FCR (Park Lawn) LP and CPPIB Park Lawn Canada Inc.

2150 Lake Shore

Energy Strategy

Issue 01 | 15 May 2020

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Job number 264635-00

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Job title	2150 Lake Shore			Job number 264635-00	
Document title	Energy Strategy			**File reference**	
Document ref					
Revision	**Date**	**Filename**	2150 LSBV_SASP Energy Strategy_190808_Draft 2.docx		
Draft 1.2	13 Aug 2019	**Description**	First issue – OPA submission		
			Prepared by	Checked by	Approved by
		Name	Antonietta Canta	Doug Walter	
		Signature			
Draft 1.3	21 Aug 2019	**Filename**	2150 LSBV_SASP Energy Strategy_190813_Draft 3.docx		
		Description	Including comments from HJ and EW		
			Prepared by	Checked by	Approved by
		Name	Antonietta Canta	Doug Walter, Henry Jeens, Edmund Wong	Ian Carradice
		Signature			
Draft 1	01 May 2020	**Filename**	2150 LSBV_Energy Strategy_200414_Draft 4.docx		
		Description	For comment		
			Prepared by	Checked by	Approved by
		Name	Antonietta Canta	Doug Walter	Ian Carradice
		Signature			
Issue 01	15 May 2020	**Filename**	2150 Lake Shore_Energy Strategy.docx		
		Description	First Issue – For planning submission		
			Prepared by	Checked by	Approved by
		Name	Antonietta Canta	Doug Walter	Henry Jeens
		Signature			

Issue Document verification with document ✓

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Executive summary

This updated Energy Strategy for the 2150 Lake Shore development has built on the previous work undertaken in August 2019 (Energy Strategy as part of OPA Submission). A design and costing exercise has been conducted on the largest tower (building D1), and the energy strategy has been tested against this building.

A parametric model has been undertaken, to identify the passive design measures that could help to achieve the very high energy efficiency standards set out in the Toronto Green Standard (TGS, version 3). The results of the study have been used to inform the architect's design for the development.

A further Ground Source Heat Pump (GSHP) model has been undertaken on the D1 building to test the ability of the technology to supply its heat and cooling. The findings of this study are that a very deep borehole (850 feet, 260m) system could provide 26% of the peak cooling demand and 47% of the peak heating demand, with 77% of the annual cooling demand and 93% of the annual heating demand being supplied. Using electric boilers to supply the remainder of the heating and air-cooled chillers to supply the remainder of the cooling results in a system that performs close to the highest TGS sustainability requirements. Further investigation into building demand reduction and then other renewable technologies (the study has found that solar thermal will be of particular value) will be required at the next stage depending on the TGS performance target for the energy strategy.

The results of the supply options study are shown below, with Option 1B being as described above. Details on the options analysed are given in section 3.2.

Table 1: Supply options summary results.

	Base case	**Option 1A**	**Option 1B**	**Option 1C**	**Option 2A**	**Option 2B**	**Option 2C**	**Option 3**
EUI (kWh/m²)	109.8	78.9	78.6	79.9	92.8	91.8	115.6	109.8
GHGI ($kgCO_2/m^2$)	11.9	5.1	3.9	4.0	7.9	4.6	16.8	11.9
Total CO_2 emissions (tCO_2/y)	7,990	3,400	2,630	2,670	5,250	3,070	11,260	7,990

Where:

1A – GSHPs coupled with gas-fired boilers and air-cooled chillers
1B – GSHPs coupled with electric boilers and air-cooled chillers
1C – Centralised GSHPs coupled with electric immersion heaters and air-cooled chillers
2A – Air source heat pumps (ASHPs) coupled with gas-fired boilers and air-cooled chillers
2B – ASHPs coupled with gas-fired boilers and air-cooled chillers
2C – ASHPs coupled with electric immersion heaters and air-cooled chillers
3 – Centralised biomass boiler couple d with centralised electric boilers and air-cooled chillers

Given the large electrical demand that the development will have, peak demand management has been considered along with the standby electrical requirement for the common areas. The study found that a lithium ion battery installation was the most appropriate, and this should be designed at the next stage.

1 Introduction

1.1 Scope of work

This Energy Strategy has been prepared by Ove Arup & Partners Limited (Arup) at the Detailed Masterplan design stage and is submitted in support of the combined Zoning By-law Amendment Application, Draft Plan of Subdivision Application, and Official Plan Amendment resubmission ('the application') for 2150-2194 Lake Shore Boulevard West and 23 Park Lawn Rd ('the site' or '2150 Lake Shore' hereafter).

It builds upon the previous Energy Strategy produced in August 2019 and adds detail to the studies carried out at this stage on strategies to address energy conservation including demand reduction, resilience to power disruptions and local integrated energy solutions to address the City's targets of carbon dioxide emissions reduction.

1.2 Existing site conditions

The site is historically known as the Mr. Christie Cookie Factory, which was closed in 2013 and demolished in 2017/2018. It is currently empty land with the exception of a Bank of Montreal building in the southwest corner (currently operational).

1.3 Proposed development

The proposed 670,000 m^2 mixed-use development includes approximately 560,000m^2 of residential units, 65,000m^2 of office space, 38,000m^2 of service/retail, institutional uses (potentially two schools), a 1 ha park, several open spaces, a new train station on the Lake Shore GO line, a TTC streetcar loop and a series of public and private roadways. See Figure 1 below for the proposed development.

The building uses are described in Table 1:

Table 2: Land Use Mix

Use Type	Gross Building Area (m^2)	Gross Floor Area (m^2)
Office	71,823	64,641
Institutional	9,548	8,593
Service/Retail	42,203	37,983
Residential	635,700	559,416
Total	**759,274**	**670,663**

Figure 1: Proposed development.

1.4 Phasing overview

The proposed phasing for the site is displayed in Figure 2.

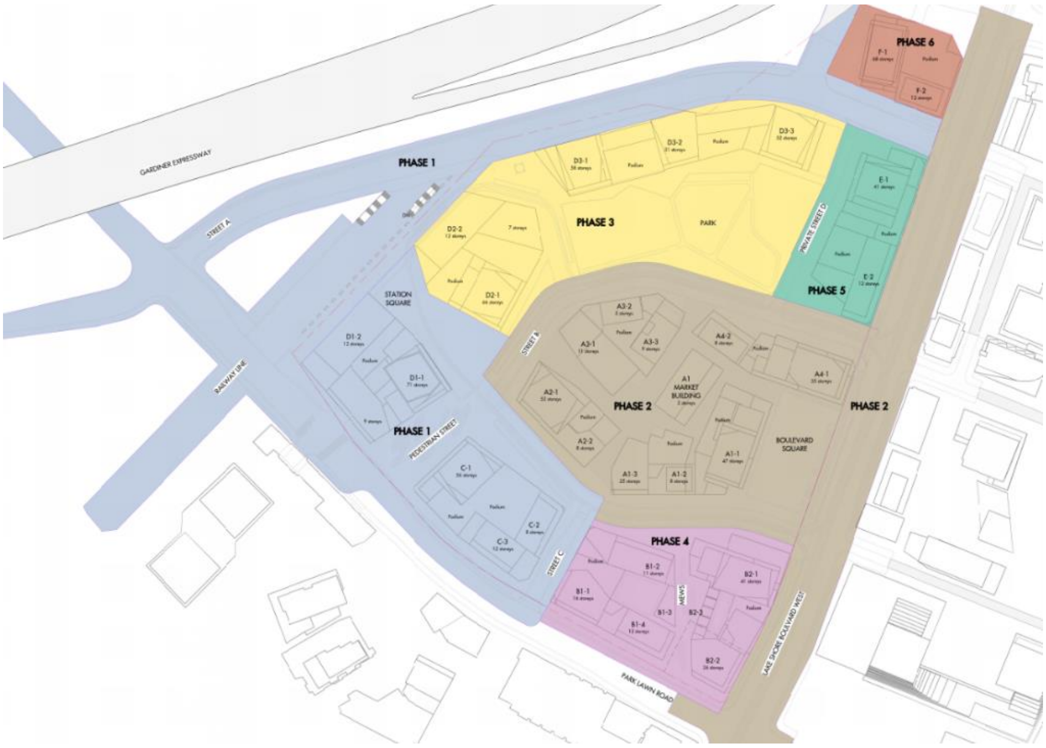

Figure 2: Proposed development phasing.

1.5 The energy context

Grid electricity in Ontario is produced by nuclear power for approximately two thirds, hydro-power for almost one quarter and the remaining 14% by a mix of wind, natural gas, solar, biomass, geothermal and petroleum (see Figure 3). This makes Ontario's electricity have a very low carbon dioxide intensity, with a carbon factor of 0.04 $kgCO_{2eq}$/kWh according to the *National Inventory Report 1990-2016: Canada's 2018 Submission to the United Nations Framework Convention on Climate Change* (2018) – about a seventh of the UK's electricity carbon intensity, as a reference.

A number of district energy systems have been developed in Toronto, highlighted in orange in Figure 4, and the city has identified 27 locations with potential to support new networks (yellow in Figure 4). There are 4 main district heating networks:

- University of Toronto Campus;
- York University Keele Campus;
- Enwave district network; and
- Regent Park district network.

The closest existing network to the site is the Enwave district network, which is about 10 km away from the site. This network comprises a steam system and a Deep Lake Water Cooling system using water from Lake Ontario and serving around 60 buildings including Toronto's City Hall.

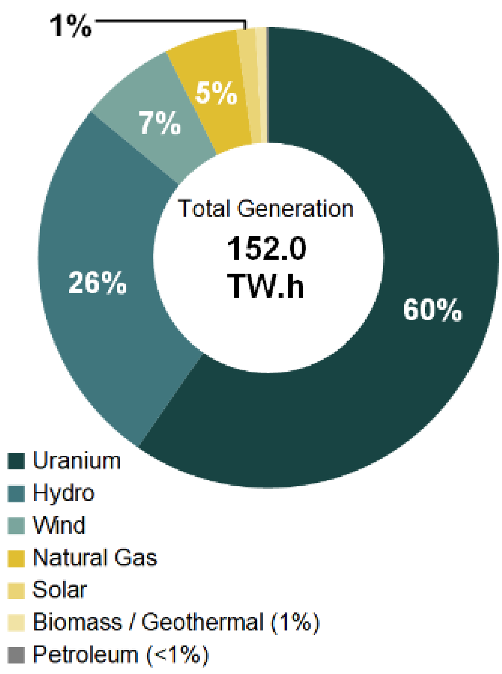

Figure 3: Ontario's electricity generation by fuel (Canada's Energy Future, NEB, 2018).

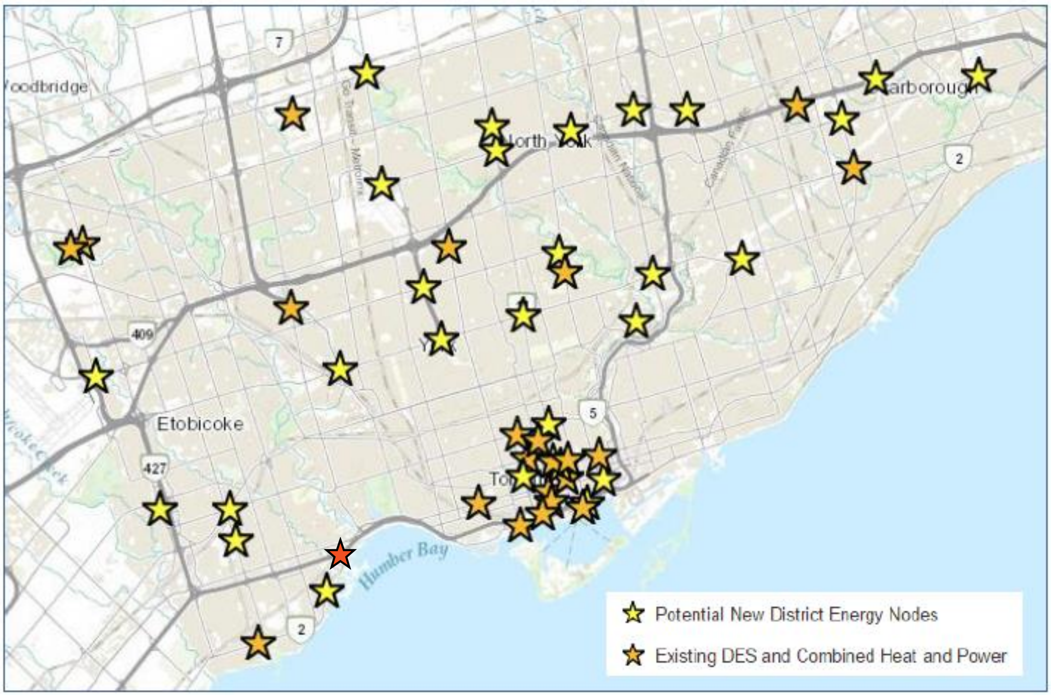

Figure 4: Existing and potential new district energy nodes (source: Design Guideline for District Energy Ready Buildings V1.1 Oct 2016) – site location highlighted by orange star.

