower in summer. The percentage of that average which is consumed in the minimum and maximum months of January and July are as follows:

	% OF ANNUAL AVERAGE	
	JANUARY	JULY
Domestic Hot Water	118%	82%

These values were derived from monitored energy use in a multi-unit building (Reference CMHC Cogeneration Paper). Energy use in each unit of the High Density Dwelling Unit includes a proportionate share of communal hot water usage attributed to laundry, etc.

2.3.2.2 Hourly

The profile of the curve which represents the daily domestic hot water consumption of any single household would tend to be very erratic. For the purposes of this study which seeks to model developments of multiple dwelling units, however, the effect of peaks and valleys would be minimized due to the diversity of users within a cluster of households.

For domestic hot water, diversification implies that due to the increased number of users on a system, the effect of varying schedules of use by different household types (variables being: social/economic standing, work schedule i.e. shift workers, family structure, working parents, etc.) would tend to ensure that a rate of consumption is established which is relatively constant throughout the day.

For the diversified domestic hot water profiles we have established 5 different user profiles. Appendix A-3 indicates the weighted averages for each. The values of each hour are multiplied by the weightings to provide the diversified domestic hot water load profile shown in the graphs.

2.3.3 Electrical

2.3.3.1 Monthly

Table 2.4 describes the annual average electrical light and appliance load for each building type and profile option. The difference in electrical loads between each dwelling type arises from family population variations.

In the case of the Energy Upgrade option, more efficient appliances, and high-efficiency fluorescents on fixed light fixtures were assumed. Field experience and references (CMHC Healthy House Competition Guide and Technical Requirements) suggest that at least 1/3 of the power consumption can be reduced with such careful fixture selections. As such, the Energy Upgrade option was considered to consume only 2/3 of the National Building Code standard dwelling for electricity consumption.

The values given in Table 2.4 are annual averages. The monthly average consumptions are higher in winter and lower in summer. The percentage of that average which is consumed in the minimum and maximum months of January and July are as follows:

	% OF ANNUAL AVERAGE	
	JANUARY	JULY
Lights/Appliances	111%	89%

These values were derived from monitored energy use in a multi-unit building. Energy use in each unit of the High Density Dwelling Unit includes a proportionate share of communal power usage attributed to hall space, parking lighting, etc.

2.3.3.2 Hourly

The profile of the curve which represents the daily electrical consumption due to lights and appliances of any single household would tend to be very erratic. For the purposes of this study which seeks to model developments of multiple dwelling units, however, the effect of peaks and valleys would be minimized due to the diversity of users within a cluster of households.

The electrical loads were derived from a monitored multi-unit building. The hour by hour profile was found to approximate a sinusoidal curve.

2.3.3.3 Space Cooling

For interest's sake, an estimate of electrical space cooling loads was conducted for the three housing configurations, based on the Ottawa region. We would expect a great deal of variability in space cooling load from year to year, from area to area, and within buildings of the same configurations due to differing occupant life-styles and the availability of central vs decentralized cooling systems.

We would expect the recovered heat from a cogeneration system to service the thermal loads only (i.e. space heating and DHW) in low-rise residential applications. Absorption chilling loads add cost and complexity to the system, and are typically not very cost effective when operated only during summer months.

2.4 Summary

Table 2.5 summarizes those loads for generic low rise residential sites relevant to the implementation of a cogeneration system.

Table 2.1

CHARACTERISTICS OF GENERIC LOW-RISE HOUSING CONFIGURATIONS

Single Unit Dwelling

- Small detached residence with one storey above grade and a basement
- Dwellings contain 3 bedrooms
- Occupancy of 4 persons (e.g. 2 adults, 2 children)
- Floor Area of a single dwelling unit is 250 m^2 (including basement)

Low Density Dwelling

- Townhouse concept with grade access to all units
- Dwellings contain 2 bedrooms
- Occupancy of 3 persons (e.g. 2 adults, 1 child)
- Floor Area of a single dwelling unit is 180 m^2 (including basement)

High Density Dwelling

- Residences are part of a small apartment building
- Dwellings contain 2 bedrooms
- Occupancy of 3 persons (e.g. 2 adults, 1 child)
- Floor Area of a single dwelling unit is 80 m^2

Table 2.2

SPACE HEATING CHARACTERISTICS BY DWELLING CONFIGURATION

BUILDING OPTION	PEAK HEAT LOAD (kW)	ANNUAL ENERGY CONSUMPTION (kWh)
NATIONAL BUILDING CODE		
Single	10.0	17150
Low Density	8.0	-
High density	7.2	11950
ENERGY UPGRADE		
Single	5.0	7200
Low Density	3.0	-
High density	2.5	3100

Table 2.3

DOMESTIC HOT WATER CHARACTERISTICS BY DWELLING CONFIGURATION

BUILDING OPTION	ANNUAL AVERAGE DOMESTIC HOT WATER (kWh/day)
NATIONAL BUILDING CODE	
Single	13
Low Density	11
High density	11
ENERGY UPGRADE	
Single	8.7
Low Density	7.3
High density	7.3

Table 2.4

ELECTRICAL LOAD CHARACTERISTICS BY DWELLING CONFIGURATION

BUILDING OPTION	ANNUAL AVERAGE LIGHTS/APPLIANCES (kWh/day)
NATIONAL BUILDING CODE	
Single	20
Low Density	15
High density	15
ENERGY UPGRADE	
Single	13.3
Low Density	10
High density	10

Table 2.5 Summary of Site Loads

Generic Site Characteristics

Site Build Standard	Dwelling type	Number of units	Area (ha)	Density (Units/ha)	Unit Peak Heating Load (kW)	Unit Daily DHW Load (kWh)	Unit Daily Electrical Load (kWh)	Total Peak Heating Load (kW)	Heating Load Density (kW/ha)	Total Average Electrical Load (kW)
National Building Code	Single	100	15	7	10.0	13	20	1,000	67	83
Energy Upgrade	Single	100	15	7	5.0	9	13	500	33	56
National Building Code	Low density	100	2	50	8.0	11	15	800	400	63
Energy Upgrade	Low density	100	2	50	3.0	7	10	300	150	42
National Building Code	High density	100	1	100	7.2	11	15	720	720	63
Energy Upgrade	High density	100	1	100	2.5	7	10	250	250	42

Figure 2.1
Monthly Energy Profile
Single Unit Dwelling
National Building Code

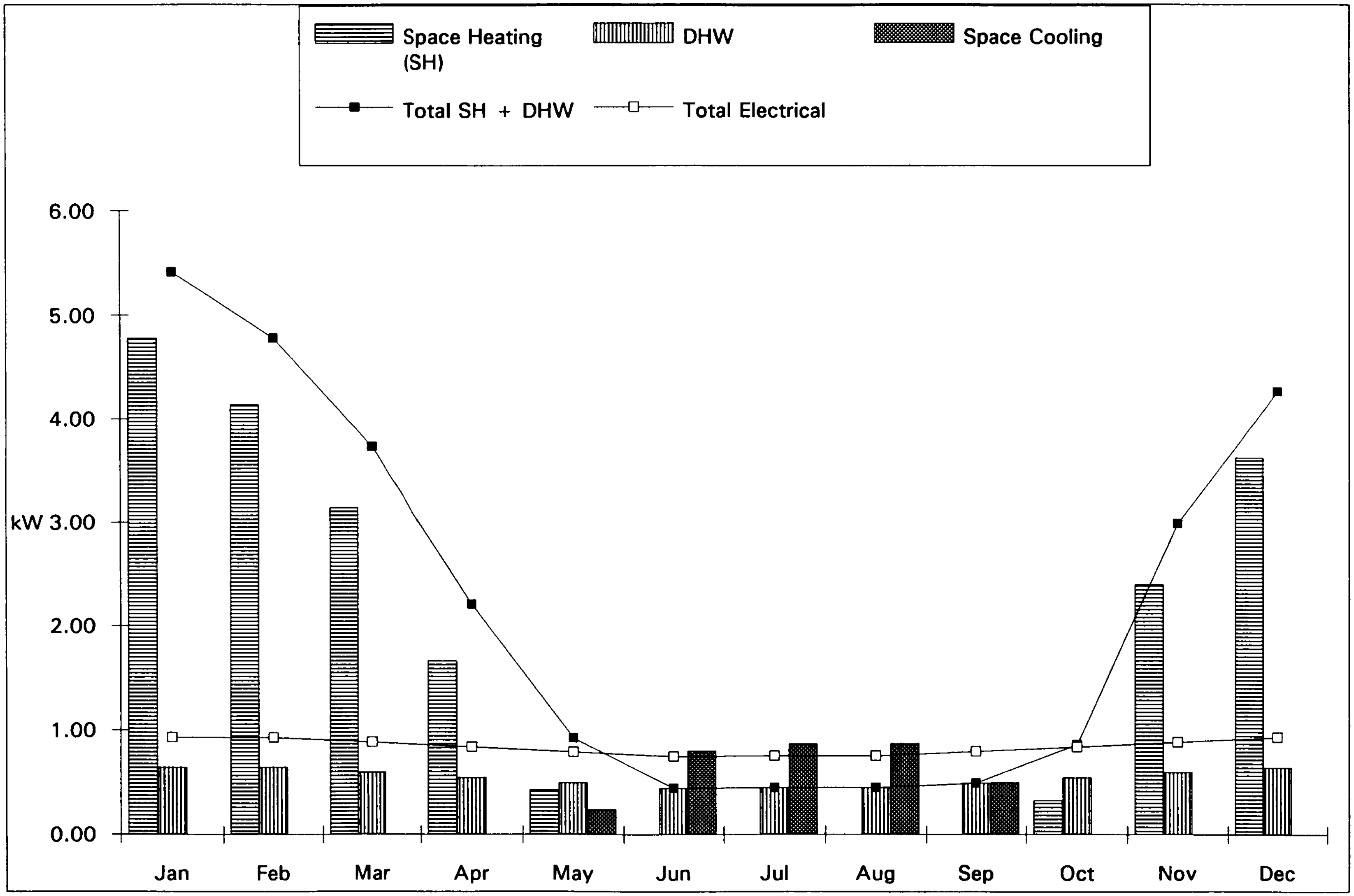


Figure 2.2
Monthly Energy Profile
Single Unit Dwelling
Energy Upgrade

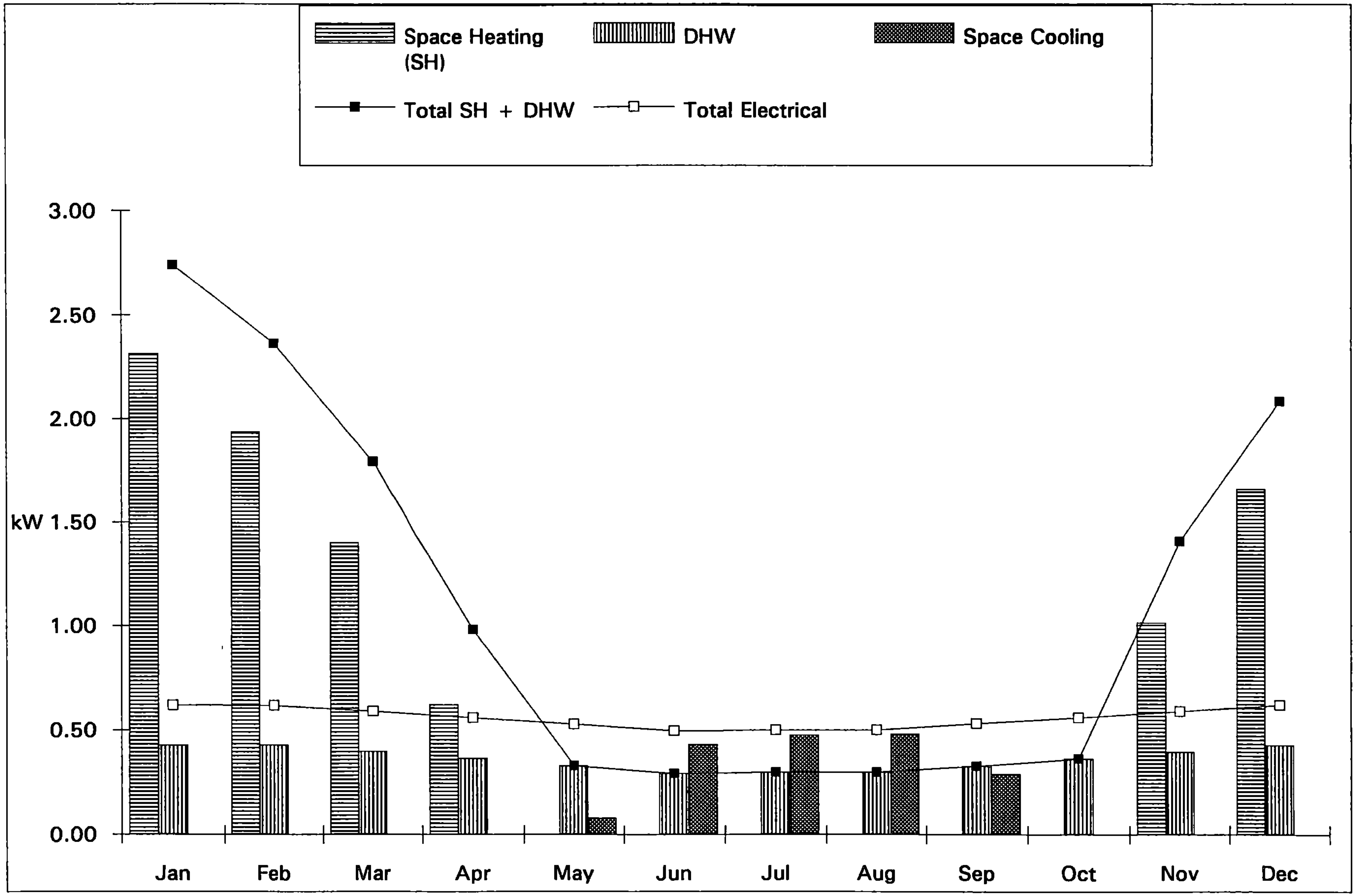


Figure 2.3
Monthly Energy Profile
Low Density Dwelling
National Building Code

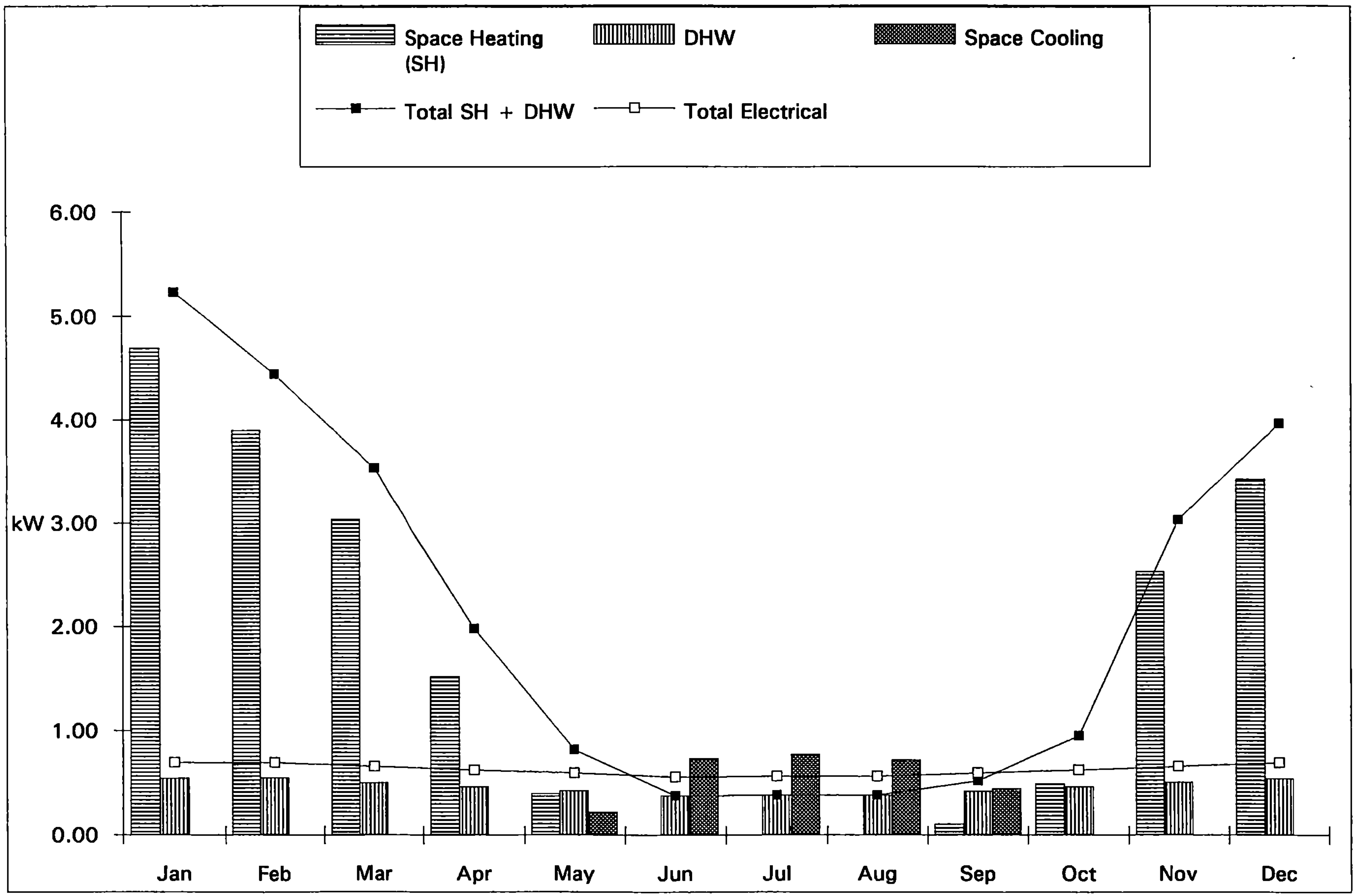


Figure 2.4
Monthly Energy Profile
Low Density Dwelling
Energy Upgrade

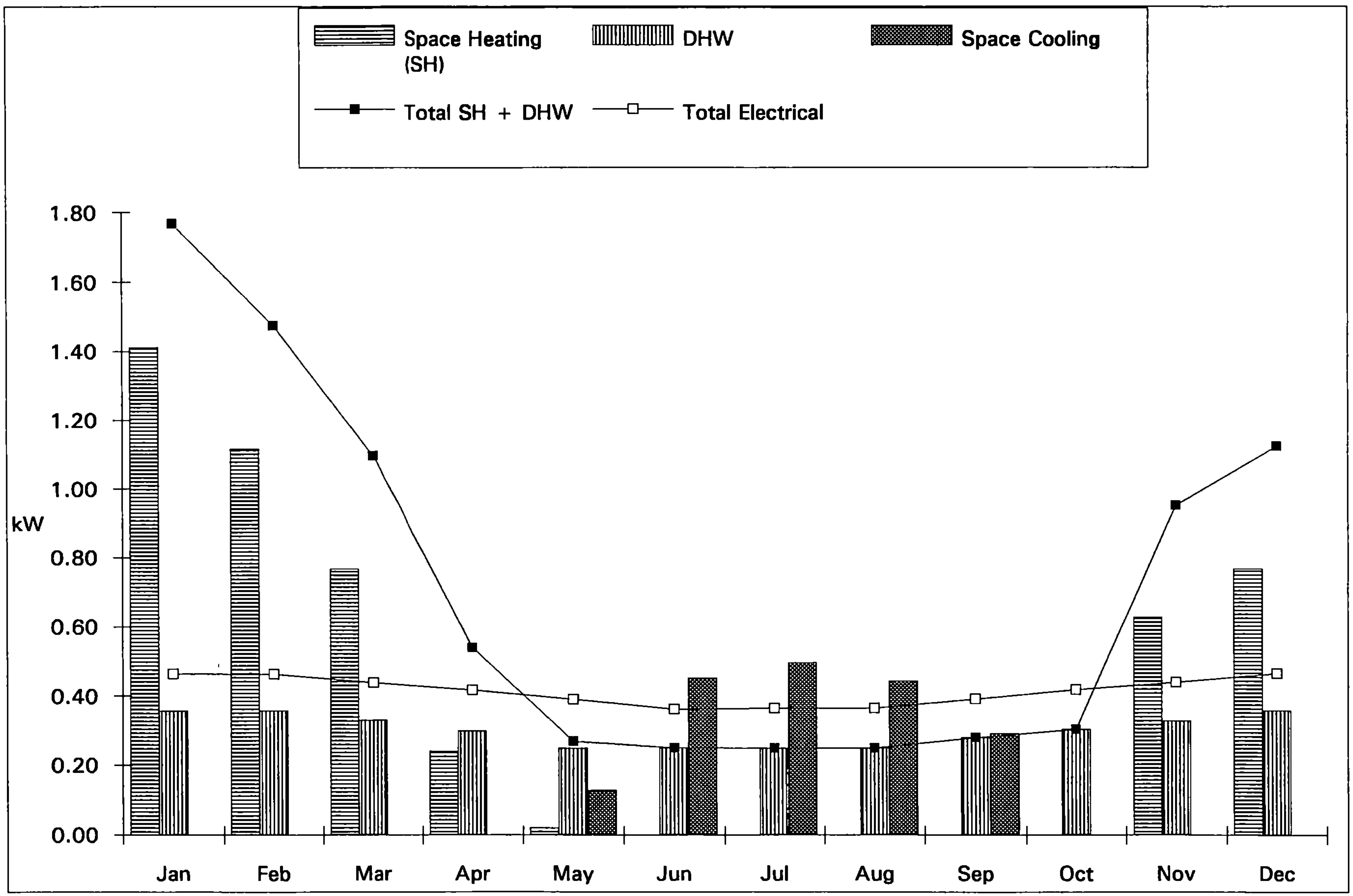


Figure 2.5
Monthly Energy Profile
High Density Dwelling
National Building Code

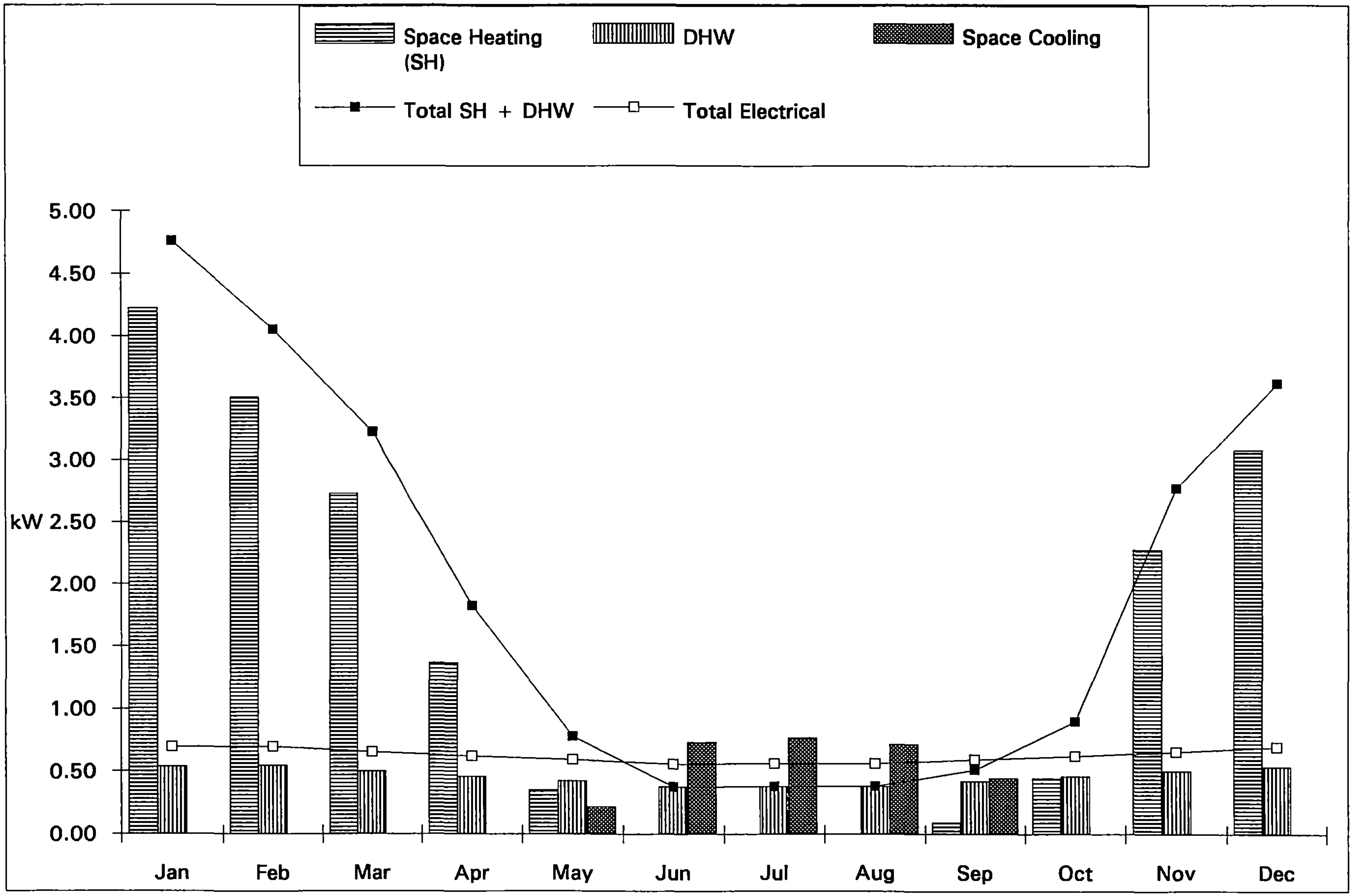


Figure 2.6
Monthly Energy Profile
High Density Dwelling
Energy Upgrade

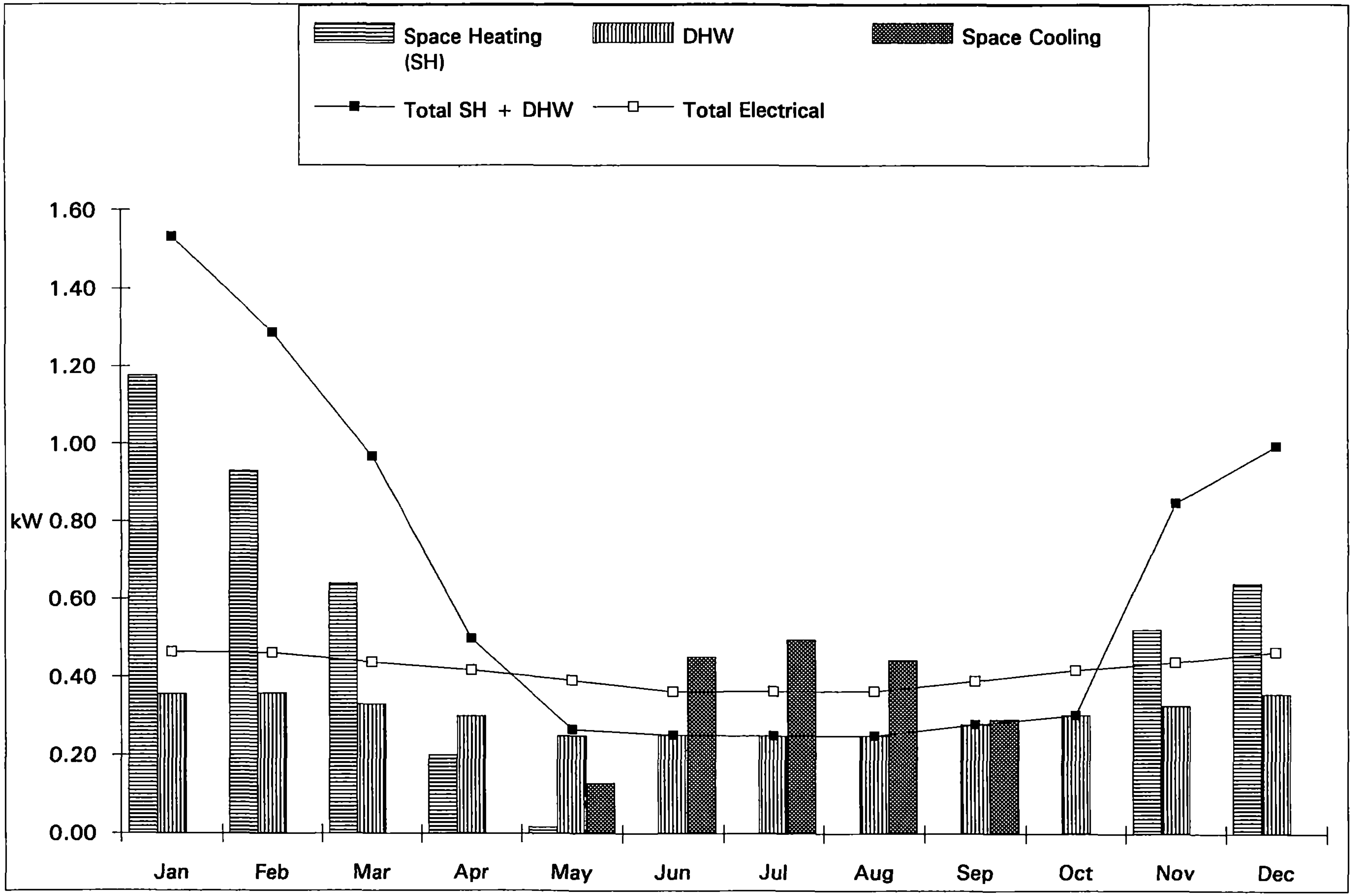


Figure 2.7
Hourly Energy Profile (Summer)
Single Unit Dwelling
National Building Code

