CITY OF VANCOUVER
2021 REZONING POLICY

PROJECT NO.: 127B-069-20
VANCOUVER, BC

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EXECUTIVE SUMMARY

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The City of Vancouver (CoV) Rezoning Policy Options Study has been written and developed for the use of Policy Officials and Industry Professionals, with the main focus to aid the CoV Policy Officials to plan and update the Green Buildings Policy for Rezoning. The CoV Rezoning Policy Options Study has been broken up into three (3) definitive parts:

1. Zero Emission Heating and Hot Water
2. Climate Resilience – Overheating Limits & Future Weather
3. Climate Resilience – Cooling Demand

The project team of AME Consulting Group, ZGF Architects, AES Engineering and BTY Group was assembled based on previous experience and breadth of knowledge and experiences on high BC Energy Step Code and Passive House projects. This project team has worked together as a complete team and/or in parts of numerous other projects within the City of Vancouver and the Lower Mainland and are recognized as experts in their disciplines.

PROCESS/BACKGROUND

Through Part 1 of this study, the project team collaborated with City of Vancouver staff to explore Zero Emission Options (heating and hot water), based on past experiences, and design strategies for real-world solutions. These solutions were then developed to a schematic level of design, and were then modelled using dynamic simulation modelling software, IES VE.

Part 2 of this study further analyzes the Zero Emission Options from Part 1, to study the impacts of the options resiliency and occupant thermal comfort for a future climate condition, and under conditions of specific “shock events”.

In Part 3, an analysis was completed to review the Zero Emission Options and their Cool Energy Demand Intensity (CEDI) performance, to aid in the development of potential CEDI performance targets for future policy updates.

CONCLUSION

Part 1 has presented that for both High- and Low-Rise residential building archetypes, that there are many solutions to providing Zero Emissions heating and hot-water that will meet the Step Code and GHGI performance targets, as well as the overheating limitations. The possible solutions are not limited to what were studied within this report, however these provides some common options available. With all of these Zero Emission Options come a variety of considerations that should be studied at the outset of the project. These considerations include, building ownership (rental, condo, non-market), building design considerations (i.e. floor area, rooftop area, floor-to-floor heights etc.), capital and operating costs, and peak energy demands.

High-Rise Residential Archetype	Capital Costs			Energy Costs			Greenhouse Gas Emissions	
Option #	Total Cost ($/sq.ft.)	Incremental Cost Over Total Construction* ($/sq.ft.)	Incremental Cost Over Total Construction Cost** (%)	Energy Cost ($/yr/suite)	Incremental Energy Costs ($/yr/suite)	Incremental Energy Costs (%)	GHGI (kgCO2e/m²/yr)	GHG Reduction (%)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$325.00	-	-	$739.39	-	-	5.9	-
Zero Emission Option 1: Baseboard + Electric DHW	$325.32	$0.32	0.1%	$892.46	$153.07	20.7%	1.2	79.7%
Zero Emission Option 2: Baseboard + ASHP DHW	$326.33	$1.33	0.4%	$778.03	$38.64	5.2%	1.0	83.1%
Baseline 2: ASHP + Gas DHW and Corridor Vent	$343.00	-	-	$723.07	-	-	5.7	-
Zero Emission Option 3: ASHP + ASHP DHW	$343.51	$0.51	0.1%	$732.23	$9.16	1.3%	1.0	82.5%
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$343.44	$0.44	0.1%	$757.40	$34.33	4.7%	1.0	82.5%
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$339.22	-$3.78	-1.1%	$940.11	$217.04	30.0%	1.2	78.9%
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$339.24	-$3.76	-1.1%	$797.54	$74.47	10.3%	1.0	82.5%
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$341.96	-$1.04	-0.3%	$722.48	-$0.59	-0.1%	0.9	84.2%
Zero Emission Option 8: PTHP + Electric DHW	$334.63	-$8.37	-2.5%	$845.49	$122.42	16.9%	1.1	84.2%

* Includes mechanical system and any associated incremental costs to architectural, electrical, or other systems/disciplines, but excludes soft costs, etc...
** This is an estimate of the total cost of construction, including all structure, envelope, foundation, services, etc.

Low-Rise Residential Archetype	Capital Costs			Energy Costs			Greenhouse Gas Emissions	
Option #	Total Cost ($/sq.ft.)	Incremental Cost Over Total Construction* ($/sq.ft.)	Incremental Cost Over Total Construction Cost** (%)	Energy Cost ($/yr/suite)	Incremental Energy Costs ($/yr/suite)	Incremental Energy Costs (%)	GHGI (kgCO2e/m²/yr)	GHG Reduction (%)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$302.00	-	-	$714.53	-	-	5.0	-
Zero Emission Option 1: Baseboard + Electric DHW	$302.51	$0.51	0.2%	$859.42	$144.89	20.3%	0.9	82.0%
Zero Emission Option 2: Baseboard + ASHP DHW	$306.44	$4.44	1.4%	$744.92	$30.39	4.3%	0.8	84.0%
Zero Emission Option 9: Baseboard + Electric In-Suite DHW	$303.24	$1.24	0.4%	$859.42	$144.89	20.3%	0.9	82.0%
Baseline 2: ASHP + Gas DHW and Corridor Vent	$317.00	-	-	$699.86	-	-	4.7	-
Zero Emission Option 3: ASHP + ASHP DHW	$321.78	$4.78	1.5%	$706.55	$6.69	1.0%	0.8	83.0%
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$317.81	$0.81	0.3%	$708.80	$8.94	1.3%	0.7	85.1%
Zero Emission Option 5: Air-Cooled VRF + Electric DHW	$317.33	$0.33	0.1%	$861.82	$161.96	23.1%	0.9	80.9%
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$314.21	-$2.79	-0.9%	$814.17	$114.31	16.3%	0.9	80.9%
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$317.14	$0.14	0.0%	$678.91	-$20.95	-3.0%	0.7	85.1%
Zero Emission Option 8: PTHP + Electric DHW	$310.69	-$6.31	-2.0%	$869.36	$169.50	24.2%	0.9	80.9%