1.6 Statutory policies

1.6.1 TransformTO

In 2007, Toronto adopted the Climate Change and Clean Air Action Plan, which outlined a number of actions to reduce the release of greenhouse gas (GHG) emissions and improve the City's air quality. Furthermore, in 2009 the City's Sustainable Energy Strategy was established which outlined specific targets for reducing electricity, conserving natural gas, and increasing renewable energy generation, as summarised in Figure 5.

SOURCE	2020 TARGET	2050 TARGET
Electricity conservation	550 MW reduction	1050 MW reduction
Natural gas conservation	730 Mm^3 reduction	1650 Mm^3 reduction
Renewable energy generation	550 MW increase	1000 MW increase
Renewable thermal energy	90 Mm^3 of natural gas displaced	200 Mm^3 of natural gas displaced

Figure 5: Targets from the City of Toronto's Sustainable Energy Strategy.

In 2017, the Toronto City Council unanimously approved the current climate action strategy called TransformTO. It lays out a set of long-term, low-carbon goals and strategies to reduce local greenhouse gas emissions. Toronto's greenhouse gas (GHG) emissions reduction targets, based on 1990 levels, are:

- 30% reduction by 2020
- 65% reduction by 2030
- 80% reduction by 2050

The following standards are the key vehicles under TransformTO to achieve the GHG emission targets related to homes and buildings.

1.6.2 The Toronto Green Standards

The Toronto Green Standard (TGS) defines Toronto's sustainable design requirements for new private and city-owned developments. The third edition of the Toronto Green Standard (TGS-v3) – the latest version in issue at the time of writing – sets out a series of objectives for the city and provides a set of targets to which new developments should adhere.

There are currently four tiers under the TGS-v3 Tier 1 is the minimum requirement to obtain planning approval; Tiers 2 to 4 are higher level voluntary standards associated with financial incentives and verified post construction.

The TGS is expected to be updated to its requirement every three years, with the next tier (2) becoming the new minimum requirement for planning approval in 2022.

Under the TGS, the section named to *Energy/GHG & Resilience for Mid to High-Rise Residential & all Non-Residential Development* is relevant for the Masterplan Energy Strategy, which presents three main objectives:

- Reduce energy loads in buildings, encourage passive design strategies and provide protection during power disruptions
- Provide low carbon energy sources of supply
- Enable self-recovery during an emergency power disruption

The first criterion of this section is Energy Efficiency, which defines targets for new buildings to achieve the four Tiers.

The following metrics are set to measure the energy efficiency of the new buildings:

- **Total Energy Use Intensity (EUI)** – to encourage higher efficiency buildings and lower energy used by buildings hence utility costs
- **Thermal Energy Demand Intensity (TEDI)** – to encourage better building envelopes, improve occupant comfort and enhance resilience
- **GHG Intensity (GHGI)** – to encourage low-carbon fuel choices and reduce carbon dioxide emissions

Depending on the Tier the project aims for, target figures are set. The absolute pathway targets for each of these building types are summarised in Table 3.

Table 3: Toronto Green Standards for offices, retail and residential buildings.

	EUI (kWh/m^2)				TEDI (kWh/m^2)				GHGI ($kgCO_2/m^2$)			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Office	175	130	100	65	70	30	22	15	20	15	8	4
Retail	170	120	90	70	60	40	25	15	20	10	5	3
Residential	170	135	100	75	70	50	30	15	20	15	10	5

In addition to Energy Efficiency, the following requirements are set for Tier 2 and above:

- Renewable energy
  - Solar readiness (Core): Ensure that buildings are designed to accommodate connections to solar PV or solar thermal technologies;
  - On-Site Renewable Energy (Optional): Design on-site renewable energy systems to supply one of the following:
    1. Minimum of 5 per cent of the building’s annual energy consumption from one or a combination of acceptable renewable energy sources; OR
    2. Minimum of 20 per cent of the building’s annual energy consumption from geo-exchange.
- District Energy Systems
  - District Energy Connection (Core): Design buildings to connect to a district energy system where one exists or is planned for development
- Operational Systems

- Benchmarking and Reporting (Core): Register the building on ENERGYSTAR® Portfolio Manager.
- Best Practice Commissioning (Core): Commission the project using best practice commissioning.
- Air Tightness Testing (Core): Conduct a whole-building Air Tightness Test to improve the quality and air tightness of the building envelope.
- Sub-metering (Optional):
  1. Install thermal energy meters for each heating/cooling appliance in all residential units; OR
  2. Install thermal energy meters for each individual tenant in multi-tenant commercial/retail buildings

- Building Resilience
  - Resilience Planning and Emergency Power Back-Up (Core): Complete the Resilience Checklist.
  - Refuge Area and Back-Up Power Generation (Optional)
    1. Residential: Provide a refuge area with heating, cooling, lighting, potable water, and power available; AND
    2. Provide 72 hours of back-up power to the refuge area and essential building systems

Additional detailed guidance is provided for each criterion, including:

- Energy Strategy Terms of Reference
- Solar Ready Buildings Planning Guide
- Design Guideline for District Energy-ready Buildings

In particular, the Energy Strategy Terms of Reference provides guidance on the minimum requirements for Energy Strategies.

1.6.3 The Zero Emissions Buildings Framework (ZEB)

The Zero Emissions Buildings Framework (City of Toronto, 2017) was created to outline the future building performance requirement under TGS.

This framework provides a set of additional prescriptive requirements to ensure that modelled performance targets within buildings are fully realised in practice and set the future target for buildings to achieve net-zero carbon emissions.

The guidance also indicates typical envelope and system performance needed to achieve the desired TGS Tier for a number of archetypes, namely high-rise multi-unit residential buildings (MURB), low-rise MURB, commercial office and commercial retail. Table 4 below shows the results from a study carried out to understand what design solutions can achieve the TGS tiers of performance for high-rise MURB, which is the prevailing archetype in 2150 Lake Shore development.

Table 4: Buildings features achieving the TGS Tiers of performance for high-rise MURB (source: Zero Emissions Buildings Framework, 2017).

	TGS v3 Tier 1	**TGS v3 Tier 2**	**TGS v3 Tier 3**	**TGS v3 Tier 4**
Target EUI	170.00 kWh/m2	135.00 kWh/m2	100.00 kWh/m2	75.00 kWh/m2
Target TEDI	70.00 kWh/m2	50.00 kWh/m2	30.00 kWh/m2	15.00 kWh/m2
Target GHG	20.0 kg/s	15.0 kg/s	10.0 kg/s	5.0 kg/s
Achieved EUI	169.50 kWh/m2	133.00 kWh/m2	99.80 kWh/m2	74.40 kWh/m2
Achieved TEDI	70.60 kWh/m2	42.20 kWh/m2	29.00 kWh/m2	9.40 kWh/m2
Achieved GHG	22.6 kg/m²	16.2 kg/m²	9.0 kg/m²	3.7 kg/m²
WWR	40%	40%	40%	40%
Wall R-Value	10	10	10	20
Roof R-value	20	20	20	20
Win U-value	0.4	0.3	0.2	0.14
Infiltration Savings	Code	25%	50%	75%
Lighting Savings	30%	30%	50%	50%
Plug Savings	0%	10%	10%	20%
Fans	ECM	ECM	ECM	ECM
Heat Recovery	65%	75%	80%	85%
Vent. Effectiveness	0.8	0.8	1	1
Corridor Ventilation	30cfm/ste	15cfm/ste	15cfm/ste	0.3 l/(s.m^2)
Heating Plant	Condensing Boilers	Condensing Boilers	50% ASHP 50% Condensing Gas Boilers	90% ASHP Electric Boilers Top Up
Heating Plant Eff.	96%	96%	4.15, 96%	4.15, 100%
Cooling Plant	Water-cooled Screw Chillers	Water-cooled Screw Chillers	ASHP	ASHP
Cooling Plant COP	5.2	5.2	3.15	3.15
DHW Savings	20%	30%	40%	50%
Heating Gas	70.60 kWh/m2	41.00 kWh/m2	25.50 kWh/m2	0.00 kWh/m2
Heating Electricity	2.90 kWh/m2	2.90 kWh/m2	2.90 kWh/m2	5.50 kWh/m2
DHW Gas	35.60 kWh/m2	31.10 kWh/m2	4.90 kWh/m2	0.00 kWh/m2
DHW Electricity	0.00 kWh/m2	0.00 kWh/m2	3.30 kWh/m2	5.70 kWh/m2
Cooling Electricity	4.90 kWh/m2	5.40 kWh/m2	12.00 kWh/m2	14.00 kWh/m2

1.7 Methodology

1.7.1 Objectives

FCR (Park Lawn) LP and CPPIB Park Lawn Canada Inc.'s 2150 Lake Shore masterplan seeks to be an exemplar project, raising the benchmark for future developments. The masterplan concept has been developed based on an ambitious sustainability vision, delivered through tailored objectives and criteria that comprehensively address sustainable development at both the masterplan and building level.

The Sustainability Strategy for the masterplan consists of seven themes and contextualizes all the criteria to be adopted by design teams in the coming stages. 'Towards zero carbon' is the relevant theme for this Energy Strategy. Based on this, the current Energy Strategy explores possible solutions to minimise the carbon emissions from buildings in the development and includes resilience considerations such as energy storage, backup power and the contribution of renewable energy strategies.

General objectives for the Masterplan Energy Strategy are to:

- Minimise and offset, where possible, carbon dioxide emissions;
- Preserve and improve, if possible, local area quality;
- Limit urban heat island effect;
- Increase resilience to climate change;
- Provide reasonable energy bills for the occupants;
- Achieve economically feasible solutions for the client.

Particularly, the carbon emissions offset will be pursued through solutions that:

- Minimise energy demand for the buildings;
- Maximise the use of renewable and low carbon technologies for energy provision;
- Ensure capability of connecting to future district energy systems;
- Avoid combustion activities on the site.

The current study aims at providing a high-level comparison of possible solutions to estimate the environmental impacts of each option at masterplan stage.

1.7.2 General approach

The current study was conducted at Detailed Masterplan design stage therefore it is mainly focused on the analysis of site-wide strategies to achieve a low carbon development.

Due to the limited information on building design, the study was based on assumptions for the determination of the building loads and energy demand as described in section 1.7.3. Based on the demand model, a number of energy supply technologies were considered and a short list of options was modelled on the site-wide scale to estimate the total energy loads and carbon emissions for the development, as described in section 1.7.4.

In parallel, a study was carried out on a sample block (D1) to guide the building design on reducing the energy demand, as described in section 2. This study sets the basis for the low carbon building design which will be further detailed at the next stage and used as a reference for how the energy strategy and district energy network will be developed in each phase of the project.

1.7.3 Energy demand modelling

The study started from a demand modelling exercise to estimate the energy demand of the buildings that form the development to base the selection of the optimal energy supply solution.

Due to the high sustainability aspirations of the project, the demand model was based on Tier 4 energy demand benchmarks as per the Zero Emissions Buildings Framework (CoT, 2017) and Arup's experience on similar projects. However, the final TGS performance target is still subject to further design development and discussions with local authorities.

In particular, the thermal energy demand for all main archetypes was assumed at 15kWh/m^2, as per TGS v3 (see Table 5 below).

Table 5: TEDI targets by building type (source: TGS v3).

Archetype	Tier 1	Tier 2	Tier 3	Tier 4
Office	70 kWh/m²	30 kWh/m²	22 kWh/m²	15 kWh/m²
High-rise MURB	70 kWh/m²	50 kWh/m²	30 kWh/m²	15 kWh/m²
Retail	60 kWh/m²	40 kWh/m²	25 kWh/m²	15 kWh/m²

The energy demand of the site was then modelled on a hourly basis using profiles from previous Arup projects and the CWEC weather file for Toronto. The model allowed to estimate the combined loads for the site and reduce the risk for overestimating the peaks. The estimated space heating, domestic hot water (DHW), cooling and electricity loads for the site during a typical year are showed in Table 6 and the following graphs (see Figure 6, Figure 7 and Figure 8).

Table 6: Energy demand for the development.

Load type	Peal load	Total annual demand
Space heating	15.8 MW	14.3 GWh
DHW	6.4 MW	15.9 GWh
Cooling	34.5 MW	19.7 GWh
Electricity (non-thermal)	13.1 MW	35.5 GWh

It should be noted that the electricity loads shown below refer only to lighting, plugs, pumps and fans (non-thermal use). The electricity loads for cooling and ventilation will vary depending on the selected solution, therefore these are calculated after selecting the preferred option.