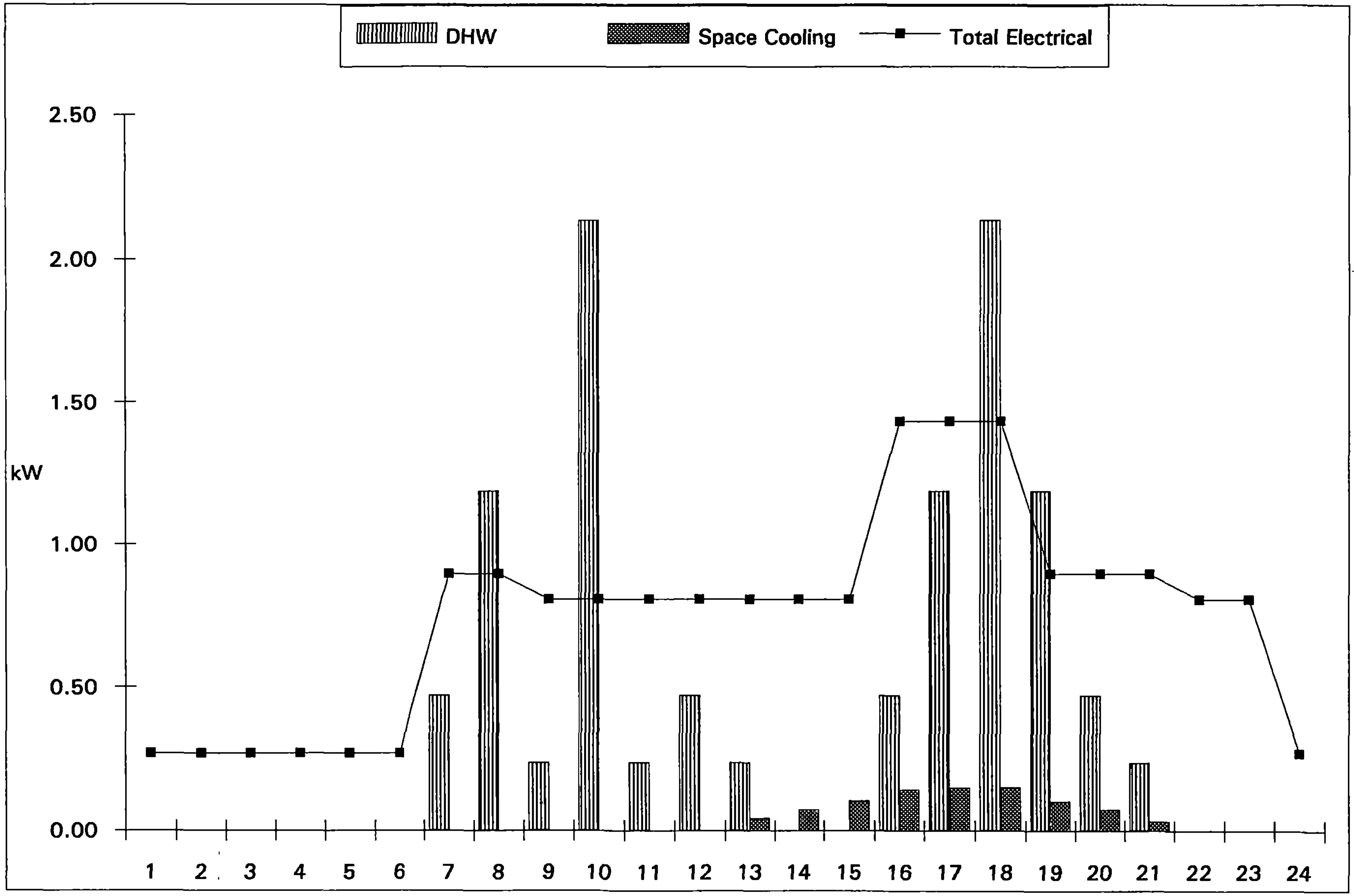


Figure 2.8
Hourly Energy Profile (Summer)
Single Unit Dwelling
Energy Upgrade

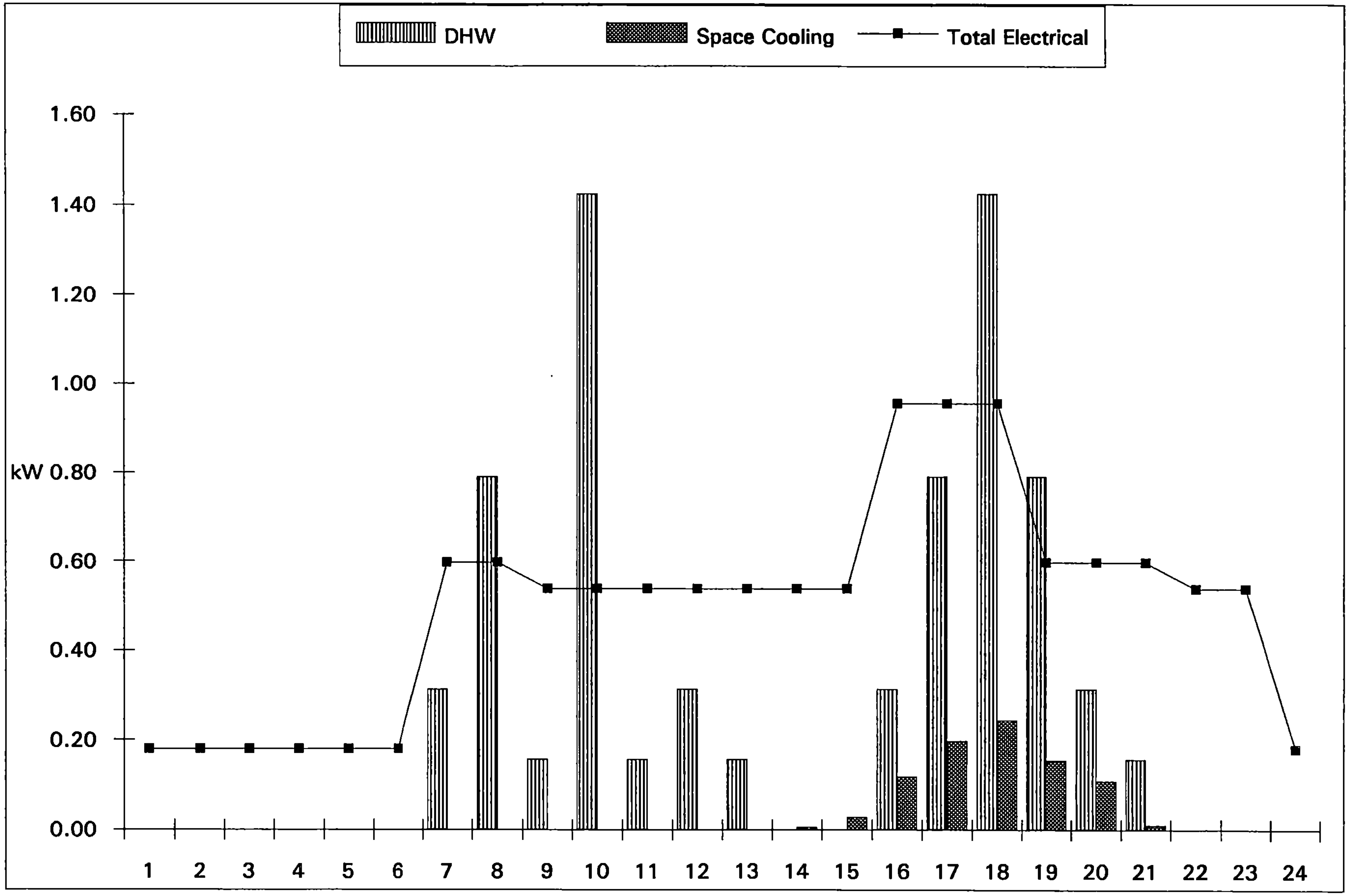


Figure 2.9
Hourly Energy Profile (Summer)
Low Density Dwelling
National Building Code

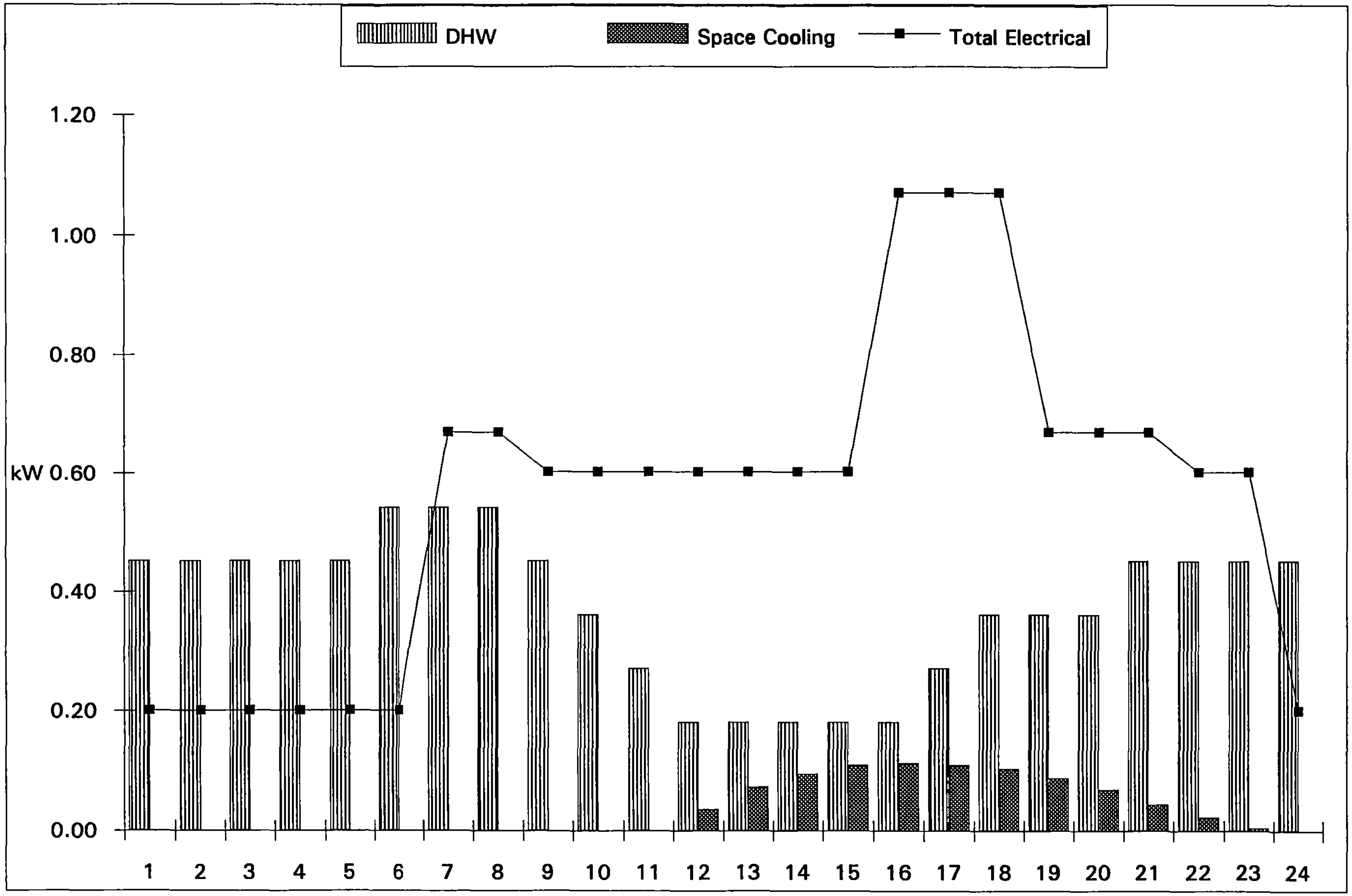


Figure 2.10
Hourly Energy Profile (Summer)
Low Density Dwelling
Energy Upgrade

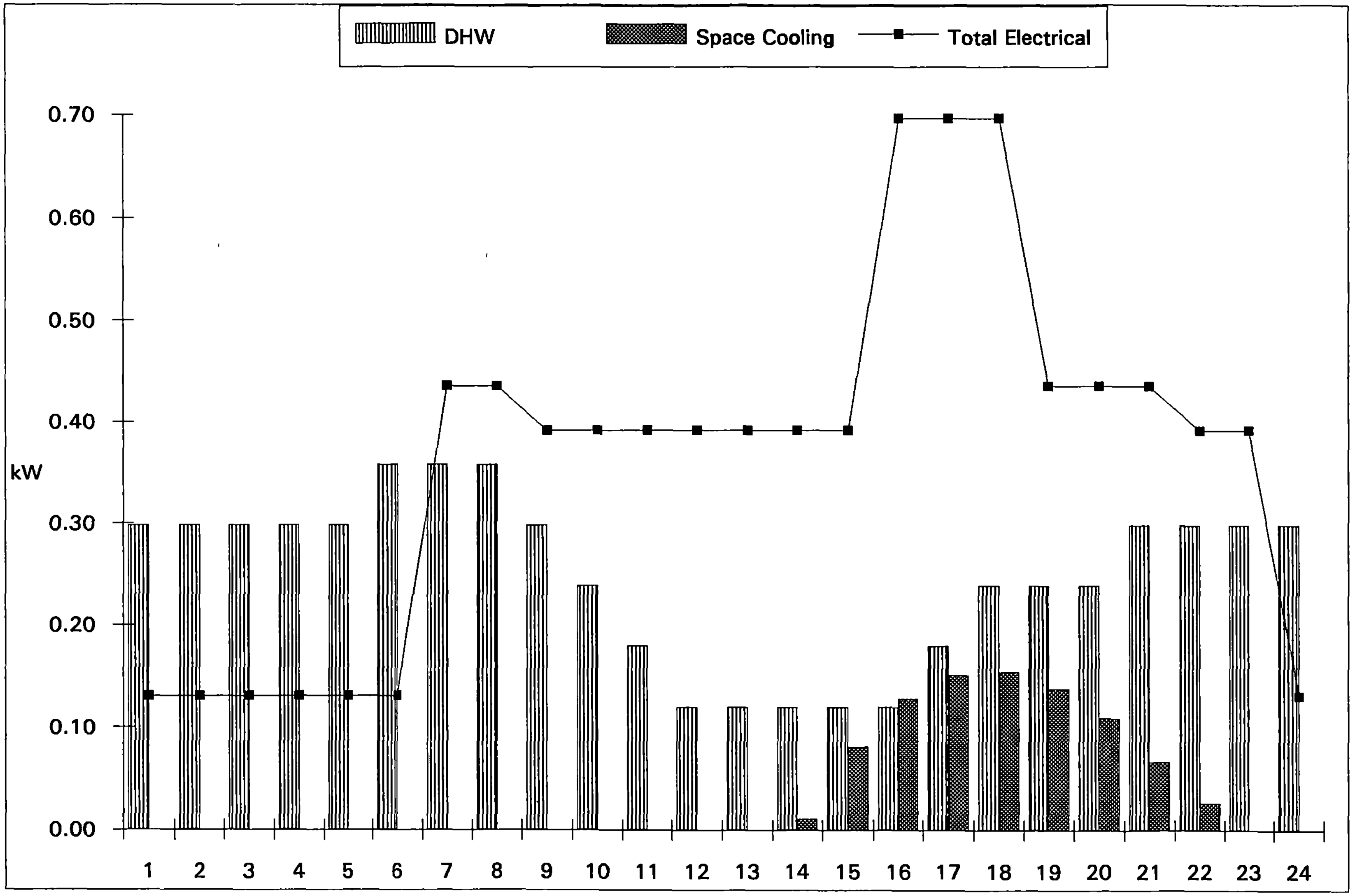


Figure 2.11
Hourly Energy Profile (Summer)
High Density Dwelling
National Building Code

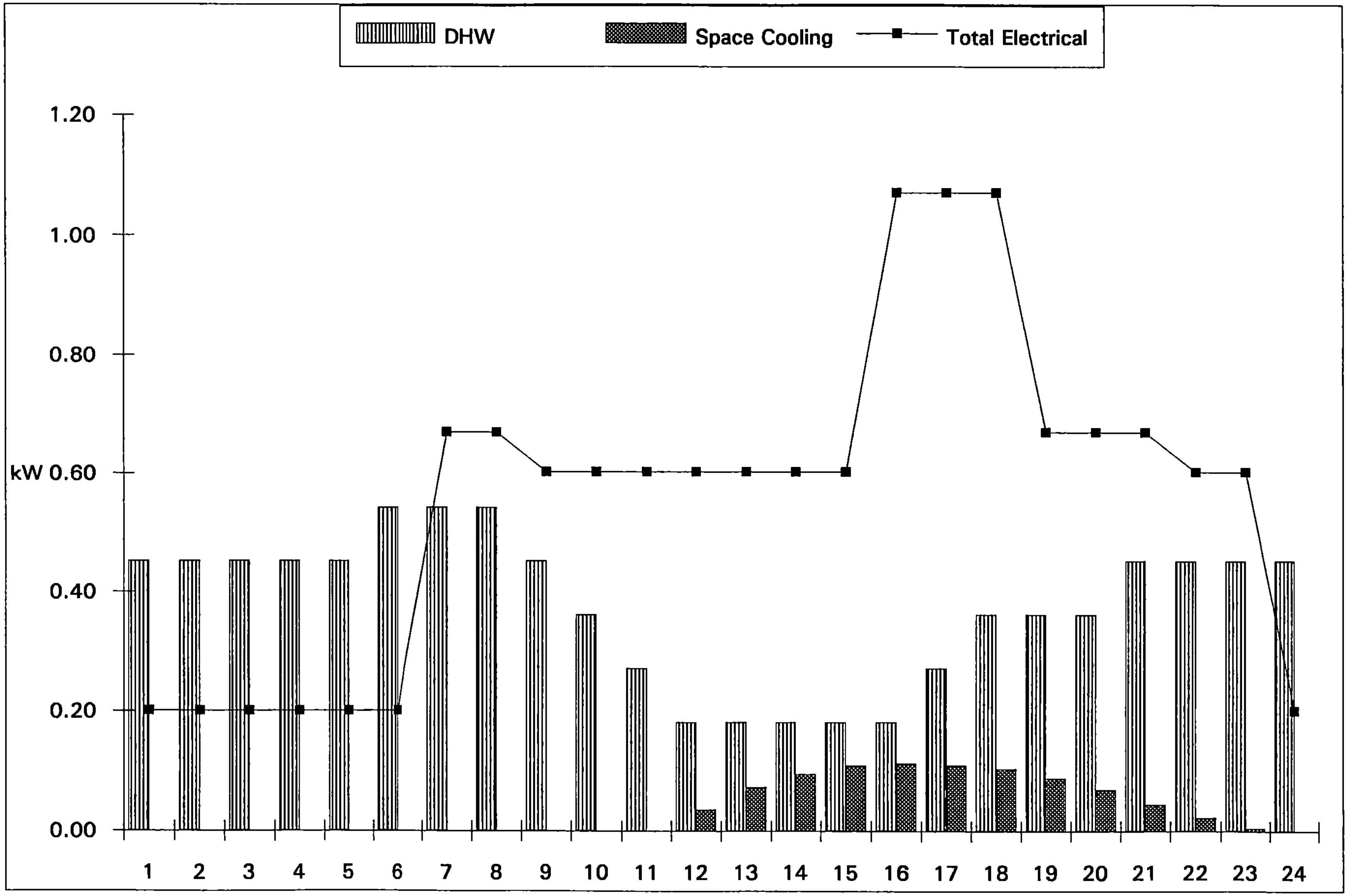


Figure 2.12
Hourly Energy Profile (Summer)
High Density Dwelling
Energy Upgrade

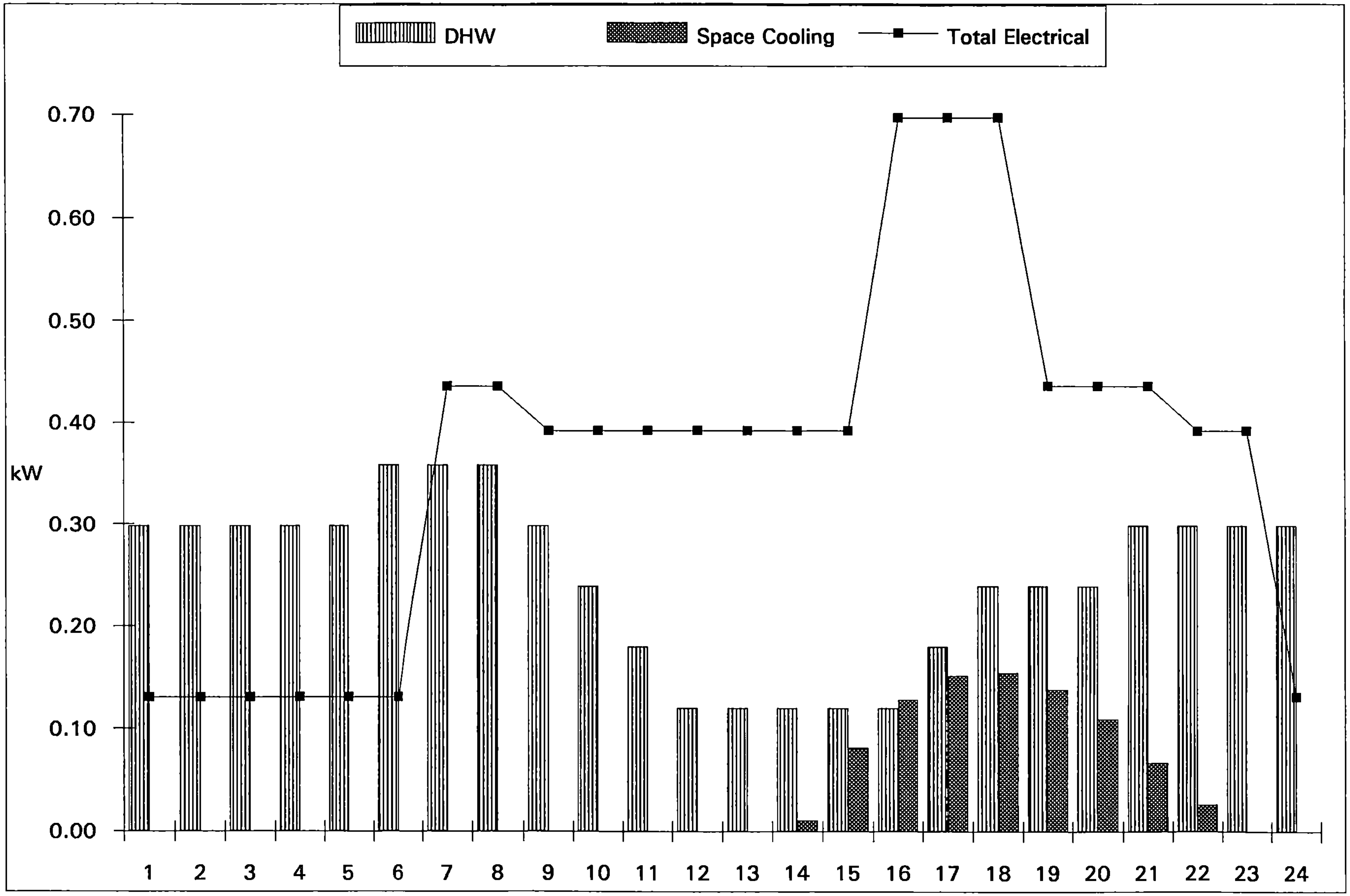


Figure 2.13
Hourly Energy Profile (Winter)
Single Unit Dwelling
National Building Code