* Includes mechanical system and any associated incremental costs to architectural, electrical, or other systems/disciplines, but excludes soft costs, etc...
** This is an estimate of the total cost of construction, including all structure, envelope, foundation, services, etc.

Part 2 studied the Zero Emission Options for both the High- and Low-Rise residential building archetypes, as outlined and developed in Part 1, in respect to thermal comfort and resiliency on how they would react to future 2050 weather conditions, a 20-hour overheating limitation, and the impact of certain “shock events”.

While the full mechanical cooling Zero Emission Options displayed no issues achieving the more stringent overheating limitations, the Heating and Passive cooling Zero Emission Options for both building archetypes, were unable to reach this target and were therefore modified in order to achieve this target. The result of the modifications allowed for a partially cooled Zero Emission Option that was able to achieve the 20-hour overheating limitation, while providing a capital cost friendly solution, as an alternative to a full mechanical cooling option. This study highlighted the benefits of the passive building design strategies to the occupant thermal comfort, although alone these strategies are unable to achieve the more stringent overheating limitations while using the future 2050 weather file.

In the Part 2 “shock event” study, three (3) scenarios were analyzed while using the future 2050 weather file: Smoke Events, High Internal Heat Gains, and Loss of Power. The full mechanical cooling Zero Emission Options typically were able to maintain thermal comfort in the “shock events”, however when there was a loss of power, these options without being provided with passive building strategies saw a significant increase in the number of overheating hours in a two-week span. The partially cooled Zero Emission Option, with its passive building design strategies implemented was able to reduce the number of overheating hours throughout these shock events, however, showed some difficulty when there was an inability to utilize the operable windows in the smoke event scenario. Through this study, it was highlighted that again, passive building design strategies played a large role in reducing the impacts to the occupant thermal comfort and overheating limitations, however these strategies have their limitations when it comes to certain “shock events” and considerations for building resiliency need to be considered at the project outset.

Part 3 of the CoV Rezoning Policy Options Study highlighted how the different building archetypes performed when reviewed against a CEDI performance target. If CEDI performance targets are not implemented through Policy or Building Code updates, in the future we are likely to put a heavy toll on existing electrical infrastructure, which may result in significant changes to the delivery of electricity, by means of load shedding (rolling blackouts), utility rate restructuring (i.e. time-of-use rates) or some other measures implemented by BC Hydro.

Based on the energy modelling it was found that the Low-Rise residential and the High-Rise office building were met with some challenges when seeking to achieve their potential CEDI performance target. During the analysis of these challenges, it was found that the more stringent heating demand (TEDI) performance targets, that currently influence the building designs, appear to affect the buildings CEDI performance while looking at future climate conditions. As these building archetypes have been developed to meet the existing Policy and Building Code requirements, the focus for building designs have mostly been to address the TEDI performance (heating demand) for the current climate conditions. By doing so, the industry has put a large emphasis on high-performance building envelopes, and improved building airtightness as two means to accomplish this.

The implementation of CEDI performance targets will shift these design approaches and will encourage the building industry to review a balanced design approach, which will look at integrating high-performance building envelopes, and passive building design strategies for both the heating and cooling demand performance targets. Future weather considerations should also be reviewed as a part of these designs to ensure these buildings are built with resiliency in mind, or future-proofed to allow for the potential impacts of an everchanging climate condition.

Further to the above noted analysis done throughout this report, additional modelling was completed which looks at Heating and Passive cooled buildings compared to the 2014 Vancouver Building By-Law (VBBL), as well as a smaller low-rise residential archetype. These energy modelling results and details can be located in **Appendix F - 2014 VBBL** and **Appendix G - Alternative Low-Rise Residential Model Results and Costing**.

The objective of the 2014 VBBL energy modelling exercise, was to review the new building modelling done previously in Part 1 of this Study and review it against a building that would have followed the preceding building by-laws. In addition to this, a new option Zero Emission Option 1b was created, which deviated from Zero Emission Option 1, by providing gas-fired corridor make-up air instead of electric. The table below summarized the Energy Performance results for both the High-Rise and Low-Rise residential building archetypes.