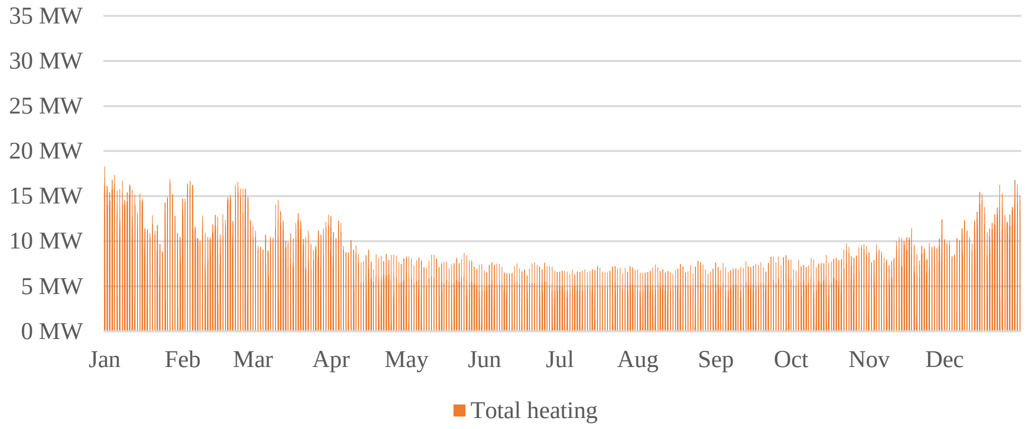

Figure 6: Site heating loads (cumulative of space heating and DHW).

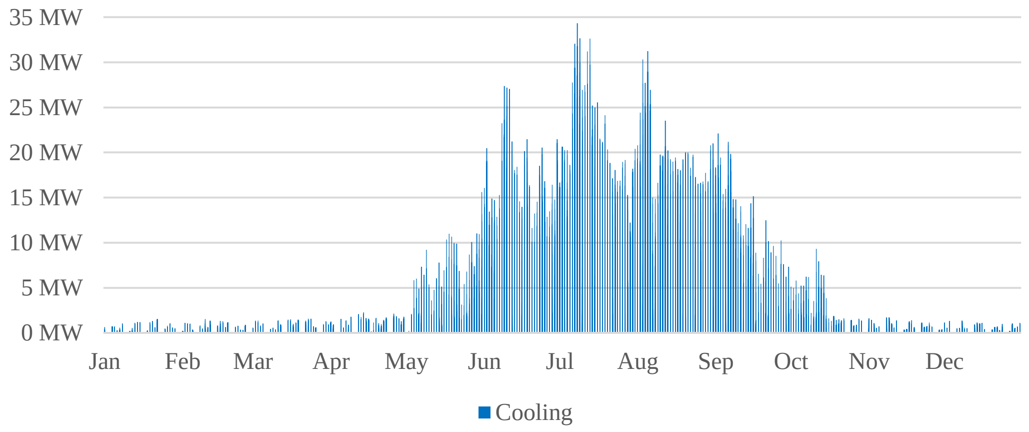

Figure 7: Site cooling loads.

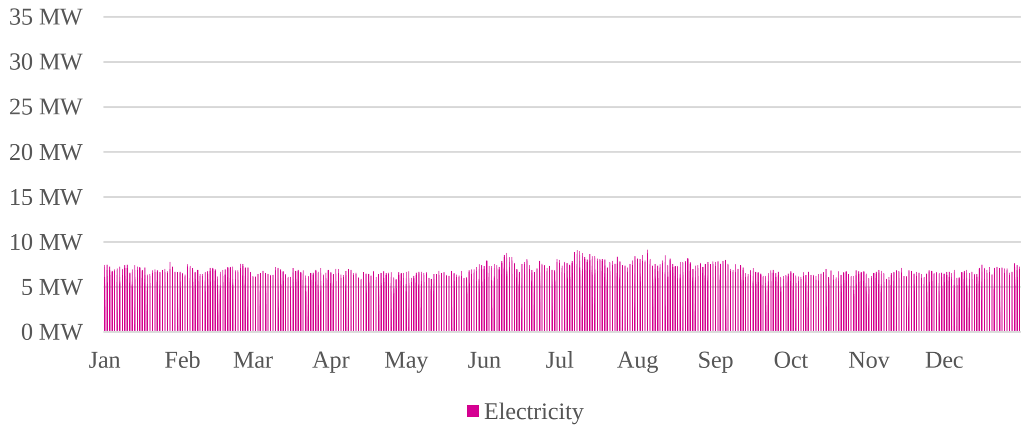

Figure 8: Site electricity loads.

1.7.4 Energy supply modelling

A long list of possible energy supply solutions was explored for the site and these were considered in relation to qualitative considerations such as site conditions, fuel availability, air quality and environmental issues, compatibility with the energy demand profile of the site. Table 7 lists all the options considered and a summary of the pros and cons for each technology.

The qualitative analysis produced a short list of technologies that have been further investigated and compared through a quantitative analysis aimed at evaluating the implications of each solution in terms of reduction in carbon emissions and cost; these were:

- Ground source heat pumps (GSHPs);
- Air source heat pumps (ASHPs);
- Biomass boilers;
- Water source heat pumps (WSHPs).

The quantitative comparative analysis of these options is included in section 3.

Table 7: List of considered supply technologies.

Supply technology	Positive aspects	Issues	Shortlisted
Gas fired boilers	• Least expensive	• High carbon dioxide emissions • Combustion on site (impact on air quality)	NO (Base case scenario)
Gas fired CHP plant	• Usually a good financial return on investment • Could supply the whole heating load	• Very high carbon dioxide emissions • Combustion on site (impact on air quality)	NO
Ground source heat pumps	• Very low carbon dioxide emissions • No combustion on site	• Cooling & heating demand needs to be balanced throughout the year, therefore need to be sized on lowest base load • Feasibility and number of boreholes to be checked • Cannot cover the whole thermal load	YES
Water source heat pumps	• Very low carbon dioxide emissions	• Expensive option due to plant required and large pipe connection to the lake • Viability of connection to the lake to be confirmed	YES
Air source heat pumps	• Low carbon dioxide emissions if used at medium temperatures	• Cannot work at very low outside air temperatures • Cannot cover the whole thermal load	YES
Solar photovoltaic (PV) panels	• Low carbon dioxide emissions	• Roof space needed	YES
Solar thermal panels	• Very low carbon dioxide emissions • Cheap option	• Roof space needed	YES
Biofuel (liquid) systems – heating only	• Capable to cover the whole heating load • Very low carbon dioxide emissions when correctly sourced • Fuel versus food problem is not sourced correctly (reused vegetable oil instead of virgin etc.) • Low capital cost but higher operation costs	• Combustion on site (impact on air quality) • High NOx emissions • Issues with transport of fuel • Large fuel storage space required	NO
Biofuel systems – CHP / CCHP	• Capable to cover the whole heating load • Very low carbon • Cheap option	• High NOx emissions • Issues with transport of fuel • Big plant space required	NO

Wind turbines	• Very cheap renewable electricity	• Wind conditions not suitable • Unlikely to find a suitable location considering building massing • Small amount of electricity produced on a high-density plot	NO
Combined cycle gas turbine CCHP	• High energy density (small footprint required)	• Very high carbon dioxide emissions • Still need electrical grid connection for resilience	NO
Open cycle gas turbine CCHP	• High energy density (small footprint required)	• Very wasteful • Very high carbon dioxide emissions • Still need electrical grid connection for resilience	NO
Anaerobic digestion	• Very low carbon dioxide emissions	• Plant produces a gas that needs to be burnt (combustion on site) • Plant could be located off site by a food court etc. and piped to site • Likely to provide insufficient energy for the site (heating and electricity)	NO
Fuel cells	• CHP technology without combustion on site • Improves air quality	• Very expensive technology to buy and maintain	NO
Smart battery storage	• Allows importing of electricity during low site demands to smooth peaks • Can be used to reduce the carbon dioxide emissions of the site	• An ‘add on’ technology that does not produce energy, it just stores it.	YES
Other solid fuel fired thermal only or CHP/CCHP	• When used with forest residue sourced virgin woodchip, a very low carbon dioxide emitting plant • Uses forest waste to heat (and potentially power) the site.	• Electrical generation plants can be wasteful • Need to be operated and maintained daily (full time site presence may be required) • Unlikely to represent doo return on investment without significant subsidies	NO

Note: each ‘plot’ includes multiple buildings (usually 2 to 3), and each building sits on a ‘lot’.

2 Reducing energy demand

2.1 The energy hierarchy

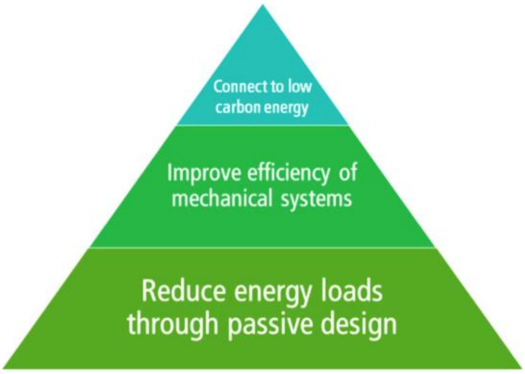

Figure 9: Low-carbon building design hierarchy (Zero Emissions Buildings Framework, 2017).

The Zero Emissions Buildings Framework recommends following the energy hierarchy showed in Figure 9 to achieve low-carbon design, namely:

1. Reduce energy loads through passive design;
2. Improve efficiency of mechanical systems;
3. Connect to low carbon energy.

The approach needs to prioritize passive strategies to minimise the demand for heating, cooling and lighting of the buildings in the first place. The reduced loads should then be met using high-efficiency systems which ensure a reduction in primary energy demand. Then the remaining demand should be provided by renewable or low-carbon technologies as far as possible and the rest should be offset.

We have followed the above hierarchy for our initial analysis in the master plan stage and it is recommended that this approach continues to be followed when designing the buildings in 2150 Lake Shore development to achieve the development's sustainability objectives and to meet the TGS requirements.

2.2 Passive design

Passive design is a building design approach based on measures that optimise the use of natural resources (climate) to improve the internal comfort conditions in the building without the need of any form of energy. It can reduce or eliminate the need for auxiliary heating or cooling system.

The use of passive strategies must be optimized throughout the year to balance the need for heating and cooling.

Based on the local climate and the building typologies, the following passive strategies can be implemented in the building design of a high-rise mixed development in Toronto:

- Optimise the window ratio for each façade of the buildings in relation to the orientation and the environmental shades and obstructions;
- Optimise U values for the opaque and transparent building envelope elements to balance cooling and heating loads;
- Optimise g values for windows to ensure high daylight levels, good amount of solar gains in winter and limited the cooling load in summer;
- Prioritize external shading devices over internal to maximise the reduction in solar gains in summer (movable external shading devices ensure full flexibility during the year);
- Optimise location and depth of balconies to block sun rays in summer and permit solar gains in winter;
- Use exposed high thermal mass in walls and ceiling in living and office areas in combination with night-time ventilation to apartmentten temperature fluctuations during the day;
- Allow for human-controlled natural ventilation and design for wider ranges of comfort temperature;
- Allow for cross ventilation where possible to maximise free cooling through natural ventilation;
- Maximise airtightness to avoid unexpected heat loss and gain through infiltration;
- Minimise thermal bridges (e.g. using continuous façade insulation and thermal break balconies);
- Create openable greenhouses on south-facing balconies to pre-heat air in winter and allow free air flow in summer;
- Create solar atria on the south side of the buildings with vertical compartments to limit excessive stack effect;
- Optimise the location of space activities to take advantage of light and solar gains when the spaces are used (see Figure 10).

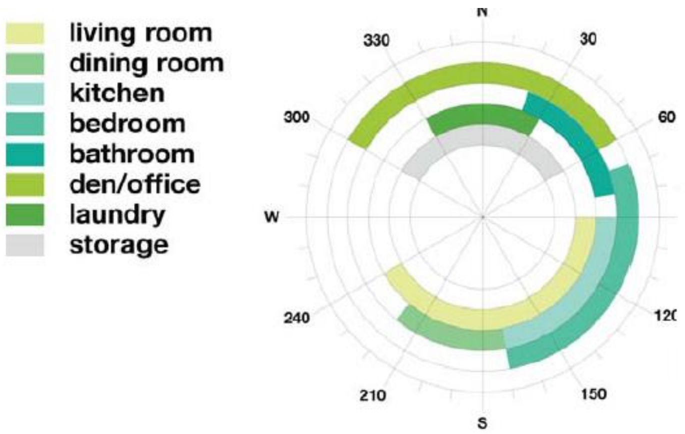

Figure 10: Optimal location of space activities (source: Roadmap to Net Zero, 2017).

2.2.1 Envelope optimisation study

A preliminary study was carried out on a sample block (D1) to identify the most effective passive strategies that minimise the thermal load on the building.

