Energy and Urban Form: Special Feature

Energy Implications of Provision of Municipal Infrastructure for Suburban Development

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This paper is a synthesis of existing research in the areas of suburban development, municipal infrastructure and embodied energy analysis. A considerable amount of interest has been generated in the area of neotraditional development, which is now popularly referred to as "new urbanism". Instead of low-density, single-family housing development seasoned with intermittent strip-malls and box stores, the emphasis is on construction of compact, mixed-use development. New urbanism strives to enhance the feeling of community and significantly reduce the transportation distances to key uses. Consequently, energy efficiency is higher due to lower transportation and infrastructure demands. While the U.S. has led the way in these types of innovative developments, Ontario examples such as Montgomery Village near Orangeville and Cornell in Markham show that this concept has applicability to Canadian municipalities.

Existing research has focussed on how new urbanism affects municipal infrastructure needs, and the positive impact upon municipal capital and operating budgets. Tied to this is the equally positive impact of energy requirements, both in terms of embodied energy for elements such as roadways and water pipes, and also operating energy for infrastructure service provision. The issue of energy savings in suburban design has received relatively little attention in the technical literature or in governmental policy development. In this paper, infrastructure requirements for both sprawl and compact development have been analyzed for a range of municipal infrastructure elements. The analyses have been conducted for representative Canadian conditions. The results show that considerable energy savings can be realized with new urbanism designs, along with the related benefits of improved air quality and reduced municipal spending in tough fiscal times. The results of this research can assist policy makers by providing information on the energy savings realized from more efficient infrastructure provision in new urbanism developments.

Keywords: municipal infrastructure; energy requirements; suburban development; new urbanism.

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I.INTRODUCTION

Communities are important to us all. How communities are designed and constructed greatly affects our daily lives, the municipal taxes we pay as residents and the ecological footprint imposed by our activities. Across Canada and throughout North America, development over the last forty years has been largely composed of low-density, single-family housing surveys located on “green fields” at the urban fringe. These developments have been criticized because of the associated consumption of farmland, the costly extension of municipal infrastructure services, the heavy reliance on automobiles due to low population densities and the absence of work or shopping opportunities within the developments. Policies have been sought to stop or dampen suburban “sprawl” in order to minimize the associated fiscal and environmental impacts and to provide more livable and sustainable communities.

Since the early 1990's, there have been a number of alternative proposals for urban fringe development (Christoforidis, 1994). The planning/architecture team of Andres Duany and Elizabeth Plater-Zyberk (Kreiger, 1992) have designed a number of neo-traditional village developments that emphasize more compact housing in close proximity to shopping, schools and other facilities. Considerable design effort has been made to develop vibrant and cohesive communities, where access by proximity is achieved. An alternative to the neo-traditional villages are the transit-oriented developments proposed by Peter Calthorpe (Calthorpe, 1993), where compact villages are clustered around a commercial main street and an express bus or commuter train station. This concept allows commuters to easily access public transit for work in a central urban core, while enjoying the amenities of small town life and the preservation of open space and agricultural lands between village developments. These and other concepts and design features have been integrated into an overall design philosophy now referred to as new urbanism. A large number of new urbanism projects have been developed in the United States, and Canadian examples exist in both Alberta and Ontario, with Markham's Cornell development in metropolitan Toronto being the largest and newest Canadian undertaking.

Beyond urban design issues, new urbanism projects have advantages over conventional development due to municipal infrastructure considerations. More compact housing leads to the sharing of a spatially-fixed amount of infrastructure by a greater number of residents, reducing the extension of watermain, sewers and improved roadways. These effects translate into municipal infrastructure cost savings, which are very important due to strained municipal budgets.

Previous research has investigated the link between sustainable compact developments and municipal infrastructure. Di Nino (1996) compared sprawl and compact development from the standpoint of municipal solid waste management infrastructure needs. Churchill (1997) developed a decision support tool for compact green fields development that could be used to assess infrastructure requirements. Long (1997) constructed a GIS-based infrastructure and planning analysis tool, which has been used to compare compact and sprawl developments at the urban fringe as well as compact infill developments in the urban core. The existing literature has compared alternative developments on the basis of costs, air emissions or vehicle-trips, but has not considered energy requirements for municipal infrastructure as a measure of comparison.

