Impact of Neighborhood Density on Building Energy Demand and Potential Supply via the Urban Metabolism

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ABSTRACT

This study demonstrates how the density of a neighborhood affects its energy demand, metabolism (energy and material flows) and its ability to produce its own energy. Single-family detached houses and row townhouses were each modeled using passive solar housing guidelines with the DesignBuilder building energy simulation software. Energy demand is then modeled within neighborhoods at two densities based on south facing windows fully un-shaded at 9:00 am, and 12:00 pm solar time on Dec. 21. The neighborhood metabolisms were then calculated based on location and density. The potential energy supply was evaluated from the spatial characteristics of the neighborhood (for solar) and the metabolism (municipal solid waste and wastewater flows.)

The energy demand for the modeled buildings was 77% to 82% less than the average Canadian single family house. Energy consumption at the neighborhood scale was 15% to 19% greater for the detached house and 3.5% to 5.7% greater for the townhouse than when modeled in isolation. Density varied by 50% in both detached house and townhouse scenarios between the high and lower solar access cases yet heating and cooling loads increased only 11% in the detached house and 8% in the townhouse scenarios. PV was able to produce 2.9 to 4.2 times the annual electricity demand. Waste sources were only able to provide 15% of the electricity demand and were insensitive to density. The heating supply from waste was able to supply 12% to 19% of the demand with higher density townhouse scenarios able to supply more of their demand.

Introduction

In 2006, 80% of Canadians lived in urban areas that account for 60% of energy consumption (Council of Energy Ministers 2009). Energy use and GHG emissions from urban areas is largely dependent on local climate, urban form, transportation systems, building policies, the energy supply and waste disposal (Kamal-Chaoui & Alexis 2009). Therefore, understanding the use of energy and potential for production of energy in urban areas to take advantage of infrastructure integration is vital so that new and existing neighborhoods facilitate in meeting municipal and national energy and GHG emission mitigation goals instead of hindering them.

One body searching for such integration is Quality Urban Energy Systems of Tomorrow (QUEST), a collaboration of industry, environmental organizations, governments and academics with the ultimate vision that all Canadian communities incorporate community energy systems. Through deliberate infrastructure and land use planning based on seven strategies: increase density, increase complementary mixed uses, improve efficiency, optimize “exergy”, manage heat, reduce waste and use renewable resources, Canada could reduce emissions by 65 Mt or 20 percent of the national 330Mt reduction target by 2020 (Bataille et al. 2009). On the community level, integrated community energy systems could result in over 43% reductions (Jaccard, Falling, Berry 1997; Bataille et al. 2009). In 2006 the Canadian Mortgage and Housing

Corporation through the EQuilibrium housing project facilitated the construction of 12 net-zero energy houses that are projected to require 80 to 88% less energy than the average Canadian detached housing stock between 2003 and 2007 (NRCan 2009a; Charron 2007).

Extending the net-zero energy goal to the neighborhood scale would potentially provide greater design flexibility, and financial and energy economy of scale. This could allow for opportunities for seasonal storage, the sharing of heat sources allowing for maximum utility, and smart micro-grids supporting electric power sharing between houses, reducing utility peak demand (Candanedo et al. 2009). Rooftops could be optimized to be solar energy collectors and supply surplus energy to those with sub-optimal orientation. Building heights and spacing could be optimized to maximize passive solar heating and cooling. Buildings that are net heat producers could be situated in shaded areas and provide surplus heat to heat consumers. Material flows such as wastewater, solid waste and organic waste generated by the community could also be harnessed for energy, creating an integrated and diverse community energy system. Extending the net-zero energy concept to neighborhoods is the focus of an upcoming follow-up EQuilibrium Communities project (CMHC 2010).