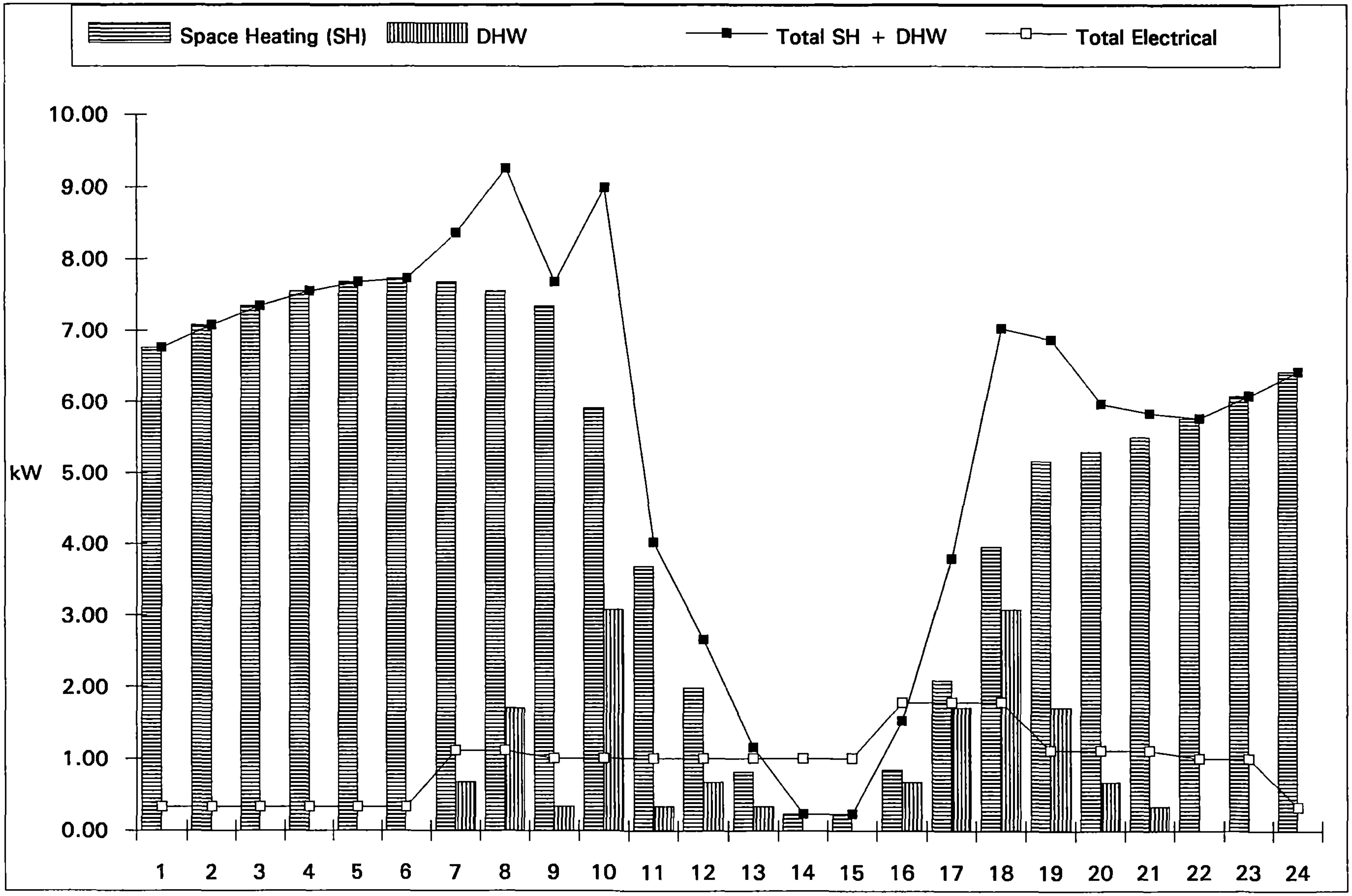


Figure 2.14
Hourly Energy Profile (Winter)
Single Unit Dwelling
Energy Upgrade

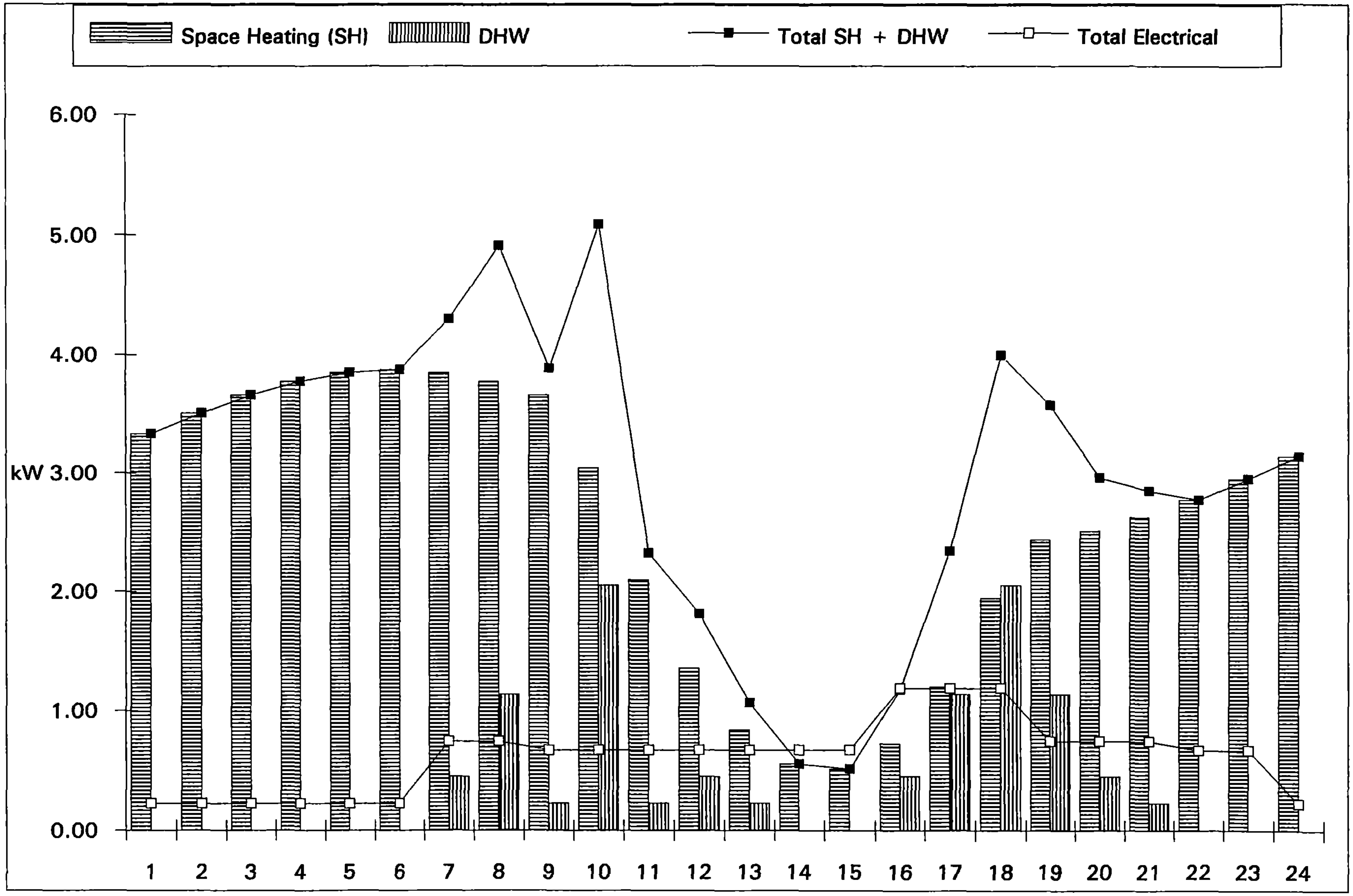


Figure 2.15
Hourly Energy Profile (Winter)
Low Density Dwelling
National Building Code

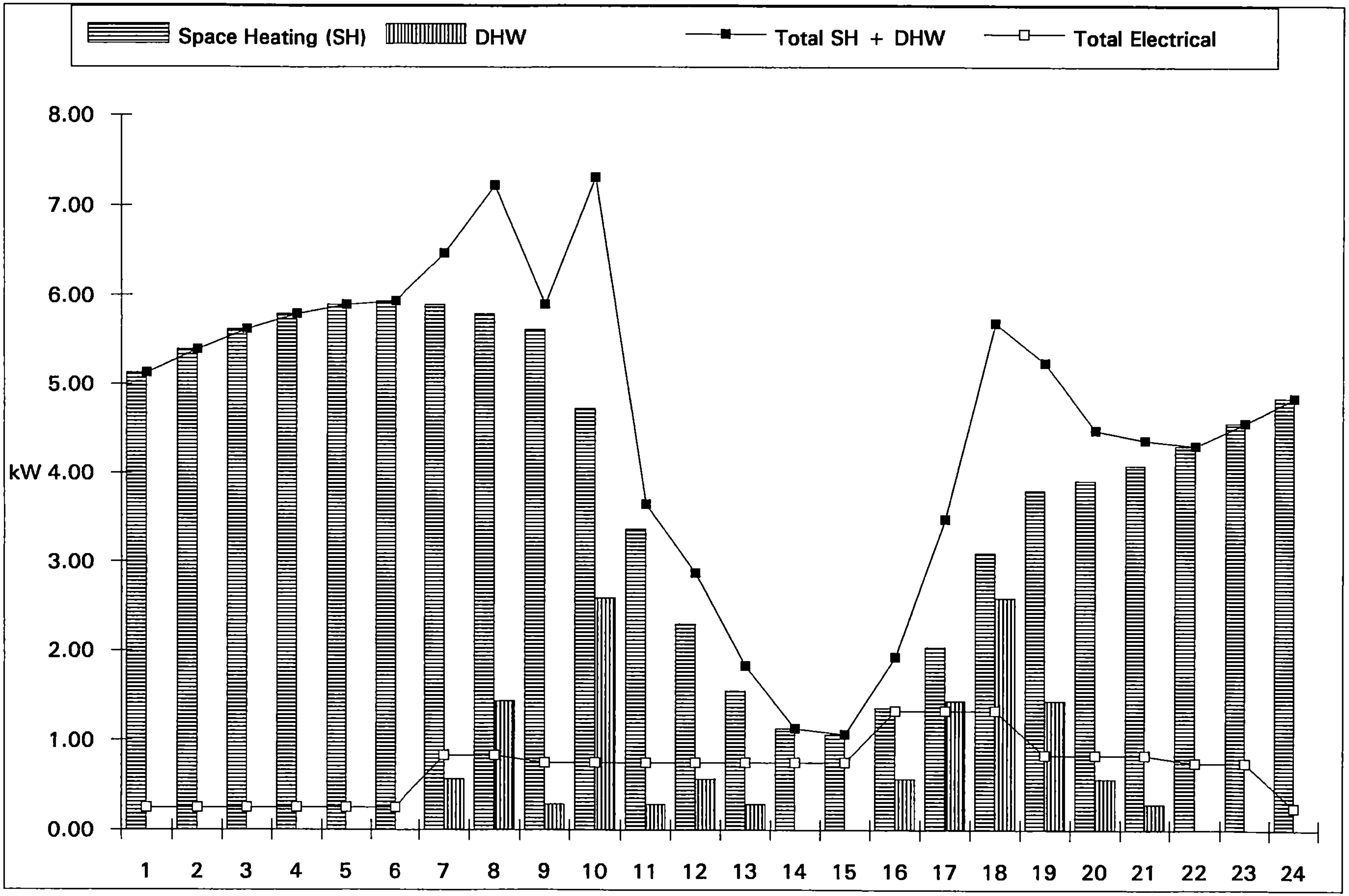


Figure 2.16
Hourly Energy Profile (Winter)
Low Density Dwelling
Energy Upgrade

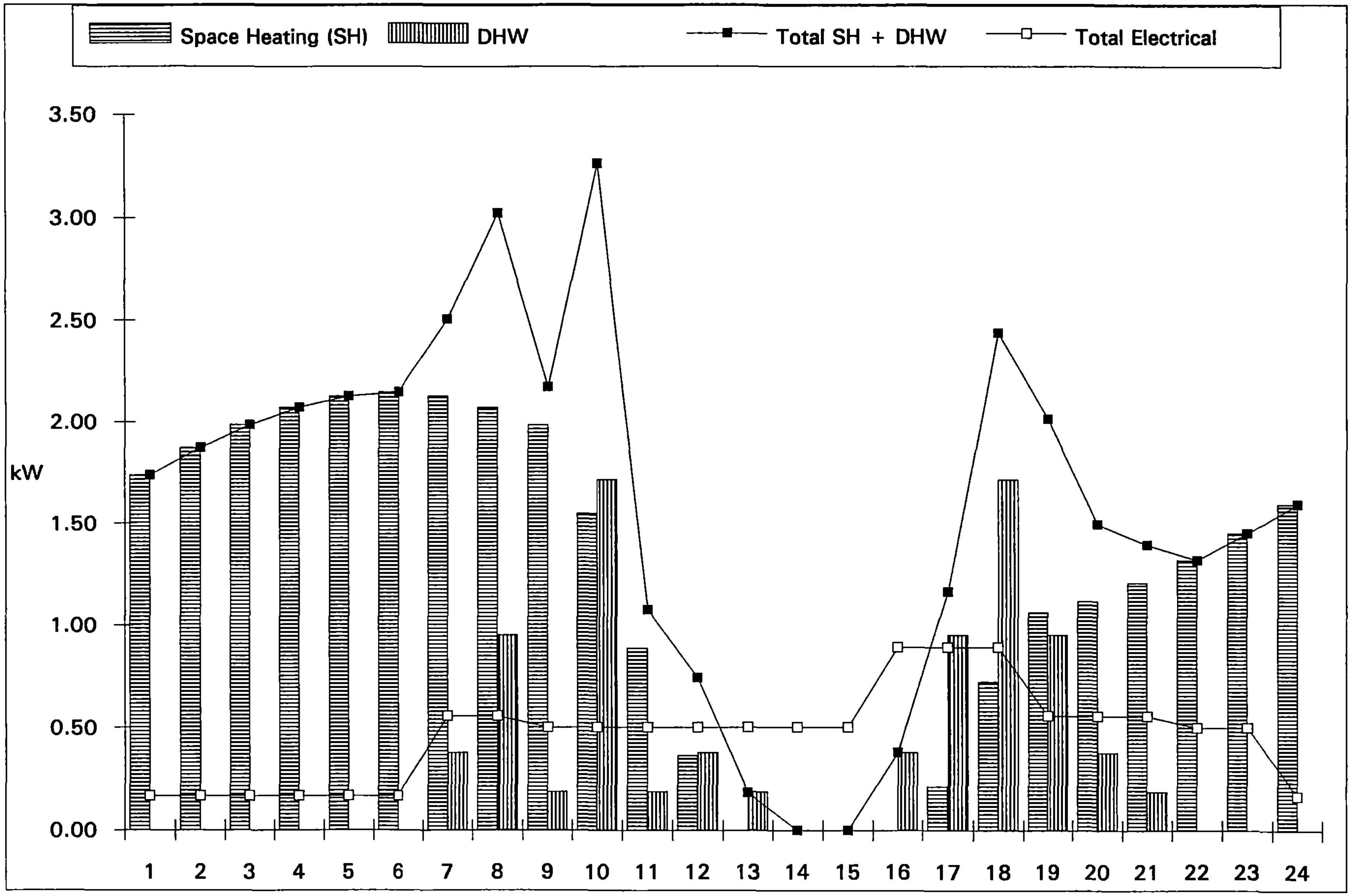


Figure 2.17
Hourly Energy Profile (Winter)
High Density Dwelling
National Building Code

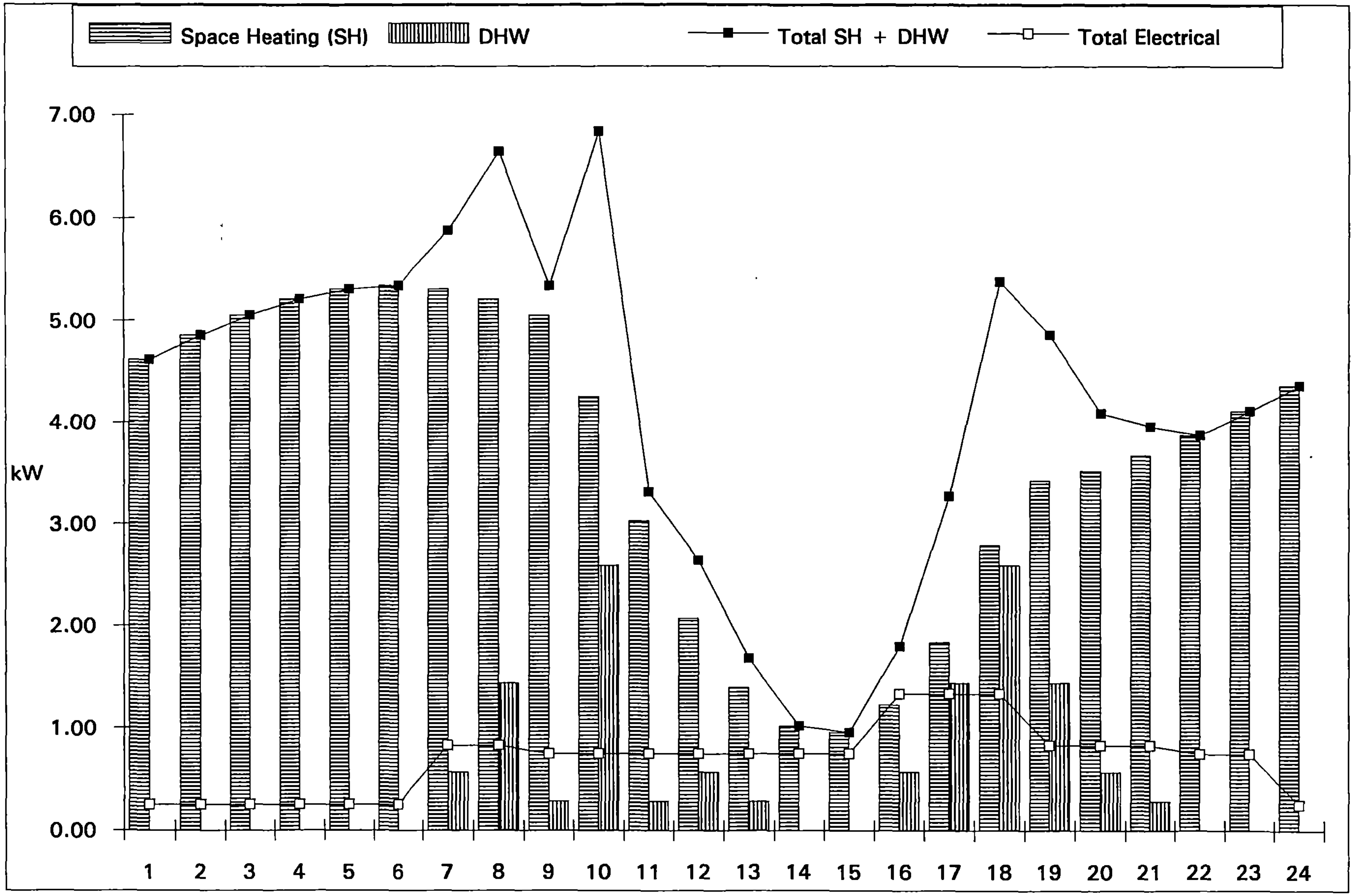
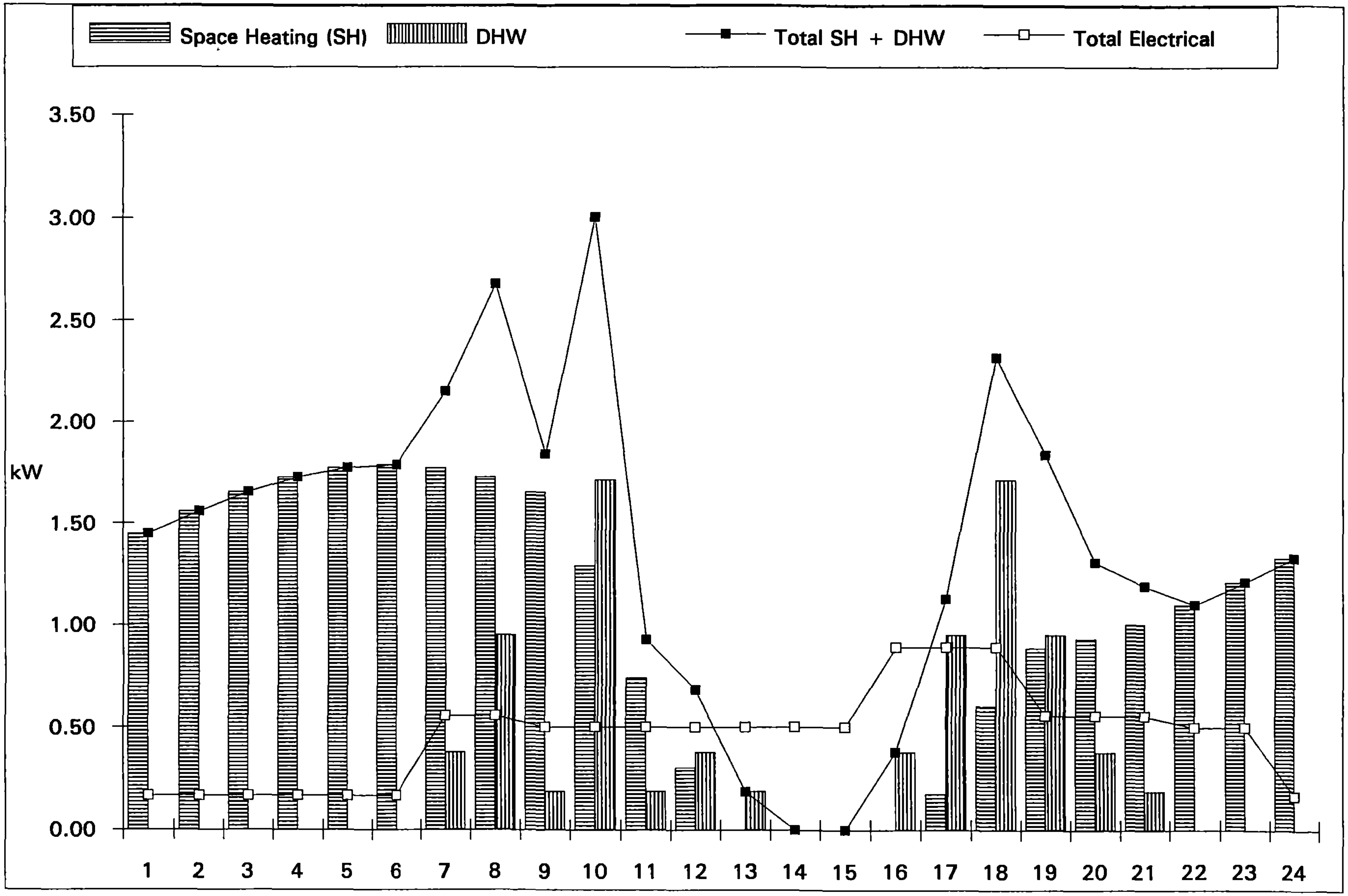


Figure 2.18
Hourly Energy Profile (Winter)
High Density Dwelling
Energy Upgrade



3.0 Cogeneration Concept and Technology

3.1 General

The purpose of this chapter is to review the existing cogeneration technology as it applies to residential cogeneration applications and present conceptual cogeneration schemes.

3.2 Cogeneration Technology

3.2.1 Generic Types of Prime Movers Available

Three generic types of prime movers are typically used in cogeneration applications. These are the steam turbine, the reciprocating engine, and the gas turbine.

Steam turbines operating on high pressure superheated steam are typically used in the larger power plants. The overall thermal power plant is only cost effective in the multi-Megawatt plant size. The steam turbine is also more efficient in larger sizes.

In smaller power plants (up to 3 MW), the reciprocating engine is typically the prime mover of choice. Its electrical power conversion efficiency of 30% and above is much higher compared to steam turbines and gas turbines in this power range. Heat can be recovered from the jacket water cooling loop in the form of low pressure steam (up to 13 psig) or hot water (up to 230 ^{0}F). Heat can be recovered from the exhaust in the form of high pressure steam (up to 300 psig), low pressure steam, or hot water. Low grade heat (up to 145 ^{0}F) can be recovered from the intercooler and oil cooler. Thus, the reciprocating engine is limited in those applications requiring high pressure steam as this can only be recovered from the exhaust which represents only one third of the recoverable heat potential of the engine.

Gas turbines are typically considered for projects above 4 MW. Below this level these have relatively low electrical conversion efficiencies compared to a their larger counterpart. For example a 620 kW Kawasaki gas turbine has an electrical conversion efficiency of approximately 20% compared to 27% efficiency for a larger 4.0 MW Allison gas turbine and 40% for a 40 MW GE gas turbine. It is noted that gas turbines are relatively compact and offer the ability to generate high pressure steam from the exhaust gas. It is also noted that gas turbines require fuel supply pressures in the range of 200 to 400 psig depending on the model and size. Such gas pressures are usually not available from the utility and a gas compressor is required. The parasitic loss of the gas compressor could lower the overall electrical conversion efficiency of the plant by 2 to 3%.

3.2.2 Gas Fired Reciprocating Engine Characteristics

The following section is provided to the reader for a general understanding of reciprocating engine characteristics. Within the gas fired reciprocating engine family, a number of options exists which must be selected to suit the particular project under consideration. These include the following:

i) Automotive vs Industrial:
Automotive engines are referred to as "disposable" engines with life expectancy of 20,000 hours. They are cheaper but less reliable. Industrial engines will last up to 20 years and are more reliable.

ii) Size (kW): Determined by the facility's thermal and electrical loads

iii) Speed (rpm): Typically 900, 1200 or 1800 rpm for prime power application. It is noted that a lower speed is best for maintenance but increases the engine-generator's initial capital cost per unit of power.

iv) Aspiration: Turbocharged vs naturally aspirated. The turbocharged version of a given engine "block" provides substantially more power then the naturally aspirated version. This has the advantage of lowering the installed cost be unit of power output. However, the turbocharged version requires natural gas pressures in the order of 25 psig which may not be available at all sites.

The naturally aspirated engine requires fuel pressures in the range of 2 to 5 psig. It is noted that certain newer turbocharged engines are available with a low fuel pressure design option and resulting in fuel supply pressure of approximately 3 psig. In this case the air and fuel are mixed prior to the turbocharger. However a certain percentage of the fuel (4%) may still need to be compressed separately depending on the engine make and model. This feature is quite useful when higher gas pressures are not available. Otherwise a gas compressor is required.

v) Lean/rich burn: Lean burn engines are designed to operate with higher excess combustion air than the rich burn engines, resulting in lower emissions of NO_x and CO. Nitrous oxide emissions for a lean burn engine are typically in the range of 2 g/HP-hr versus 10 g/HP-hr for the rich burn engine. However, the increased exhaust gas flow is lower in temperature which results in lower heat recovery from the exhaust boiler and increased heat load in the aftercooler.

It is noted here that rich burn engines can be equipped with catalytic converters to lower NO_x and CO emissions to approximately 0.5 g/HP-hr. However these catalytic converters have significant pressure drops associated with them. One must ensure that the combination of heat recovery boiler, supplemental muffler and catalytic converter does not exceed the engine exhaust back pressure rating of most medium speed engines on the market place. This pressure is typically in the range of 9 to 12 inches of water column. Exceeding the exhaust back pressure rating can be damaging to the engines exhaust system and the valves.

vi) Cooling Mode (ebullient cooled vs. forced circulation):

An ebullient cooled engine will produce steam from the engine jacket in the form of low saturated pressure steam (13 psig nominal). Alternatively heat can be recovered from engine jacket in the form of hot water in a forced circulation system. The final choice is made based on the thermal requirements of the facility.

Some representative Canadian (Ontario) reciprocating engine cogeneration suppliers include:

. Caterpillar	65 kW, and up	Industrial engines
. Waukesha	100 kW and up	Industrial engines
. Tecogen	30 kW and up	Automotive engines
. North American Cogen.	15kW and up	Automotive engines

3.2.3 Absorption Chillers

Absorption chillers utilize heat as energy inputs and produce chilled water as an output. The refrigerant used is distilled water operating under high vacuum. Lithium bromide is used as an absorbent and the cycle is free of any chlorinated fluorocarbons (CFCs).

Absorption chillers are categorized as either single effect or double effect chillers. Single effect chillers use hot water and low pressure steam as the heat source and have heat consumption rates of approximately 18,000 BTU/ton. Double effect chillers are much more efficient with a heat consumption rate of approximately 10,000 BTU/ton but require medium pressure steam of approximately 125 psig..

Some suppliers of absorption chillers in the canadian market include the following:

. Yazaki	10 tons and up
. Trane	90 tons and up
. Carrier	90 tons and up
. York	90 tons and up

3.3 Cogeneration and District Heating/Cooling Schemes

3.3.1 Basis for Selecting the Size of the Cogeneration Plant

In Ontario, energy in the form of electricity is currently worth five to six times an equivalent amount of energy in the form of heat produced from natural gas. Particular attention must therefore be given to the overall electrical conversion efficiency of a cogeneration plant.

To maximize the return on investment, a cogeneration system should be sized to maximize the period of time during which the prime mover can operate at rated electrical output and maximize the utilization of thermal energy recovered. An oversized cogeneration system would operate frequently at part load resulting in low operating cost savings relative to the original investment. The size selection of the prime mover is generally based on the following approach:

1) Determine the size of a cogeneration plant which will meet the building thermal or electrical load, whichever is the limiting factor. Supplemental heat required to meet the facility's loads are met with the existing boilers. Supplemental electricity required to meet the facility's demand is purchased from the utility.

2) Select a cogeneration scheme which is compatible with the grade of heat required in the existing distribution system.

3) With attractive buyback rates, electrical export to the utility could be considered if the building thermal load can accommodate the output of a larger engine. Similarly, wheeling excess power to other facilities is another option if permitted by the utility.

3.3.2 Cogeneration Plant Conceptual Design for Single Housing Unit

The design of a cogeneration system for a single unit dwelling poses some interesting challenges. The main challenge comes from the relative "mis-match" between the instantaneous thermal and electrical loads due to inherent low diversity factor of a single dwelling unit. As depicted in Chapter 2, the average electrical load of a single unit dwelling is approximately 1kW with a demand of approximately 2 kW. These are relatively low loads compared with the cogeneration equipment available in the market place. However the purpose of this section is to take a fresh design approach to this problem and design a conceptual scheme without consideration to present limits to equipment availability or regulatory barriers.

A novel cogeneration scheme is presented in Figure 2.1 based upon a small reciprocating engine-generator rated for nominally 5 kW of electrical output and 7 kW of thermal output. A central hot water storage tank is used to levelize the thermal load of the facility as the source of space heating and domestic hot water. The engine generator would operate in parallel with the utility power supply and use the grid as a "storage" means to levelize the electrical load.

The proposed control would be as follows. Hot water stored in the central tank is circulated in a closed loop and used for space heating and domestic hot water. Once the temperature drops below a preset point, the cogeneration system automatically starts and operates at full capacity thereby operating at maximum efficiency. Heat produced by the engine jacket and exhaust gas is recovered and stored. The electricity produced is either used inside the house (if the load exists) or it is exported to the utility via an import/export meter. Once the thermal storage tank temperature has reached its higher set point the small generator stops and wait for the temperature to reach its lower set point in the thermal storage tank. Any electricity required in the house during this period is purchased from the utility. The balance owing at the end of the month will simply be the difference between power exported and power imported from the utility. The final sizing of the engine-generator and thermal storage tanks should reflect an acceptable generator cycling period.

The small engine could be of the automotive type with a small induction 120V single phase generator. Overall efficiency would be expected at 80% with approximately 25% electrical conversion efficiency.

This design approach offers the following benefits:

- Solves the problem of instantaneous electrical and thermal load mismatch by using a thermal load following approach and levelizing thermal and electrical loads to make them compatible with a cogeneration system

- Power and heat are produced at maximum possible efficiency because the engine-generator never operates at part load.