The study started from the preliminary architectural design provided by Allies & Morrison in February 2020. A sample apartment was modelled in 3D using Rhino 6 (see Figure 11) and the geometry was imported into Grasshopper3D where the energy performance were tested using the Honeybee, a plugin for Grasshopper3D that connects the 3D model to validated simulation engines such as EnergyPlus, Radiance, Daysim and OpenStudio for building energy, comfort, daylighting and lighting simulation[1]. This combination of software makes it possible to run optimisation analysis towards a target objective.

In this case, a number of passive strategies were tested, as reported in Table 8. All possible combinations were tested for all four possible orientations of the apartment and three sample floor levels, low, middle and high, in order to also test the impact of surrounding shades on the façade performance (see Figure 13). A total of 5,184 combinations of the possible passive design measures were simulated.

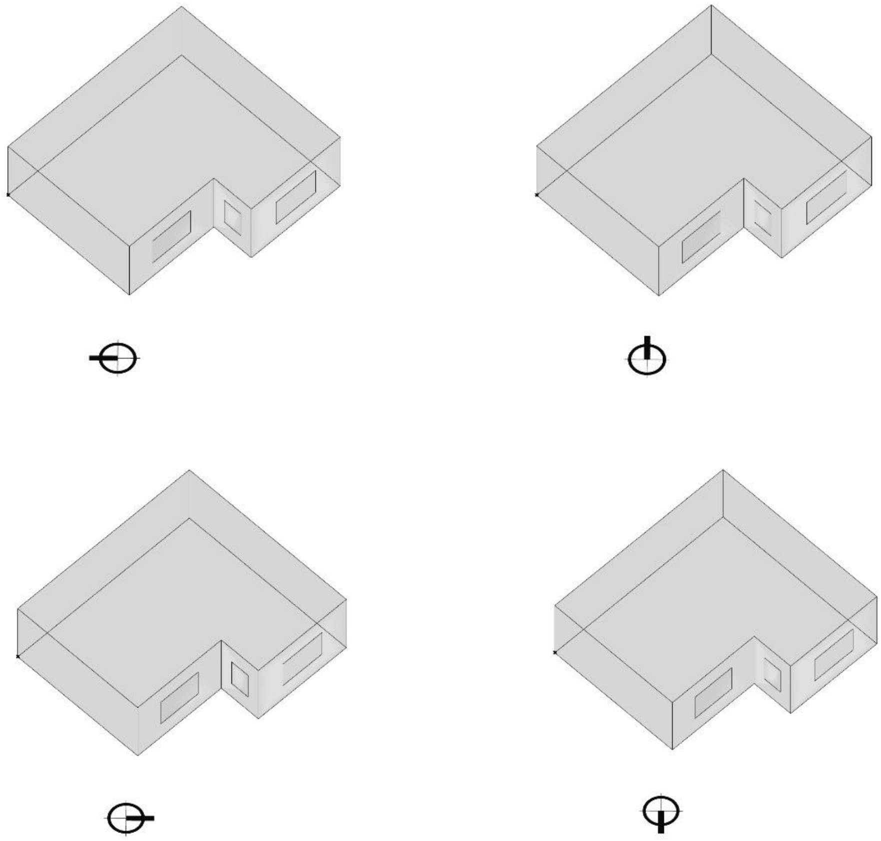

Figure 11: Sample apartment in all four orientations.

[1] https://www.food4rhino.com/app/ladybug-tools

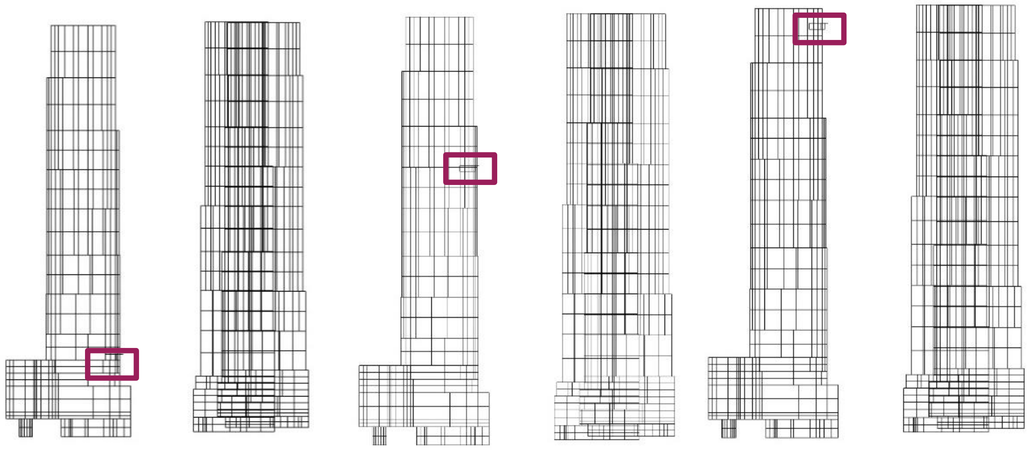

Figure 12: Sample apartments in different floor levels and building positioning.

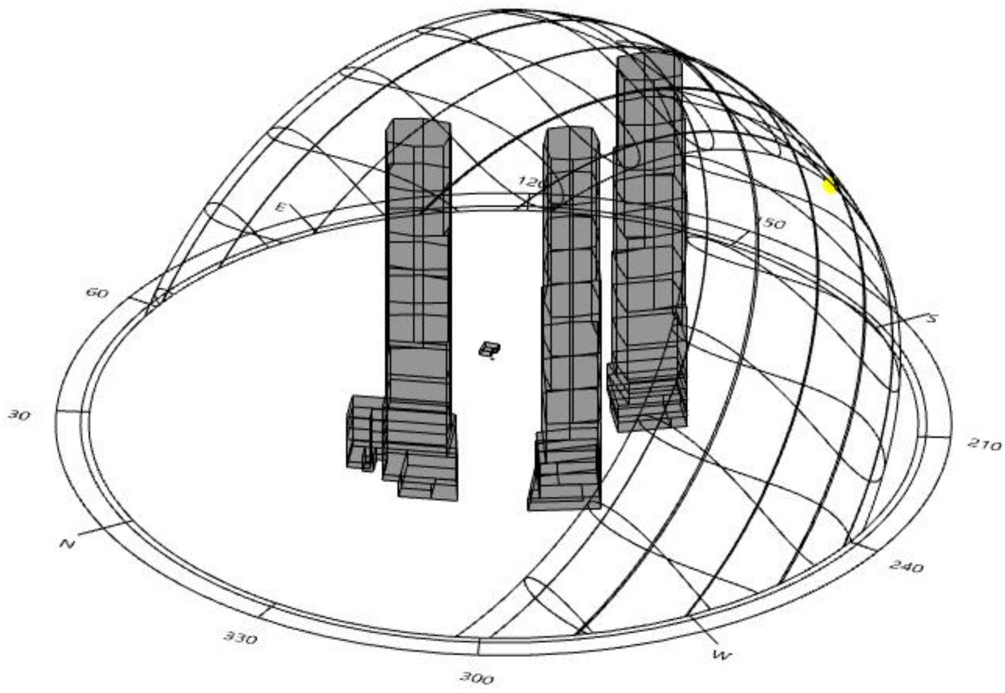

Figure 13: Sample apartments in context of shading.

Table 8: Passive design strategies tested.

Element	**Measure**	**Performance level**
External wall U value [W/(m^2.K)]	Typical	0.20
	Improved	0.15
	PassivHaus standards	0.10
Window-to-wall ratio [%]		20%
		40%
		60%
		80%
Window U value [W/(m^2.K)]	Typical	1.40
	High performance double glazed	1.12
	Triple glazed	0.80
Window g value [-]	Typical	0.63
	Reduced emissivity	0.50
	Very low emissivity	0.35
Shading	None	-
	Projected balcony	1.5m
Infiltration [m^3/s per m^2 of façade @4Pa]	Typical	0.000285
	PassivHaus standards	0.000071

For each simulation, the model was set to report the thermal load intensity and the percentage of internal area achieving a good daylight, namely a daylight factor of 2% or above. The daylight parameter was used to filter out the solutions that did not ensure good daylight levels, considered necessary to achieve good design for the occupants. (see Figure 14).

The early-stage energy model described accounts only for ideal loads, meaning that no building services nor heat recovery efficiencies are considered in the analysis; for this reason, the thermal load parameter was used instead of the TGS's TEDI parameter to estimate the ideal heating load in the apartment per unit of internal floor area and the reduction in load due to the selected passive design measures.

The results from all 5,184 simulations were then analyzed and high-level construction costs were assessed for each combination of measures. The results from the energy model and the cost analysis were plotted in a graph for each sample apartment analysed to show the most effective solutions in terms of cost and demand reduction. The graph in Figure 15 shows, as an example, the cost and benefit of all passive design measure combinations for the low-level north-east facing apartment.

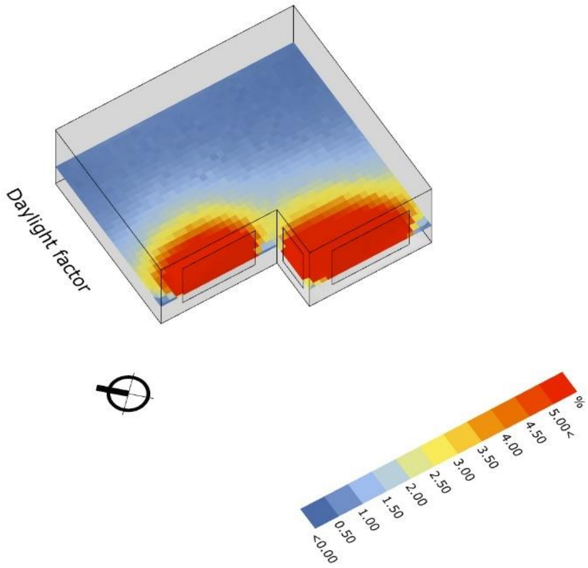

Figure 14: Visualisation of daylight simulation on the sample apartment facing south-west.

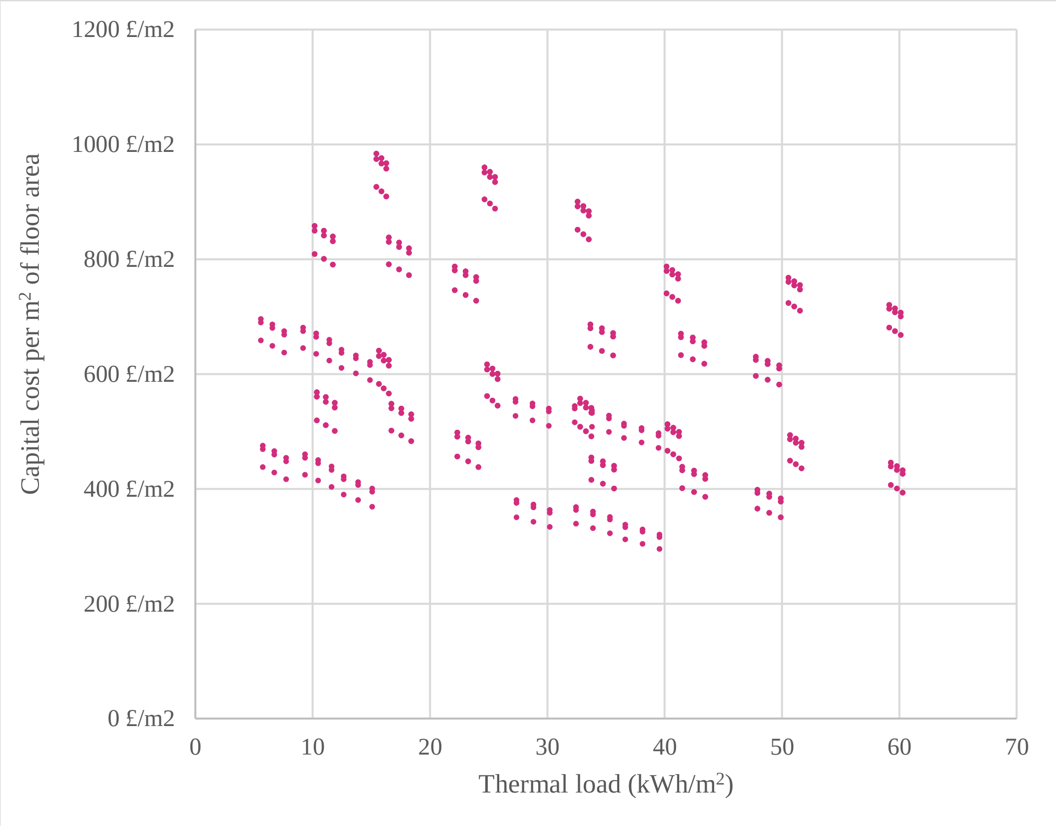

Figure 15: Sample cost-benefit graph of passive design measures for low level apartment facing north-east extracted from simulations where each dot represents a simulation scenario (note £1 = C$1.7).