The objective of this study is to explore the impact of density and reduced solar access on the performance of passive buildings and the generation potential from on-site sources in relation to the total community demand. Two scenarios of varying densities on a 16 ha neighborhood are studied. Scenario 1 consists of detached houses while scenario 2 consists of row houses. Both housing types and neighborhood design are based on passive design principles. The strategy of this study is first to develop a low energy building model for single-family house and row house to provide a variation in density. The building characteristics provide the spatial constraints such as available roof area and building height and width which will determine optimal building spacing and the density of the development. The density of the development establishes the total energy demand, total roof surface area for solar collectors and the metabolism of materials flows through the development to determine the total potential energy supply. The potential supply is then compared with the demand in each of the density scenarios. This study is based on a community located in Toronto; however the methodology could be applied anywhere. The results would vary depending on latitude, climate, and assumed occupancy in each dwelling.

Energy Demand

Low-Energy Building Model

The average Canadian single-family and townhouse consume 38,600 kWh (249 kWh/m^2) and 28,500 kWh (222 kWh/m^2) annually, respectively (NRCan 2009a). Heating alone consists of 57% – 66% of the total energy demand (NRCan 2009a). Passive buildings take advantage of the surrounding climate and building components to maximize natural ventilation, day lighting, heating and cooling thereby reducing the building’s overall energy consumption and the size of mechanical equipment. This is accomplished by controlling heat transfer through radiation, conduction and convention and thermal storage of the structure itself (Mikler, et al. 2008). A well designed passive-solar-heated building may provide 45% to 100% of daily heating requirements (ASHRAE, 2007). Studies on passive houses in the U.S. show a cost premium of between 10% and 15% over a conventional house (Klingenberg, Kernagis & James 2008).

While there is a significant amount of literature available on passive solar design, (Chiras 2002, CMHC 1998, Charron & Athienitis 2006; Hastings & Wall 2007; Galloway 2004), many of the strategies, and rules of thumb do not necessarily apply for situations where neighborhood density could impact on availabilty of solar gains. Furthermore, many building simluation programs are uncapable of conducting shading calculations from neighboring buildings, resulting in optimistic potential solar gains in the winter and overly conservative estimated overheating potential in the fall. As a result, relatively detailed information of the building characteristics is required to effectively model a passive building at a neighborhood scale. For example, while more simplified programs require only a percentage of glazing to wall area or number of windows for each building face, the exact position of windows is essential to evaluate shading impacts. Similairly, the location and extent of thermal mass such as partitions, floor surface area and the circulation of air throught the building can affect results significantly. Internal gains from appliances and occupants provide a significant contribution to the heating and cooling requirements of a low energy building and in turn the optimal glazing for solar heat gain. DesignBuilder building energy simulation software was selected due to its ability to model shading from surrounding building, and its capability to conduct detailed hourly simluations via EnergyPlus. Two archytype low-energy detached and townhouse models were developed based on an extensive literature review of passive buildings and numerous simulation iterations, (Table 1).

The buildings are located in Toronto at 43.67N longitude and -79.63E latitude and are oriented due south. Both houses have an aspect ratio of 1.3. They have a total floor area 185m^2 divided over two stories for the detached house and over three stories for the townhouse and have no basement. Both buildings have unconditioned, single car width attached garages to maintain a compact building form. The attached garage provides a buffer for the wall and floor attached to the house sheltering part of the western wall of the house from wind. The roof pitch is 45^o to distribute available solar energy for PV and thermal applications more to the winter when it is most required. This also increases the availability of the solar system as it is less likely that there will be snow accumulation at steeper angles and mitigates overheating of the thermal collectors in the summer.

Initially, the buildings were modeled in isolation excluding external shading to be able to evaluate the design more effectively against the design guidelines found in literature. The garage and roof were designated unconditioned spaces. The conditioned spaces were divided into 4 zones, a north and a south zonefor each floor to evalute indoor comfort levels. The zones were divided by a 105 mm brick partition to provide thermal mass. Thermal mass was also provided by 100 mm concrete floor slabs.

Glazing was emphasized on the south side of the buildings while glazing on the north and east sides of the house was limited. No glazing was provided on the west side of the house. In a neighbhourhood context, east and west facing glass have even less value than a building in isolation since they are typically shaded by adjacent buildings. South facing windows have awnings so that the windows are completely un-shaded on December 21 and fully shaded on June 21.