The difficulties in implementing this design are as follows:

- Under prevailing regulations, electrical utilities will likely not accept the export of electrical power at the retail rate. Power purchased from the grid would be at retail value while power exported to the grid would likely be sold at a lower rate.

- There is no local availability of a small cogeneration package suitable for this application (5 kW +/-). Kohler had marketed a 5 kW package specifically targeting this market (see Appendix B). However this package never reached the market. Management informed us that the high capital cost (in excess of $3000/kW equipment only) was perceived as prohibitive. A larger cogeneration package as supplied by North American Cogeneration (15kW +/-) could potentially be used with suitable duty cycling design. However the utilization factor may make this option cost prohibitive.

3.3.3 Cogeneration Plant for Multiple Housing Units

Cogeneration is best suited to those sites with central heating and electrical distribution networks. This allows widespread use of the electrical and thermal output of the plant, with the added benefit of levelizing the demand profiles due to load diversity. The viability of cogeneration improves as the plant size increases. Combining the thermal and electrical loads of a large number of housing units is a logical direction to take.

A conceptual central cogeneration plant servicing a number of housing units is presented in Figure 3.2. Again the design approach of this system is divorced from present regulations and utility practices which may put impediments on design of the optimum system. The final ownership structure of this "communal" power plant will play an important role in the final design and cost sharing practice. Anticipated benefits and any technical and regulatory difficulties are listed hereafter.

The central cogeneration plant would house a single or preferable multiple engine-generators operating in parallel with the existing utility supply. Power produced would be metered and exported on a local feeder . Local houses, part of the common district heating pool, would draw power from the same feeder against the credited power produced by the cogeneration plant. Using the utility distribution system in this fashion minimizes the electrical interface cost with each individual house and permits purchase of additional power from the utility as required.

Heat recovered from the engine jacket and exhaust would be recovered in the form of hot water. The space heating and domestic hot water loads of all units would be serviced by a common district heating system. In the case of multiple unit dwellings without common walls, this system could be a two pipe system shallow buried in trenches. The nature of the soil and the housing density will affect the final construction cost as discussed in other sections. Each household would be equipped with circulating pumps and heat exchangers necessary to interface with the loop. A representative system has been recently installed in the Ouje-Bougoumou native community in Quebec (see Chapter 6). The final number of engines and capacity of the central plant will be a function of the type of housing unit (low density, high density) and the total number of houses serviced by the plant. The reader is referred to Chapter 2 for an appreciation of the typical electrical and thermal load profiles for generic housing configurations.

The configuration of the central cogeneration plant could vary from site to site. Some of the design options are as follows:

- Include multiple engine-generator units to operate at optimum efficiency and increase reliability. Final size will depend on the number and type of housing units.

- Include additional hot water boilers for standby and peaking source of heat.

- Consider thermal storage to levelize thermal load.

- Consider central space cooling using absorption chillers. In this case a separate pipe system would be required if domestic hot water is to be serviced also from the central cogeneration plant all year. Optionally each household could have a small sperate fired

DHW tank which would free the central piping system for space cooling in the summer months.

From a technical perspective, the above proposed scheme would not pose any difficult challenges. The cogeneration equipment, district heating concept and parallel generation design are elements that have all been tried and proven in the Canadian climate. The major difficulties expected in implementing this scheme are regulatory in nature and are as follows:

- The ownership of the central power plant is an important issue. In Ontario, only municipal utilities and Ontario Hydro have the right to sell power to individual rate payers. In other words an individual has the right to self-generate but cannot sell power to others. Therefore the central cogeneration plant in this case could not be owned by a third party developer who would sell or wheel power to the individual house owners. However it is possible that this difficulty could be overcome if the central power plant were owned by a cooperative type of arrangement which would also be the recipients of the electrical power. Other factors as the operation and maintenance cost associated with the plant must be addressed from the perspective of overall accounting.

- As for the single unit dwellings, it is doubtful that utilities would allow the power produced from the central cogeneration plant to be credited at retail value to a number of privately owned housing units. Typically the options available include selling to the utility typically at lower rates then retail rates or wheeling to other facilities owned by the same group. The wheeling concept could be acceptable if the utility permits it with acceptable wheeling charges. In other words the power metered at the cogeneration plant would be credited to all owners of the power plant minus a wheeling charge. The other option is for the community to own the distribution network .

- A fairly large number of houses would need to be integrated into the district heating system to achieve a reasonably cost effective cogeneration plant size. Based on the load analysis results developed in Chapter 2, approximately 500 to 600 households would need to be incorporated in a central heating plant for a typical 500 kW central cogeneration plant This rating may vary depending on the heat utilization factor acceptable to the project. However, this figure puts the issue of distribution network in perspective.

3.4 Environmental Benefits of Cogeneration

In addition to operating cost reductions, cogeneration offers environmental benefits. Although the environmental benefits of cogeneration are not the main thrust of this study, they are highlighted briefly to demonstrate that cogeneration can play a significant role in helping governments meet their emission reduction goals.

Significant reductions in overall fuel consumption and carbon dioxide emission can be realized with cogeneration. This is true when cogeneration is compared to the option of purchasing electrical power generated by utility in a remote fossil fuel fired power plant while the customer produces on site thermal energy in separate boilers. The reason is simple. Fossil fuel fired electrical power generating plants are thermodynamically limited to efficiencies of approximately 30% to 35%. Line losses will further reduce the overall efficiency. Since there is limited need for the low grade heat generated in a utility owned power plant, it is wasted. In other words, approximately 70% of the input energy is typically discarded as heat to the environment. This point is demonstrated in Figure 3.3. On the other hand, a cogeneration plant not only generates electrical power (approximately 30% of fuel input) but the thermal energy produced by its prime mover is also recovered and utilized on site resulting in achievable overall efficiencies of 80% as depicted in Figure 3.4. The recovered heat from the prime mover displaces fuel which otherwise would be needed in the on-site boilers to meet the steam or hot water needs. As a result, by producing a portion or all of a given facility's thermal and electrical energy needs a cogeneration plant yields a net reduction of approximately 50% in overall fossil fuel consumption.

A detailed estimate of carbon dioxide, nitrous oxide and sulphur dioxide reductions is presented in the Table 3-1 for a typical 250 kW cogeneration plant. This plant could service approximately 250 to 300 homes. The following emission rates have been used in calculating the estimate:

<u>CO_2</u>	
CO_2 production rate for natural gas fired boiler:	50 g/MJ input
CO_2 production rate for coal fired boiler:	85 g/MJ input
<u>NO_x</u>	
NO_x production rate for lean burn engine:	2 g/HPh)
NO_x production rate for rich burn engine:	10 g/HPh
Efficiency of rich burn catalytic converter:	95%
NO_x production rate for commercial natural gas fired boiler:	60 mg/MJ input
NO_x production rate for coal fired boiler:	258 mg/MJ input
<u>SO_x</u>	
SO_x production rate for coal fired boiler:	2000 mg/MJ input

The results indicate that attractive reductions in CO_2, NO_x and SO_x are achievable through implementation of cogeneration. The increased overall thermal efficiency of the cogeneration schemes compared to the conventional approach of local boilers and utility-supplied electricity reduces CO_2 production due to reduced fuel consumption. In a similar vein, NO_x production is also reduced due to reduced fuel consumption. Because the cogeneration schemes studied here are fuelled by natural gas or diesel, which has no sulphur content, the implementation of cogeneration directly displaces SO_x produced by the utility's coal-fired boilers. Significant CO_2 reductions (1,550,000 kg/yr), NO_x reductions (5,800 kg/yr) and SO_x reductions (48,000 kg/yr) are achieved with a rich burn reciprocating engine equipped with a catalytic converter.

3.5 Economic Analysis

In the following sections, a simple economic model is introduced which will allow a project developer to quickly assess the economic feasibility of cogeneration at a specific site. The developer determines certain site-specific parameters (fuel price, electricity price, capital cost, O&M cost) which are then inserted into the model. The model then provides a simple payback period and allows the developer to quickly determine the degree of sensitivity of the site parameters on project payback.

As with all models, some simplifying assumptions have been made, and a developer using this model should be aware of its limitations and range of uncertainty.

Later in this report, the model is applied to five case studies to assist in determining the economic viability of cogeneration at each site.

3.5.1 Capital and O&M Costs

One of the key variables affecting payback period is installed cost. This includes not only the capital cost of the cogeneration prime mover and heat recovery equipment, but also the mechanical and electrical infrastructure needed to transfer the energy to the point of consumption. In the case of a community district heating installation, the infrastructure costs can comprise a significant fraction of total installed cost. Some representative costs are developed in Chapter 6.

A major equipment cogeneration package for applications under 1 MW typically includes the following:

- Reciprocating engine
- Generator
- Heat recovery boilers (steam or hot water)
- Heat dump radiators
- Exhaust stack
- Control equipment
- Building or enclosure

Associated valves, pumps and switchgear necessary to integrate the system to the site thermal and electrical loads are normally contracted separately by the developer and installed by the contractor at the site.

The reciprocating engine family can be divided into two classes. The automotive class (5-65 kW) is originally designed for automotive use and is then redesigned or derated for a continuous industrial application. The industrial class (over 65 kW) is designed at the outset for continuous use in an industrial or cogeneration application.

The following estimate of capacity costs is based upon recent experience in the Canadian market for small cogeneration systems in non-district heating applications:

Size (kW)	Equipment Cost ($/kW)	Infrastructure and Installation Cost ($/kW)	Total Capacity Cost ($/kW)
5-65	1500	1500	3000
65-300	1000	1000	2000
300-800	800	800	1600
over 800	700	700	1400

A second key variable affecting payback period is the system operating and maintenance (O&M) costs. These typically include daily, monthly, annual and life cycle costs for all equipment components. In the case of a reciprocating engine-based cogeneration system, a significant fraction of total O&M costs are in support of engine maintenance.

These costs include parts and labour for:

- oil changes, on a monthly basis
- minor overhauls (valve rework), typically after 2-3 years continuous operation
- major overhauls (engine rework), typically after 4-6 years continuous operation

The following estimate of O&M costs is based upon recent experience in the Canadian market for small cogeneration systems in non-district heating applications:

Size (kW)	Operating and Maintenance Cost ($/kWh)
5-65	.015
65-300	.013
300-800	.012
over 800	.011

For small applications, no additional building staff are needed to operate or maintain the cogeneration system. Existing staff are responsible primarily for routine system monitoring, and startup/shutdown as required. Maintenance can be contracted to the supplier and costs levelized over the life of the equipment.

3.5.2 Economic Performance

A typical cogeneration project will not proceed until a detailed cash flow analysis has been conducted which quantifies all relevant factors to a tolerable level of uncertainty.

These parameters include:

- Equipment performance, rating and installed cost for the specific engine under consideration.
- Actual utility rates for electricity and fuel.
- Operation and Maintenance cost, including the parts and labour cost of regular maintenance, minor and major overalls as estimated from data received from the engine supplier. This is incorporated into the analysis as a year by year annual cost, representing true maintenance expenses as they are expected to occur during the life of the engine.
- Existing load profiles of the host site for both heat and electricity.
- Monthly operating period of the cogeneration system, taking into account equipment availability.
- System energy performance, outlining electrical power production and waste heat recovery and utilization.

Monthly operation costs and avoided costs are calculated and totalled for each year. Individual inflation rates are applied to electrical power, natural gas and maintenance. Tax implications are included where applicable. Then, using a discounted cash flow analysis, the rate of return on total capital, net present value and the capital payback period are calculated. Sensitivity analysis are then conducted to determine the degree of risk associated with a change in any of the key variables.

As a quick method of determining the economic feasibility of a cogeneration project, we have developed a simplified model which incorporates only the most important variables, as follows:

$$PB = \frac{CC}{\{ES - [(1-\frac{HR}{BE})FC + MC]\}OH}$$

where:

PB = Payback period (years). The calculated payback period is a simple payback period only as it does not include any effects of inflation on fuel, electricity, and O&M costs.

CC = Capacity cost ($/kW). The total installed cost of the cogeneration system, including all necessary infrastructure per unit of power output..

ES = Average electricity savings ($/kWh). Includes both demand and energy charges displaced by the cogeneration system.

HR = Heat recovery rate (%). The amount of thermal energy recovered and utilized from the cogeneration system as a fraction the total fuel energy delivered to the engine. This is typically 40-50% if all potentially recoverable heat is used continuously.

BE = Boiler efficiency of space heating system (%, LHV) for which fuel is displaced by the cogeneration plant. For existing boilers, (or alternative thermal energy source) is typically 87%, LHV.

FC = Fuel cost per unit of electrical energy output ($/kWh). The product of the engine fuel consumption provided by equipment supplier (i.e. m3/hr, BTU/hr or GJ/hr) and the cost of fuel (i.e. $/m3, $/BTU or $/GJ). Alternatively, fuel cost may be determined from the gross electrical power generation efficiency of the system (typically 30% for a reciprocating engine).

Example:

$$\text{Fuel cost (\$/kWh)} = \frac{\text{3412 (BTU/kWh) x fuel cost (\$/m3)}}{\text{Fuel heat content (BTU/m3) x electrical power generator efficiency (\%)}}$$

Fuel heat content and cost for typical cogeneration fuels are as follows These values will vary across Canada depending on location:

Fuel	Heat Content	Cost
Natural gas	32,500 (BTU/m3)	0.16 $/m3
Diesel oil	130,000 (BTU/gal)	2.25 $/gal
Propane (liquid)	91,500 (BTU/gal)	1.10 $/gal

MC = Operating and maintenance cost ($/kWh). Typically between 0.011 and 0.015 $/kWh for reciprocating engines.

OH = Operating hours (hrs/yr). Includes shutdown time for scheduled and unscheduled maintenance. For a system operated continuously, with a typical availability of 95%, the OH is 0.95*24*365 = 8322 hrs/yr.

Results from the model are displayed in Generic Cogeneration Economics Figures 3.5-3.10 for the following scenario:

Capacity cost	1500 - 6500 $/kW
Electricity savings	0.05 - 0.10 $/kWh
Heat recovery rate	40%

Boiler efficiency	87%, LHV
Fuel cost (natural gas)	0.10 - 0.20 $/m3
Fuel heat content (natural gas)	32500 (BTU/m3)
Electrical efficiency	30%
Maintenance cost	0.011 $/kWh
Operating hours	8300

To use the Generic Cogeneration Economics Figures, estimate the capacity cost, electricity savings, and natural gas price for the proposed cogeneration system. Choose the appropriate figure closest to one of the plotted values for capacity cost (i.e. 1500 - 6500 $/kW). Choose the appropriate electricity savings line (i.e. 0.05 - 0.10 $/kWh). Intersect with the estimated natural gas price on the horizontal axis. The corresponding value on the vertical axis represents an estimated payback period. Interpolation may be necessary between figures if the capacity cost is between any two of the six plotted values.

Example:

Capacity cost	2500 $/kW
Electricity savings	0.07 $/kWh
Fuel cost (natural gas)	0.16 $/m3
Payback period	11 years (from Figure 3.6)

3.6 Summary of Site Evaluation Considerations

For quick reference purposes, Table 3.2 summarizes some of the important issues to consider when evaluating the merits of cogeneration sites. These include a number of technical, financial and regulatory issues which must be considered.

Table 3.1

Environmental Benefits of Cogeneration

Reciprocating Engine Scheme

Performance Data			
Cogeneration Plant Rating (kW)	250		
Cogeneration Plant Fuel Consumption - HHV (MJ/yr)	25,900,000		
Cogeneration Plant Electrical Energy Production (kWh/yr)	2,000,000		
Cogeneration Plant Operating Hours (hrs/yr)	8,300		
Fuel Displaced in Dwelling's Space Heating Boilers via heat recovery (MJ/yr)	16,200,000		
Fuel Displaced in Electrical Utility's Boilers to produce equivalent amount of electrical energy (@ 30% overall utility efficiency including line losses (MJ/yr))	24,000,000		

CO2 Accounting			
CO2 Produced by Cogeneration Plant (kg/yr)	1,300,000	CO2 production rate for lean burn engine:	50 g/MJ input
CO2 Displaced in Dwelling's Existing Boilers (kg/yr)	810,000	CO2 production rate for natural gas fired boiler:	50 g/MJ input
CO2 Displaced in Electrical Utility's Boilers (kg/yr)	2,040,000	CO2 production rate for coal fired boiler:	85 g/MJ input
Net Reduction in CO2 (kg/yr)	1,550,000		

NOx Accounting			
NOx Produced by Cogeneration Plant (kg/yr)	1,400	NOx production rate for lean burn engine:	0.5 g/Hph
(mg/MJ)	54		
NOx Displaced in Dwelling's Existing Boilers (kg/yr)	1,000	NOx production rate for natural gas fired boiler:	60 mg/MJ input
NOx Displaced in Electrial Utility's Boilers (kg/yr)	6,200	NOx production rate for coal fired boiler:	258 mg/MJ input (present)
Net Reduction in NOx (kg/yr)	5,800		

SOx Accounting			
SOx Produced by Cogeneration Plant (kg/yr)	0		
SOx Displaced in Dwelling's Existing Boilers (kg/yr)	0		
SOx Displaced in Electrical Utility's Boilers (kg/yr)	48,000	SOx production rate for coal fired boiler:	2000 g/MJ input
Net Reduction in SOx (kg/yr)	48,000		

Table 3.2

Cogeneration in a "Healthy Housing" Context
Site Evaluation Criteria

A. Technical Considerations

Site

- New housing construction at design stage: Easier to incorporate cogeneration at this stage and eliminate retrofit costs. Engineering and construction cost lower as part of larger system
- Retrofit of existing facilities: Requires space availability for cogeneration plant and distribution network interface must be carefully studied and costed.

Housing categories

- Single unit dwellings
- Low density lowrise and building cluster
- High density low rise

Each category will have varying degree of energy density and distribution requirements

Energy Efficiency

Enhancement in Context of "Healthy Housing"

Consider implementing energy enhancement measures prior to sizing cogeneration plant - Readily implemented include:

- Building envelope
- HVAC heat recovery
- Load shifting
- Control systems
- Appliances

Energy Profile

Establish accurate energy profiles including averages and hourly profiles in order to size cogeneration plant suitably including the following:

- Electrical load (average and peak)
- Thermal load (average and peak)
- Quality of thermal load
  -Hot water, LP &HP steam
- Use measures to levelize electrical and thermal loads
- Consider potential sale of thermal energy over the fence
- Establish minimum threshold energy profile for cogeneration feasibility and district heating

Fuel Supply

- Natural gas: Consider
  -Availability
  -Pipeline capacity
  -Pressure
  - Interruptible vs Firm

Alternative fuels for remote areas:

- Diesel
- Propane

Cogeneration Plant

- Determine size from thermal and electrical load analysis.
- Consider backup for electrical and heat.
- Reciprocating engine choice
  - automotive packages (15-65 kW)
  - industrial packages (65-800 kW)
- Other Systems
  - Heat dumps
  - Thermal storage
  - Absorption chillers
- Consider for local availability
  -Equipment
  -Engineering expertise
  -Maintenance expertise

Interconnect to Housing Unit(s)

- Electrical distribution
  - Distributed vs Centralized
- Thermal distribution
  - Distributed vs Centralized
  - review viability of district heating and cooling for the given geography, soil condition and energy density
- Location of boiler plant
  - consider engine exhaust

Interconnect to Electrical Utility

- Review import/export option
- Investigate sale and or wheeling

B. Economic Considerations

Energy Commodities

- Fuel purchase price
- Electrical purchase price
- Electrical sale price (if feasible)
- Electrical utility standby costs

Difference between electricity and fuel prices is a driving factor

Capital Costs

Do detailed capital cost estimate which will include

- Equipment ($/kW)
- Installed cost ($/kW)
- Engineering cost ($/kW)
- All applicable taxes ($/kW)

Operating & Maintenance Costs

Consider the following:

- Requirement for technical staff
- Maintenance cost ($/kW-hr) Obtain actual life cycle analysis from the supplier.
- Maintenance contract availability

Cash Flow Analysis

Perform simple payback analysis initially . Perform sensitivity analysis on key variable. If economics are attractive perform detailed cash flow analysis showing:

- Monthly and Annual Savings
- Net Present Value
- Return on Investment
- Payback period

Financing

Some alternatives include

- Lease
- In house financing
- Alternate ESCO approach

Consider tax treatment of class 34

C. Regulatory Considerations

Environmental

- Local issues
  - -Noise
  - -Emissions

Table 3.2 (Continued)

  - -EMF shielding
  - -Aesthetics
  - -Municipal by-laws
  - -Fire regulations
- Global benefits
  - -Overall net reduction in fossil fuel consumption and associated emissions
  - -Potential use of freon-free absorption chillers
  - -Reduction of nuclear and coal fired power

Federal & Provincial Governments

- Generally good attitude toward cogeneration

Investigate potential help from:

- Energy efficiency programs
- Economic incentives

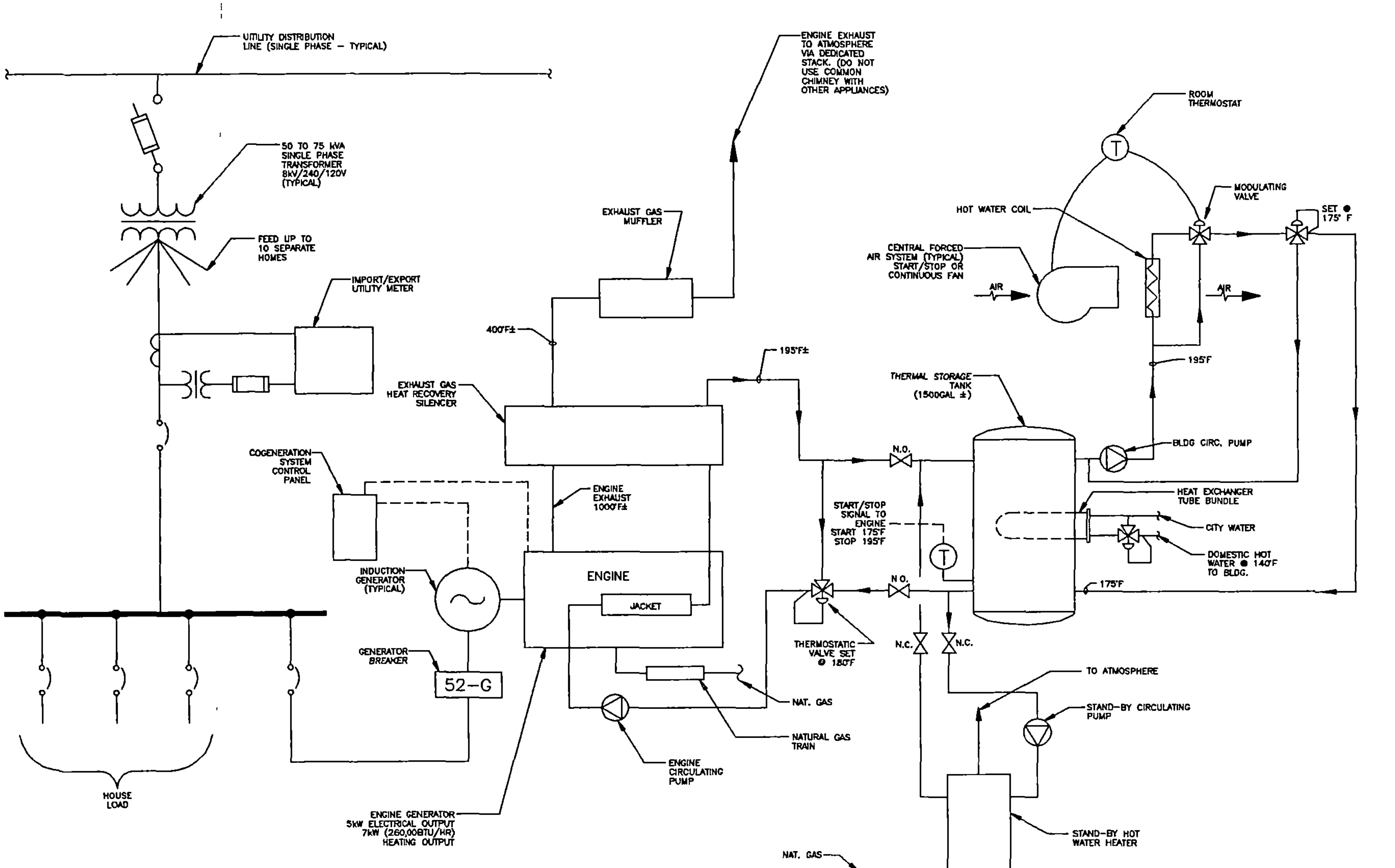
Electrical Utility

- Local attitude toward cogeneration may vary from supportive to resistant
- Availability of technical guidelines for parallel generation will vary between utilities

Approvals

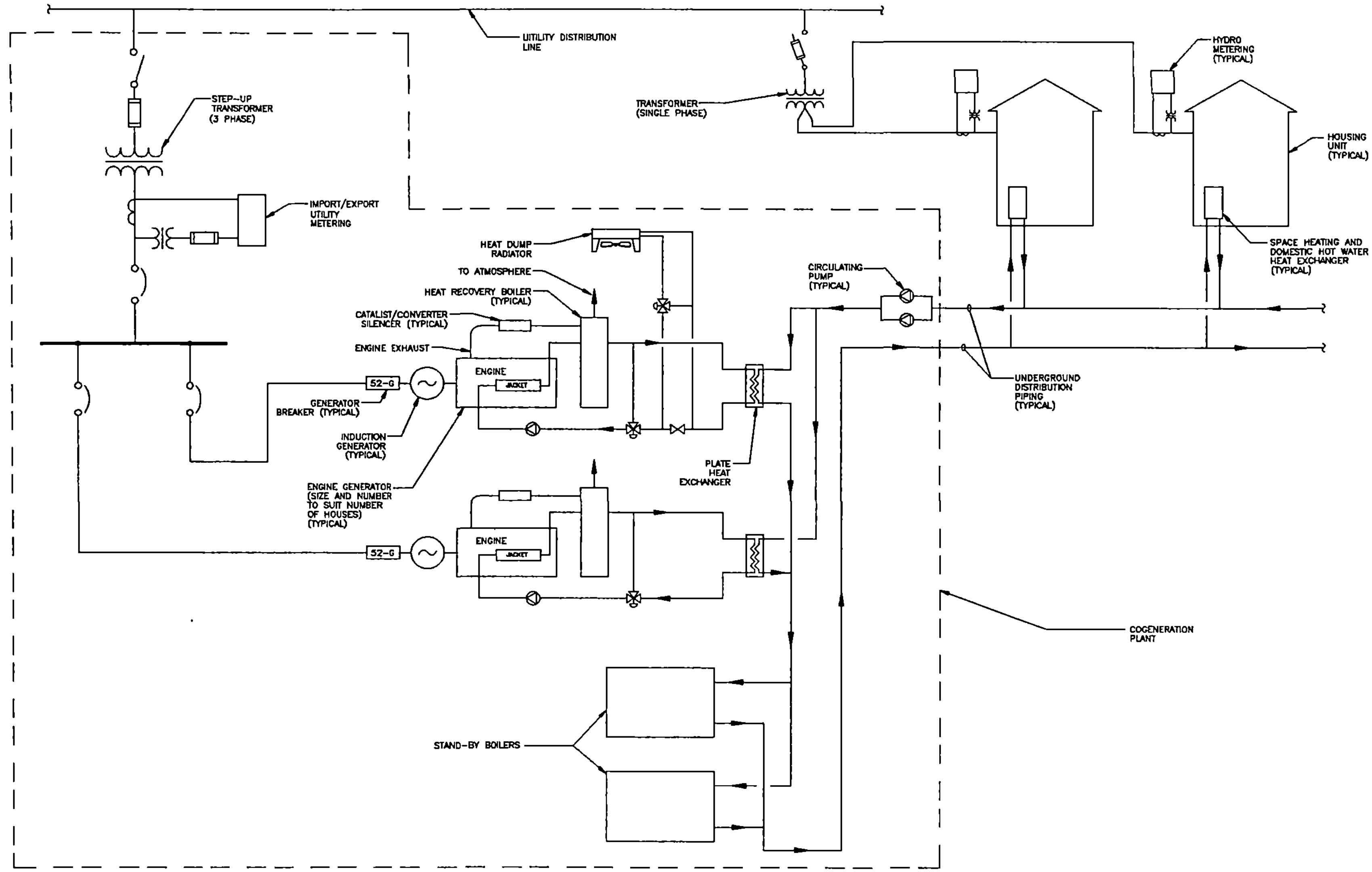
The following permits and approvals are typically required for the implementation of a cogeneration plant;