Performance Metrics	TEUI (kWh/m²/yr)	TEDI (kWh/m²/yr)	GHGI (kgCO2e/m²/yr)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2014 Code Baseline	162.5	69.9	19.6	$229,838.00	$801	-	-
2017 Rezoning Baseline 1	108.4	28.9	5.9	$212,205.00	$739	33%	8%
Zero Emission Option 1	106.9	28.9	1.2	$256,137.00	$892	34%	-11%
Zero Emission Option 1b	107.3	28.9	1.3	$247,534.00	$862	34%	-8%
Zero Emissions Option 2	92.4	28.9	1.0	$223,294.00	$778	43%	3%

Performance Metrics	TEUI (kWh/m²/yr)	TEDI (kWh/m²/yr)	GHGI (kgCO2e/m²/yr)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2014 Code Baseline	152.4	54.2	17.7	$105,061.00	$947	-	-
2017 Rezoning Baseline 1	84.2	12.9	5.0	$76,910.00	$693	45%	27%
Zero Emission Option 1	82.4	12.9	0.9	$93,903.00	$846	46%	11%
Zero Emission Option 1b	82.7	12.9	1.2	$90,233.00	$831	46%	14%
Zero Emissions Option 2	70.6	12.9	0.8	$81,194.00	$731	54%	23%

The 2014 Baseline buildings have much higher TEUI, TEDI, and GHGI values than the Baseline 1 and zero emission options for both the high and low-rise residential buildings. This means the baseline and zero emission options in Part 1 study have a significant improvement in energy use and emissions from a typical 2014 code compliant building. The resulting energy cost savings from the 2014 Baseline to Baseline 1 are 8% and 27% for the high and low-rise residential buildings, respectively.

Compared to Option 1, Option 1b shows a small increase in GHGI. The increase is small mainly due to the corridor pressurization adjustment rule in the CoV Modelling Guidelines, which allows a higher adjustment amount for gas MUA than electric MUA. Due to the cheaper gas rates than electricity in BC, the energy costs for Option 1b is lower than Option 1. The energy costs for Option 1b in the high and low-rise residential buildings are $862 and $813 per suite annually.

In addition to the Low-Rise residential building archetype mentioned and detailed throughout this Study, an alternative building was reviewed. This building reduces the amount of units from 110 to 41, and looks at a smaller floor plate which is indicative of a building with a pad mounted transformer instead of a unit substation (Vista switch). Through this energy modelling exercise, only the Heating and Passive Cooled Zero Emission Options were reviewed (Zero Emission Options 1 & 2). The table below summarized the Energy Performance results.

Performance Metrics	TEUI (Target 100)	TEDI (Target 15)	GHGI (Target 5)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2017 Rezoning Baseline 1	86.2	14.6	4.8	$30,601.00	$746	-	-
Zero Emission Option 1	84.6	14.6	0.9	$36,903.00	$900	2%	-21%
Zero Emissions Option 2	73.3	14.6	0.8	$32,225.00	$786	15%	-5%

REPORT INTRODUCTION
AND OVERVIEW

INTRODUCTION & REPORT OVERVIEW

The City of Vancouver (CoV) Rezoning Policy Options Study report has been developed to assist the City of Vancouver planned update to the Green Building Policy for Rezonings in 2022. The objective of this Study is to evaluate potential new energy and emissions intensity targets, and climate resilience targets through schematic design considerations for mechanical, electrical, and architectural design impact supported by energy modelling and costing data.

PART 1 is set out to provide a variety of typical heating and hot water options for High- and Low-Rise residential building archetypes to achieve a goal of zero emissions, while reviewing the energy performance, costing, and building design implications.

The High-Rise residential building for Part 1 had a total of eight (8) Zero Emission Options, along with two (2) baselines. All of the baselines and options were designed to Step 3 of the BC Energy Step Code, Greenhouse Gas Intensity (GHGI) targets as identified in the CoV Green Building Policy for Rezoning[1] and a 200-hour overheating limitation target per the CoV Energy Modelling Guidelines v2.0[2]. The baselines were developed to provide a typical installation with one baseline being a heating only solution, and the other providing a full heating and cooling system. Both of these baselines have been developed with the use of natural gas for corridor ventilation and domestic hot-water production, to provide a comparison of how the Zero Emission Options will perform against capital cost (Class D), GHGI, energy cost and energy intensity considerations. Of the eight zero emission options, six (6) were provided with full mechanical cooling, while the other two (2) relied on passive cooling measures (i.e. operable windows, shading etc.).

The Low-Rise residential building for Part 1 had a total of nine (9) Zero Emission Options, along with two (2) baselines. All of the baselines and options were designed to Step 4 of the BC Energy Step Code, GHGI targets as identified in the CoV Green Building Policy for Rezoning and a 200-hour overheating limitation target per the CoV Energy Modelling Guidelines v2.0. The baselines were developed to provide a typical installation with one baseline being a heating only solution, and the other providing a full heating and cooling system. Both of these baselines have been developed with the use of natural gas for corridor ventilation and domestic hot-water production, to provide a comparison of how the Zero Emission Options will perform against capital cost (Class D), GHGI, energy cost and energy intensity considerations. Of the nine zero emission options, six (6) were provided with full mechanical cooling, while the other three (3) relied on passive cooling measures (i.e. operable windows, shading etc.).

A Class D costing exercise was completed for all baselines and Zero Emission Options, to provide additional details in which to analysis the trade-offs, and rationale for choosing between the Zero Emission Options with respect to building ownership, building design considerations, capital and operating costs, and peak energy demands.

PART 2 analyzes the Zero Emission Options from Part 1, to study thermal comfort and building resiliency to “shock events” while using the future 2050 climate data, provided by the Pacific Climate Impacts Consortium’s (PCIC)[3].