Energuide standard conditions for lighting and appliance loads are 24 kWh/day (Lee 2007). However, calculations of energy and water saving appliances by Tse, et al., (2009) for a similar size net-zero house in Toronto demonstrate that total electricity loads can be reduced to 7.77 kWh/day by using the most energy efficient lights and appliances. Typical hot water usage in Canada is 225 L/day at a temperature of 55^{o}C. Tse, et al., (2009) also found that this demand could be conservatively reduced to 100 L/day through water saving appliances. Natural ventilation is available between April 15 and Oct 15 to cool the buildings during occupancy when the outside temperature is cooler then the inside temperature. The heating system was assumed to have COP of 1.0 so it could be easily equated to the supply required from various fuel sources. A high efficiency air conditioning unit with a COP of 3.5 was also considered. However, a geoexchange system could reduce heating demand by at least a factor of 3 and obtain cooling COP of 4.0.

Table 1: Building Characteristics

	Detached House	**Townhouse**
Number of stories	2	3
Floor area (m^2)	185	185
Width (m)	11.7	9.5
Depth (m)	9.0	7.3
Total building height (m)	10.5	12.3
Roof area (m^2)	161.6	98.1
Thermal resistance values:		
Exterior wall	7 W/m^{2}K	
Ceiling	12 W/m^{2}K	
Slab on grade	2.5 W/m^{2}K	
Exposed slab	7 W/m^{2}K (slab above unconditioned garage)	
Door	1.14 W/m^{2}K	
Thermal mass	1st & 2nd floor 100 mm concrete slab, 105 mm brick partition north and south zones.	
Window type	Triple glazed, low-e, argon (U=1.058, SHGC=0.579) with fiberglass frame.	
Size and number of windows:		
North	4 @ 1.2m x 1.2m	3 @ 1.2m
South	8 @ 1.5m x 1.5m	10 @ 1.5 x 1.5m
East	2 @ 1.2m x 0.9m	0
West	0	0
% South lazing of floor area/ south wall	11.2% / 36.5%	13.8% / 37.3%
Shading Strategy	Fixed awnings 0.3 m offset and 0.9 m projection.	
Occupants	2 Adults and 2 Children occupied from 16:00 - 9:00	
Set point temperatures	Heating set point 21^{o}C, cooling set point 24^{o}C: Schedule: 6:00 – 9:00, 16:00 – 23:00 Heating setback 19^{o}C, cooling set back 26^{o}C, Schedule: 9:00 – 16:00, 23:00 – 6:00	
Internal loads:	Energy efficient based on Tse, et al., (2009).	
Major appliances	3.77 kW/day, schedule: refrigerator 24hrs; dishwasher, stove, washer, 6:00am – 8:00 am, 17:00 – 20:00	
Minor appliances	3.0 kW/day, schedule: 6:00 – 9:00, 14:00 – 23:00	
Indoor lighting	1 kW/day, schedule: 6:00 – 9:00, 14:00 – 23:00	
Exterior loads	1.85 kW/day, result in no internal gains	
Heat recovery ventilator	88% apparent sensible effectiveness @ 60 L/s, operating at 36L/s.	
Air change rate	0.6 ACH @ 50Pa	
Natural ventilation for cool	Available April 15 - Oct 15, set point 22^{o}C.	
Domestic hot water load	100 L/day with water efficient appliances based on Tse, et al., (2009)	
Heating and cooling	Auxiliary heating with COP 1.0, fan distribution efficiency of 80%. Central air conditioning with COP of 3.5.	

Passive Community Model

The site location has a significant impact on the heating and cooling demands of a building as well as potential for on-site energy generation. Local weather conditions such as temperature, solar irradiance, wind speed and direction and relative humidity all determine what design strategies are most suitable for a particular site. Additionally, external factors such as vegetation, neighboring buildings, terrain are local factors that can helpfully or adversely affect site energy requirements.