The work described in this paper attempts to fill this void, by making a reasonable estimate of the energy requirements for municipal infrastructure construction and operation for different suburban development alternatives. The general approach is described in the next section. These data are used within the developed approach for a representative application, followed by discussion and concluding remarks.

2. APPROACH FOR EVALUATING ENERGY REQUIREMENTS FOR MUNICIPAL INFRASTRUCTURE

There is a considerable amount of infrastructure needed to serve the residents of a municipality. Some of this infrastructure is centralized, and the degree of centralization depends upon the particular service. For example, a public library may serve all of the residents within a municipality while a landfill may serve all of the residents within a region composed of many municipalities. Decentralized infrastructure, provided throughout the residential areas of a municipality, is most affected by urban design decisions and will be the focus of the work described within this paper.

The de-centralized infrastructure can be broken down into those elements that are constructed and maintained over a certain service life and those elements that are operational in nature and do not involve a construction component. Table 1 provides a listing of infrastructure elements for de-centralized infrastructure in these two general categories.

Table 1 Infrastructure Elements for De-Centralized Municipal Infrastructure

Constructed Elements
• Roadways • Sidewalks and Curb/Gutter • Sanitary Sewers • Storm Sewers • Watermain
Operational Elements
• Garbage Collection • Recyclables Collection • Snow Removal • Street Sweeping

There are other infrastructure elements, provided to individual streets, beyond those listed in Table 1. These would include elements such as hydro provision, natural gas lines, phone lines, cable and fibre optics lines. These elements are considered to be beyond the infrastructure provided and maintained by a municipality, but may be considered in further research on the energy requirements of comprehensive infrastructure provision.

The approach for the constructed elements begins with the determination of the amount of a particular constructed infrastructure element for a certain development area. The amount will depend upon the specific design parameters and the road network. For a given unit of infrastructure element (e.g., m^2 of roadway), an embodied energy value was obtained from the literature. The embodied energy, sometimes referred to as primary energy content (Alexander, 1994), reflects the combined energy requirements at each stage of raw material extraction, transport, processing, production and placement for the particular infrastructure element in question. This unit value for "life cycle" energy is then multiplied by the amount of constructed infrastructure required for the particular element, to obtain the total energy requirement for the production and construction of this infrastructure component. This total energy requirement is then divided by the expected design life of the particular infrastructure element to obtain an equivalent annual energy requirement for producing and constructing this infrastructure. This process is repeated for all constructed elements, to obtain a total annual energy requirement for all constructed infrastructure.

The approach for the operational elements begins with the lineal distance of the street network that must be serviced, and the expected number of times per year the service is provided (e.g., garbage pickup is typically provided once per week, while street sweeping may only be provided once per month for non-winter months). The product of the service frequencies and the distance to be serviced is the total annual distance for the particular infrastructure service; and this is divided by the fuel efficiency of the service vehicle to obtain the annual quantity of fuel consumed in providing the service. The energy value of the fuel is then used to determine the total annual energy consumed for the particular operational infrastructure element, and the process is repeated for all service elements.

The total annual energy value for constructed elements and operational elements are summed together to yield a total annual energy value for the municipal infrastructure provided to the suburban development. Since compact developments will have more residents per hectare than conventional developments, this total energy value is divided by the design population to determine a per capita annual energy value for municipal infrastructure provision.

Available data and related assumptions are listed in Appendix A. These data, in conjunction with the approach described in this section, were used to quantify the energy requirements for municipal infrastructure for a representative example situation. This application is described in the following section.

3. APPLICATION OF DEVELOPED APPROACH

Suburban development typically occurs at the urban fringe on privately owned land. The representative example illustrated here is for development on a 400 m by 250 m land parcel, with a total area of 10 ha. Development layouts were done for this area using the decision support system developed by Churchill (1997), for a conventional scenario and for a new urbanism scenario. Table 2 lists the outputs for each of these scenarios, which are used within the developed energy requirement approach. The two suburban layouts are shown in Figures 1 and 2, and are described as follows:

Conventional Design

The large lot and right-of-way dimensions for this scenario allow only 103 dwellings in the design area. This corresponds to a gross density of 10.3 units per hectare, or 4.1 units per acre.