The Thermal Comfort analysis reviews a stricter overheating limitation that have been reduced from the 200-hours studied in Part 1, to 20-hours aligning with the latest CoV Energy Modelling Guidelines for vulnerable groups (i.e. seniors housing, supportive housing, daycares etc.). The Zero Emission Options were analyzed and modified (where needed) to achieve these strict overheating limitations.

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[1]CoV Green Building Policy for Rezoning (https://guidelines.vancouver.ca/G015.pdf)

[2]CoV Energy Modelling Guidelines v2.0 (https://vancouver.ca/files/cov/guidelines-energy-modelling.pdf)

[3]Pacific Climate Impacts Consortium (https://www.pacificclimate.org/data/weather-files)

[4]Vancouver Building By-law – 10.2.2.5 (https://www.bccodes.ca/vancouver-bylaws.html)

Further to the thermal comfort analysis, a Sensitivity Study was performed to investigate how these Zero Emission Options perform under the stresses of "shock events", such as a smoke event, increased internal heat gains, and a loss of power.

The building design considerations, capital (Class D) and operating costs, and peak energy demands were provided as part of the analysis for the modified Zero Emission Options.

PART 3 analyzes the Cooling Energy Demand Intensity (CEDI) performance of the Zero Emission Options, to determine a potential CEDI target for future policy updates. In Part 3, both the High- and Low-Rise residential building archetypes were reviewed, and an additional High-Rise office building was also studied. All of the building archetypes were reviewed using the current and future 2050 weather data to provide insight to future policy making.

The High-Rise residential building was studied to meet a CEDI performance target equivalent to a Step 3 Thermal Energy Demand Intensity (TEDI) of 30 kWh/m²/yr.

The Low-Rise residential building was studied to meet a CEDI performance target equivalent to a Step 4 TEDI of 15 kWh/m²/yr.

The High-Rise office building was studied to meet a CEDI performance target of 30 kWh/m²/yr, which aligns to an equivalent TEDI target for 'Office Occupancies' as outlined in the VBBL[4].

APPENDICES included in this study are noted below:

- Appendix A - Energy Modelling Inputs
- Appendix B - Mechanical Option
- Appendix C - Architectural Plant Considerations & Infographics
- Appendix D - Detailed Energy Modelling Results
- Appendix E - Costing Details
- Appendix F - Vancouver Building By-Law 2014 Baseline Model Results
- Appendix G - Alternative Low-Rise Residential Model Results And Costing

SUMMARY

The three (3) parts of the CoV Rezoning Policy Options Study reviewed Zero Emission heating and hot water solutions, these options were then studied for how they perform in terms of thermal comfort and resiliency, and as how the building archetypes performed against potential CEDI performance targets.

Throughout these parts of this study some main factors were identified that provided different successes and shortfalls, however, there are some interrelated themes that happen to appear throughout. These main factors that show up throughout the three (3) parts are: passive building design strategies, high-performance building envelope and airtightness, and mechanical cooling.

These main factors appeared and provided input to Zero Emissions heating and hot water solutions, occupant thermal comfort during future 2050 climate conditions and "shock events", as well as building archetype CEDI performance. These factors in various combinations, will help provide Zero Emission Option and building archetype with an improved level of performance, occupant thermal comfort and overall building resiliency in respect to the climate conditions.

The Part 2 “shock event” study, there were three (3) scenarios that were analyzed while using the future 2050 weather file: Smoke Events, High Internal Heat Gains, and Loss of Power. The purpose of this study was to analyze the thermal comfort implications and the resiliency of the Zero Emission Options for the High- and Low-Rise residential building archetypes. Based on the results, the full mechanical cooling Zero Emission Options continued to provide occupant thermal comfort, however, was unable to maintain this level of comfort during a loss of power. While the Zero Emission Option with passive building design strategies, that provided partial cooling to the suites was able to maintain a reasonable number of overheating hours during the loss of power, but struggled with the smoke event, as this option relied on operatable windows (included as a passive building design strategy). Throughout Part 2 of the CoV Rezoning Policy Option Study it was highlighted the benefits of the passive building design strategies to the occupant thermal comfort for both current and future weather files.

The analysis in Part 3 was based around review of the fully mechanically cooled Baseline and Zero Emission Options to review the potential of setting of CEDI performance targets for three (3) building archetypes; High-Rise residential, Low-Rise residential, and High-Rise office building. As these CEDI performance targets have not yet been introduced by Municipalities or the BC Building Code, this study will assist policy makers and stakeholders in determining the impacts of CEDI performance targets and will also provide some insight on the resiliency in respect to the future 2050 weather conditions.

While analyzing the High-Rise residential building with the potential CEDI performance target, based on the Step Code 3 Thermal Energy Demand Intensity (TEDI) it was found that for the baseline and Zero Emission Options 3 through 8, the performance target could be achieved for the current and future 2050 weather files. Based on the energy modelling and the potential CEDI performance target, it was found that there was opportunity for a more stringent performance target, or potential for modifying the building design and the overall Architectural expression (i.e. increasing the window-to-wall ratio, reducing glazing performance etc.).

While analyzing the Low-Rise residential building with the potential CEDI performance target, it was found that for the baseline and Zero Emission Options 3 through 8, the performance target could be achieved for the current weather files, however, was not be achieved for the future 2050 weather file. Based on the energy modelling and the potential CEDI performance target, it was found that the performance target may be too aggressive for the building archetype, especially when reviewing this performance target for long term sustainability and building resilience.