Buildings and lot lines often follow roadway alignment; therefore orientation and street pattern are critical characteristics to maximize solar access. Ideally streets should be oriented in the east-west direction so that buildings can be oriented due south; however, orientation within 22.5^o of due south can assure proper winter gain and effectiveness of awnings and shading features without significant loss of performance (Erley, Jaffe, & Lurie 1979). Local fog, temperature and atmospheric pollutant conditions can affect insolation by as much as 20% and could warrant orientation slightly west of due south so that diffuse radiation is collected in the morning while direct solar gain is maximized in the afternoon hours (Galloway 2004; Erley, Jaffe, & Lurie 1979). Time of day electrical pricing could influence the desired building orientation however, solar collector efficiency is not as sensitive to orientation as passive solar features, as 95% of solar potential can be provided within 30 degrees of south (Hastings & Wal 2007). On-site and off-site shading sources including self shading features, terrain, neighboring buildings and vegetation need to be carefully evaluated. Appropriately placed trees and vegetation can effectively shelter the building from wind and shade in the summer. Features should be evaluated by the shadow pattern formed in mid-winter projected at 45 degree angles from the south-east and south-west corners of the object (Erley, Jaffe, & Lurie 1979). Ideally unobstructed solar access on passive solar features is desired between 9:00 am and 3:00 pm or at least been 10:00 am and 2:00 pm (Chiras 2002).

In this study, houses were arranged in a grid pattern over a 16 hectare area (400 m x 400 m) with parallel streets running east to west. This size of study area was selected to represent a development with a sufficient scale to evaluate changes energy supply and demand among varying densities. The study area is assumed to be flat, free from vegetation and there are no obstructions surrounding the development to impede the solar access on the subject plot. Two densities for each housing type were considered based on the level of unobstructed solar access on south facing windows on Dec 21:

- Scenario 1a: All detached houses spaced based on solar noon.
- Scenario 1b: All detached houses spaced based on 9:00 am solar time.
- Scenario 2a: All row-houses spaced based on solar noon.
- Scenario 2b: All row-houses spaced based on 9:00 am solar time.

The setback between detached houses in the east-west direction is 1.2 m. Attached row-houses run continuously in the east-west direction. The minimum house spacing was determined by the shadow projection from the top of the house on the south side of the street to the bottom of the first floor window of the house located on the north side of the street. The position of windows is as relevant as the building height in assessing passive solar availability. Windows positioned higher allow higher densities, whereas windows or glass doors positioned closer to the ground will have lower densities. In both buildings, ground floor south facing windows were positioned 0.9m from the ground. The prototype buildings were the modeled among shading components of similar dimension to determine building energy usage in each of the neighborhood scenarios, (Figure 1).

Figure 1: Scenario 1, Detached Housing (Left) and Scenario 2, Row Housing (Right)

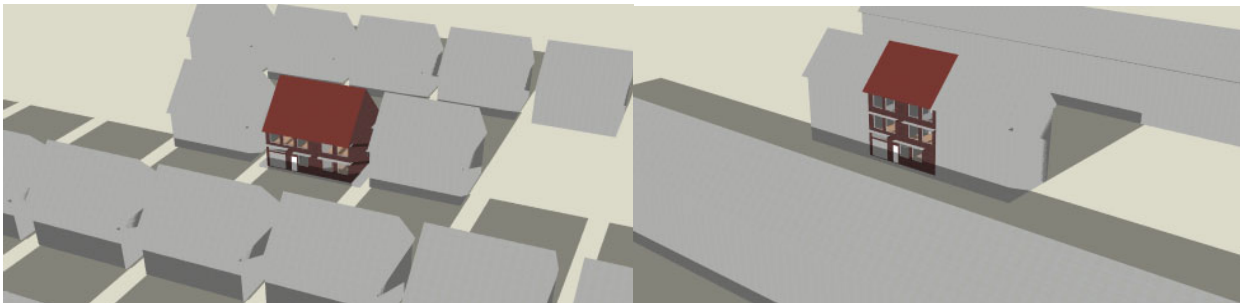


Table 2: Community Characteristics

	Scenario 1a	Scenario1b	Scenario 2a	Scenario 2b
Minimum Spacing (m)	17.6	31.3	22.3	38.3
# of rows in east –west direction	28	28	41	41
# of columns in north-south direction	15	10	12	8
Total # of units	420	280	492	328
Density units/ha	26.2	17.5	30.7	20.5
Total Population	1,680	1,120	1,970	1,310
Population Density cap/ha	105	70	123	82
Total Roof Area (m^2)	75,100	50,000	87,900	58,600