- Air emissions certificate from provincial Ministry of the Environment
- Parallel generation approval from utility.
- utility inspection for electrical installation
- Natural gas installation inspection
- Building permit



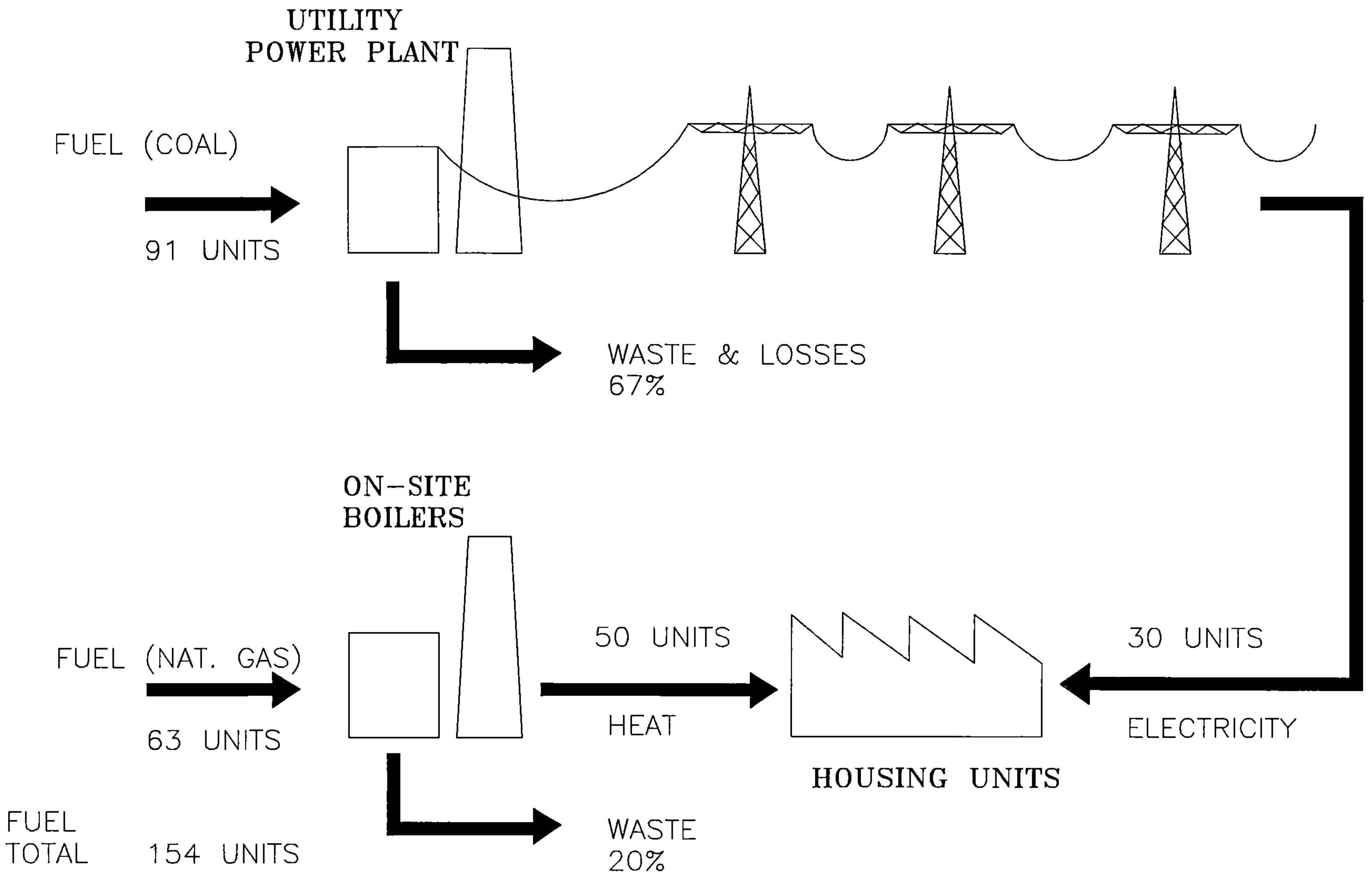
NOTE:
CONCEPTIONAL DESIGN/
NOT FOR CONSTRUCTION

Project	Drawing Title	Drawing No.
CHMC Community Energy Systems	SINGLE HOUSING UNIT COGENERATION CONCEPT	Fig. 3.1
ALCO Engineers Inc.		

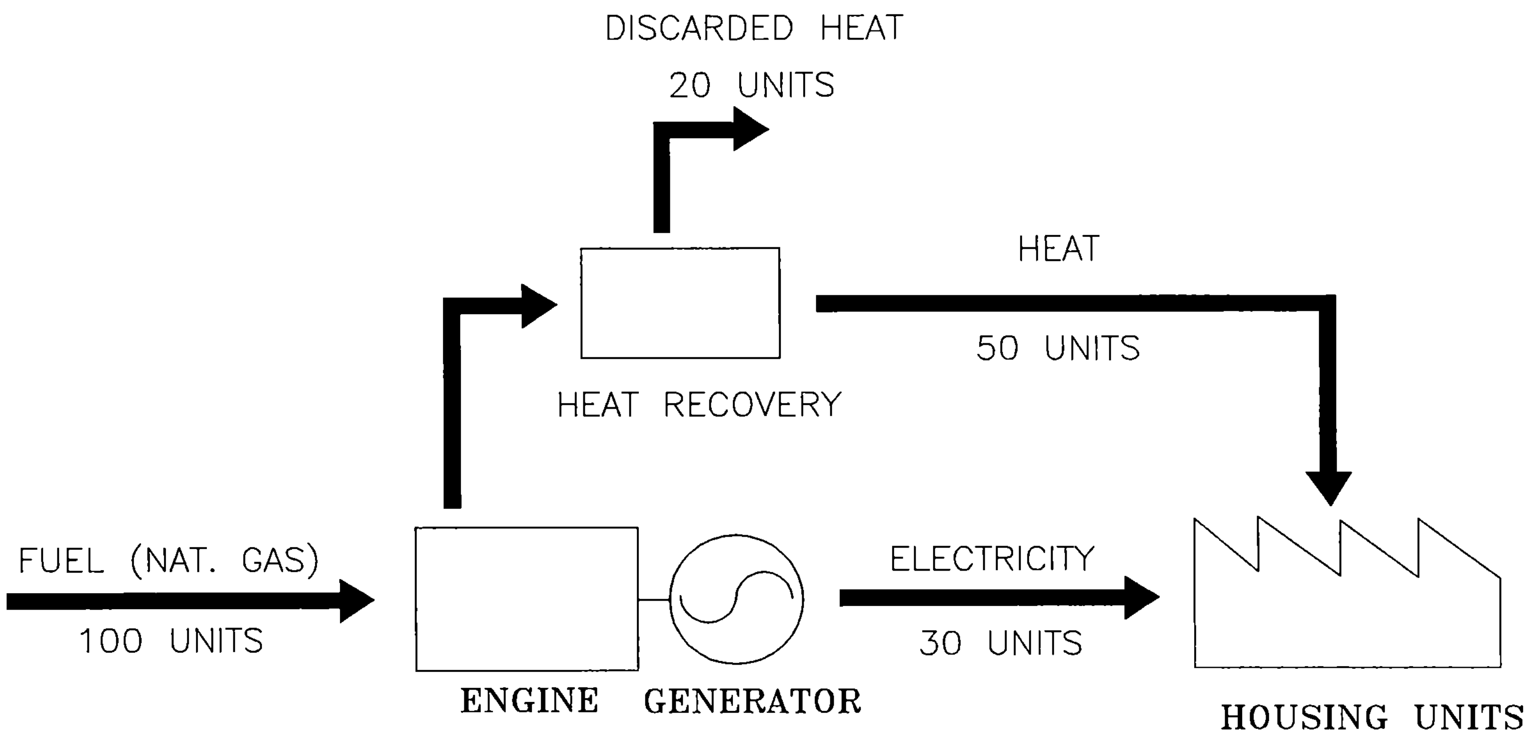


NOTE:
CONCEPTIONAL DESIGN/ NOT FOR CONSTRUCTION

Project	Drawing Title	Drawing No.
CHMC Community Energy Systems	MULTIPLE HOUSING UNITS COGENERATION CONCEPT	Fig. 3.2
ALCO Engineers Inc.		



Project	Drawing Title	Drawing No.
CHMC Community Energy Systems	CONVENTIONAL ENERGY SUPPLY	Fig. 3.3
ALCO Engineers Inc.		



RELATIVE DIFFERENCE IN TOTAL FUEL CONSUMPTION

$$\frac{154 \text{ UNITS} - 100 \text{ UNITS}}{100 \text{ UNITS}} \times 100 = 54\%$$

Project	Drawing Title	Drawing No.
CHMC Community Energy Systems	COGENERATION ENERGY SUPPLY	Fig. 3.4
ALCO Engineers Inc.		

Figure 3.5

Generic Cogeneration Economics

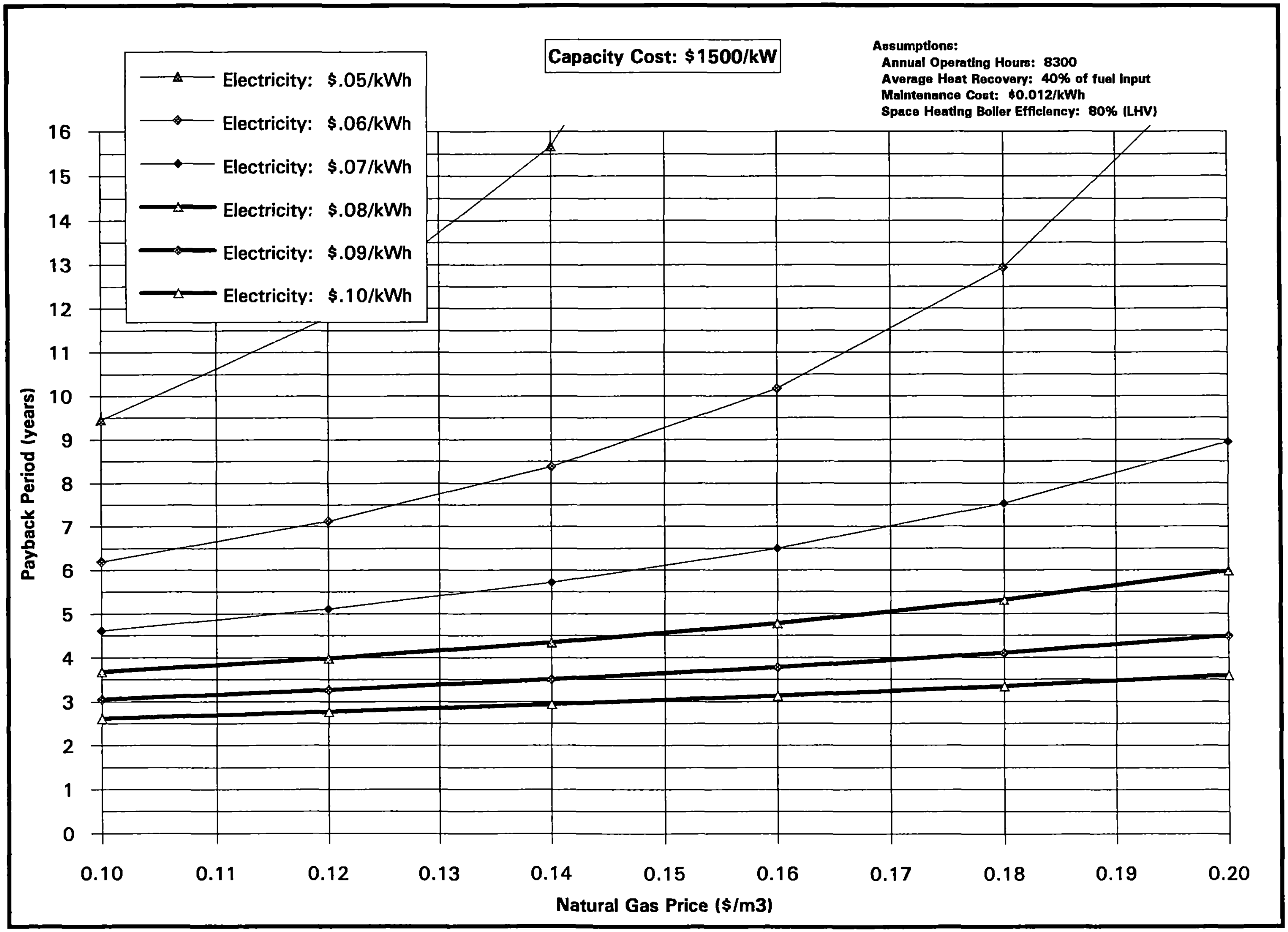
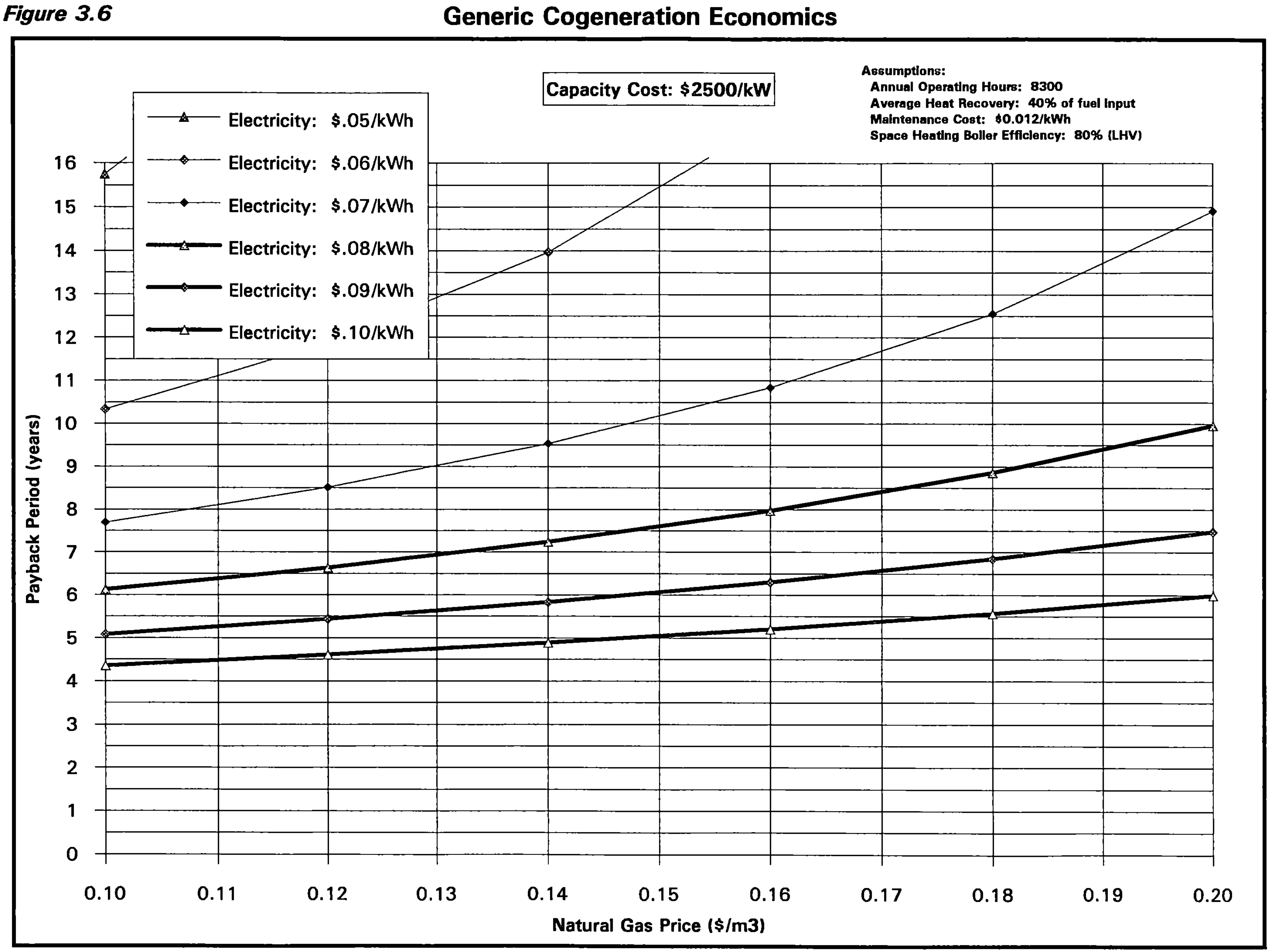


Figure 3.6



Generic Cogeneration Economics
Capacity Cost: $2500/kW
Assumptions:
Annual Operating Hours: 8300
Average Heat Recovery: 40% of fuel input
Maintenance Cost: $0.012/kWh
Space Heating Boiler Efficiency: 80% (LHV)
Electricity: $.05/kWh
Electricity: $.06/kWh
Electricity: $.07/kWh
Electricity: $.08/kWh
Electricity: $.09/kWh
Electricity: $.10/kWh
Payback Period (years)
Natural Gas Price ($/m3)
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0
1
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Figure 3.7 **Generic Cogeneration Economics**

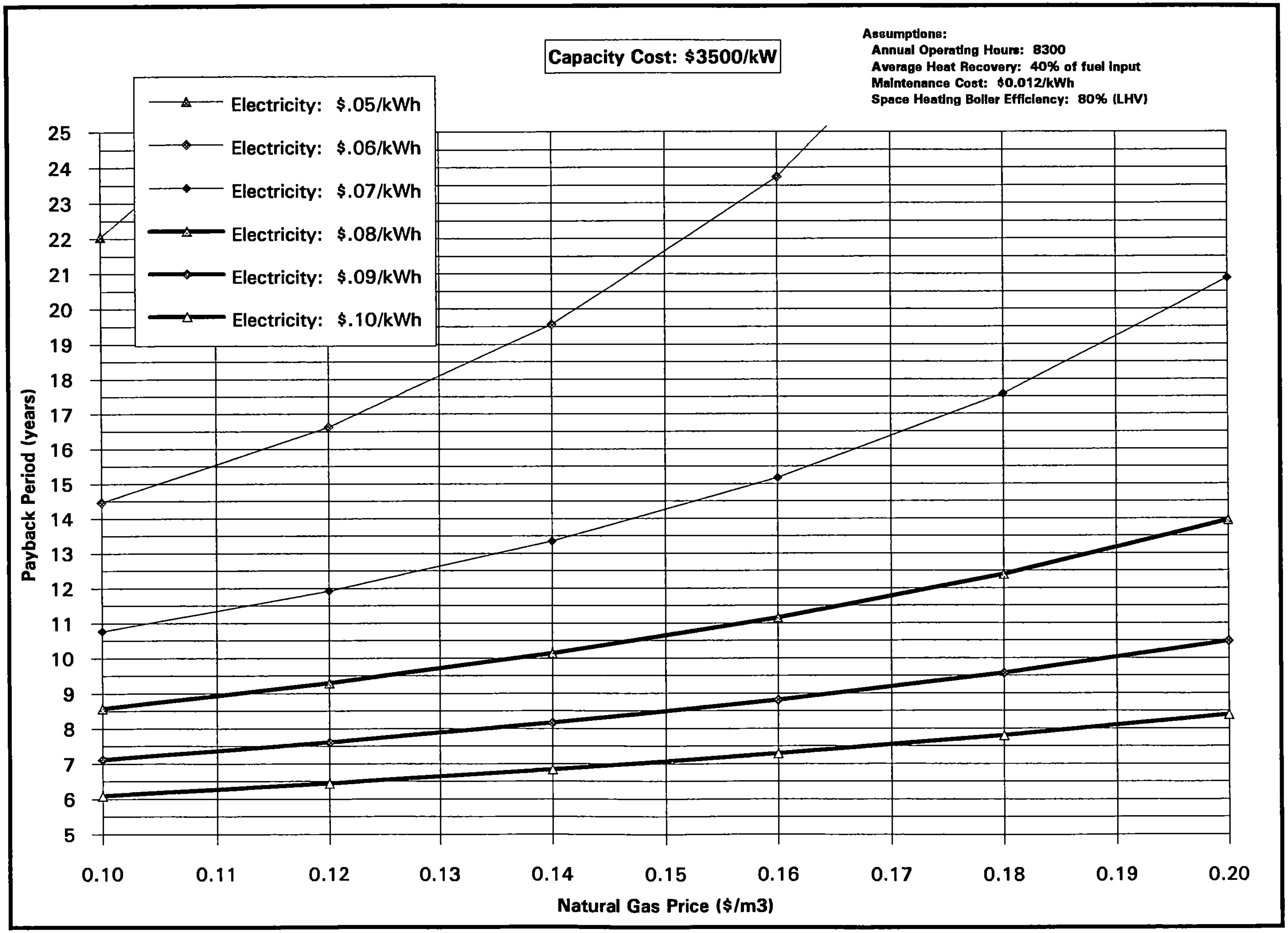


Figure 3.8

Generic Cogeneration Economics

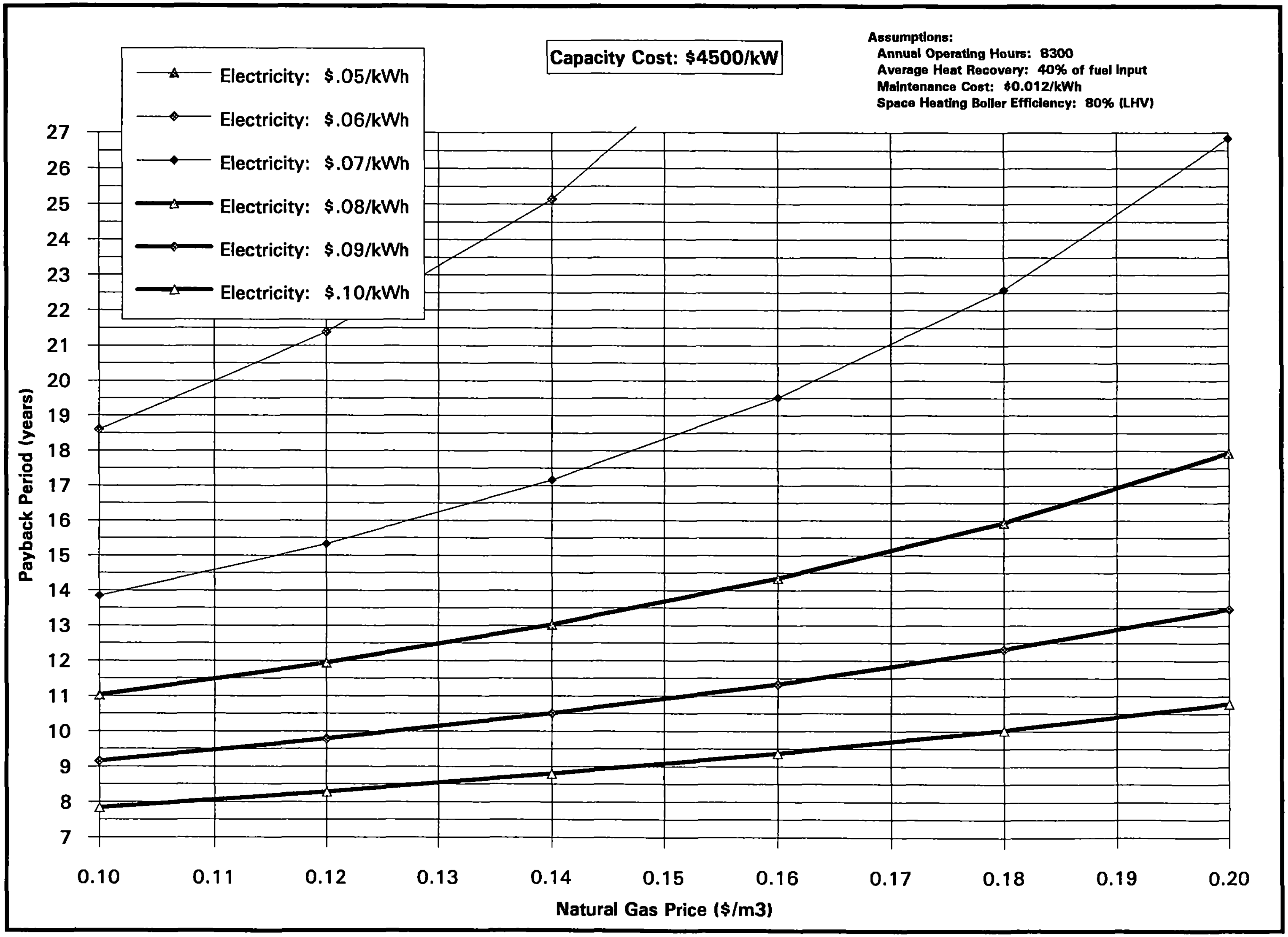


Figure 3.9 **Generic Cogeneration Economics**

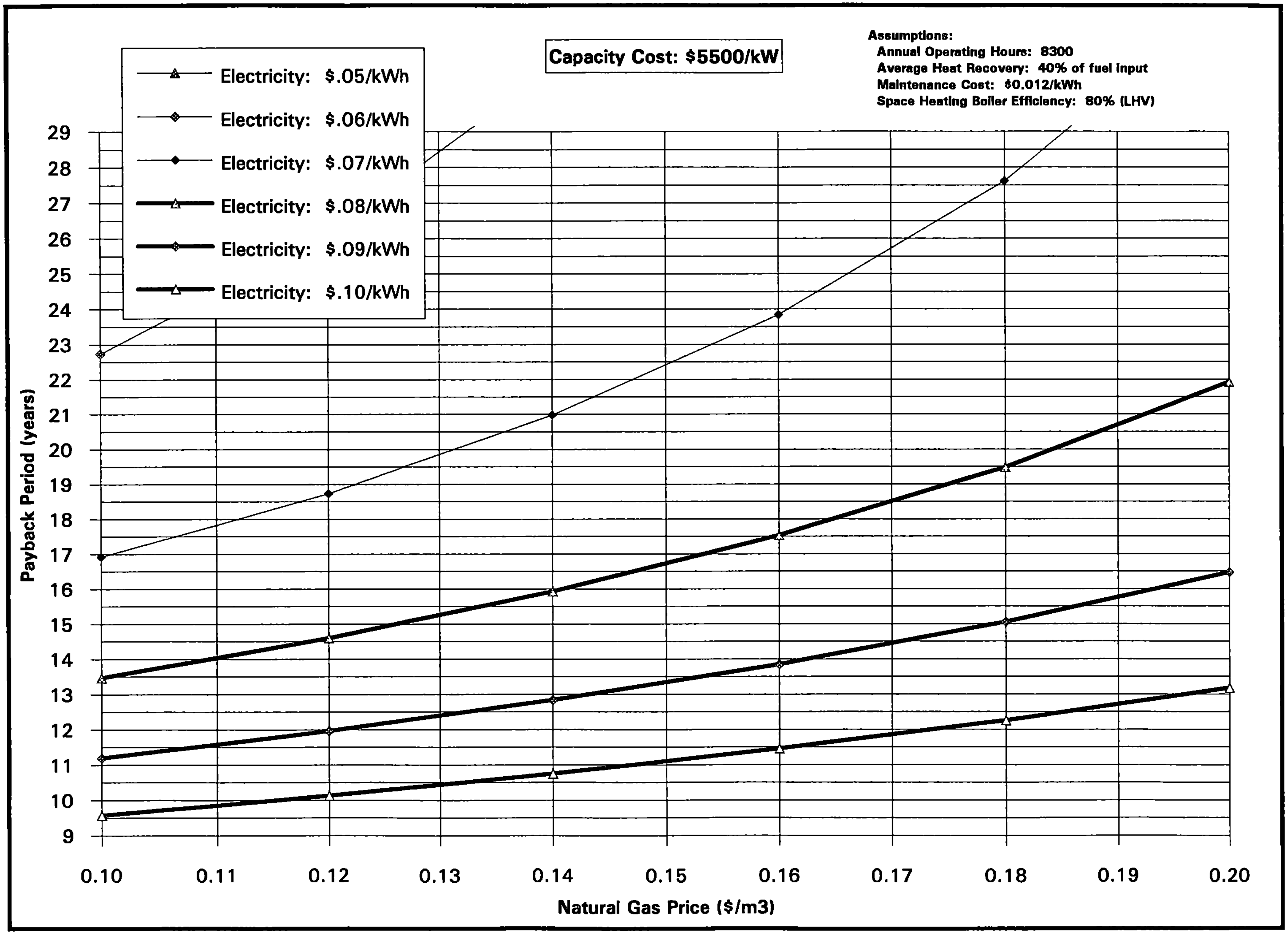
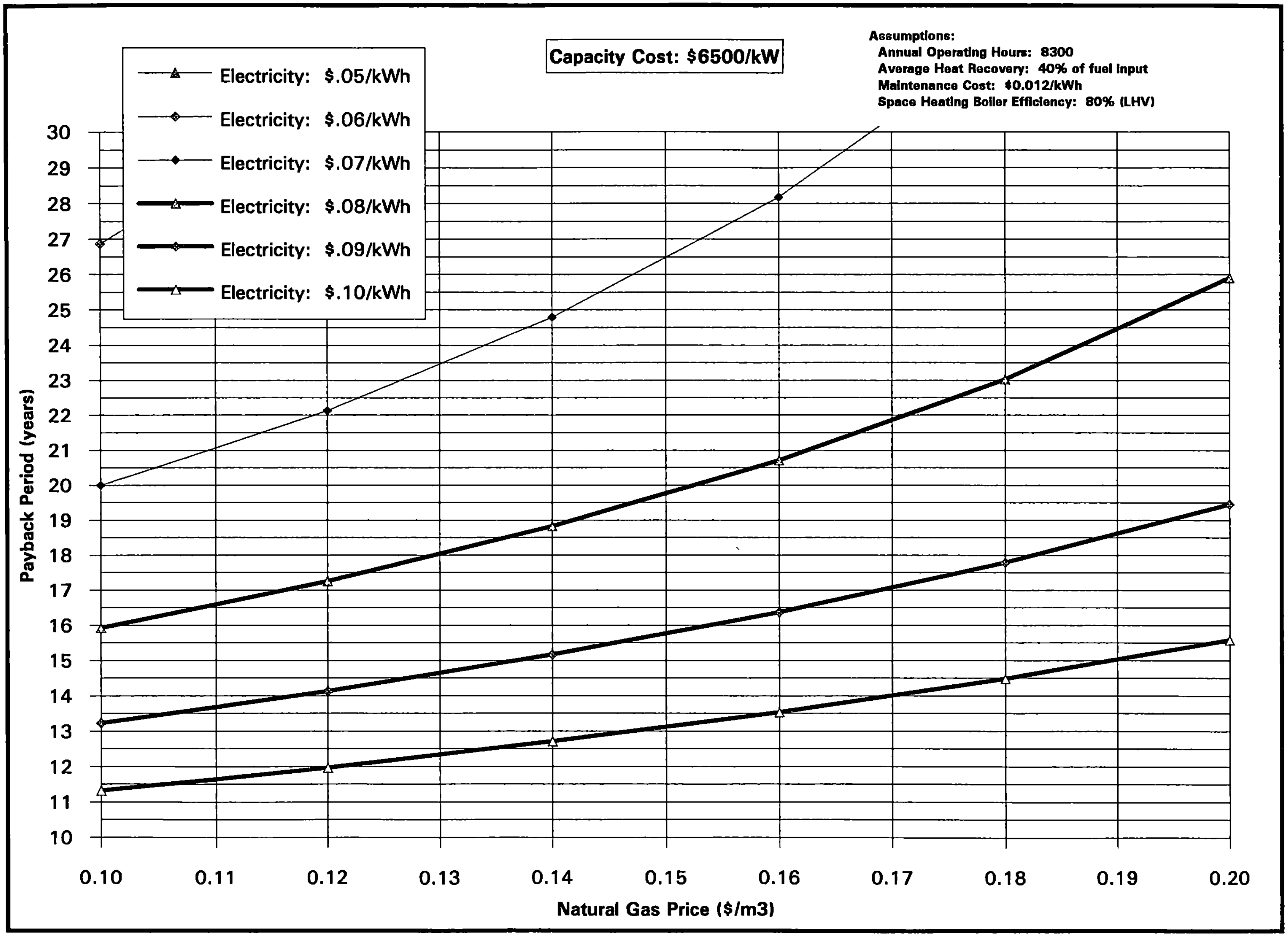


Figure 3.10

Generic Cogeneration Economics



4.0 Alternative Energy Enhancement Measures

4.1 Introduction

The application of cost-effective cogeneration should also be consistent with healthy housing in a local and global context in regards to outdoor environment. Clearly energy efficient housing allows more residents to be serviced per unit of primary fuel as well as reducing mechanical capital cost.