The results show that the same reduction in thermal load – and consequently in energy consumption – can be achieved through a number of different combinations. The selection of the preferred option should be conducted at the next design stage for each plot on a building-by-building basis, based on the specific conditions and drivers.

The main findings from the study and key recommendations are reported below for each sample floor level.

Low level sample apartment

- Minimum 40% glazed area required for NE and SE oriented apartments to ensure good daylight
- Minimum 60% glazed area required for NW and SW oriented apartments to ensure good daylight
- Maximum 60% glazed area on all orientations to reduce heat losses
- Window g value has a limited impact on thermal loads
- Triple glazing is recommended on NW and SW orientations where surrounding buildings prevent adequate solar gains
- Higher wall U values (0.20 W/(m2.K)) can be allowed if counter-balanced by reduced glazed area or triple glazing
- Balconies are acceptable on NE and SE orientations which are not shaded by surrounding buildings
- Very high airtightness is recommended (at PassivHaus level) to balance the reduced solar heat gains in winter due to shades from surrounding buildings

Middle level sample apartment

- Minimum 40% glazed area required for NE and SE oriented apartments to ensure good daylight
- Minimum 60% glazed area required for NW and SW oriented apartments to ensure good daylight
- 80% glazed area is acceptable on all orientations if balanced with other measures to reduce heat losses
- Window g value has a limited impact on thermal loads
- Double glazing is sufficient on all orientations if balanced with other measures
- Higher wall U values (0.20 W/(m2.K)) can be allowed if balanced by reduced glazed area or triple glazing
- Balconies are acceptable on all orientations
- Very high airtightness is recommended on NE and NW orientations but is not necessary on SE and SW orientations

High level sample apartment

- Minimum 40% glazed area required on all orientations to ensure good daylight
- 80% glazed area is acceptable on all orientations if balanced with other measures to reduce heat losses
- Window g value has a limited impact on thermal loads
- Double glazing is sufficient on all orientations if balanced with other measures
- Higher wall U values (0.20 W/(m$_2$.K)) can be allowed if balanced by reduced glazed area or triple glazing
- Balconies are acceptable on all orientations
- Very high airtightness is recommended on NE and NW orientations but is not necessary on SE and SW orientations

2.2.2 Next steps

The analysis described above is aimed at reducing the heating load during winter and consequently minimising the TEDI for the building.

Further strategies to minimise the risk for overheating in summer and the cooling loads shall be explored at the next stage once the design of the building and the residential units is brought to a higher level of detail in terms of envelope design and façade materials. Particularly, the following solutions should be explored:

- Use of natural ventilation combined with high thermal mass should be maximised and cross ventilation should be allowed where possible;
- The use of external shading devices such as balconies and external louvres should be optimised to allow solar gains in winter and block direct sun in summer.

It is also recommended to carry out a detail façade study to minimise thermal bridging and the related unwanted thermal losses. Possible strategies are:

- Prefer recessed balconies to projected balconies;
- Use thermal break balcony connectors for projected balconies;
- Provide continuous external insulation to the envelope;
- Put extra care in window and junctions detailing.

2.3 Efficiency of mechanical services

MEP strategies consist of the selection of high-efficiency systems to provide the remaining building's energy needs while consuming the minimum primary energy possible.

When selecting the building services systems for 2150 Lake Shore, the following selection should be prioritized:

- Low temperature heating distribution systems;
- Variable frequency drives for circulation pumps and ventilation fans;
- High efficiency motors incorporated into all building services;
- Time & temperature zone control, occupancy demand-controlled ventilation (for commercial properties), the use of free cooling (weather permitting), optimum start/stop and weather compensation to optimise plant performance;
- High efficiency mechanical ventilation system with heat recovery (local heat recovery to be used within residential towers);
- Minimise specific fan power of ventilation systems;
- LED lighting and high efficiency lighting design;
- Provision of a lighting control system with daylight linking and occupancy sensing where appropriate to limit unnecessary use of electric lighting;
- Provision of a building energy management system with energy metering to control and monitor all major energy consuming plant and systems – to be further explored in coordination with digital strategy for the master plan.

When evaluating the efficiencies of MEP systems, the minimum requirements of the following standards should be met and surpassed where possible:

- ASHRAE 90.1;
- ASHRAE 62.1;
- Toronto Green Standard (TGS);
- Supplementary Standard SB-10;
- Ontario Building Code (OBC);
- National Energy Code of Canada Buildings (NECB).

A further review of energy efficiency measures will be undertaken throughout the design stages as the design develops to meet the Client's brief.

3 Efficient and low carbon energy supply

Once the energy loads for the buildings have been minimised through passive and active strategies, the remaining energy needed should be delivered using the most efficient and lowest-carbon solutions to ensure that the carbon emissions of the buildings are minimised and offset.

This section explores and compare a series of possible low-carbon energy technologies that were considered viable for 2150 Lake Shore.

3.1 Possible technologies

As a result of the qualitative analysis presented in section 1.7.4, a short list of technologies was selected as possible main strategies. These were then further investigated and compared through a quantitative analysis aimed at evaluating the implications of each solution in terms of reduction in carbon emissions and cost; these were:

- Ground source heat pumps (GSHPs)
- Air source heat pumps (ASHPs)
- Biomass boilers
- Water source heat pumps (WSHPs)

3.1.1 Ground source heat pumps

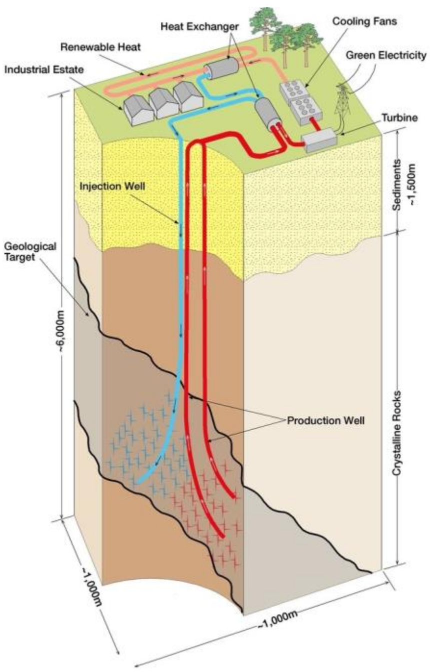

Figure 16: Geothermal system (open loop).

Ground Sourced Heat Pump (GSHP) systems use geo-thermal heat exchange to produce heating and cooling for buildings. They are generally used in conjunction with closed loop pipework systems installed either horizontally, approximately 2 metres below ground level, or vertically in bore holes with bore hole depths varying depending upon site ground conditions. Vertical pipe loops can often be accommodated within pile foundations to provide a more cost- and space-effective installation.

Ground-coupled heat pumps are not considered wholly renewable due to electrical energy required to generate heating/cooling, but when utilised can substantially reduce building carbon emissions thanks to the high efficiencies which lead to negligible use of primary energy compared to traditional systems.

GSHPs can generate cooling in summer, using the temperature of deep water in the ground, and heating in winter, which has to be produced at low temperature (in the order of 40-50℃) in order to keep high levels of efficiency.

The capacity of the system depends on the availability of soil to install boreholes and the system should be designed to balance the heat extracted from the ground in winter and the one injected back in summer.

Geo-exchange is an increasingly common low-carbon option in Ontario and does not present relevant feasibility issues, requiring little maintenance and low operational costs. However, the system has higher capital cost and operating energy cost compared to traditional natural gas-based systems.

This solution can be implemented on a plot by plot basis or on a centralised system, with the GSHP located in an energy centre and connected to the buildings to a district cooling and heating network. Both solutions have been considered in the comparative analysis, however the centralised solution does not present advantages in terms of economy of scale and increased efficiency, still involving higher capital cost and plant over-sizing issues.

A preliminary analysis has proven that the site's available ground area cannot yield sufficient geo-exchange capacity to provide the whole energy demand for the site due to the high density of the development. Therefore, the system needs to be supplemented by gas-fired or electric boilers and chillers.

3.1.2 Air source heat pumps

Figure 17: Air source heat pumps (source: Daikin UK website).

Air Source Heat Pump (ASHP) systems use the ambient air as the medium from which heat is extracted. Heat from the air is absorbed at low temperature into a fluid. This fluid then passes through a compressor where its temperature is increased and transfers its higher temperature heat to the heating and hot water circuits of the building.

The building design for heating would have to be adapted to cater for lower grade heat output from the ASHPs, typically 45°C maximum flow temperature, as oppose to conventional design, typically at 80°C flow temperature.

ASHPs operate very inefficiently at low external temperature conditions and typically cannot operate at temperatures below -5℃. For this reason, this option requires supplementary boilers or local immersion heaters in the apartments to meet the heating loads in winter.

ASHPs are a relatively simple system with no feasibility issues and very low maintenance required.

This solution is not effective on a centralised system due to the very low temperature of the heat generated which would lead to high distribution losses on a district heating network. Therefore, only a plot-by-plot solution has been considered in the comparative analysis.

3.1.3 Biomass boilers

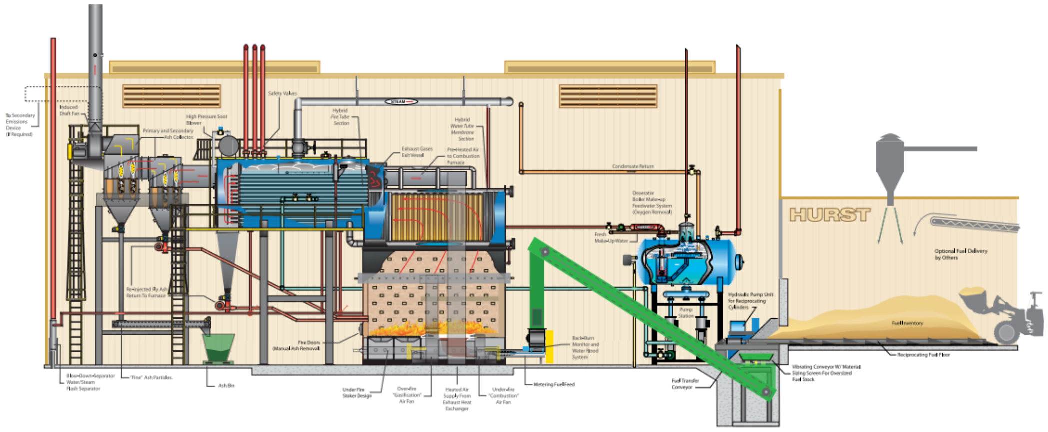

Figure 18: Typical biomass boiler sketch (source: Hurst website).

Biomass boilers can be used to provide heating at high temperature to the buildings. Biomass is generally considered a renewable source since the material burnt into the boilers comes normally from sustainably managed forest that replant trees regularly; however, additional carbon emissions are involved in transporting and refining the material.

These systems present significant technical challenges and require many additional components, such as a storage facility, handling, delivery access, ash removal, thermal storage.

Fuel is normally delivered via trucks; therefore, careful consideration must be given to space requirements on site, vehicle turning radius and location of fuel store. Additionally, in urban environments, logistics and security of fuel delivery can also be an issue.

In addition, wood chips/pellets are usually housed indoor in order to avoid decay due to humidity and rain; thus, storage facilities would have to be built inside the energy centre, increasing the capital cost and reducing the useful floor area of the development.

Carbon dioxide intensity for biomass in Ontario is higher than the one of gas; additionally, biomass-fuelled heating systems can produce a large amount of NOx and so they have a negative impact on the local air quality and may cause problems with obtaining planning consent.

3.1.4 Water source heat pump

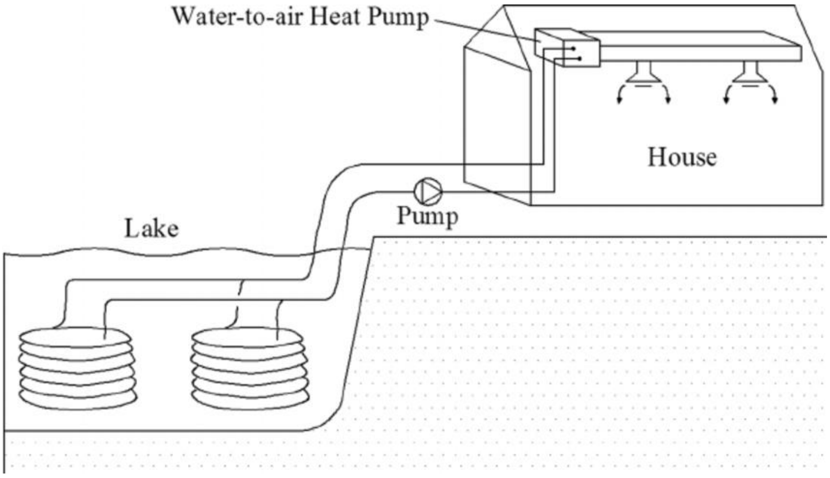

Figure 19: Water source heat pump sketch (source: Journal of Renewable and Sustainable Energy, 2014).