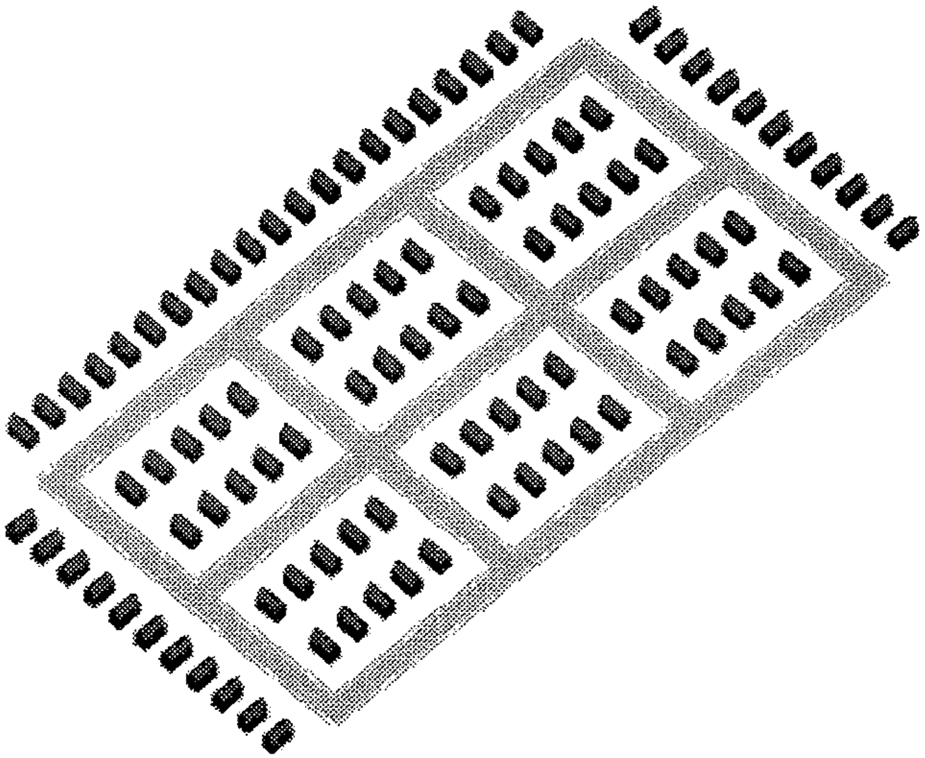

Figure 1 Layout of Conventional Design

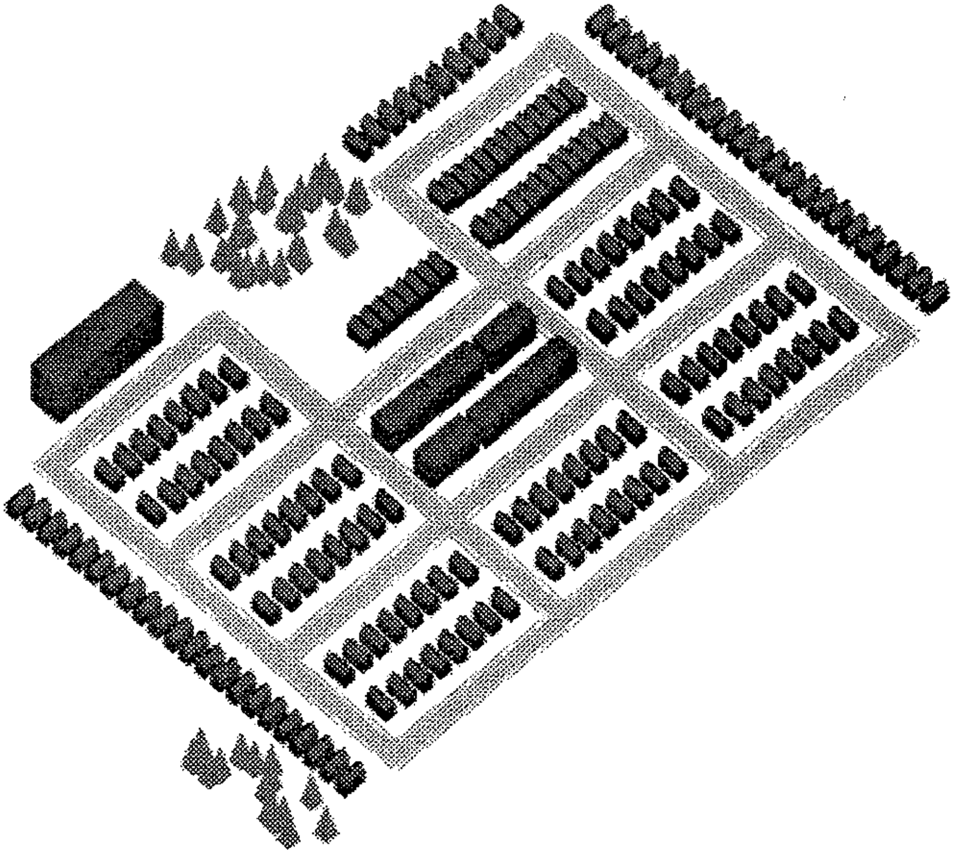

Figure 2 Layout of New Urbanism Design

This value falls at the upper end of the range for the typical density of a conventional subdivision comprised exclusively of single family dwellings, which is 2 to 4 dwelling units per acre (De Chiara and Koppelman, 1975).

New Urbanism Design

The largest change from the conventional design is the reduction in lot size, both width (9 metres down from 14 metres) and depth (from 30 to 25 metres). The remaining adjustments, such as the two metre reduction in the right-of-way, were relatively minor in comparison. The result was almost a doubling in the number of dwelling units within the community, which corresponds to a population increase of approximately 79%.

The density, both net and gross, of this scenario is almost double that of the first scenario. This is due not only to the reduction in lot size and the smaller right-of-way, but the addition of townhouses and apartments as well. In terms of mass transit feasibility, the number of dwelling units per net hectare to support bus service is 17 or greater (Lowe, 1991). The second scenario value of 28.1 dwelling units per net hectare easily satisfies this requirement, as well as that for light rail which is 22 units per hectare (Lowe, 1991).

Table 2 Outputs for Two Development Scenarios

	Conventional	New Urbanism
Paved Road Width (m)	9	8
Paved Road Area (m^2)	12204	13424
Number of Residents	361	645

The developed approach was applied with the information from these two scenarios and the technical information presented in Appendix A. The resulting annual energy requirement values are shown in Table 3. The conventional development has approximately 50% greater per capita energy requirements