Differing from the High- and Low-Rise residential building archetypes used throughout the CoV Rezoning Policy Options Study, a High-Rise office building was modelled to provide information on this specific building archetype to aid and evaluate the potential CEDI performance target in a future rezoning policy. The High-Rise office building potential CEDI performance target, was based on the Vancouver Building By-laws (VBBL) Office Occupancies TEDI equivalent of 30 kWh/m²/a prior to June 2021, as well it was reviewed against a Step Code 3 TEDI performance target of 20 kWh/m²/a. This energy modelling showed that similarly to the Low-Rise residential building, that the current weather file could meet the CEDI performance when comparing the VBBL performance target prior to June 2021, however, was unable to achieve this for the future 2050 weather file. When reviewing this building against the Step Code 3 performance target, the building was unable to meet this for either the current or future 2050 weather files. Based on these energy modelling results, it was found that these CEDI performance target ranges may be too aggressive for this building archetype, or that future office buildings may need to be envisioned when it comes to the overall Architectural expression if these CEDI performances are implemented.

PART 1

ZERO EMISSIONS HEATING & HOT WATER

INTRODUCTION

Part 1 of the report is set out to provide a variety of typical heating and hot water options for High- and Low-Rise residential building archetypes to achieve a goal of zero emissions, while reviewing the energy performance, costing and building design implications.

The High-Rise residential building for Part 1 had a total of eight (8) Zero Emission Options, along with two (2) baselines. All of the baselines and options were designed to meet Step 3 of the BC Energy Step Code, GHGI targets as identified in the CoV Green Building Policy for Rezoning and a 200-hour overheating limitation target per the CoV Energy Modelling Guidelines v2.0. The baselines were developed to provide a typical installation with one baseline being a heating only solution, and the other providing a full heating and cooling solution. Both of these baselines have been developed with the use natural gas for corridor ventilation and domestic hot-water production, to provide a comparison of how the Zero Emission Options will perform against capital cost (Class D), GHGI, energy cost and energy intensity considerations. Of the eight (8) Zero Emission Options, six (6) were provided with full mechanical cooling, while the other two (2) relied on passive cooling measures (i.e. operable windows, shading etc.).

The Low-Rise residential building for this report had a total of nine (9) zero emission options, along with two (2) baselines. All of the baselines and options were designed to meet Step 4 of the BC Energy Step Code, GHGI targets as identified in the VBBL and a 200-hour overheating limitation target per the CoV Energy Modelling Guidelines v2.0. The baselines were developed to provide a typical installation with one baseline being a heating only solution, and the other providing a full heating and cooling solution. Both of these baselines have been developed with the use natural gas, to provide a comparison of how the Zero Emission Options will compare. Of the nine (9) Zero Emission Options, six (6) were provided with full mechanical cooling, while the other three (3) relied on passive cooling measures (i.e. operable windows, shading etc.).

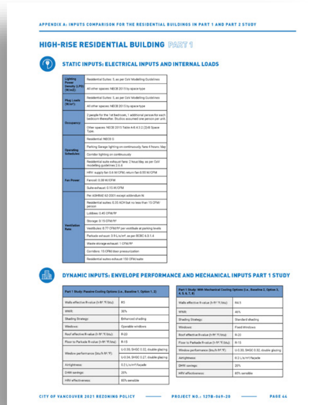
Table 1.1 (below) provides a summary of the energy and GHGI performance targets for Part 1 of this report.

Building Archetype	BC Energy Step Code	TEUI ($kWh/m^2/yr$)	TEDI ($kWh/m^2/yr$)	GHGI ($kgCO_2e/m^2$)*
High-Rise Residential	3	120	30	6
Low-Rise Residential	4	100	15	5
* GHGI performance targets in the CoV Green Building Policy for Rezoning				

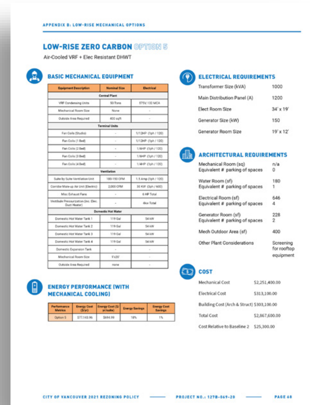
Table 1.1: Part 1 Performance Targets

A Class D costing exercise was completed for all baselines and Zero Emission Options, to provide additional details in which to analyze the trade-offs, and rationale for choosing between the Zero Emission Options with respect to building ownership, building design and considerations, capital and operating costs, and peak energy demands.