Water source heat pumps (WSHPs) are similar systems to ground source heat pump but use the water typically from a lake or a river as the medium for heat transfer. Lake-connected WSHPs can be deep or surface water system, depending on the depth at which the pipework is installed, with different issues related to permission and environmental impacts.

Deep lake water cooling is a non-viable solution for the site due to the lack of a water treatment plant nearby and the fact that the Humber Bay has a shallow water depth relatively to the water near Centre Island. The site is also located far away to downtown Toronto's deep lake water cooling system, thus the connection to the existing Enwave network is not viable.

An alternative option would be represented by creek or lake surface water, however in this case the temperature of the water can drop to near or below freezing point in winter being not effective for heat pump systems.

In addition, the use of surface or deep lake/creek water requires obtaining a certificate of approval from the Ministry of Environment, Conservation and Parks. Approval by MOECP is granted on a case-by-case basis and process requirement and timeline is not certain. Scientific studies, including but not limited to ecological, hydrological and hydrogeological study, are also required. Also, the connection to Mimico Creek or Lake Ontario requires easement in public right-of-way and/or private properties.

A preliminary analysis was carried out to estimate the potential to connect to the Mimico Creek; however, results have shown that the system would be capable to provide only a very small portion of the energy demand of the site; therefore, considered the difficult permission process and the financial implications related to such a system, this solution has been discarded.

3.1.5 Solar technologies

The use of solar technologies was also explored as an additional source of energy through renewable generation. These were considered compatible with any of the main technologies and therefore can be applied to any solution.

The potential of solar technologies has been explored through a preliminary solar analysis. The aim of the analysis was to define the optimal size and location of a solar system which could deal with the landscape requirement to have the lower level roof spaces free for green roofs and terraces.

Two scenarios were explored:

1. All available roof area used for solar panels;
2. Solar panels only on the tallest roofs of each plot (28% of the total roof area).

The study proved that in the second scenario, with only 28% of the total roof area used for panels, the annual radiation available was more than 55% than the first scenario, where 100% of the available roof area was considered.

It is therefore recommended that the design of the roof space accounts for the benefit of allocating the higher-level roof areas to solar panels installation to maximise the system efficiency in terms of carbon emission reduction and costs.3

The second step of the analysis compared the carbon dioxide reductions related to solar photovoltaic panels to produce electricity and solar thermal panels to produce hot water.

The study considered horizontal panels located on 80% of the total roof available with effective area of 50% and efficiency equal to 15% for photovoltaic and 80% for solar thermal.

Assuming that all the renewable energy generated can be used, the renewable energy produced was:

- 3.8 GWh from solar thermal;
- 0.7 GWh for photovoltaic.

3.1.6 Battery energy storage

The integration of electricity storage systems into a network can be utilised in various manners depending on the topology and setup, common uses are to:

- Offset peak load demand (“peak shaving”);
- Smoothen the integration of renewable on-site generation;
- Provide back-up in case of emergency;
- Support utility grid stability.

Battery energy storage systems (BESS) traditionally comprises of medium to large scale battery bank(s) connected to the electrical distribution network via series of alternating / direct current (AC/DC) converters. The system has an overall high efficiency (> 85%) due to being static, with losses contributed mainly to the conversion from DC to AC and vice-versa. The connection point of the BESS into the electrical network can be strategically selected to allow for closer integration with photovoltaic (PV) technologies or electrical vehicle (EV) charging reducing the amount of conversion required in the system. BESS are easily scalable permitting staged deployment future proofing against changes in demand.

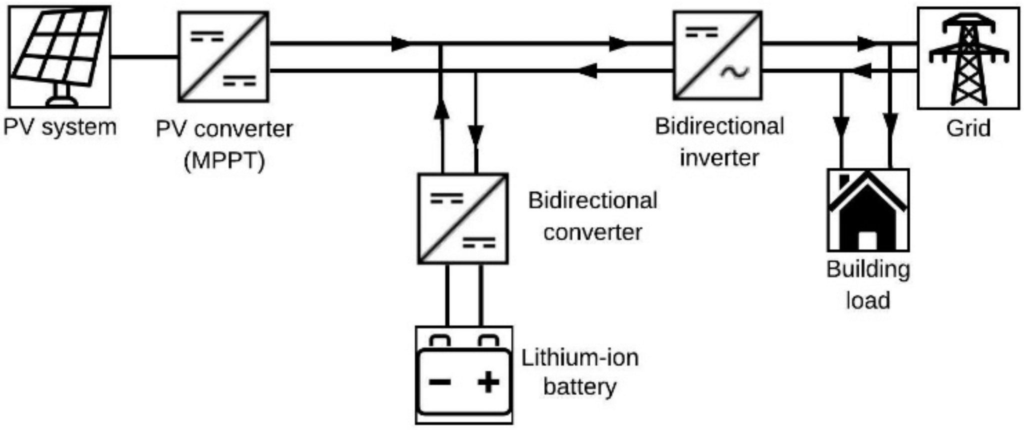

Figure 20: Battery Energy Storage System (BESS) integration into a building.

The power flow through the system is bi-directional, adapting to the daily load demand profile compared to available generation. Intelligent energy monitoring and management is responsible for scheduling charging and discharging cycles that offset peak demand when required. The systems will further optimise cycles to ensure battery life longevity.

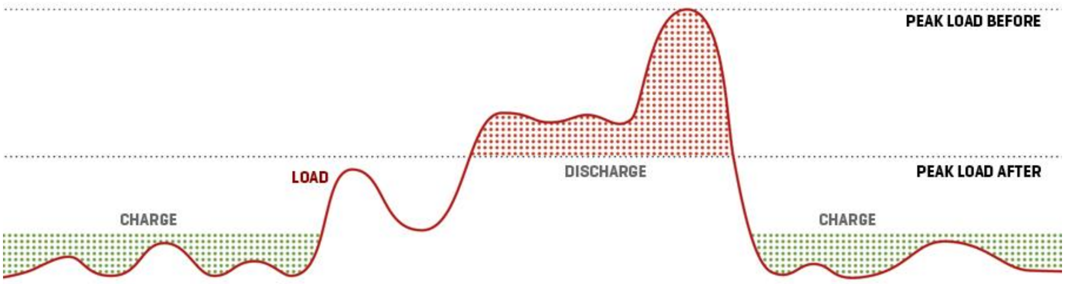

Figure 21: Example of peak load shaving.

A major advantage of the BESS as an energy sources is the fast response to unpredictable variations of demand and generation. With increasingly more renewable systems connected to the grid, energy storage is needed to support grid stability and smoothen large fluctuation. Further discussion with the local network operator is required to establish feasibility of paralleling with the grid and potential reduction in electricity charges.

Typically, battery energy storage has centralised topology with a single bank located in dedicated technical areas with ventilation and fire containment and suppression requirements. If placed in the vicinity to parking areas in a basement it allows for easier integration with electric vehicle (EV) charging, whereas a roof location can be combined with solar technologies.

Battery Technology Comparison

Various battery technologies are currently available on the market and recent innovation advances in the field suggest further improvements to the safety and the efficiency of the products offered on the market.

A high-level assessment of the technologies suitable for small to medium sized applications (up to 1MW) are detailed below.

Advanced Lead-Acid Batteries

Technology Description	Flooded or gel cells with electrodes immersed in an electrolyte
Maturity & Cost	Well-established technology with relatively low cost in comparison to other technologies
Energy Density	Average (30-50Wh/kg), resulting in large installation footprint
Lifecycle	150-200h Limited service life span, approximately 5 years Average number of cycles can be tolerated
Environmental / Safety Considerations	Hydrogen gas release upon charging that requires dedicated extract system Requires handling of hazardous materials Optimum operating temperature – 20°C Widely recyclable

Li-Ion Batteries

Technology Description	Lithium ions moving between positive and negative charged electrodes
Maturity & Cost	New technology with rapid commercial adoption. Relatively higher cost to other technologies but declining quickly in recent years
Energy Density	High (110-160Wh/kg), resulting in compact installation footprint
Lifecycle	>500h Service life span, approximately 5-10 years Large number of cycles can be tolerated
Environmental / Safety Considerations	Fire hazards related to overheating Optimum operating temperature – 20°C. Ambient temperature can be elevated to 30°C with no impact on battery operation. Currently they are only partially recyclable (with further recycling technology being developed)

High Energy Supercapacitors

Technology Description	Energy is stored as electric charge between two or more plates
Maturity & Cost	New technology with slow adoption due to high cost. More suitable for short-term applications relevant to power conditioning
Energy Density	Low 8-10Wh/kg
Lifecycle	30,000h Long life span, approximately 10-15 years. Unlimited number of cycles can be tolerated
Environmental / Safety Considerations	None noted

Flow Batteries

Technology Description	Two liquid electrolytes separated by ion-selective membrane. Electrolyte is stored in separate tanks and pumped in the battery to mix when required and is therefore an easily scalable technology
Maturity & Cost	Not commercially mature technology.
Energy Density	Average 40Wh/kg
Lifecycle	10,000h Long service lifespan, approximately 20 years Average - tolerates high number of cycles
Environmental / Safety Considerations	Large footprints associated with additional pumps and tank storage Electrolyte contents are reusable Less flammable that Li-Ion batteries

Fuel Cells

Technology Description	Electrochemical device combining hydrogen with oxygen to produce electricity
Maturity & Cost	Technology mature in industrial applications only Prohibitively high cost for small scale installations Not suitable for emergency back-up due to slow start-up response
Energy Density	Low
Lifecycle	5,000 – 40,000h (depending on technology and operation) Long service lifespan, approximately 15-20 years Average - tolerates high number of cycles
Environmental / Safety Considerations	Environmentally friendly Safety concerns associated with hydrogen storage

3.2 Comparative analysis

In order to advise the best solution in terms of energy provision for the site, a number of supply options have been considered and evaluated in terms of environmental impacts, namely:

Ground Source Heat Pumps

Option 1A	Ground source heat pumps (GSHPs) providing heating and cooling coupled with gas-fired boilers and air-cooled chillers providing cooling - by plot
Option 1B	Ground source heat pumps (GSHPs) providing heating and cooling coupled with electric boilers and air-cooled chillers providing cooling - by plot
Option 1C	Centralised ground source heat pumps (concentrated system of boreholes to supply the entire master plan) providing heating and cooling coupled with electric immersion heaters in each apartment for DHW top-up and air-cooled chillers providing cooling by plot

Air Source Heat Pumps

Option 2A	Air source heat pumps (ASHPs) providing heating coupled with gas-fired boilers in the basement and air-cooled chillers providing cooling - by plot
Option 2B	Air source heat pumps (ASHPs) providing heating coupled with gas-fired boilers on the roof and air-cooled chillers to provide cooling - by plot
Option 2C	Air source heat pumps (ASHPs) by plot providing heating coupled with electric immersion heaters in each apartment for DHW top-up and air-cooled chillers providing cooling by plot

Biomass

Option 3	Centralised biomass boiler to cover the heating base load coupled with centralised electric boilers and air-cooled chillers to provide cooling by plot

All the options were compared to a business-as-usual scenario (base case) involving gas-fired condensing boilers providing heating and air-cooled chillers providing cooling on a plot-by-plot basis.

The Toronto Green Standards targets for all tiers were calculated for the whole site, area-weighting the targets for the different archetypes. The model was built considering very efficient building design (Tier 4 TEDI figures were assumed, but subject to further design development and confirmation of TGS performance targets for the project).

The following table and graphs show the results of the comparative analysis between the considered options in terms of EUI and GHGI.

Results show that very deep pile GSHP with electric boilers can perform close to the requirements of Tier 4 of the Toronto Green Standard.

In terms of carbon emissions, though, the all-electric option (1B) achieves considerably better performances, with an additional 30% reduction over the hybrid solution (1A), meaning that it is the most carbon-effective solution.

Option 1B was considered the preferred option to achieve the highest reduction in energy demand and carbon emissions. Additional renewable technologies can be implemented to further improve the performance of the development and reduce the environmental impact of the site, such as solar photovoltaic and solar thermal panels. A high-level solar analysis was carried out for this purpose and is described in the following paragraph.

Table 9: Supply options summary.