for its municipal infrastructure than the new urbanism development. Even if the actual unit embodied energy values are somewhat different than the estimated values employed here, the relative overall differences between the two development approaches will be in the 50% range

Table 3 Energy Requirements for Application Scenarios

	Conventional	New Urbanism
Constructed Elements (GJ/year)		
• Roadways	205	225
• Sidewalks and Curbs/Gutter	109.4	135.1
• Sanitary Sewers	73.1	90.4
• Storm Sewers	73.1	90.4
• Watermain	79.0	97.7
Sum of Constructed Elements (GJ/year)	539.6	638.6
Operational Elements (GJ/year)		
• Garbage Collection	1.02	1.26
• Recyclables Collection	0.76	0.94
• Snow Removal	0.16	0.19
• Street Sweeping	0.20	0.24
Sum of Operational Elements (GJ/year)	2.14	2.63
Sum of All Elements (GJ/year)	541.7	641.23
Per Capita Annual Energy Requirements for Infrastructure (GJ/resident/year)	1.50	0.99

The operational elements have energy requirements two orders of magnitude below a number of the values for the constructed elements. The operational energy calculations were determined from fuel consumption only, and would be higher if the embodied energy in the service vehicles themselves had been included. For reasonable operational vehicle lives, it is hypothesized that energy requirements for operational elements would still be very small compared to those for the constructed elements.

For the constructed elements, the building of roadways and sidewalks/curbs/gutters represents the largest fraction of the total energy requirements for municipal infrastructure. Further work in this area could lead to refinements in the constructed element estimates to include embodied energy values for the construction equipment and periodic maintenance, which are not currently available in the technical literature.