Building Energy Demand

Building energy demand was modeled with DesignBuilder software. The buildings were initially modeled in isolation and then modeled within the neighborhood context, (Table 3). Energy consumption at the neighborhood scale was 15% to 19% greater for scenario 1 and 3.5% to 5.7% greater for scenario 2 than when modeled in isolation. Heating loads were significantly higher in all neighborhood scenarios not only due direct shading by neighboring buildings, but also a reduction in ground reflectance. Density varied by 50% between scenario 1a and 1b and scenario 2a a and 2b yet heating and cooling loads increased only 11% in the detached house and 8% in the townhouse scenarios due to restricted solar access.

Table 3: Annual Household Energy Demand

	Isolated		Scenario 1a		Scenario 1b		Isolated		Scenario 2a		Scenario 2b	
	kWh/m2	kWh/hh	kWh/m2	kWh/hh	kWh/m2	kWh/hh	kWh/m2	kWh/hh	kWh/m2	kWh/hh	kWh/m2	kWh/hh
Space Heating	10.1	1,870	16.5	3,050	14.7	2,730	7.64	1,410	10.2	1,900	9.35	1,730
Water Heating	4.86	900	4.86	900	4.86	900	4.86	900	4.86	900	4.86	900
Appliances	17	3,150	18.3	3,380	18.3	3,380	18.3	3,380	18.3	3,380	18.3	3,380
Lighting	1.97	365	1.97	365	1.97	365	1.97	365	1.97	365	1.97	365
Space Cooling	1.3	241	0.97	179	1.06	196	1.33	245	0.98	182	1.04	192
System Fans	1.44	267	1.17	216	1.26	233	1.4	259	1.16	215	1.21	225
Total	36.7	6,800	43.7	8,090	42.2	7,800	35.5	6,560	37.5	6,940	36.7	6,790

A solar domestic hot water (SDHW) system was modeled using RETScreen energy analysis software. The system was designed to supply a daily hot water load of 100 L at 55^{o}C. Based on the daily demand, the system consisted of a Thermo Dynamics G32-P 3.0 m^2 roof mounted flat plate solar collector with a 160 L storage tank. This system provides 1.3 MWh of heating, 63% of the annual hot water requirements. A secondary tank and heat source is required to provide the remaining 900 kWh.

The Urban Metabolism

The urban metabolism has been commonly used to provide a picture of the demands of a city to compare how efficiency it consumes resources relative to other cities and evaluate its overall sustainability (Kennedy, John & Engel-Yan 2007). In identifying the producers and consumers of these flows and their processes opportunities the metabolism can be optimized thus creating a more sustainable city (Codoban & Kennedy 2008). By integrating land-use and transportation planning, management of solid waste, liquid waste, solar access, potable water, energy systems, greenhouse gas (GHG) reduction strategies and infrastructure, cities could become more efficient and maximize the recovery of "value" from waste resource streams and provide new net revenue sources for municipalities (Slater 2009). Neighborhood scale is important to recognize how to develop communities to maximize the potential value. The metabolism for this study is based on the building and neighborhood characteristics discussed in the previous sections along residential solid and liquid waste data for the City of Toronto. Table 4 shows the total community energy requirements.

Table 4: Energy Demand

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
SDHW (MWh)	546	364	640	426
Space Heating + Supplemental Hot Water (MWh)	1,650	1,040	1,340	848
Space Cooling (MWh)	84.0	58.5	105.0	71.6
Auxiliary Energy (MWh)	1,420	946	1,660	1,110

Residential solid waste for single-family homes in Toronto in 2008 was calculated based on the results of a single-family neighborhood waste audit study which reported annual average household waste to be 874kg/household. Of that, 22% is reported to be residual waste, 39% is compostable organic waste and 39% is recyclable (City of Toronto Solid Waste Management Services 2008). The daily indoor water demand in single-family households in Toronto is 320 L/capita (City of Toronto 2002). Of that, 11% is due to leaks. The remaining demand is split between the clothes washer, bath/shower, faucet, dishwasher and toilet. If reductions are possible proportionate to those for hot water requirements excluding losses due to leaks, the total water demand could be reduced to 160 L/capita. Assuming similar figures for wastewater, the actual volume to the wastewater treatment plant would be 144 L/capita or 576 L/household. Table 5 shows the resulting neighborhood waste streams.