In terms of energy conversion, cogeneration of electricity and thermal output makes use of primary fuel much more efficiently than coal or nuclear electricity production. Gas cogeneration produces - approximately 50% of the CO_2 compared to coal-fired electricity and conventional on-site boiler .

These numbers are impressive and reduce the environmental impact significantly. However, natural-gas- (or diesel-) fired cogenerators still consume non renewable resources. Properly managed, biomass fuels (wood, methanol, biogas) can be considered renewable since the carbon released is not additional to the natural carbon cycle. To avoid all emissions, renewable energy production in the form of photovoltaics, small-scale hydro, wind, and solar thermal should be considered.

Operationally, three scenarios relate to cogeneration:

1. **Load Levelling**

   To allow a cogenerator to operate most efficiently, constant and relatively continuous loads are desirable. Load-shifting or shedding to remove peaks and to fill in valleys in load demand is desirable. Load matching between electrical and thermal demands is also required.

2. **Renewable Peak Shedding or Load Displacement**

   To maximize cogenerator efficiency and reduce non-renewable supply, peaks above base load may be supplied by renewable systems. Alternately, it may be more efficient to not operate the cogenerator during some periods (e.g. no thermal demand) and use renewable electrical power.

4.2 Electrical Load Reduction

Some points of consideration in lowering electrical loads are:

- daylighting design
- efficiency lighting
  - T8's
  - compact fluorescents
- appliances
  - high efficiency
  - dryer: outdoor drying,
  - refrigeration: free cool as ventilation preheat
  - cooking - fuel choice: gas, biomass
  - Ref: CMHC Energy Needs and Availability

. fans and pumps
- reduce/remove
- use high efficiency motors (e.g. CMHC fan study)
- use passive mechanical design

4.3 Thermal Load Reduction

Some points of consideration in lowering electrical loads are

. domestic hot water
- need to change expectations
- lower temperature supply
- reduce need for hot water (e.g. cold clothes or hand washing)

. space heating
- building design
  - passive solar
  - thermal mass
- envelope
  - high insulation levels
  - airtight
  - high performance glazing for high value and passive solar gains
  - reduction due to high radiant component in comfort equation
  - setback (not always applicable)

- space cooling
  - building design
    - shading (overhangs)
    - clerestories atria (free cooling)
    - siting for passive cooling, shading
  - envelope
    - same as for space heating, except high solar shading coefficient with high visible light transmittance
  - comfort issues
    - radiant component
    - humidity
    - air speed at skin

4.4 Electrical and Thermal Load Profile Modification

Goal: to maximize operation of cogeneration within efficient limits (continuous, mostly near optimum capacity)

- Thermal Storage
  - creates ability for fluctuating daily r thermal load to be satisfied with constant (daily average) supply
  - usually enlarged tank size for lower recovery rate (as per CMHC cogen study)

- Occupant Use Modification
  - voluntary or incented time of use
  - automatic demand management (e.g. control all washers and dryers to allow demand management)

4.5 Renewable Energy Use in Small Scale Cogeneration and District Heating

Wide scale use of gas cogeneration and community space heating can conceivably supply future electric power needs displacing central coal, nuclear, or new hydraulic stations at lower costs, reduced environmental impact, and with greater flexibility. Second law efficiencies of cogen could reduce overall fossil fuel usage and net carbon dioxide emissions by 50% for thermal and electrical loads. Nevertheless bonafide sustainability is only realizable with renewable energy supply. Where natural gas is available, current pricing makes most renewable options unattractive. Until adequate leadership and market intervention is addressed gas cogeneration with district heating should be viewed as a beneficial interim solution.

There are a number of ways that deployment of community energy systems are complementary to renewable energy options. These include:

1. Hot water generation using biomass, solar/thermal conversion, or thermal recovery;

2. Central thermal storage both short term and seasonal;

3. Biomass fuels including wood, solid waste, methane from anaerobic digestion of food, garden scraps, sewage, and landfill, agricultural fuels such as ethanol;

4. Decentralized electrical supply with photovoltaics, wind, small scale hydraulic, regenerative breaking energy systems;

5. Cooling distribution and renewable options.

Each of these aspects may shape the selection and design of a cogeneration community energy system.

4.5.1. Renewable Source Thermal Cogeneration

Wood-fired boilers using cut wood waste are in common usage with district heating systems. They are being commercialized in native communities but are deployed in cities such as the system in Ajax, Ontario. This is often the least cost fuel and is sometimes a negative cost where dumpage fees are high.

Solar collectors may also be productively employed with district heating so that rooftops and sites with solar exposure can supply equitably to all on the system. Domestic hot water heating would be supplied more cost-effectively than with individual systems. Direct solar cogeneration is also facilitated as with water-cooled photovoltaics or high-temperature collectors with steam turbines (see Spilling engines). Heat recovery from sources such as laundry facilities or refrigeration could also be added to a thermal distribution system.

4.5.2. Central Thermal Storage

Load diversity, economics of scale, and low surface-to-volume ratio all favour large scale communal thermal storage. Such systems ranging from diurnal up to seasonal storage have been employed in Europe, particularly in Sweden (i.e. regulation, benefits, operating conditions, sizing costs and efficiency of cogeneration equipment). Storage also accommodates intermittent renewable and thermal recovery sources.

4.5.3. Biomass Fuels

The infrastructure of district energy systems permits future conversion to biofuels. Wood from sustainable forestry may be the fuel of choice in more remote communities. Methane from curbside-pickup community composting and sewage treatment can be directly substituted while serving two other community needs (see Danish example from ICLEI). Transportable agricultural fuels may eventually displace fossil fuels making all sites operable with renewable energy.

4.5.4. Decentralized Electrical Supply

Where grid power is unfeasible, district energy systems employing renewables may be the least cost option. Electrical storage may be reduced or eliminated by running the cogenerator on demand when renewable supply is inadequate.

Even with grid connection there is a growing awareness of the merits of decentralized supply with its greater robustness and shortened power transmission.

4.5.5. Distribution and Renewable Options

Systems that incorporate district cooling distribution yield opportunity to supply "free cooling" from renewable sources. Seasonal storage as ice, deep lake or ground water sources, and absorption refrigeration are candidates for supply options.

5.0 Status of Small Cogeneration in Canada

As mentioned earlier in this report, the economic feasibility of cogeneration is largely determined by only a few key factors: the cost of fuel, electricity and cogeneration equipment. These are examined in further detail in this section, along with other non-economic factors affecting the viability of cogeneration.

- Fuel and Electricity Pricing

Natural gas prices have been relatively stable since the deregulation of the mid-1980's. However, recently short term prices have risen in light of increased export demand to the U.S. Methods of reducing long term price uncertainty for natural gas include entering into long term supply contracts with producers and transportation contracts with pipelines.

The transportation infrastructure for natural gas is regulated by provincial and federal energy boards. Major urban centers in western and central Canada are currently serviced. The eastern provinces are not part of the national pipeline system and therefore do not currently represent a viable natural gas fired cogeneration market. Included in this section is a listing of all towns in Ontario which currently have access to natural gas. Similar listings are available for other provinces from the Canadian Gas Association.

Those areas not served by natural gas face the alternative of oil-fired cogeneration or biomass fuels. The availability and economics of these fuel alternatives will determine the viability of cogeneration. In particular, for remote areas that do not have access to electricity from a provincial grid system, cogeneration using alternative fuels could remain viable.

The most recent EMR report "Electric Power in Canada - 1991" indicates that the average annual growth in unit revenue for electric utilities was 5.5 percent during 1981-90, while the national inflation rate, as measured by the CPI, was 5.9 percent over the same period. Electricity rates are regulated by provincial governments and are intended to cover a utility's costs, so rate increases tend to parallel the rate of inflation. Recent rate increases by Ontario Hydro, however, have been in excess of inflation for reasons including declining demand and the requirement for debt service of large nuclear facilities. Included in this section are comparative rates for electricity across Canada.

As the difference between electricity and fuel prices increases, cogeneration becomes more economically attractive. In some areas in Canada, the fuel/electrical differential is not high enough to warrant cogeneration investment. Furthermore, low prices for energy do not provide sufficient incentives to fully exploit energy efficiency enhancement measures as has been done in countries with considerably higher energy costs.

- Equipment

The technology of small cogeneration is mature and low risk. Reciprocating engines are approaching thermal efficiencies of 34 percent. Gas turbines have thermal efficiencies in the range of 20-40%, depending upon the size and model. In general, the smaller the turbine, the lower the efficiency and the higher the capacity cost.

Local availability of the technology remains important when considering life cycle aspects such as maintenance, spare parts and qualified operating personnel. Major U.S. suppliers are represented in Canada either by branch offices or through representative agents. Manufacturing is undertaken largely in the U.S. with packaging, installation and maintenance conducted locally.

- Electric Utility

Unlike some areas of the U.S., electrical utilities in Canada have no provision for reduction of customer energy consumption through the export of power to their grid for credit. Customers could reduce their electricity costs by buying power during times of high demand, and returning power during times of low demand. Credit to the customer would be at retail rates whenever net consumption is positive, and at wholesale rates in the case of net power production. This "electricity bank" approach would provide an incentive to develop cogeneration applications that use aggressive thermal load following (potentially operating at a low capacity factor.) This would allow a cogeneration design that better exploits the potential of the existing thermal load and achieves higher efficiency levels.

A central office at the utility level for dealing with electrical interface issues would avoid differing standards and levels of expertise currently experienced among the municipal utilities.

Current applications for wheeling are being delayed by Ontario Hydro while the policy undergoes review. A supportive wheeling policy on the part of utilities adds flexibility to cogenerators who are geographically dispersed.

Extending this concept further, a policy allowing the sale of power from a cogeneration plant to an unrelated buyer in an arm's length transaction eliminates the utility from the power generation sale. The role of the utility is then redefined to that of operating and maintaining the transmission infrastructure, similar to the role of TransCanada PipeLines in the natural gas realm.

Invoking legislation similar to PURPA in the US whereby utilities are bound to buy power from qualifying facilities if the cost is equal to or lower than the utility avoided cost would encourage independent power production. This could be linked to a minimum efficiency standard to ensure that cogeneration potential is maximized.

In Ontario, the major public utility is committed to maintaining its existing revenue base due to its significant debt burden. The utility is therefore not supportive of independent power production (and currently will not buy power from producers). Furthermore, the utility has recently contemplated an overt strategy of subverting load displacement cogeneration via a new "Load Retention Rate Structure" available only to those customers with both the capability and intention of developing an economically viable cogeneration project. This would result in a portion of the rate base, unable to cogenerate, subsidizing those who can.

- District Heating Infrastructure

District heating infrastructure is not well established in Canadian communities. Recently, major urban centers (Toronto, Kingston, Edmonton and Cornwall) have examined the feasibility of large scale district heating employing cogeneration.

Regulations concerning district heating infrastructure in all new housing developments, establishing its equivalence to electricity, communications, water, sewage services, would encourage local governments and developers to consider energy planning as part of the overall design.

- Financial

Availability of risk capital will determine the levels of cogeneration investment in this country. In an emerging market using unproven technology, debt providers will demand higher equity participation (say 50/50). Recent experience in the U.S., which now has a mature independent power generation market, has indicated that high debt/equity ratios of 90/10 are being offered, suggesting that the risk level has declined during the past decade as the technology, design and construction industries have matured.

Real interest rates affect the volume of investment capital available for cogeneration projects. Rates are affected by government fiscal and monetary policies. In the current environment, short term real interest rates are low, while long term interest rates are higher. This benefits the construction phase of financing, but places emphasis on those projects with shorter payback periods.

- Environmental

Environmental tax credits or carbon taxes provide incentives to consume less fuel and increase efficiency.

Tradeable emissions credits within a defined geographic region would establish a market to encourage installation of the most cost efficient emission reduction technologies.

- Attitude

The attitudes held by various stakeholders toward cogeneration technology is vitally important to the success of a project. Major cogeneration projects have been halted in the U.S. due to intense resistance within the local community. On the other hand, small cogeneration projects have been enthusiastically supported by communities faced with existing air pollution, high electricity costs and unemployment.

Governments and utilities attitudes can be reflected through policies which encourage the growth of the industry (tax incentives), encourage risk-taking (financial support for feasibility studies), and recognize the social benefits (environmental incentives).

- Existing Projects

In Table 5.1 is a recent summary of cogeneration projects installed in Ontario.

- Social Dimensions of District Heating

District energy systems within residential neighbourhoods have definite sociological implications. Community based ownership of the mechanical plant necessarily fosters inter-dependence between residents and cohesion within the community. Such inter-dependence presupposes the existence of a managerial framework through which to co-ordinate issues of tenureship and maintenance.

Given the resultant cohesiveness of communities which adopt district cogeneration this technology has to date been primarily adopted by Native, Co-op housing, retirement and church groups where inter-dependence and cohesion are the norm.

While such communities have been uniquely positioned to take such initiatives, barriers may exist in areas where affinity groups do not exist and where lifestyles have evolved towards independence and segregation between individuals. Hence, within new developments and urban residential neighbourhoods retrofitted with district energy systems the sociological implications will necessitate prior planning to make transition towards inter-dependence as painless as possible.

Here the managerial framework mentioned above is key, the specifics of which will require further study. The Condominium Act could have some bearing upon its makeup.

As well, architecture and planning may be used as a vehicle to articulate the specific goals of the managerial framework. Architecture may foster inter-dependence by providing places and spaces which encourage community gathering.

Further, the managerial framework and its architectural expression should be such that they readily facilitate the later inclusion of other communal systems, i.e. sewage, waste material handling, recycling, reusing, food production, etc

Table 5.1

Summary of Existing Cogeneration Projects in Ontario (under 1 MW)

Project	Location	Capacity	Date of Installation
Lutherwood School	Waterloo	20 kW	1989
Tage Hansen	Leamington	425 kW	1989
Union Gas	Chatham	30 kW	1990
Fanshawe College	London	60 kW	1990
Westbrook Greenhouse #1	Grimsby	550 kW	1991
Etobicoke Olympium	Etobicoke	250 kW	1991
Rosa Flora Greenhouse	Dunnville	2 x 800 kW	1992
Canada Trust	Kitchener	250 kW	1992
St. Vincent Hospital	Ottawa	420 kW	1993
Port Colborne Hospital	Port Colborne	150 kW	1993
Temiskaming Hospital	New Liskeard	225 kW	1993
W.G. Thompson	Port Albert	700 kW	1993
Mohawk College	Hamilton	810 kW	1993
Tatry Pathways	Mississauga	2 x 65 kW	1994
Warkworth Institution	Warkworth	570 kW	1994
Agriculture Canada	Vineland	265 kW	1994
Brock University	Thorold	8 x 800 kW	1994
CityHome	Toronto	100 kW	1994
Westbrook Floral	Grimsby	520 kW	1994
Kitchener City Hall	Kitchener	250 kW	1994
Orillia Hospital	Orillia	765 kW	1994

6.0 Cogeneration/ District Heating Conceptual Site Examples

6.1 General

A number of existing sites are used in this section as a means of demonstrating the potential application of cogeneration in various low rise residential applications. Sites were chosen to represent a cross section of urban and remote applications including various housing densities. The site characteristics are summarized in Table 6.1.

Sizes of cogeneration plant were based on load analysis estimated in Chapter 2 and modified to suit the characteristics of each site. The parallel generation interface is as per described in Chapter 3 for multiple units. In other words the costs estimates assume herewith are for a relatively simple import export interface from the cogeneration plant to the grid.

Cogeneration equipment and installation capital cost estimates are based on representative figures experienced in the size ranges discussed herewith. District heating cost estimates are included in section 6.6 of this chapter. These estimates are only for demonstration and screening analysis purpose and must be refined through a detailed feasibility study if a given site is selected for implementation

Table 6.1 Summary of Case Study Loads

Case Study Site Characteristics

Site	Dwelling type	Number of units	Area (ha)	Density (Units/ha)	Unit Peak Heating Load (kW)	Unit Daily DHW Load (kWh)	Unit Daily Electrical Load (kWh)	Total Peak Heating Load (kW)	Heating Load Density (kW/ha)	Total Average Electrical Load (kW)
1. Couchiching	Single	100	16.5	6	6.7	9	13	670	41	54
2. Ouje Bougoumou	Single	125	10.5	12	10.0	13	20	1,250	119	104
3. Fenwick Ave.	Low density	78	1.9	41	9.0	11	15	702	369	49
4. Bain Co-op	High density	260	2.2	118	5.0	11	15	1,300	591	163
5. Royce/Dupont	Low density	24	0.4	60	2.0	7	10	48	120	10

6.2 Generic Single Dwelling Unit

Any reasonably sized single dwelling unit could be used as a demonstration site for the cogeneration design developed in Chapter 3. A generic case study is developed in this section to demonstrated the economic merits of such an approach. The Kohler 5 kW cogeneration package costing is used as a reference.

Main elements

- 5 kW cogeneration package (Kohler or equiv.)
- 1500 gal hot water storage tank
- Back up hot water heater

Table 6.2

Conceptual Case: Single Unit Dwelling

Capital Cost Summary	
Cogeneration Plant Rating (kW)	5
Capital Cost ($)	
1) Cogeneration Plant	
Equipment supply	15,000
Installation	4,000
Cogeneration Plant Total	19,000
Total Estimated Capital Cost ($)	19,000
Total Capacity Cost ($/kW)	3,800

Economic Summary	
Number of Housing Units	1
Annual Operating Hours	4,000
Fuel Type	Natural Gas
Fuel Cost ($/m3)	0.22
Electricity Savings ($/kWh)	0.075
Average Heat Recovery (% of fuel input)	55
Electrical Conversion Efficiency (% of fuel input, LHV)	25
Operating and Maintenance Cost ($/kWh)	0.012
Simple Payback Period (years)	33

6.3 Frog Creek Subdivision

The Frog Creek subdivision is located within the Couchiching First Nation Indian Reserve in Fort Francis, Ontario. The subdivision is contained within a 16.5 hectare site. It is currently under construction and will contain some 100 homes at its completion yielding a density of 6.1 housing units per hectare. Refer to Figure 6.1 for an appreciation of the housing layout.

District Energy System Description

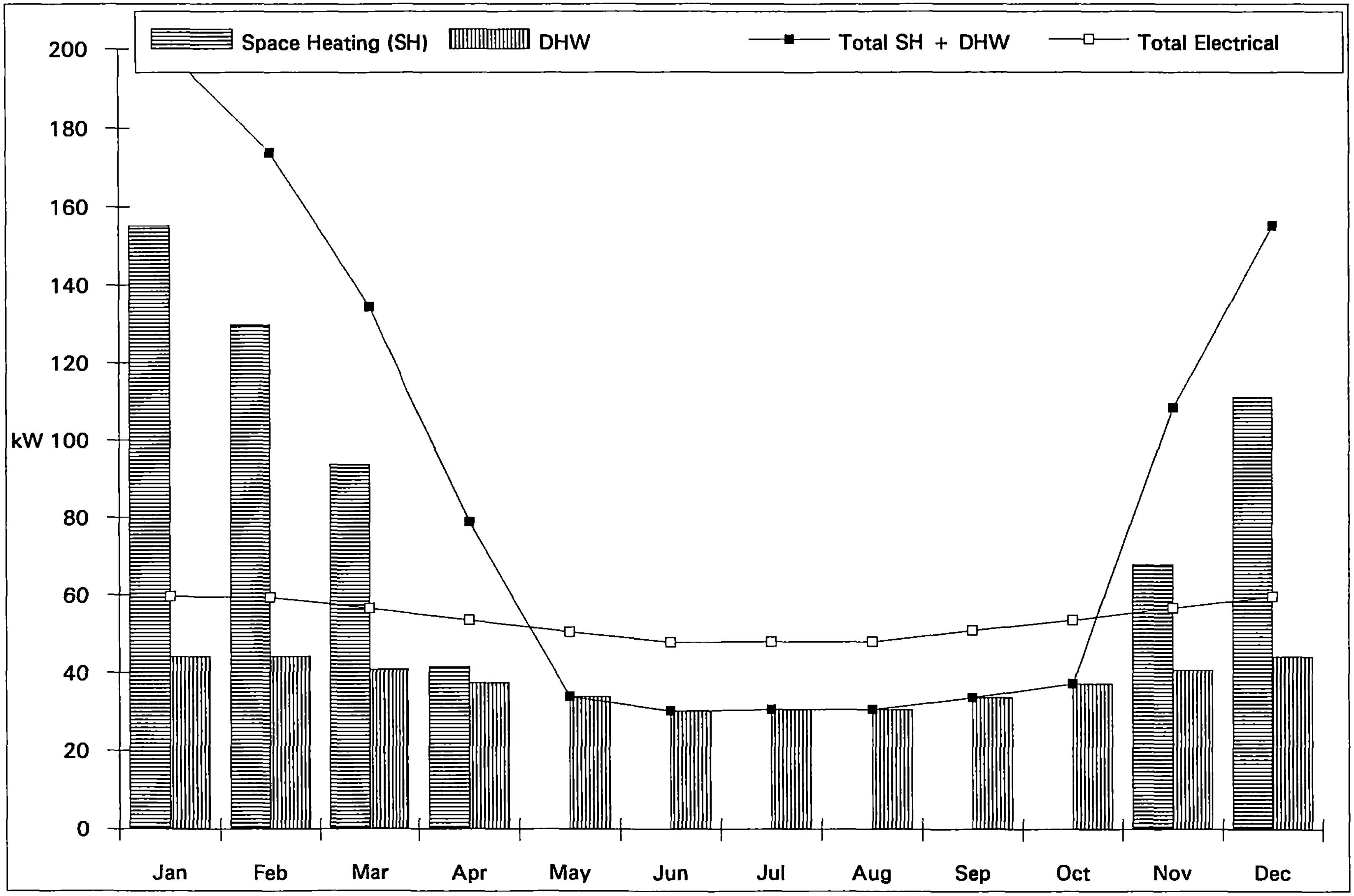
Base Case

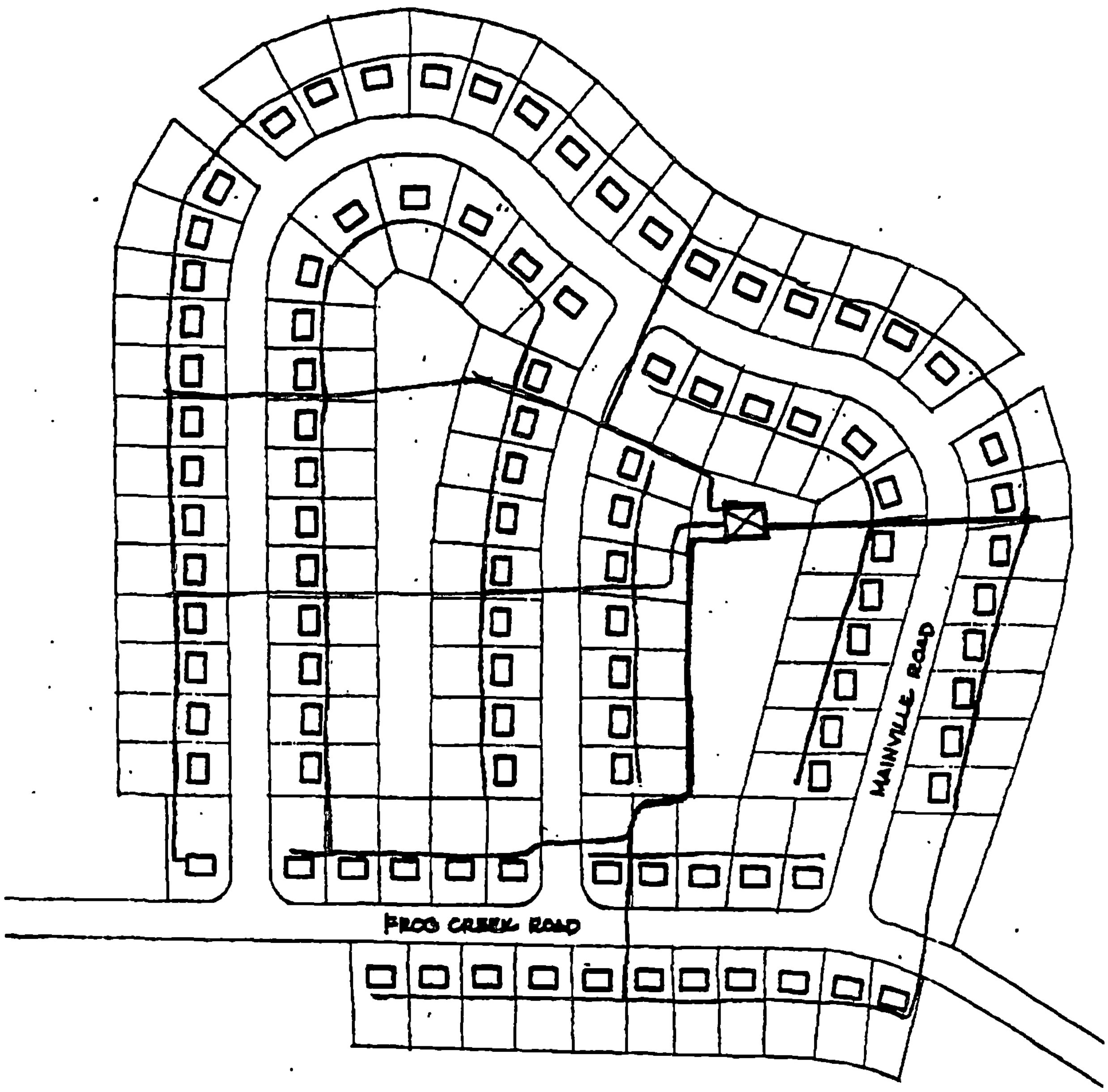
- energy upgraded envelope
- energy efficient lights and appliances
- 5 kW peak thermal load (space heating and DHW)
- individual oil furnaces, electric hot water tanks
- central a/c in each home (electric)
- grid connected electricity

Cogen/District Heating Case

- central plant c/w gas 60kW engine cogen set and backup gas boiler
- import/export parallel generation
- heat dumping radiators for waste heat
- combined space heating, DHW distribution piping to homes
- PEX piping (25 mm-65 mm dia.) with vermiculite fill, approximately 5100 m
- water supply 80°C, return 40°C
- system pressure 6 bar
- customer connection c/w direct connection to space heating; indirect DHW tank
- local electrical distribution

Case 1: Frog Creek
100 x Energy Upgrade Single Units





Project	Drawing Title	SCALE
CHMC Community Energy Systems	SITE No.1 FROG CREEK SUBDIVITION– COUCHICHING RESERVE FORT FRACIS, ONTARIO	1:3500 Fig 6.1

Table 6.3

Case 1: Frog Creek

Capital Cost Summary		
Cogeneration Plant Rating (kW)	60	60
Trenching Option	Insulated in trench	Preinsulated & Special
Capital Cost ($)		
1) Cogeneration Plant		
Equipment supply	150,000	150,000
- Cogeneration equipment		
- Boilers		
Installation	120,000	120,000
- Electrical and mechanical ties		
- Building		
Engineering	50,000	50,000
Cogeneration Plant Total	320,000	320,000
2) District Heating Infrastructure	160,000	600,000
3) Avoided cost of conventional DHW & heating system	(90,000)	(90,000)
Total Estimated Capital Cost ($)	390,000	830,000
Total Capacity Cost ($/kW)	6,500	13,833

Economic Summary		
Number of Housing Units	100	100
Annual Operating Hours	8,300	8,300
Fuel Type	Natural Gas	Natural Gas
Fuel Cost ($/m3)	0.18	0.18
Electricity Savings ($/kWh)	0.081	0.081
Average Heat Recovery (% of fuel input)	35	35
Operating and Maintenance Cost ($/kWh)	0.012	0.012
Simple Payback Period (years)	25	53
Simple Payback Period (years) (assuming district heating already in place)	15	same

6.4 Ouje-Bougoumou

The Ouje-Bougoumou Community was developed by native peoples of Cree aboriginal ancestry. It is located in northern Quebec, approximately 1000 km north of Montreal near the non-native towns Chibougamau and Chapais.