	Base case	**Option 1A**	**Option 1B**	**Option 1C**	**Option 2A**	**Option 2B**	**Option 2C**	**Option 3**
EUI (kWh/m^2)	109.8	78.9	78.6	79.9	92.8	91.8	115.6	109.8
GHGI ($kgCO_2/m^2$)	11.9	5.1	3.9	4.0	7.9	4.6	16.8	11.9
Total CO_2 emissions (tCO_2/y)	7,990	3,400	2,630	2,670	5,250	3,070	11,260	7,990

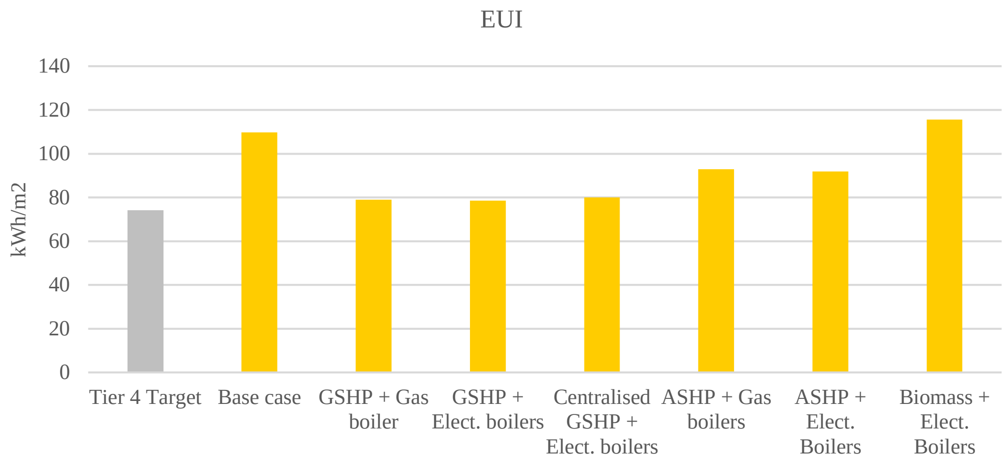

Figure 22: Total Energy Use Intensity figures for the supply options.

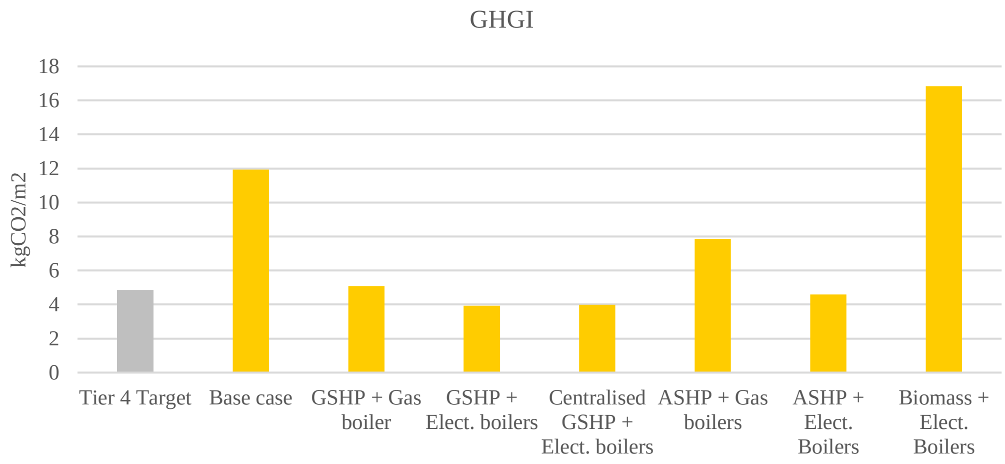

Figure 23: Greenhouse Gas Intensity figures for the supply options.

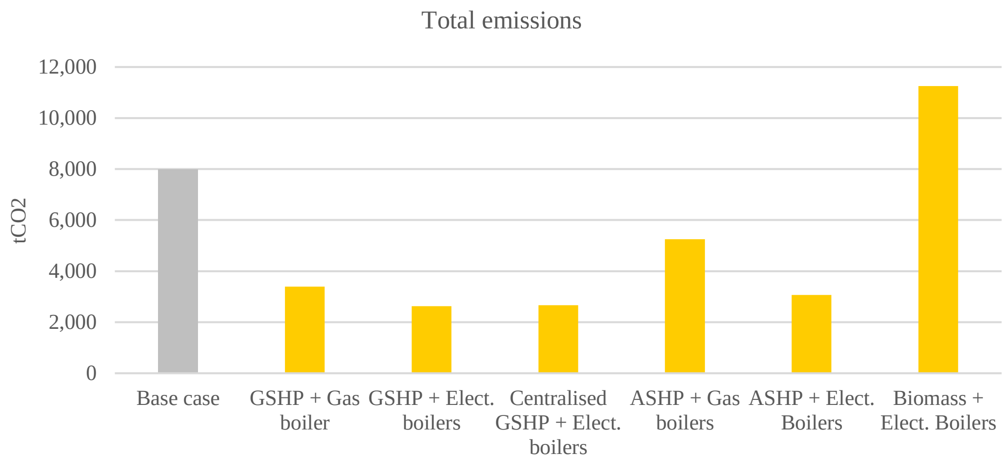

Figure 24: Comparative annual carbon dioxide emissions for the supply options.

3.3 Preferred solution

Based on the comparative analysis, Option 1B (GSHP + Electric boiler by plot) was selected as the proposed energy supply solution for the concept masterplan.

The strategy involves the following technologies installed on each plot:

- Ground source heat pumps (GSHPs) to provide space heating, pre-heat for the DHW and cooling;
- Electric boilers to top-up the DHW temperature and as a back-up solution;
- Air-cooled chillers to top-up the cooling.

It is relevant to note that although a detailed cost analysis was not carried out as part of the optioneering process, these technologies present a higher capital cost (capex) but a likely lower operational cost (opex) when compared to other solutions. Also, the impact of carbon taxes associated with the life-cycle assessment of other options could also place these technologies in a preferred position.

A GSHP feasibility study was carried out by Arup's Geotechnics Team to investigate the site-wide available capacity for geo-exchange and ensure annual heat balance with the ground. Further modelling has been carried out on a sample building (D1) as described in section 3.3.1.

The site-wide model showed that a GSHP system with boreholes installed below each building can provide annually 12 MW heating and 16 MW cooling capacity. For simplicity, at this stage, a proportion of this was assigned to each plot based on the total floor areas.

The following assumptions were considered:

- GSHP: SCOP in heating mode = 3.5; SCOP in cooling mode = 5.6;
- Electric boilers: 99% efficient;
- Air-cooled chillers: Average EER = 6.7;
- Buildings distribution losses: 6%.

Results of the preliminary analysis showed that the preferred solution has the potential to achieve the following targets:

- EUI = 78.6 kWh/m^2;
- GHGI = 3.9 $kgCO_2/m^2$;
- Annual carbon dioxide emissions: 2,630 tCO_2 (-19% compared to the base case).

Additional solar energy generation can be combined with the main strategy to achieve Tier 4 targets for EUI (74.1 kWh/m^2 calculated for the whole site) as suggested in section 3.1.

The high-level solar analysis had shown that, based on scenario 2 (see section 3.1.5):

- Solar thermal can produce 3.8 GWh of energy equal to 7.3% of the total energy demand for the site;
- Solar PV can produce 0.7 GWh of energy equal to 1.4% of the total energy demand for the site.

The use of smart batteries for energy storage is recommended to optimise the system and reduce the instantaneous peak electricity demands. The recommended technology to be applied is based on lithium-ion batteries, due to the commercial maturity of the technology, overall compact footprint of the installation and suitability to handle quick load variations in power demand. The integration of batteries in the system shall be investigated as part of the next design stage.

The solar analysis was based on a preliminary estimate of the roof area available; the actual renewable energy production available should be calculated at the next stage once the design of the roof areas is coordinated with plant and green roof requirements and the possible integration with the main building systems can be explored and optimised. The selection of the battery energy storage shall be also considered at that stage.

Although solar thermal shows a much higher potential in reducing the energy demand and the carbon emissions from the buildings, the integration of solar heating generation with the GSHP system can present issues in terms of constructability and pipework distribution, with cost and space implications particularly relevant for high-rise buildings. Therefore, the selection of the best system shall be conducted based on a more detailed design at building level.

3.3.1 Ground source heat pump modelling

3.3.1.1 Assumptions

An initial evaluation of the capacity of the GSHP system was carried out for a sample block of 2150 Lake Shore development, namely block D1.

The analysis was conducted using Ground Loop Design (GLD) Premier Edition to assess the capacity of the GSHP system. Should a GSHP be carried into design, additional numerical analysis using GLD or similar will be performed and documented. The evaluation presented here was based on the following assumptions:

- 100 boreholes, each to a depth of 650 feet (200m) on a minimum 20-foot (6m) spacing between boreholes;
- Peak heating and cooling capacity of around 12.7 Btu/h/ft (40W/m) (noting that different capacities were trialled as part of the analysis);
- The annual heat extracted from the ground must be equal to the annual heat rejected to the ground (for cooling);
- Adjusted heating (space heating + DHW) and cooling hourly loads to ensure loads on the ground are balanced;
- A heat pump comprising a ‘generic high efficiency’ heat pump;

- A geo-exchange fluid within the closed loops containing an antifreeze additive such as propylene glycol or ethylene glycol, at a concentration of around 15% by volume. Noting that the use, type, and concentration of additives will be evaluated during detailed design and based on any regulatory constraints.

Given the low permeability ground conditions, and assumed absence of structural piles, closed loop vertical boreholes have been selected as the preferred GSHP technology.

3.3.1.2 Results

The evaluation used the current design heating (space heating and DHW) and cooling loads as a starting point for calculating the loads that could be delivered from the borefield. The peak cooling load was then capped at the maximum that the borefield (100 boreholes of 650ft depth) can yield. The heating loads were then adjusted to ensure that the total annual amount of energy extracted in heating and cooling mode are balanced. This approach ensures that there is not net overheating or overcooling of the ground in the long term, and that the GSHP system continues to operate efficiently and as designed.

The results of the analysis indicate that the following (building side) is feasible, based on the above assumptions:

- Peak cooling capacity of 196 tons (691 kW), with an annual cooling load of 0.47Mton-hr (1,649MWh);
- Peak heating capacity of 1.96 MMBtu/hr (575 kW), with an annual heating load of 8,586 MMBtu (2,516 MWh);
- In percentage terms, the GSHP system can provide 20% of the peak cooling and 33% of peak heating loads for building D1;
- The annual capacity of the GSHP system would deliver 69% of the total annual cooling demand and 83% of the annual heating demand.

A summary of the monthly loads that the GSHP system could deliver is given in Table 10 below. Figure 25 presents these loads together with the building design loads for comparison.

Table 10: GSHP Estimated building-side loads for 100 x 650ft boreholes.

Month	Cooling		Heating (DHW & Space heating)	
	Total (kWh)	Peak (kW)	Total (kWh)	Peak (kW)
Jan	31,439	398	314,205	575
Feb	33,180	388	280,733	575
Mar	52,890	431	277,343	575
Apr	74,158	553	201,859	575
May	147,555	691	159,676	575
Jun	281,917	691	139,231	575

Month	Cooling		Heating (DHW & Space heating)	
	Total (kWh)	Peak (kW)	Total (kWh)	Peak (kW)
Jul	330,284	691	138,168	575
Aug	320,634	691	139,404	575
Sep	209,518	691	145,688	575
Oct	87,099	691	185,616	575
Nov	45,226	398	237,878	575
Dec	34,898	343	296,372	575
	Total	Peak	Total	Peak
	1,648,797	691	2,516,173	575

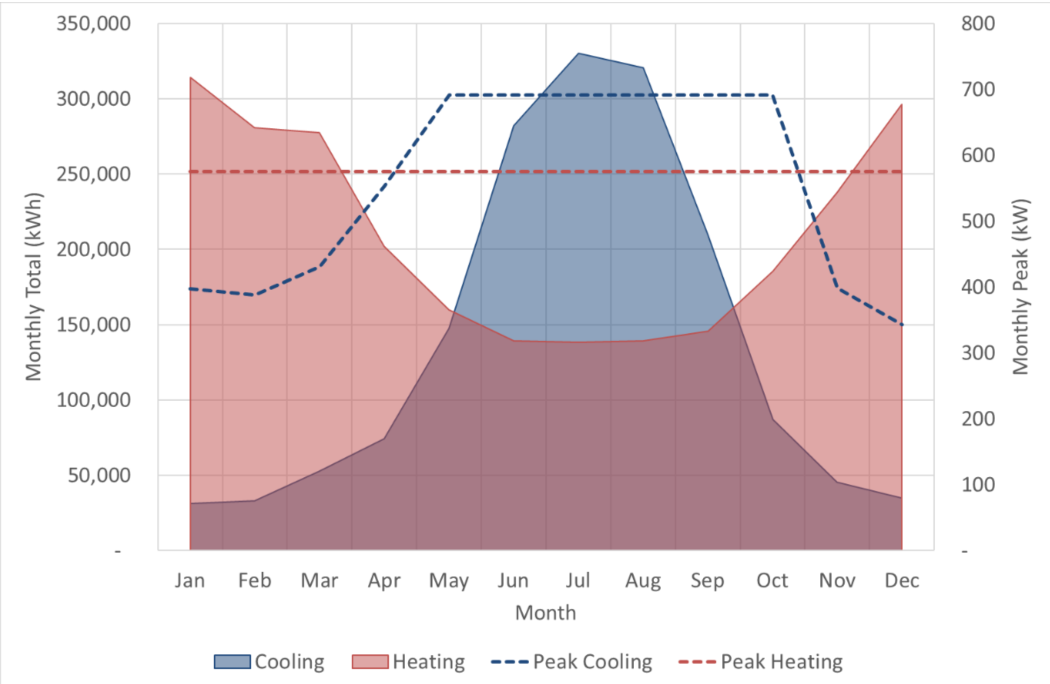

Figure 25: Modelled monthly (total and peak) heating and cooling loads for 100 x 650ft boreholes.