Table 5: Mass Content of Waste Streams per Year

	Kg/Capita (Kg/unit)	Scenario 1a (kg)	Scenario 1b (kg)	Scenario 2a (kg)	Scenario 2b (kg)
Compostable Waste	86 (345)	145,000	96,600	170,000	113,000
Residual Waste	151 (191)	80,200	53,500	94,000	62,600
Recyclable	85 (338)	142,000	94,600	166,000	111,000
Wastewater	140 (560)	85,800,000	57,200,000	101,000,000	67,000,000

Energy Supply Potential

Although there are numerous clean energy technologies available, this study will look at those technologies that can be produced in the neighborhood locally such as solar PV or source from potential wastes that flow through the neighborhood. The objective is to demonstrate that at higher densities, less solar energy is available on a per capita basis; however, demand also decreases while the mass of content and potential energy on the neighborhood scale would increase. Because solar PV is intermittent and energy from waste may not necessarily be produced on site the objective is for enough potential energy to be produced to displace the demand from the community. PV would ideally supply a surplus of electricity for dwellings that may not be able to produce their own energy. A geothermal system could be extended to community energy systems, however this would be only beneficial in neighborhoods with diverse heating and cooling demand to maximize use of the installed capacity. A similar problem occurs with solar thermal systems which tend to have excess heat capacity in summer and would require load diversity or thermal energy storage to maximize the utility of the energy. The suitability of certain technologies in a district system and costs is discussed in greater detail in Wilson, (2007).

Solar PV

Solar photovoltaic cells (PV). The performance of the PV system is largely dependent on slope and azimuth of the collectors, local climatic conditions, the collector efficiency, and the operating temperature of the cells. Monocrystalline and polycrystalline silicone cells are the most popular capturing 65% of global market share in 2006 (IEA-PVPS 2007). Common collector efficiencies for these cells range from 12% – 18% however, cells with up to 24.7% efficiency have been developed (Poissant & Kherani 2009).

Fixed roof-top solar collectors were selected for south facing roof areas. It is assumed that 90% of this area suitable for PV panels excluding 3m^2 required for the SHDHW system. RETScreen Clean Energy Production Analysis software was used to calculate the total potential energy produced. A Sanyo mono-Si solar panel with 17.4% efficiency was selected because of its above average efficiency readily availability in Canada. The assumed inverter efficiency was 95%, miscellaneous losses to account for snow cover, debris accumulation and maintenance were assumed to be 12%, along with and an additional 5% loses during power conversion were included (Myrans, 2009). The townhouses have 30% less collector area and PV production than the detached houses. Thus, per capita solar availability reduced in the townhouse scenario. The total PV production for each scenario is shown in Table 6.

Table 6: Neighborhood PV Production

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
Collector area per dwelling	80.4	80.4	54.4	54.4
MWh per dwelling	15.5	15.5	10.5	10.5
MWh total neighbourhood	6,510	4,340	5,170	3,440

Waste

The use of waste as an energy source maximizes the use of a resource that otherwise would be wasted as well as provides a potential revenue source for a municipality (Corps, et al.

2008). Municipal solid waste can be used to produce energy through methane capture at the landfill from anaerobic decomposition of organic matter or incineration, pyrolysis or gasification to co-generate heat and electricity (Harvey 2010a). Separation of recyclables and compostable organics from residuals allows for wastes to be matched with the most appropriate energy recovery methods. Recyclables themselves require less energy to produce the same material from raw material and thus have far greater value than if used for energy generation processes (Harvey 2010a). Recovering energy from waste is especially valuable because it can provide a constant energy supply unlike other intermittent energy sources. The maximum energy extracted from a material is generally provided through co-generation. Residual waste that cannot be recycled or decomposed can be incinerated. The overall energy recovery can be low if the waste stream contains many components that yield no energy value or contain a large water content which reduces the overall energy potential. Efficiencies for co-generation have been reported to be between 22.6% and 45.2% for heat extraction and 25% to 29% for electricity production (Harvey 2010a). Table 7 shows the higher heating value (HHV) energy content calculated for the total residual waste assuming latent heat of condensation is captured by the cogeneration (Harvey 2010a).