The community incorporates 125 single-family residences with various community buildings. The residential component is spread over roughly 10.5 hectares yielding a housing density of 12 housing units per hectare.

District Energy System Description

Base Case

- Phase 1 (1992-1994) - existing
- central plant c/w 900 kW waste wood chip boiler and peaking oil boiler (see KMW energy)
- district heating piping (two pipe)
- preinsulated PEX piping (25 mm-50 mm dia.)
- preinsulated steel piping (65 mm - 100 mm dia.)
- water supply 90°C, return 50°C
- system pressure 6 bar
- 125 x 10 kW homes (DHW and space heating)
- 450 kW of public buildings (DHW and space heating)
- grid connected electricity
- customer connection c/w direct connection to space heating; instantaneous DHW

Planned Future Development

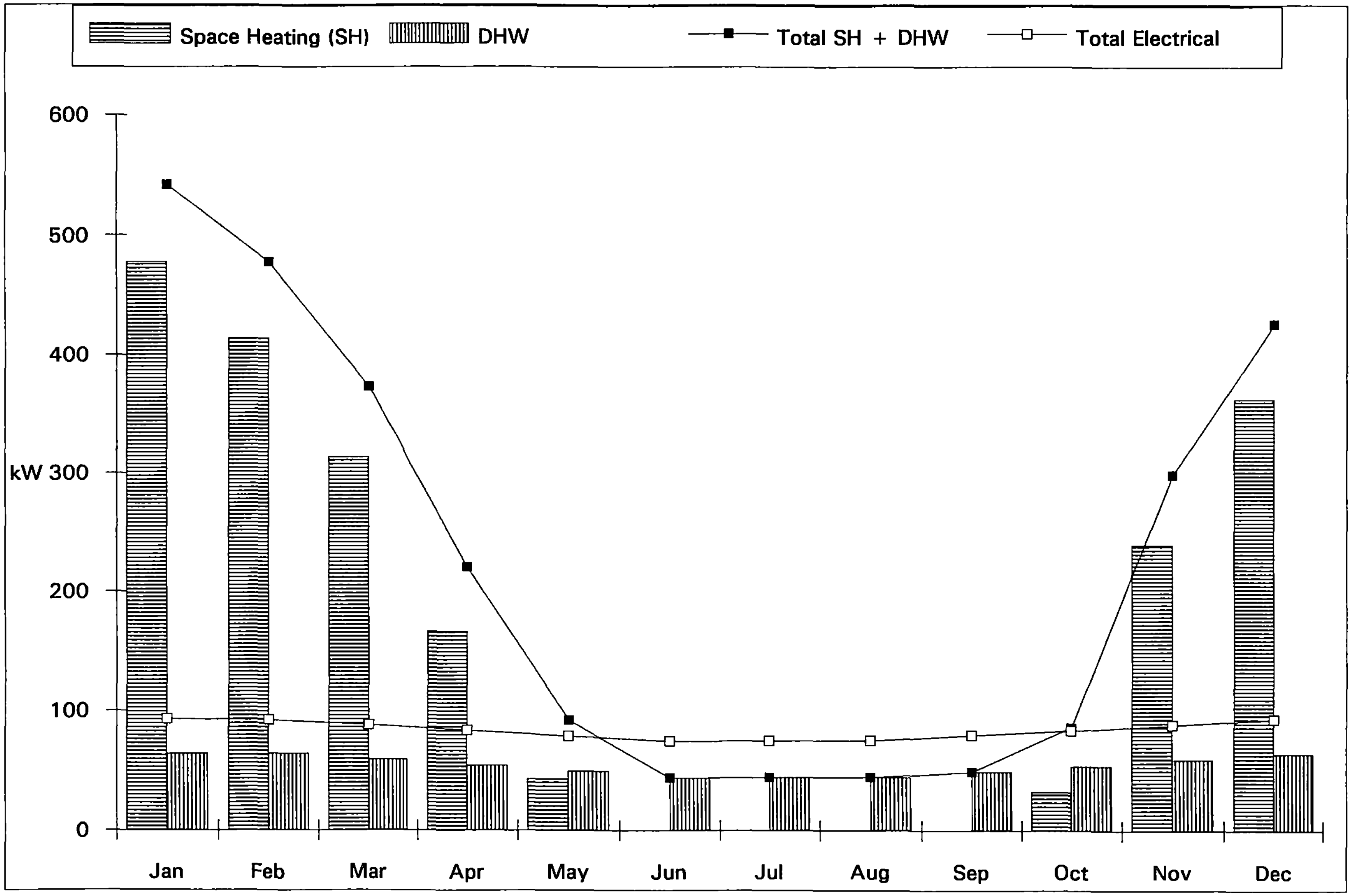
- Phase 2 (1995-1998) - add 50 residential units and piping to east of village (peak load 2200 kW)
- Phase 3 (1999-2002) - add 50 residential units and piping to north-east of village (peak load 2700 kW)
- Phase 4 (2003-2006) - add 60 residential units and piping to north-east of village (peak load 3300 kW)
- final thermal load (incl. 0.80 diversity) = 2640 kW

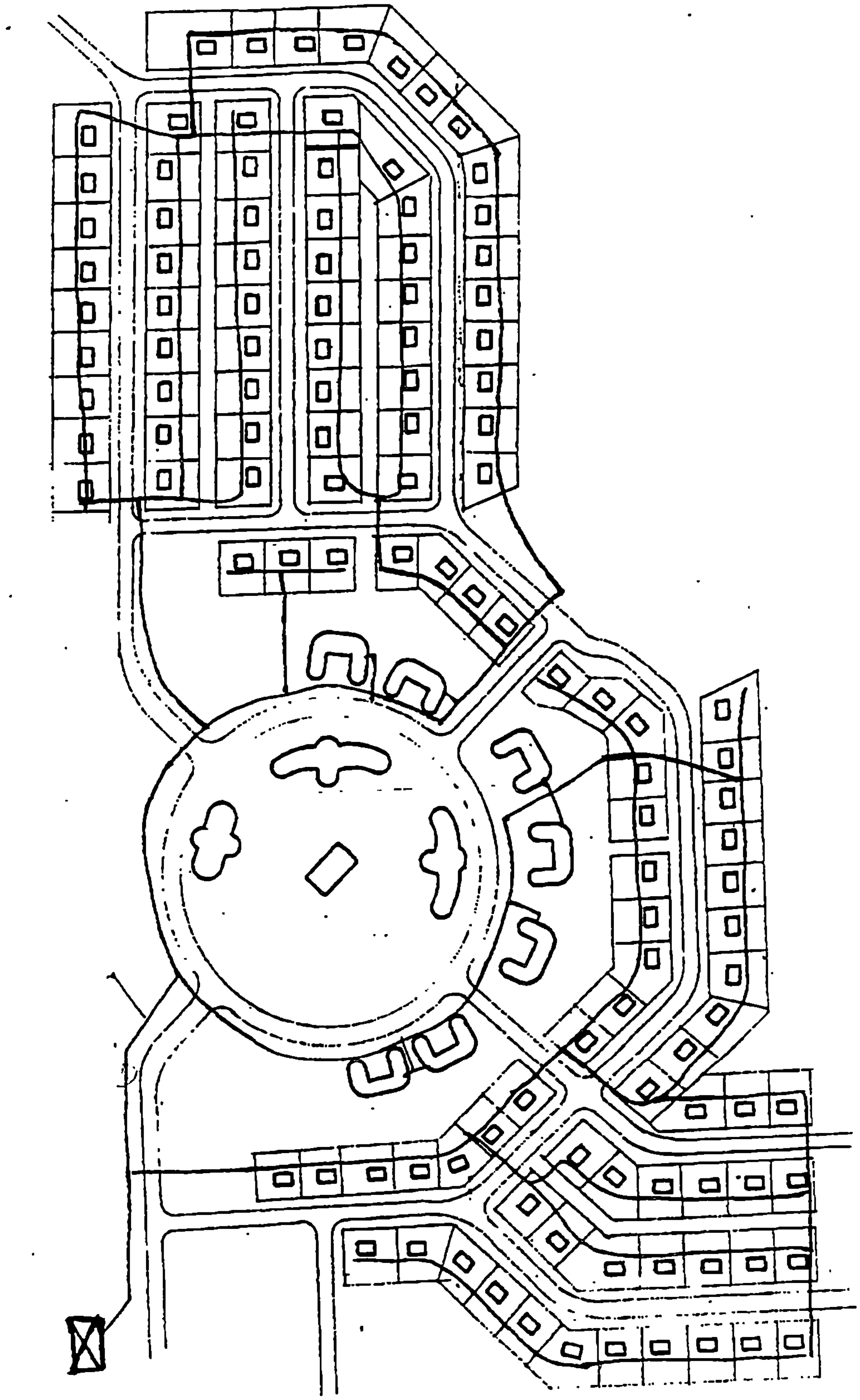
Cogen/District Heating Case

- central plant c/w diesel fired cogeneration set.
- import/export parallel generation connection
- heat dumping radiators for waste heat
- use of local electrical distribution system

- An option a novel steam based cogeneration scheme is suggested for further consideration . This would require modification of the existing wood fired boiler to produce higher pressure steam (200 psig nom.) Steam would be expanded through a Spilling steam to produce electricity and with a back pressure of approximately 15 psig to be condensed in a steam to hot water heat exchanger for district heating.

Case 2: Ouje Bougoumou
125 x NBC Single Units





Project	Drawing Title	SCALE
CHMC Community Energy Systems	SITE No.2 OUJE–BOUGOUMOU COMMUNITY QUEBEC	APPROX. 1:3500 Fig 5.2

Table 6.4

Case 2: Ouje Bougoumou

Capital Cost Summary	
Cogeneration Plant Rating (kW)	100
Trenching Option	Insulated in trench
Capital Cost ($)	
Cogeneration Plant	
Equipment supply	160,000
- Cogeneration equipment	
Installation	140,000
- Electrical and mechanical ties	
- Building	
Engineering	50,000
Cogeneration Plant Total	350,000
Total Estimated Capital Cost ($)	350,000
Total Capacity Cost ($/kW)	3,500

Economic Summary	
Number of Housing Units	125
Annual Operating Hours	8,300
Fuel Type	Diesel
Fuel Cost ($/gal)	1.90
Electricity Savings ($/kWh)	0.050
Average Heat Recovery (% of fuel input)	35
Operating and Maintenance Cost ($/kWh)	0.012
Simple Payback Period (years)	infinite
	(fuel cost > electricity savings)

6.5 Typical City Block - Fenwick Avenue

Fenwick Avenue represents a typical low-rise residential city block. The full extent of the site actually considered contains two blocks and is bound by Logan Avenue to the west, Carlaw Avenue to the east, Danforth Avenue to the north, McConnell Avenue to the south and is bisected by Fenwick Avenue which runs north-south.

These two blocks contain 78 housing units, 21 commercial units fronting Danforth Avenue and one school fronting Carlaw Avenue. The 78 housing units are distributed over a 1.9 hectare portion of the site yielding a density of 41 units per hectare.

The 78 units are distributed within 31 buildings. 6 of these are detached homes, 15 are semi-detached and 10 are row houses.

District Energy System Description

Base Case

- mixed efficiencies
- 78 x 10 kW homes (space heating and DHW)
- individual oil, gas and electric furnaces, electric or gas hot water tanks
- central a/c or local a/c in some homes (electric)
- grid connected electricity

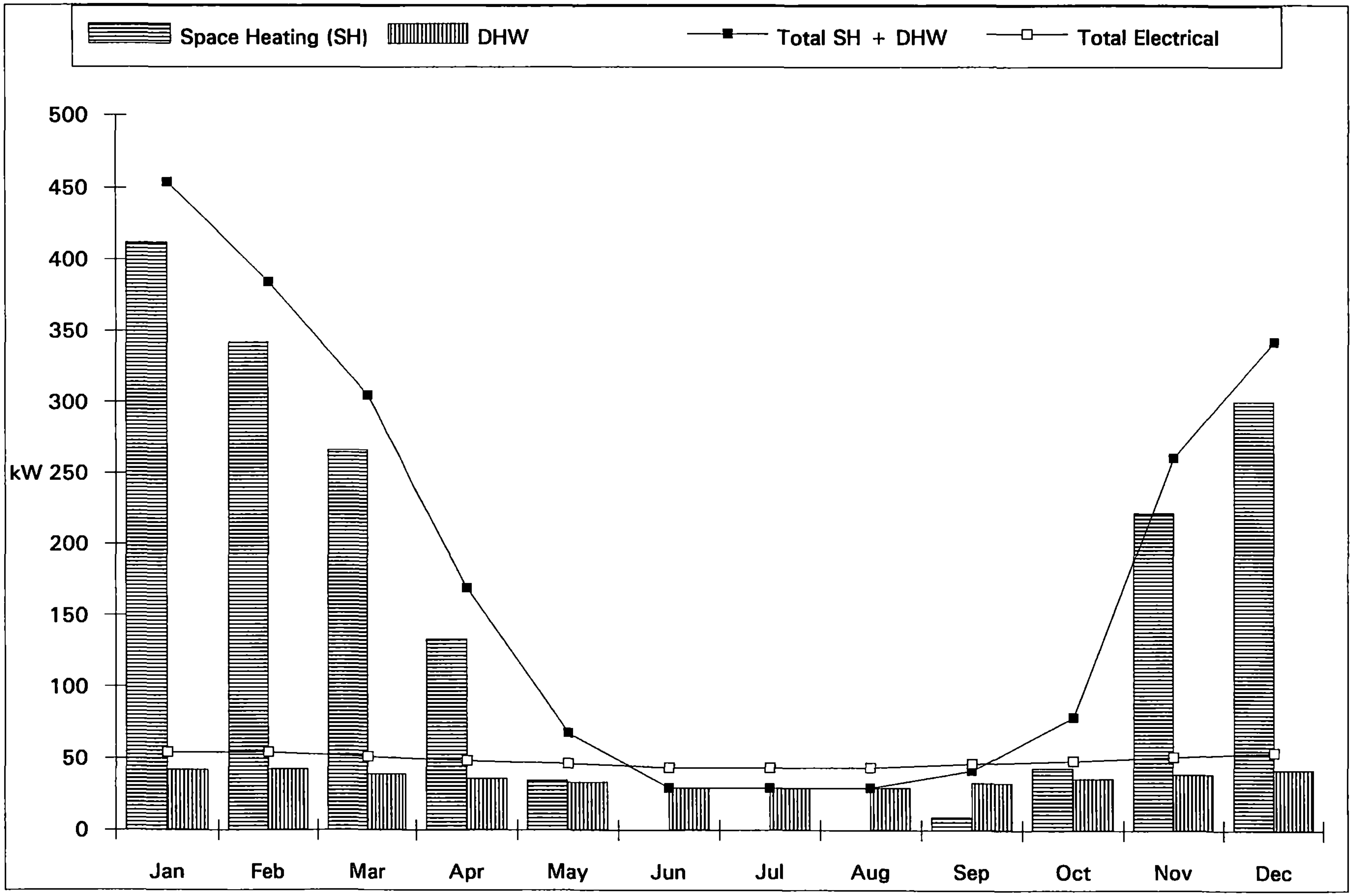
Cogen/District Heating Case

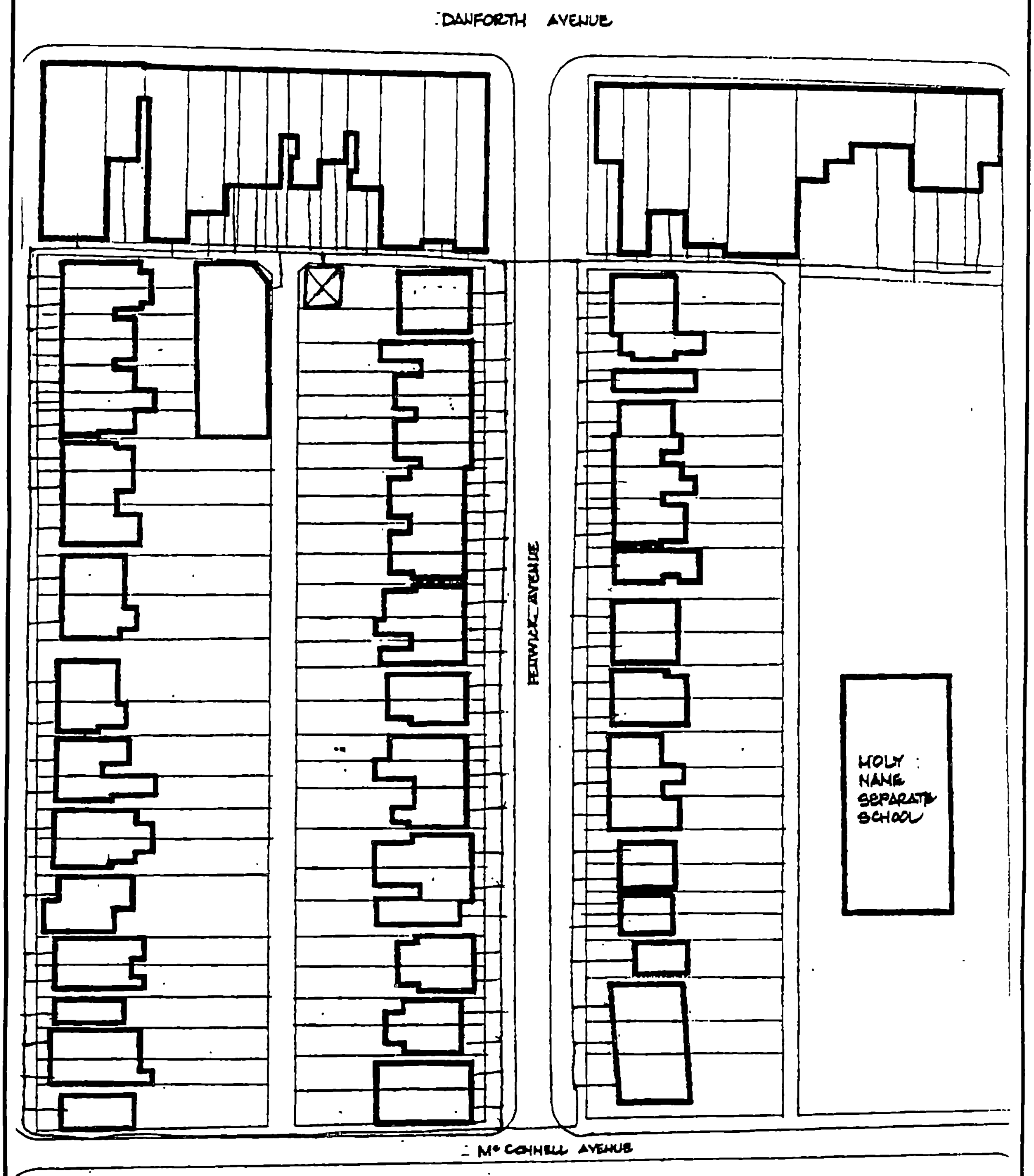
- central plant c/w gas engine cogen set and backup gas boiler
- electric load following cogen
- heat dumping radiators for waste heat
- combined space heating, DHW distribution piping to homes
- PEX piping (25 mm-65 mm dia.) with vermiculite fill, approximately 3600 m
- water supply 80°C, return 40°C
- system pressure 6 bar
- customer connection c/w direct connection to space heating; indirect DHW tank
- local electrical distribution

Cogen/ District Heating and Cooling Case

- central plant c/w gas engine cogen set and backup gas boiler
- electric load following cogen
- heat dumping radiators for waste heat
- PEX piping (25 mm-65 mm dia.) with vermiculite fill, approximately 7200 m
- separate secondary piping for DHW and space heating/cooling (total of 5 pipes including cold water)
- cooling provided by absorption chiller (1st stage) and electric chiller (2nd stage)
- electric chiller uses cogen electricity
- water supply 80°C, return 40°C
- system pressure 6 bar
- customer connection c/w direct connection to space heating/cooling loop; direct connection to DHW loop DHW tank in houses)
- local electrical distribution

Case 3: Fenwick Avenue
78 x NBC Low Density Units





Project	Drawing Title	SCALE
CHMC Community Energy Systems	SITE No.3 FENWICK AVENUE TORONTO, ONTARIO	APPROX. 1:1000
		Fig 6.3

Table 6.5

Case 3: Fenwick Ave.

Capital Cost Summary		
Cogeneration Plant Rating (kW)	50	50
Trenching Option	Insulated in trench	Preinsulated & Special
Capital Cost ($)		
1) Cogeneration Plant		
Equipment supply	130,000	130,000
- Cogeneration equipment		
- Boilers		
Installation	120,000	120,000
- Electrical and mechanical ties		
- Building		
Engineering	50,000	50,000
Cogeneration Plant Total	300,000	300,000
2) District Heating Infrastructure	150,000	475,000
3) Retrofit to interface to existing DHW & heating system	70,000	70,000
Total Estimated Capital Cost ($)	520,000	845,000
Total Capacity Cost ($/kW)	10,400	16,900

Economic Summary		
Number of Housing Units	78	78
Annual Operating Hours	8,300	8,300
Fuel Type	Natural Gas	Natural Gas
Fuel Cost ($/m3)	0.15	0.15
Electricity Savings ($/kWh)	0.075	0.075
Average Heat Recovery (% of fuel input)	35	35
Operating and Maintenance Cost ($/kWh)	0.012	0.012
Simple Payback Period (years)	40	64
Simple Payback Period (years) (assuming district heating already in place)	28	same

6.6 Bain Apartment Co-operative

The Bain Apartment Co-operative represents an 80 year old, high-density, low-rise building complex. It is situated along Bain Avenue in Riverdale, an urban community within Toronto.

The complex is contained within a 2.2 hectare site distributed on two plots of land on opposite sides of Bain Avenue. The complex contains a total of 260 housing units distributed within 25 buildings, yielding a density of 118 units per hectare.

23 of these buildings are three storey stacked with basements where each bay contains two units: one occupying the basement and first floor and the second occupying the second and third floor. 2 of the buildings are semi-detached and one is a four-plex.

The complex contains a central mechanical plant distributing steam.