APPENDIX A



APPENDIX B



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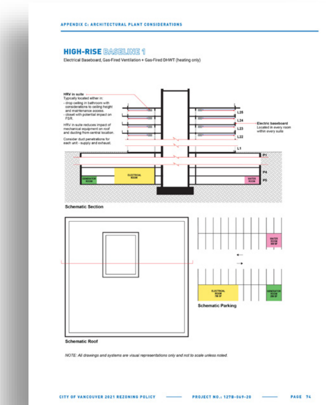

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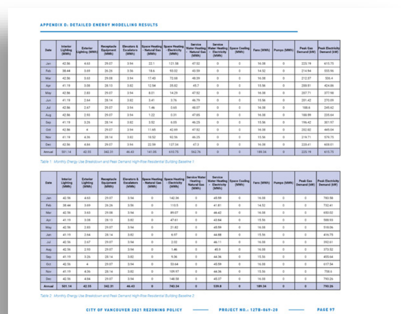
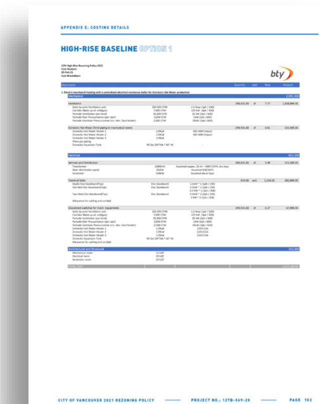


APPENDIX E



The noted appendices are to be read in conjunction with Part 1, these appendices provide additional information on the building inputs, Zero Emission Options and infographics, energy modelling results and detailed costing breakdowns.

ZERO EMISSIONS HEATING & HOT WATER METHODOLOGY

Part 1 evaluates a variety of typical heating and hot water options for High- and Low-Rise residential building archetypes, the intent of these options is to create a Zero Emission Option that achieves Step Code performance targets, Step 3 for the High-Rise and Step 4 for the Low-Rise. Further to these performance based goals, these options will be reviewed for capital and energy costs as well as building design considerations for each Zero Emission Option.

The Zero Emission Options for each building archetype were developed to have four (4) main design components, as follows:

1. Heating & Cooling System Options
2. Corridor Ventilation
3. Suite Ventilation
4. Domestic Hot Water System Options

The baselines for both archetypes were chosen to be a typical system option that includes the use of natural gas for corridor ventilation and domestic hot-water production. Baseline 1 provides a heating only system, while Baseline 2 provides a heating and cooling system solution for the buildings.

The Zero Emission Options were developed from these two baseline options, and developed around Heating and Passive Cooling, and full Heating and Cooling options. A detailed breakdown and comparison of these Zero Emission Options and their respective baselines are identified in Tables 1.3 and 1.4 for the High-Rise archetype, and Tables 1.14 and 1.15 for the Low-Rise archetype. A schematic level of design was established for the Zero Emission Option, which helped identify building considerations (architectural, structural, electrical) while also developing the Class D costing.

The baselines and Zero Emission Options were developed with industry standard envelope design considerations and constructions to achieve the Step Code performance targets, Step 3 for the High-Rise and Step 4 for the Low-Rise. Passive building design strategies were reviewed and applied to each Zero Emission Options being developed for Heating and Passive Cooling, to assist in achieving their performance targets. These passive building design strategies include operable windows, enhanced shading (fixed exterior shading) and reduced window to wall ratios (WWRs). The enhanced shading was reviewed and applied to the East, South and West facades for both the High- and Low-Rise buildings. Standard shading was modelled for the Zero Emission Options with full Heating and Cooling, which includes the shading provided by the building structure, such as balconies. These assumptions have been detailed within **Appendix A – Energy Modelling Inputs**.

Further to the building envelope, each Zero Emission Option was reviewed for specific building requirements and implications on roof area, and their requirements for service room (mechanical, water and electrical rooms) areas.

	Utility Rate
BC Hydro (Electricity)	$0.117/kWh
FortisBC (Natural Gas)	$0.0.39/kWh

Table 1.2: BC Hydro & FortisBC Utility Rates

The energy modelling for this part of the report was completed using a dynamic modelling software (IES VE), to determine the building energy performance, overheating hours, and GHGI performance. The modelling for this report followed the CoV Energy Modelling Guidelines v2.0, and current utility rates, as shown in Table 1.2. Electricity and natural gas utility costs were based on data collected in September 2020 from the BC Hydro[5] and FortisBC[6] websites.

[5]https://app.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/residential-rates.html

[6]https://www.fortisbc.com/accounts-billing/billing-rates/natural-gas-rates/residential-rates

HIGH-RISE RESIDENTIAL BUILDING

The following section of this study will be broken down into four distinct parts as follows:

- Mechanical Options
- Building Considerations
- Costing
- Energy Results

As these Zero Emission Options and the respective baselines were developed to a schematic level of design with building considerations and area requirements, a Class D costing exercise was completed to provide additional insight to analyze the trade-offs, and rationale for choosing between the Zero Emission Options with respect to building ownership, building design and considerations, capital and operating costs, as well as peak energy demands. The costing was developed for the Zero Emission Options, with a total building cost per square foot to determine the overall cost differences of the Zero Emission Options compared to the baseline options.

The energy modelling for Part 1 was developed to determine the building energy performance targets, overheating hours, and GHGI performance that could be used to evaluate the Zero Emission Options relative to the associated baseline, as well as between options.