As an alternative, Arup has recently designed deeper boreholes in Toronto to a depth of 850 feet (260 m) each. While these deeper boreholes would incur additional drilling costs, they would also provide additional (building side) energy capacity:

- Peak cooling capacity of 257 tons (905 kW), with an annual cooling load of 0.53Mtons-hr (1,856MWh);
- Peak heating capacity of 2.84 MMBtu/hr (835 kW), with an annual heating load of 9,663 MMBtu (2,832 MWh);

- In percentage terms, the GSHP system could provide 26% of the peak cooling and 47% of peak heating loads for building D1;
- The annual capacity of the GSHP system would deliver 77% of the total annual cooling demand and 93% of the annual heating demand.

A summary of the monthly loads that 850ft deep boreholes could deliver is given in Table 11 below.

The results show that, by increasing the depths of the boreholes from 600 to 850 feet, a 18% increase in annual capacity is feasible. A lifecycle cost assessment should be carried out at the next stage to select the optimal borehole depth.

Table 11: GSHP estimated building-side loads for 100 x 850ft boreholes.

Month	**Cooling**		**Heating (DHW & Space heating)**	
	Total (kWh)	**Peak (kW)**	**Total (kWh)**	**Peak (kW)**
Jan	31,439	398	385,790	835
Feb	33,180	388	345,211	835
Mar	52,890	431	322,513	835
Apr	74,158	553	218,758	835
May	154,435	905	165,233	835
Jun	330,162	905	142,270	752
Jul	395,310	905	140,332	723
Aug	382,450	905	141,987	757
Sep	233,503	905	149,788	826
Oct	87,949	905	195,385	835
Nov	45,226	398	266,313	835
Dec	34,898	343	358,317	835
	Total	**Peak**	**Total**	**Peak**
	1,855,601	905	2,831,898	835

3.3.1.3 Below ground requirements

The following has been assumed for the master planning stage:

- Borehole diameter of 5 inches (125mm) to a depth of 650ft (with an option to 850ft);
- Pipe type of standard dimension ratio (SDR) 11 of diameter 1.25” (32mm);
- Borehole sealed by tremie grouting with a minimum thermal grout conductivity of 1.73W/m-K (1 Btu/hr-ft-°F);
- Assumed ground thermal conductivity of 2.7W/m-K;

- Borefield separated into 10 distinct zones or circuits, consisting of 10 boreholes per zone. Each zone will have a separate sub-manifold which will then feed into a central main manifold at or inside the Plant Room;
- Feed and return piping to the boreholes from the sub-manifolds as reverse return piping;
- Conveyance piping installed below the frost zone within a rounded gravel or sand trench, with tracer tape.

The GSHP system design (if carried forward) will be refined during the detailed design, which will require thermal response testing to obtain site specific values for the thermal properties of the ground.

4 Energy resilience

According to the Resilient Design Institute, "Resilience" is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance.

Designing for resilience means, therefore, to account for future changes in climate, fuel availability and technologies when designing a building, allowing for enough capacity and flexibility to cope with increased loads and changes in the technologies available, as well as to respond to events of stress or distruption.

4.1 Adaptability to future changes

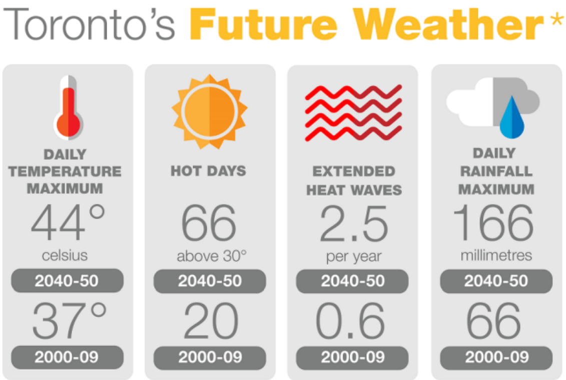

Figure 26: Toronto's future weather figures (source: Toronto's Future Weather and Climate Driver Study, 2011).

The City of Toronto has carried out studies to understand the impact of climate change on Toronto's climate which were summarised in Toronto's Future Weather and Climate Driver Study, which provided a series of climate projections from 2040 to 2049. Key predictions for Toronto's future climate include:

- An increase in average summer temperatures by 3.8°C
- An increase in extreme daily minimum temperatures by 13°C
- An increase in the number of days above 20°C from 133 to 160
- An increase in the number of days above 0°C by 16%
- An increase in the number of "heat waves" from an average of 0.57 occurrences per year to 5 occurrences per year
- An increase in the number of days requiring air conditioning
- A decrease in the number days requiring extra heating
- Slightly more precipitation overall, with the highest increases expected for the months of July (+80%) and August (+50%)
- A smaller number of storm events, but an increase in the amount of precipitation in these events
- A threefold increase in extreme daily rainfall in the month of June

While Toronto's climate has been traditionally a heating-driven climate, the presented scenario shows that the trend is toward a warmer and more humid climate; thus, it will be particularly important to design the buildings to reduce the need for cooling in the warm season.

Using a ground source heat pump system for thermal energy supply is in line with this objective, as it allows the generation of cooling from geothermal exchange. The detailed design of the system will have to ensure balance throughout the year between heat extracted and injected into the ground, also considering the future energy demands.

The selection of a decentralised scheme instead of a centralised one is also key to ensure future-proofing design to the scheme; in fact, a plot-by-plot system allows for greater flexibility compared to a centralised solution in case of a change of generation system or delivery temperature, as there is no district network to be adapted to the new system.

4.2 Resilience to power disruption

The Toronto Green Standards dictate requirements for additional resilience of power supplies to essential loads in multi-unit residential buildings (MURBs) in case of area-wide power outages. The backup power requirement is in addition to base requirements for emergency power necessary for life-safety. Table 12 below illustrate the TGS requirements for both emergency and back-up power.

Table 12: Emergency and back-up power requirements from TGS.

Emergency Power Requirements	**Back-up Power Requirements**
Required for life-safety, emergency evacuation, firefighting and fire-fighting access	Required for safety and well-being of population during extended power outage
Supply to Critical systems – • Fire suppression (sprinkler systems) • Fire-fighting elevators • Smoke extraction systems • Emergency lighting	Supply to Essential systems – • Domestic water supply and treatment • Elevators • Heating • Basic telecommunications
Minimum duration: 2h	Minimum duration: 72h
To be designed to statutory laws and regulations	To be designed to non-statutory standards and guidance documents

In addition, in the case of 2150 Lake Shore, the power back-up is a crucial point of the Energy Strategy considered that heating and cooling are provided 100% via electric sources.

A combination of the following can be considered towards securing power supply resilience of the site:

- Natural gas / diesel / dual-fuel generators;
- Energy storage systems;

- On-site power/heat generation (e.g. Solar Technologies);
- Secondary utilities supply.

Using the on-site available technologies in an integral matter aids the energy strategy objectives to minimise combustion activities on site and optimise the use of low carbon systems.

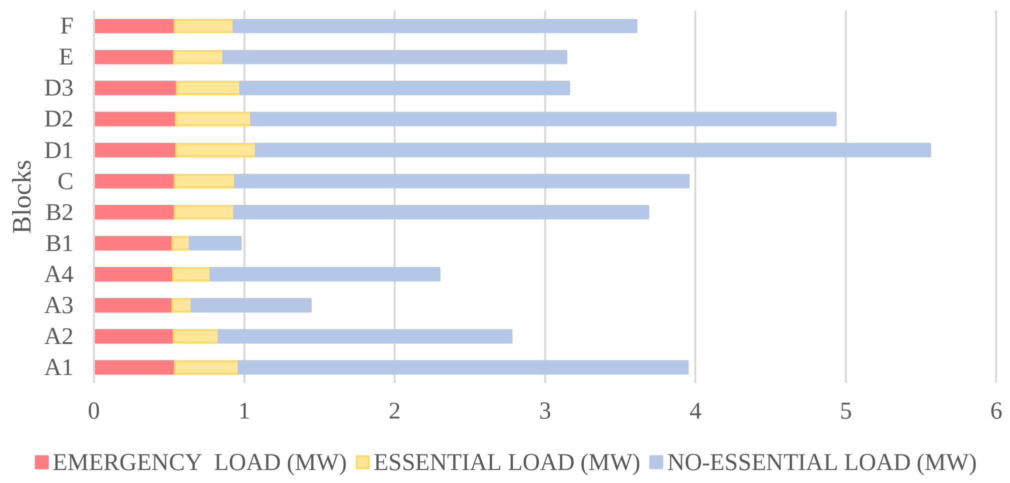

Figure 27: Emergency and back-up power peak demand profile.

Back-up power supply is traditionally provided via diesel or natural gas generators. Individual back-up generators can be located at basement levels serving one or multiple buildings. Generator plant sizing and fuel requirements can be therefore tailored to individual building or plot demand. Using de-centralised topology has the added benefit of localising resilience to each building, keeping plant area to minimum and simplifying load management schemes.

To suit both emergency and back-up power requirements, the generator system is required to start in less than 15 seconds (code requirement). For natural gas systems, which are inherently slower in becoming available to take load, a load management system can facilitate the fast start-up (<15 seconds) to support critical loads first and later gradually add essential loads.

Further mitigation is through the implementation of dual-fuel engines, which can be natural gas and diesel or natural gas and biofuel. The use this technology further increases resilience guarding against power and gas supply lines being simultaneously interrupted. Minimum requirement for on-site fuel storage, filtration and distribution can be facilitated locally to the main back-up generation plant.

Energy storage and on-site generation is normally intended for peak load shaving under normal circumstances. This function can be extended during site-wide power outage, so that stored capacity is used to support portion of the essential loads reducing the required size of a back-up generation system.

A smart system can be further engaged in fully supporting the site during short power interruptions. Tracking the demand profile compared to stored or generated capacity can inform on the decision not to starting up the back-up generation system that may run for minimum time duration (e.g. 1h) regardless of the duration of the interruption.

An alternative option to be further investigated with the local power network operator is to derive secondary supply from an alternative substation or branch of the distribution network so that a power failure affects only portion of the plot demand. Critical and essential loads can be transferred to an alternative supply via automatic change-over devices and supported in case of emergencies. In combination with energy storage, this is the only option guaranteeing power resilience eliminating the reliance on fossil fuels.

5 Conclusions and next steps

Conclusions

This Energy Strategy for 2150 Lake Shore explored viable solutions to reduce the site carbon emissions through energy demand reduction and low carbon energy supplies strategies.

A number of passive and active design measures are suggested for the buildings to reduce the energy demand in the first place. Then, a comparative analysis was carried out to identify the most effective solution to provide the remaining energy need through low carbon technologies.

The proposed option is a plot-by-plot solution including:

- Ground source heat pumps (GSHPs) to provide space heating, pre-heat for the DHW and cooling;
- Electric boilers to top-up the DHW temperature and as a back-up solution;
- Air-cooled chillers to top-up the cooling.

This solution has been modelled for the development and results show that it can achieve:

- EUI = 78.6 kWh/m^2;
- GHGI = 3.9 $kgCO_2/m^2$;
- Annual carbon dioxide emissions: 2,630 tCO_2.

The integration of solar technologies for renewable energy generation and smart batteries for energy storage shall be investigated as part of the next design stages at building level.

Next steps

- Definition of TGS performance targets for the project and specifically for the energy strategy to confirm assumptions outlined throughout this report;
- The optimal passive strategies should be selected on a building by building level, to reduce the thermal load and consequent thermal energy need to the minimum;
- Consequently, the design of building services should be conducted to optimise the interactions between all components (GSHP, boilers, solar panels, etc.) and maximise the efficiency of the energy delivery;
- Detailed solar analysis based on hourly modelling to evaluate effective solar energy available and investigate integration of solar system into the main plots' system should be carried out at building design level, based on a coordinate design of the roof areas;

- Appointment of a cost consultant recommended to carry out detailed cost analysis on the selected options and assess the impact of variations such as centralised vs decentralised solutions;
- A whole life cost analysis should be carried out to optimise the number and depth of boreholes for the GSHP on each building based on the specific demands and load profiles;
- Energy back-up and energy storage solutions to be further investigated and sized to ensure resilience and reduce peak demands on a building-by-building level;
- Cost benefit analysis between different generator technologies for back-up power should be carried out to guide the selection.