The per capita energy savings for municipal infrastructure for new urbanism development versus conventional development are not large relative to the total per capita consumption values in North America. However, the results show that considerably more per capita infrastructure is required for the construction and servicing of conventional development, and this equates to resources which must come from municipal taxpayers. Secondly, the new urbanism developments will have significant transportation energy savings from a reduction in vehicle trips, due to the proximity of housing to many destinations. Therefore, a quantification of this transportation-related energy savings should be done, and the results aggregated with this municipal infrastructure analysis to obtain a total picture of possible energy savings from new urbanism development.

4. CONCLUDING REMARKS

Development at the urban fringe is less desirable than infill development in the urban core, from a variety of environmental, social and economic perspectives. Nonetheless, suburban development will continue to occur over the short and intermediate term, and municipalities will have a choice between conventional development or development based on new urbanism principles. Beyond the aesthetic and cohesiveness benefits of new urbanism developments, there are tangible cost and energy savings associated with the decreased per capita municipal infrastructure requirements. As energy issues become increasingly important due to resource limitations and concern over climate change, the energy savings from both municipal infrastructure and private transportation that are possible in new urbanism developments will be of increasing interest to decision-makers. Municipal councils should consider these and related issues when reviewing official plan amendments and site plan approvals for new suburban developments. Provincial decision-makers should also consider these issues when establishing growth and settlement guidelines for their wider jurisdictions, and provide incentives for development that is more economically and environmentally sound.

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APPENDIX A:

LISTING OF AVAILABLE ENERGY REQUIREMENTS FOR DATA AND RELATED ASSUMPTIONS

1) Constructed Elements

Roadways

- unit embodied energy value of 266,000 Btu/yd^2 for a full depth asphalt concrete pavement (The Asphalt Institute, 1979).
- unit conversions: 1.19 yd^2/m^2; 1055.87 J/Btu
- design life of 20 years

Sidewalks and Curb/Gutter

- placement on both sides of road, with a 1.25 m equivalent width
- unit embodied energy value of 511,200 Btu/yd^2 for an 8 inch Portland cement concrete cross-section (The Asphalt Institute, 1979).
- unit conversions as for roadways
- design life of 20 years

Sanitary Sewers

- one 300 mm diameter concrete pipe placed under roadway
- unit embodied energy value of 43.8 kWh/m (Alexander, 1994)
- unit conversion of 3.6×10^6 J/kWh
- design life of 20 years

Storm Sewers

- one 300 mm diameter concrete pipe placed under roadway
- unit embodied energy value of 43.8 kWh/m (Alexander, 1994)
- unit conversion of 3.6×10^6 J/kWh
- design life of 20 years

Watermain

- one 200 mm diameter PVC pipe placed under roadway
- unit embodied energy value of 68 kWh/m (Alexander, 1994)
- unit conversion of 3.6×10^6 J/kWh
- design life of 20 years

Earthwork for Pipe Placement

- watermain, storm and sanitary sewer to be placed in a 30 m^2 cross-section
- in situ soil density and constructed soil density to be 145 lb/ft^3 (2322.7 kg/m^3)
- removal and placement of trench materials to be each done with a unit energy requirement of 17,000 Btu/ton (The Asphalt Institute, 1979)
- unit conversions of 1055.87 J/Btu; 907.18 Kg/ton
- total energy requirement for removal and replacement = 2.76 GJ/m of roadway

2) Operational Elements

Garbage Collection

- pick up both sides of street
- pick up once per week
- vehicle efficiency of 2.0 kWh/km (adapted from Di Nino (1996))

Recyclables Collection

- as for garbage collection
- vehicle efficiency of 1.5 kW/h/km (adapted from Di Nino (1996))

Snow Removal

- plough both sides of the roadway
- plough 8 times per winter season
- vehicle efficiency of 2.0 kWh/km (adapted from Di Nino (1996))

Street Sweeping

- sweep both sides of roadway
- sweep 8 times per year
- vehicle efficiency of 2.5 kWh/km (adapted from Di Nino (1996))

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