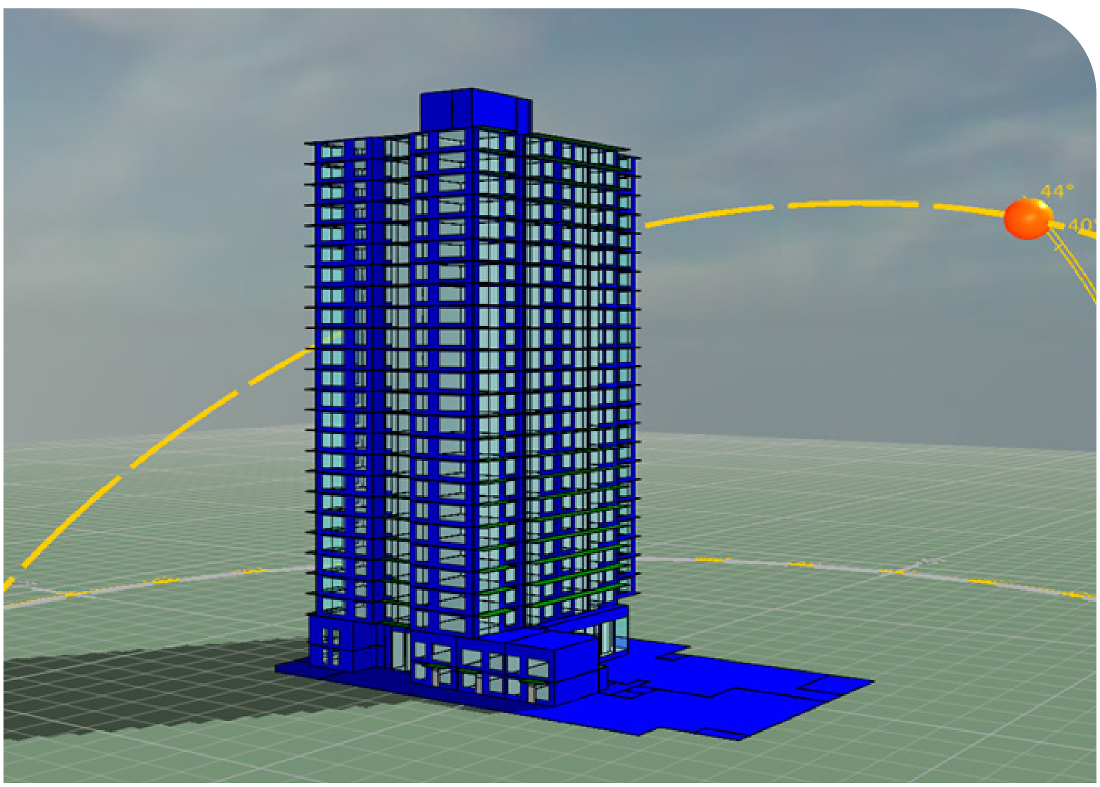


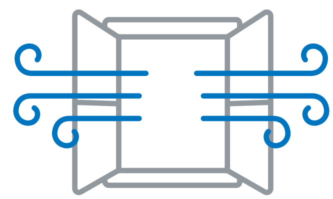
Figure 1.1: High-Rise Residential Building Energy Model Geometry and Orientation

HIGH-RISE RESIDENTIAL BUILDING: MECHANICAL OPTIONS

The High-Rise Zero Emission Options were developed for energy-efficiency, thermal comfort abilities, operation and maintenance as well as impact on building considerations. These options are provided with additional details, including energy performance, energy costs, and electrical requirements in **Appendix B – Mechanical Options**. The baselines were grouped according to the approach to cooling – passive and active cooling strategies. All Baselines and Zero Emission Options are provided with in-suite HRV providing suite ventilation.

HEATING & PASSIVE COOLING ZERO EMISSION OPTIONS

BASELINE 1: Electric baseboard heating with gas-fired hot water production and corridor ventilation system.



ZERO EMISSION OPTION 1: Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 2: Electric baseboard heating with an Air-Source Heat Pump (ASHP) domestic hot water production system and electric resistance heating for the corridor ventilation system.

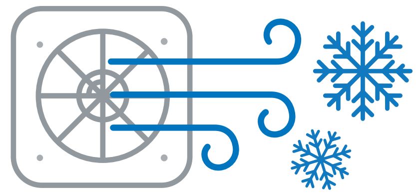
Option #	Heating Source	Cooling Source	Corridor Ventilation Heating Source	Suite Ventilation Strategy	Domestic Hot Water
Baseline 1	Electric Baseboard	N/A	Gas-Fired	In-Suite HRV	Centralized Gas-Fired
Zero Emission Option 1	Electric Baseboard	N/A	Electric Resistance	In-Suite HRV	Centralized Electric Resistance
Zero Emission Option 2	Electric Baseboard	N/A	Electric Resistance	In-Suite HRV	Centralized Air-Source Heat Pump

Table 1.3: Zero Emission Option Comparisons to Baseline 1

HIGH-RISE RESIDENTIAL BUILDING: MECHANICAL OPTIONS

HEATING & COOLING ZERO EMISSION OPTIONS

BASELINE 2: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas fired hot water production and corridor ventilation.