District Energy System Description

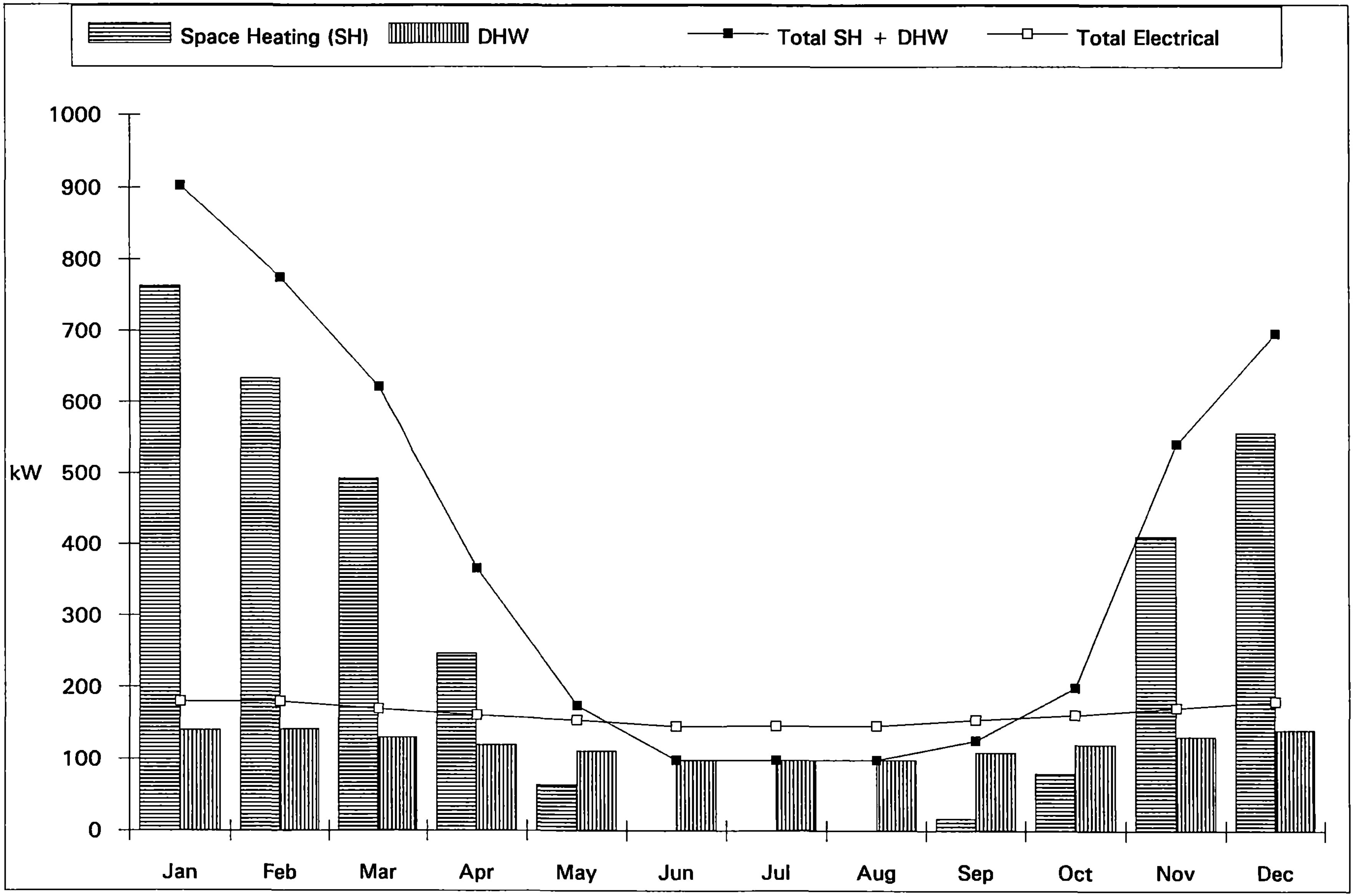
Base Case

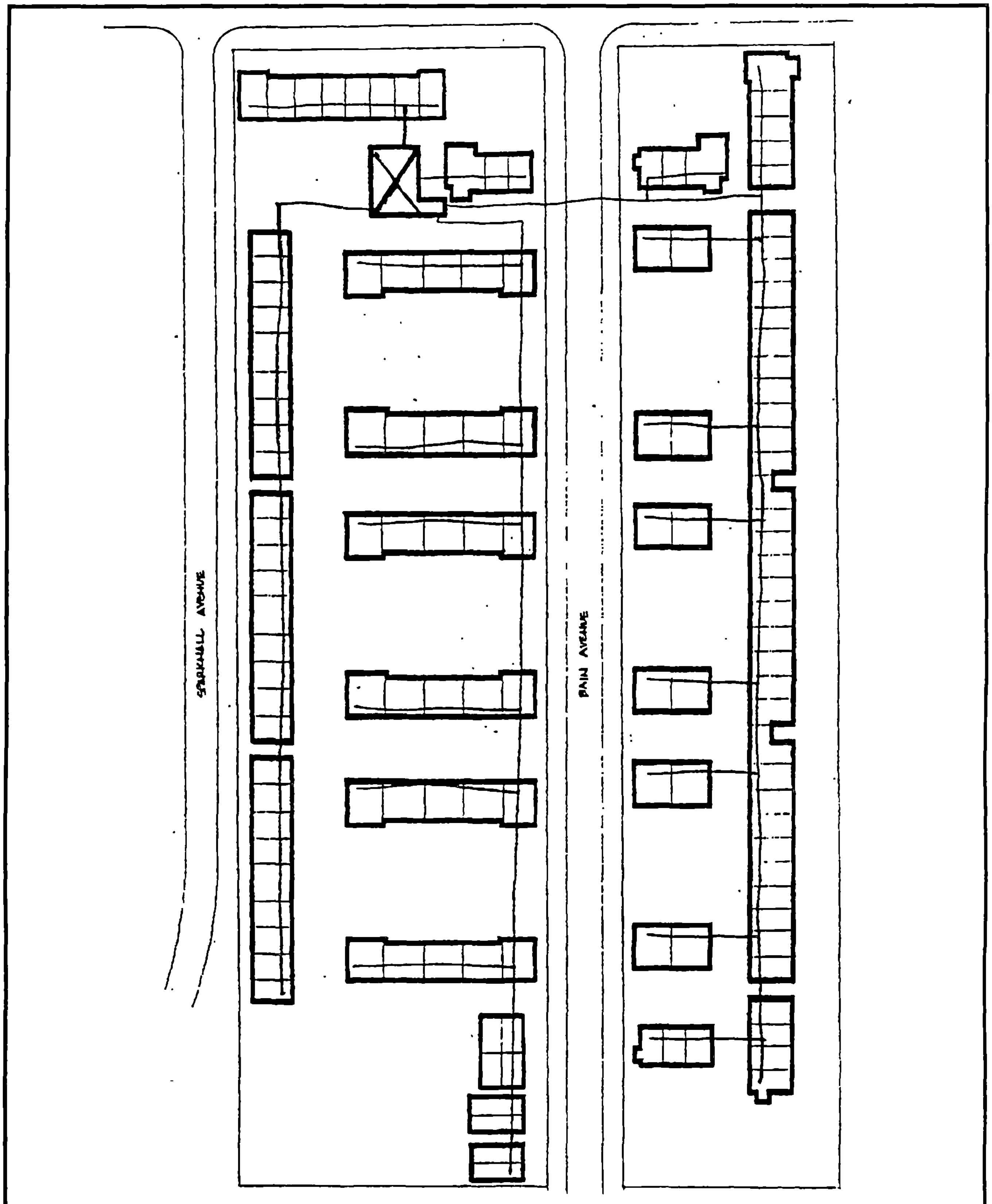
- 260 x 7 kW homes (space heating and DHW)
- existing gas-fired boiler with steam distribution piping providing space heating and indirect DHW
- decentralized domestic hot water tanks in each building
- local a/c in some units
- grid connected electricity

Cogen/District Heating Case

- central plant c/w gas engine cogen set and backup gas boiler
- electric load following cogen
- heat dumping radiators for waste heat
- retrofit steam distribution system for hot water distribution
- water supply 80°C, return 40°C
- system pressure 6 bar
- customer connection c/w direct connection to space heating
- domestic hot water via building tanks as before
- local electrical distribution

Case 4: Bain Co-op
260 x NBC High Density Units





Project	Drawing Title	SCALE
CHMC Community Energy Systems	SITE No.4 BAIN APARTMENT CO-OPERATIVE TORONTO, ONTARIO	APPROX. 1:1000 Fig 6.4

Table 6.6

Case 4: Bain Co-op

Capital Cost Summary		
Cogeneration Plant Rating (kW)	180	180
Trenching Option	Insulated in trench	Preinsulated & Special
Capital Cost ($)		
1) Cogeneration Plant		
Equipment supply	200,000	200,000
- Cogeneration equipment		
- Boilers		
Installation	180,000	180,000
- Electrical and mechanical ties		
- Building		
Engineering	60,000	60,000
Cogeneration Plant Total	440,000	440,000
2) District Heating Retrofit (Hot water to steam)	140,000	375,000
3) Miscellaneous interface to DHW & heating system	100,000	100,000
Total Estimated Capital Cost ($)	680,000	915,000
Total Capacity Cost ($/kW)	3,778	5,083

Economic Summary		
Number of Housing Units	260	260
Annual Operating Hours	8,300	8,300
Fuel Type	Natural Gas	Natural Gas
Fuel Cost ($/m3)	0.15	0.15
Electricity Savings ($/kWh)	0.075	0.075
Average Heat Recovery (% of fuel input)	35	35
Operating and Maintenance Cost ($/kWh)	0.012	0.012
Simple Payback Period (years)	14	19

6.7 Royce/Dupont

The Royce/Dupont site is located north of Dupont Street in Toronto with frontages on Perth Avenue to the west and Symington Avenue to the east. The site is bounded to the north by the CP right-of-way approximately 90m north of the site.

The site occupies 0.4 hectares of land. 18 buildings which once stood on the site have been demolished making it available for residential development. Estimates suggest that the site could support 100 housing units in a three storey development thus yielding a housing density of 250 housing units per hectare.

District Energy System Description

Base Case

- energy upgraded envelope
- efficient lights and appliances
- 100 x 2 kW units (space heating and DHW)
- in-suite water loop heat pumps (heat/cool)
- central heating plant - gas fired
- central chilling plant - electric
- cooling tower for chillers
- central DHW tank - gas fired
- grid connected electricity

Cogen/District Heating Case

- central plant c/w gas engine cogen set and backup gas boiler
- electric load following cogen
- heat dumping radiators for waste heat
- combined space heating, DHW distribution piping to homes
- preinsulated PEX piping (25 mm-65 mm dia.), approximately 550 m
- water supply 80°C, return 40°C
- system pressure 6 bar
- customer connection c/w direct connection to space heating; indirect DHW tank
- local electrical distribution

Cogen/District Heating and Cooling Case

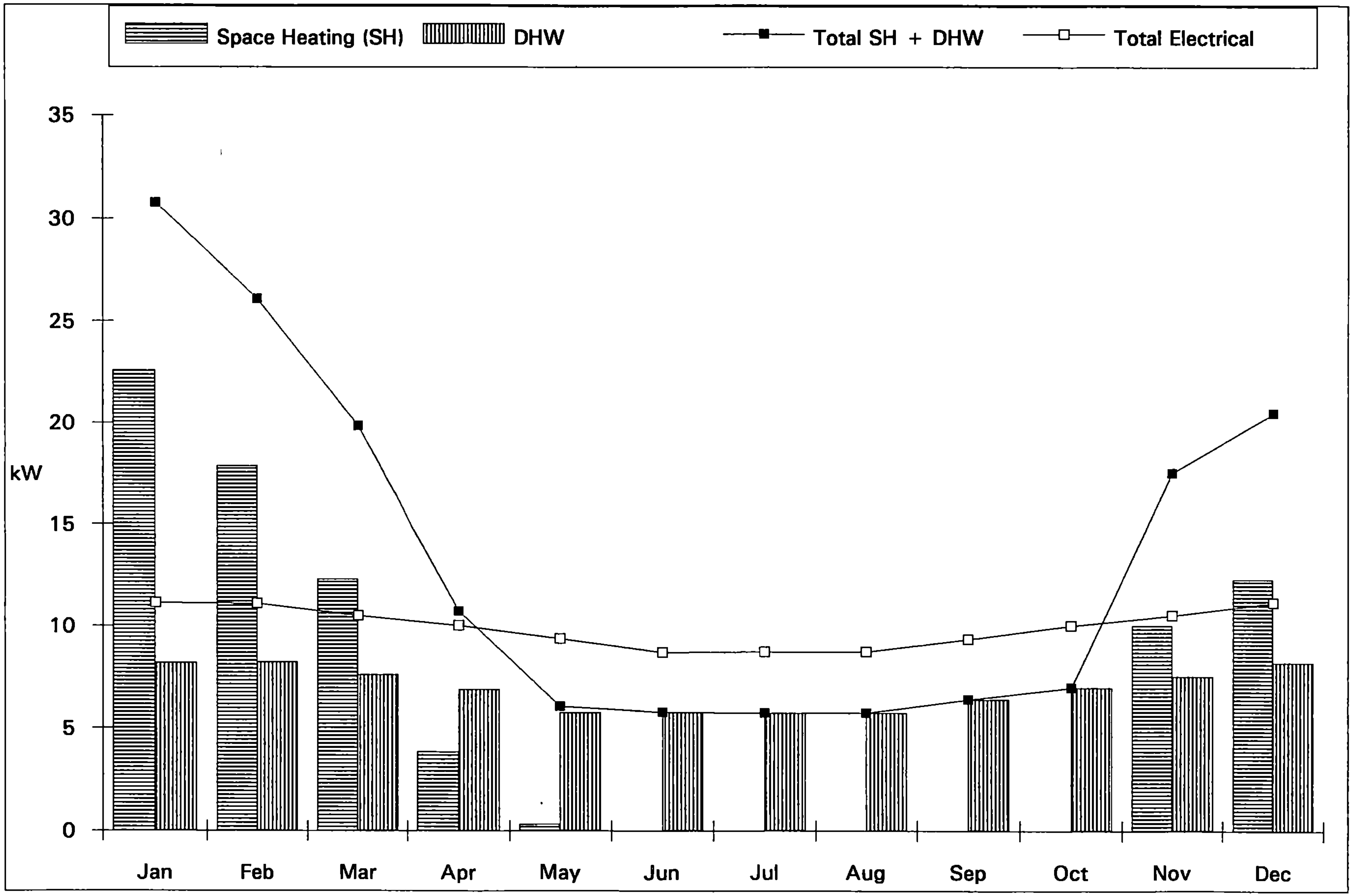
- central plant c/w gas engine cogen set and backup gas boiler
- electric load following cogen
- heat dumping radiators for waste heat
- cooling provided by absorption chiller (1st stage) and electric chiller (2nd stage)
- absorption chiller uses waste heat from cogen
- electric chiller uses cogen electricity
- preinsulated PEX piping (25 mm-65 mm dia.), approximately 1100 m

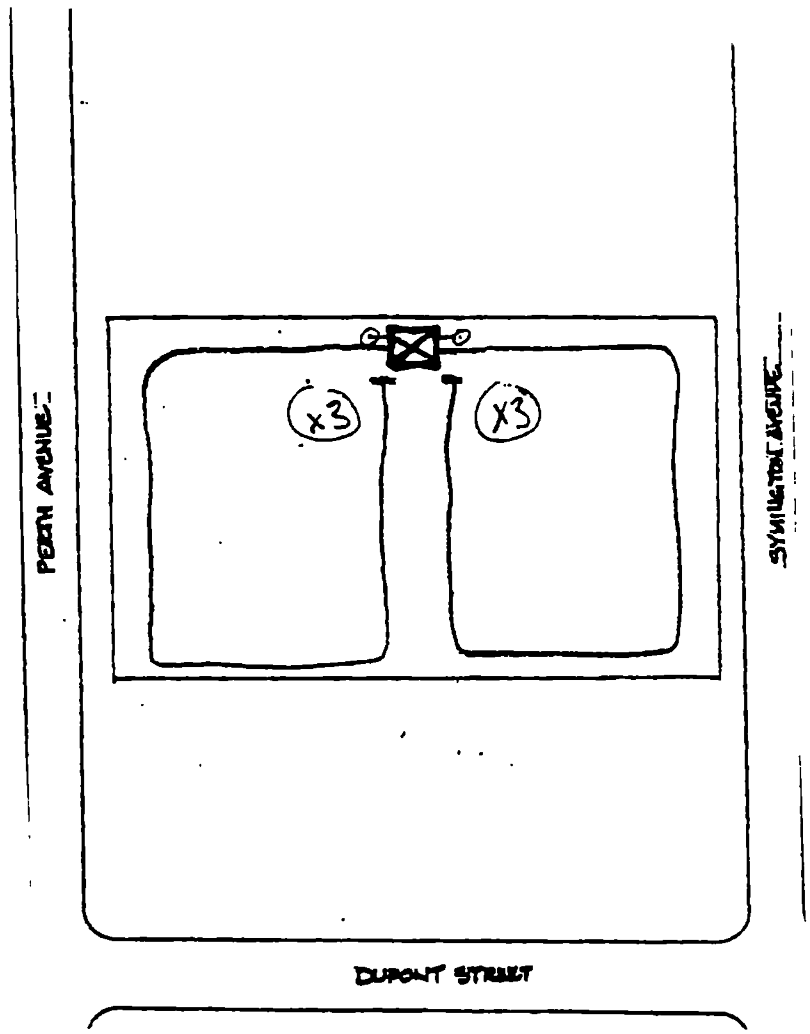
6.8 Summary of District Heating Cost Estimates

Table 6.6 outlines estimated total piping and trenching costs for the case studies analysed in this section for several scenarios as follows:

- Base case (1a) is PEX piping with vermiculite insulation backfill, native backfill, and trenching in medium soil.
- Case 2a uses preinsulated PEX for areas where drainage is an issue.
- Case 3a uses preinsulated PEX and special backfill (gravel and sand) for areas such as roads, where compaction and settling are key factors.
- Case 1b, 2b and 3 b are the same as above except the soil is rock, requiring pneumatic hammers for excavation.

Case 5: Royce/Dupont
24 x Energy Upgrade Low Density Units





Project	Drawing Title	SCALE
CHMC Community Energy Systems	SITE No.5 ROYCE/DUPONT STREET TORONTO, ONTARIO	1:1000
		Fig 6.5

Table 6.7

Case 5: Royce/Dupont

Capital Cost Summary		
Cogeneration Plant Rating (kW)	10	10
Trenching Option	Insulated in trench	Preinsulated & Special
Capital Cost ($)		
1) Cogeneration Plant		
Equipment supply	20,000	20,000
- Cogeneration equipment		
- Boilers		
Installation	30,000	30,000
- Electrical and mechanical ties		
- Building		
Engineering	30,000	30,000
Cogeneration Plant Total	80,000	80,000
2) District Heating Infrastructure	20,000	47,000
3) Avoided cost of conventional DHW & heating system	(21,600)	(21,600)
Total Estimated Capital Cost ($)	78,400	105,400
Total Capacity Cost ($/kW)	7,840	10,540

Economic Summary		
Number of Housing Units	24	24
Annual Operating Hours	8,300	8,300
Fuel Type	Natural Gas	Natural Gas
Fuel Cost ($/m3)	0.15	0.15
Electricity Savings ($/kWh)	0.075	0.075
Average Heat Recovery (% of fuel input)	35	35
Operating and Maintenance Cost ($/kWh)	0.012	0.012
Simple Payback Period (years)	30	40
Simple Payback Period (years) (assuming district heating already in place)	22	same

6.9 Discussion of Results

None of the sites offer an application which "stands out" as a potential champion based on conventional investment criteria. However the following remarks are made:

- The cost of retrofitting existing multiple unit housing development to district heating is generally unattractive if the cost is borne by the savings generated by the cogeneration plant.

- The Bain Cooperative shows the most promise as a potential site. The facility has high housing density. District heating infrastructure is existing, but must be reviewed in detail to determine the actual cost to retrofit the district heating from steam to hot water.

- The development of a small cogeneration package suitable for single unit housing could be considered. However the experience has been in other cases that the resulting capital costs are usually too high.

- The option of using a steam engine at the Ouje Bougoumou site should be reviewed.

Table 6.8 District Heating Infrastructure Cost Summary

Piping	Meters				
Diameter (mm)	1 Couchiching	2 Ouje Bougoumou	3 Fenwick Ave	4 Bain Co-op	5 Royce/Dupont
90	0	4000	0	0	0
75	0	0	0	400	0
63	800	1200	1200	300	0
50	500	1200	600	400	0
40	500	2000	400	200	350
32	700	600	200	400	100
28	400	600	200	1000	50
22	2200	2000	1000	300	50
Total	5100	11600	3600	3000	550

	Preinsulated PEX (material cost, installed)				
Diameter (mm)	$1 Couchiching	$2 Ouje Bougoumou	$3 Fenwick Ave	$4 Bain Co-op	$5 Royce/Dupont
90	$0	$604,800	$0	$0	$0
75	$0	$0	$0	$62,160	$0
63	$82,880	$124,320	$142,080	$41,070	$0
50	$37,800	$90,720	$51,840	$39,960	$0
40	$25,200	$100,800	$23,040	$13,320	$23,310
32	$31,360	$26,880	$10,240	$23,680	$5,920
28	$14,560	$21,840	$8,320	$48,100	$2,405
22	$61,600	$56,000	$32,000	$11,100	$1,850
Total	$253,400	$1,025,360	$267,520	$239,390	$33,485

	PEX with Vermiculite (material cost, installed)				
Diameter (mm)	1 Couchiching	2 Ouje Bougoumou	3 Fenwick Ave	4 Bain Co-op	5 Royce/Dupont
90	$0	$380,400	$0	$0	$0
75	$0	$0	$0	$39,780	$0
63	$39,120	$58,680	$66,480	$19,155	$0
50	$17,850	$42,840	$24,120	$18,420	$0
40	$14,550	$58,200	$13,040	$7,430	$13,003
32	$15,750	$13,500	$5,000	$11,300	$2,825
28	$7,680	$11,520	$4,240	$23,800	$1,190
22	$34,980	$31,800	$17,400	$5,805	$968
Total	$129,930	$596,940	$130,280	$125,690	$17,985

Trenching		($/m)			
System/ Soil	Trenching	Gravel & Geotextile	Backfilling Native	Sand	Cost per m of trench
1a. Insulated in trench	7	0	6	0	$13
2a. Preinsul + native	7	0	6	0	$13
3a. Preinsul + special	7	25	3	12	$47
1b. Insulated in trench	91	0	18	0	$109
2b. Preinsul + native	91	0	9	0	$100
3b. Preinsul + special	91	25	9	12	$137

Soil types: a. medium soil b. rock

	1 Couchiching	2 Ouje Bougoumou	3 Fenwick Ave	4 Bain Co-op	5 Royce/Dupont
Meters of Trench	2500	5000	1500	1000	100
System/Soil					
1a	$32,500	$65,000	$19,500	$13,000	$1,300
2a	$32,500	$65,000	$19,500	$13,000	$1,300
3a	$117,500	$235,000	$70,500	$47,000	$4,700
1b	$272,500	$545,000	$163,500	$109,000	$10,900
2b	$250,000	$500,000	$150,000	$100,000	$10,000
3b	$342,500	$685,000	$205,500	$137,000	$13,700

Total Distribution System (Piping & Trench)

System/ Soil	1 Couchiching	2 Ouje Bougoumou	3 Fenwick Ave	4 Bain Co-op	5 Royce/Dupont
1a	$162,430	$661,940	$149,780	$138,690	$19,285
2a	$285,900	$1,090,360	$287,020	$252,390	$34,785
3a	$370,900	$1,260,360	$338,020	$286,390	$38,185
1b	$402,430	$1,141,940	$293,780	$234,690	$28,885
2b	$503,400	$1,525,360	$417,520	$339,390	$43,485
3b	$595,900	$1,710,360	$473,020	$376,390	$47,185

7.0 Conclusions and Recommendations

- The implementation of cogeneration in multi unit low rise housing development can offer substantial environmental and operating cost savings benefits but also poses some challenges.

- The technology required to implement cogeneration is well proven. Numerous cogeneration projects have been implemented in recent years in the residential, commercial and institutional load displacement market. They range in size from 15kW to multiple units of 800 kW. Of note is the fact that the majority of the smaller projects were implemented as part of demonstration projects with marginal economic performance. On the other hand, the larger projects (500 kW +/-) offer very attractive operating cost savings and attractive rates of return.

- The main difficulties identified in this report for the implementation of cogeneration in multiple unit low rise housing development are as follows:

  - A cogeneration plant's cost effectiveness increases with plant pant size. In order to attain a reasonable plant size, a relatively large number of dwellings must be combined via a district heating infrastructure to common the space heating, domestic hot water and potentially space cooling loads. The cost of this infrastructure is quite significant and when compared to the conventional energy supply option it makes the rate of return on the overall proposition relatively unattractive by conventional investment standards.

  - The routing of electrical power from the cogeneration plant to the individual housing units could be achieved in a number of ways. Using the utility distribution system is the only cost effective approach for large number of units. Parallel generation is a well proven concept, however the difficulties that arise here are regulatory in nature. Ownership of the plant and wheeling and power purchasing options must be carefully reviewed in light of the prevailing regulations. In the end the value of the electricity produced must remain high enough relative to the fuel used to offer acceptable operating cost savings.

- The main difficulty identified in implementing cogeneration in a single housing unit is as follows:

  - There is no small cogeneration package (5 kW +/-) available in the local marketplace suitable for this application.

  - The thermal and electrical loads are inherently "mismatched" on an instantaneous basis due to the poor diversity factor of a single dwelling. Thermal storage combined with the use of the electrical grid as "electrical bank" is required to operate the cogeneration at optimum efficiency. The latter proposition would need a change of attitude by electrical utilities.

  - A small generator in this size range will have a high installed cost per unit of power output. The need for thermal storage and backup heat supply also increases the cost of the overall project.

- Natural gas price at the residential level tend to be higher then the gas price of larger loads.
- Preliminary costing and economic performance analysis indicate this option to be relatively unattractive from an economic point of view.

. Five sites were studied in this report for potential application of cogeneration. The design of the cogeneration systems and district heating infrastructures were conceptual in nature and costing on a preliminary basis. None of the sites offer an application which "stands out" as a potential champion based on conventional investment criteria. However the following remarks are made:

- The option of using a steam engine at the Ouje Bougoumou site should be reviewed.
- The Bain Cooperative shows the most promise. The facility has high housing density. District heating infrastructure is existing, but must be reviewed in detail to determine the actual cost to retrofit from steam to hot water.

. New housing developments should consider common district heating/cooling option at the design stage to overcome some of the retrofit costs. However, regulatory issues associated with ownership and power distribution and savings sharing must be reviewed.

. The environmental benefits of cogeneration as compared to conventional energy supply options are very significant and should be considered when making a design choice. This criterion weighs heavily in the framework of "Healthy Housing." However, it is difficult to translate into the "boardroom" of potential developers. Some incentives are needed at this level.

APPENDIX A

LOAD ANALYSIS SUPPORT DATA

Appendix A-1

THERMAL ENVELOPE

Two thermal envelopes were considered; NBC (National Building Code) and Energy Upgrade. The Energy Upgrade option exhibits the following improvements over the NBC house:

- Improved insulation levels;
- High performance windows (triple glazed double low E, double argon, in single unit dwelling, double glazed single low E, single argon, in high density low rise dwelling, insulated edge spacer, insulated fibre glass frame);
- Solar dominant glazing or, if not possible, other equivalent thermal improvements;
- Water efficient fixtures;
- More efficient appliances and light fixtures;
- Architectural design which allows adequate daylighting to offset use of lighting during daytime hours;
- Improved ventilation strategies using heat recovery ventilators with low fan power;
- In the High Density Low Rise Dwelling balanced room by room ventilation is provided;
- In all dwelling types the OBC Part 9 new ventilation standard has been applied.

Table A-1 and A-2 each delineate the insulation values for the above and below grade walls, floor slabs, windows, doors, ceiling components and air exchange due to infiltration and mechanical ventilation as they apply to the Single Unit Dwelling, the Low Density Dwelling and the High Density Dwelling.

Insulation values for corresponding building components differ in Table A-1 and A-2 due to the variation in construction practices and perceived economics.

In Table A-1, although the insulation values are the same for the Single Unit Dwelling and for the Low Density Low Rise Dwelling, the infiltration of building envelope and mechanical ventilation values differ and are specified separately in the table.

The Single Dwelling Unit option is based upon actual data for a single detached unit. The High Density Dwelling Unit option is based upon actual data derived from a 300 unit apartment building. The Low Density Dwelling Unit envelope is thermally similar but adjustments have been made to infiltration to account for the relatively lower exterior envelope.

Table A-1

SINGLE UNIT DWELLING & LOW DENSITY DWELLING

COMPONENT	NBC	ENERGY UPGRADE
Insulation Levels: R S I		
Above Grade Walls	3.50	4.75
Below Grade Walls	2.10	4.00
Floor Slabs	0.20	2.00
Windows	0.35	0.77
Doors	1.20	1.20
Ceilings	5.60	7.00
Air Exchange: AC/h (L/s)		
Single Unit Dwelling:		
Air Infiltration	0.30 (47.5)	0.05 (8.0)
Mech. Ventilation	0	0.22 (35)
Low Density Low Rise Dwelling		
Air Infiltration	0.25 (30.0)	0.04 (5.0)
Mech. Ventilation	0	0.23 (27)
Heat Recovery Effectiveness	0	75%

Table A-2

HIGH DENSITY DWELLING

COMPONENT	NBC	ENERGY UPGRADE
Insulation Levels: R S I		
Above Grade Walls	3.00	4.85
Floor Slabs	0.50	4.00
Windows	0.26	0.50
Ceilings	3.50	5.00
Air Exchange: AC/h (L/s)		
Air Infiltration	0.93 (63.5)	0.05 (3.4)
Mech. Ventilation	0	0.77 (24)
Heat Recovery Effectiveness	0	70%

Appendix A-2

CLIMATIC VARIATIONS FOR SPACE HEATING

	HEAT LOAD	ANNUAL ENERGY CONSUMPTION
NATIONAL BUILDING CODE & ENERGY UPGRADE		
Ottawa	100%	100%
Vancouver	67%	52%
Winnipeg	121%	135%
Edmonton	114%	118%
Fredericton	99%	88%
Toronto	84%	81%
Montreal	99%	95%
Halifax	81%	92%
St. John's	78%	122%

Appendix A-3

USER PROFILE CHARACTERISTICS

	WEIGHTING
3 Person 2 adults, 1 child 1 parent at home with child, 1 working	0.25
3 Person 2 adults, 1 child 2 parents working, child at daycare	0.25
3 Person 1 adult, 2 children 1 parent at home with children	0.15
4 Person 2 adults, 2 children 1 parent at home with children, 1 working afternoon shift	0.10
4 Person 2 adult, 2 child 2 parents working, children at school	0.25
	---- 1.00