Table 7: Energy Content of Residual Solid Waste Stream

Waste Type	**HHV (MJ/kg)~**	**% In Residual Waste Stream-**	**Energy Content (MJ)**			
			Scenario 1a	**Scenario 1b**	**Scenario 2a**	**Scenario 2b**
Paper	13.1	2	21,000	14,000	24,600	16,400
Plastic	33.5	18	484,000	322,000	567,000	378,000
Other Materials /w Heating Value^	10	25	201,000	134,000	235,000	157,000
Other Materials w/o Heating Value	0	65	0	0	0	0
Total			705,000	470,000	826,000	551,000

~ Source: Reported in (Harvey 2010a), data from tables A3.36 and A 3.37 of EC (2001) Reference Document on Best Available Techniques in the Glass Manufacturing Industry, www.eippcb.jrc.es/pages/FActivities.htm.
- Source: (City of Toronto Solid Waste Management Services 2008).
^ Household special solid waste.

Solid organic waste can either be diverted to a biogas digester to produce methane for vehicles or to produce combined heat and power. The total potential energy produced depends on the composition of the feedstock; however a typical heat value of biomass is 18 – 20 MJ/kg in which a specially designed digester can produce methane gas with an energy content of 10 MJ/ton (Harvey 2010b). The methane gas could be used for cogeneration of heat and power. Combustion of methane gas in a combined heat and power boiler can yield 60 – 90% net efficiency for systems between 0.1 – 1 MW with common electrical efficiencies of 30-40% possible (Harvey 2010b).

For wastewater, biogas from anaerobic digestion can produce a net efficiency of 10-15% for electricity production in addition to producing low grade heat (Harvey 2010b). The energy content in Toronto’s municipal wastewater is 1.0 GJ/capita (City of Toronto Solid Waste Management Services 2008). This number was proportionately scaled 0.45 GJ/capita to represent reduced demand per capita from water efficiency measures.

Assuming the average of the efficiency ranges described could be obtained, the resulting potential energy from waste sources is presented in Table 8.

Table 8: Potential Energy Production from Waste Sources

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
Residual Solid Waste				
Heat (MWh/year)	66.4	44.3	77.8	51.9
Electricity (MWh/year)	52.9	35.3	62.0	41.3
Organic Solid Waste				
Heat (MWh/year)	161	107	189	126
Electricity (MWh/year)	141	93.9	165	110
Wastewater				
Electricity (MWh/year)	26.3	17.5	30.8	20.5

Conclusions

This paper provides a quantitative analysis of the relationship of the impact of density on building energy demand and potential energy supply from surfaces and flows through the community. Passive design and energy efficiency measures were able to achieve overall energy consumption between 77% and 82% less than the average Canadian single family house. Energy consumption at the neighborhood scale was 15% to 19% greater for the detached house and 3.5% to 5.7% greater for the townhouse than when modeled in isolation. This is largely due to significant variations in heating and cooling demand which differed by as much as 50% compared to the denser neighborhood scenario. The discrepancy could be attributed to both direct shading from the neighboring buildings on south facing windows and a reduction in ground reflectance. The significance of this finding is that rules of thumb for maximum glazing and thermal mass for passive buildings may not apply in a neighborhood context.

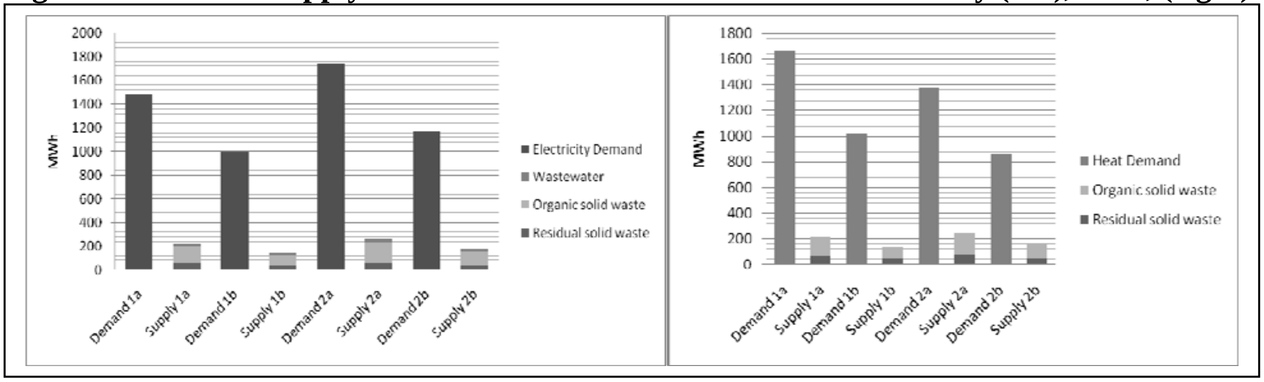
Despite density varying by 50% for neighborhood scenarios, heating and cooling loads increased only 11% in the detached house and 8% in the townhouse scenarios. This demonstrates that density can be increased significantly knowing that heating and cooling loads will increase by a smaller proportion. From a total energy use perspective, the benefits of density due to lower transportation energy use could offset the benefits of maximizing solar access.

The specific location and distribution of glazing becomes more important when evaluating buildings in a neighborhood context. Shading by neighborhood buildings could mean that traditional rules of thumb for maximum glazing to floor area may not apply. Simulation in a neighborhood context therefore is useful to assess the sensitivity of such impacts on building energy use. Municipalities may have development by-laws for maximum height of buildings, minimum setback distances and road widths. These rules limit density and it is important to understand what impact they have on building energy demand. Occupancy and plug loads vary significantly and are difficult to predict however, they have an important contribution in the overall heating and cooling in passive buildings. A good understanding of expected plug loads and occupancy loads is very important to understand the impact of passive solar on heating and cooling requirements.

Occupancy and density defines the metabolism flows through the neighborhood and roof area available for PV. PV was able to produce between 2.9 and 4.2 times their electricity demand with higher densities able to generate more energy. The townhouses due to their smaller available roof area per dwelling produced less than their demand then the detached houses. If neighborhoods were designed specifically for solar access, they could become net energy producers for buildings with sub-optimal solar access. An ideal building height to roof area ratio and resulting density likely exists so that a building can meet exactly all of its electricity needs from PV.

Waste sources were only able to provide 15% of the electricity demand and were insensitive to density. The heating supply from waste was able to supply 12% to 19% of the demand with higher density townhouse scenarios able to supply more of their demand, (Figure 2). Unlike heating demand, electricity demand does not differ significantly between the detached houses and townhouses explaining why the share of waste electricity production to electricity demand is generally proportional with increases in density.

Figure 2: Potential Supply and Demand from Waste Sources: Electricity (left), Heat, (right)



Specific costs are not included in the scope of this study, however, a menu of potential energy sources and their orders of magnitude are identified. The most suitable combinations will depend on government financial incentives available for a particular technology, the relative carbon intensity of regional electrical and heating supply, and the local infrastructure to support the technologies such as smart grids, wastewater heat recovery, and energy from waste recovery. Thermal energy from thermal solar collectors or waste requires a nearby demand to make it feasible unlike electricity which has year round demand and can be transported greater distances. The use of thermal energy storage systems is a promising way to store heat energy throughout the year and draw from it during the heating season. This type of system would enable communities to increase energy production through combined PV and thermal collectors, increasing the efficiency of the PV array by reducing their operating temperatures while increasing the utility of summer solar thermal gains from the heat storage.

This study looked only at uniform building types; however, prototypes for other buildings could be developed to provide load diversity in the community and opportunities to cascade waste heat from producers such as large office buildings and supermarkets to consumers throughout the development such as residential buildings in a district system. Ideally, a transient model could be developed that is able to model and integrate a network of multiple energy sources to model the potential for district energy systems from both continuous, intermittent sources as well as the cascading of heat in mixed use neighborhoods.

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