ZERO EMISSION OPTION 3: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP domestic hot water production system and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 4: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 5: Water-cooled variable refrigerant flow heating/cooling system (consisting of cooling tower and electric boilers) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 6: 2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 7: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 8: Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

Option #	Heating Source	Cooling Source	Corridor Ventilation Heating Source	Suite Ventilation Strategy	Domestic Hot Water
Baseline 2	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Electric resistance	In-Suite HRV	Centralized Gas-Fired
Zero Emission Option 3	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized Air-Source Heat Pump
Zero Emission Option 4	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized Air-Source Heat Pump w/ Electric top up
Zero Emission Option 5	Water-cooled VRF	Water-cooled VRF	Electric resistance	In-Suite HRV	Centralized Electric Resistance
Zero Emission Option 6	2-Pipe Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Electric resistance	In-Suite HRV	Water to Water Heat Pump
Zero Emission Option 7	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized On-Demand DHW from Heating/ Cooling System
Zero Emission Option 8	Packaged Terminal Heat Pump	Packaged Terminal Heat Pump	Electric resistance	In-Suite HRV	Centralized Electric Resistance

Table 1.4: Zero Emission Option Comparisons to Baseline 2

HIGH-RISE RESIDENTIAL BUILDING: ARCHITECTURAL CONSIDERATIONS & DISTRIBUTION

The High-Rise residential building was based on a real-world 25-storey concrete residential tower and the building envelope strategies were updated to reflect a Step Code 3 target. For Part 1 the Zero Emission Options were grouped according to the approach to cooling – passive and active cooling strategies.

Considerations from a TEDI perspective include the effective wall insulation level (R4.5-R5 with a window wall system) and a high performing aluminum framed double glazed system. One value that was kept consistent is the modelled infiltration rate. The modelled infiltration rate values used were based on current CoV Energy Modelling Guidelines v2.0, a lower rate can be used and achieved during construction, but detailing and working with the installing contractors is of the utmost importance. The use of a lower airtightness value can be a cost-effective measure to achieve a TEDI target, however in this study to simulate typical construction processes this was not included. Table 1.5 (below) shows a summary of the values used for these two groupings; additional energy modelling inputs can be found in **Appendix A – Energy Modelling Inputs**.

Heating & Passively Cooled Baseline 1 and Zero Emission Options 1 & 2		Heating & Cooling Baseline 2 and Zero Emission Options 3-8	
Wall R-Value	R-5	**Wall R-Value**	R-4.5
Roof R-Value	R-20	**Roof R-Value**	R-20
Floor R-Value	R-15	**Floor R-Value**	R-15
WWR	30%	**WWR**	46%
Window Performance	U-0.30 (SHGC – 0.32) & U-0.34 (SHGC – 0.27)	**Window Performance**	U-0.30 (SHGC – 0.32)
Shading	Enhanced (Fixed Exterior Shading)	**Shading**	Standard (Balcony Overhangs)
Airtightness	0.2 L/s/m² of façade	**Airtightness**	0.2 L/s/m² of façade

Table 1.5: Building Envelope Performance

Each mechanical baseline and option were evaluated for impact on roof and parkade areas (refer to Table 1.6 below), where these spaces impacted parkade areas the number of equivalent parking stalls have been provided and have been based 14 sq.m. (150 sq.ft.) per parking stall.

HIGH-RISE ARCHITECTURAL PLANT CONSIDERATIONS

Option #	Mechanical Room (sq.ft.)	Equivalent Parking Spaces	Water Room (sq.ft.)	Equivalent Parking Spaces	Electrical Room (sq.ft.)	Equivalent Parking Spaces	Generator Room (sq.ft.)	Equivalent Parking Spaces	Mech Outdoor Area (sq.ft.)	Total Equivalent Parking Spaces
Baseline 1: Baseboard + Gas DHW and Corridor Vent	N/A	0	300	2	780	5	299	2	N/A	9
Zero Emission Option 1: Baseboard + Electric DHW	N/A	0	300	2	800	5	299	2	N/A	9
Zero Emission Option 2: Baseboard + ASHP DHW	N/A	0	300	2	800	5	299	2	800	9
Baseline 2: ASHP + Gas DHW and Corridor Vent	500	3	300	2	800	5	299	2	1600	12
Zero Emission Option 3: ASHP + ASHP DHW	500	3	300	2	800	5	299	2	1600	12
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	550	4	300	2	800	5	299	2	1600	13
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	150	1	300	2	840	6	299	2	800	11
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	250	2	350	2	840	6	299	2	800	12
Zero Emission Option 7: ASHP + Heat Exchanger DHW	400	3	252	2	840	6	299	2	800	13
Zero Emission Option 8: PTHP + Electric DHW	N/A	0	300	2	840	6	299	2	N/A	10

Table 1.6: High-Rise Zero Emission Option Spatial Considerations

The development of all Zero Emission Options requires coordination between the entire design team (architectural, structural, electrical and mechanical) at the outset of the project to indicate major mechanical and electrical room requirements, roof area required and/or the location of large shaft spaces needed throughout the building. The coordination required by the design team is crucial to determine overall building height, floor-to-floor heights, desired ceiling heights (where appliable), and usable floor area.

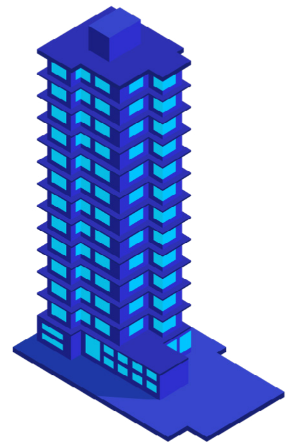
Design considerations include the location of the in-suite ventilation unit (i.e. ceiling space of the bathroom, storage rooms etc.), duct routing and the required envelope penetrations. The in-suite ventilation system option was chosen over a centralized option, as it has been found to reduce the complexity of running vertical duct shafts (which will reduce usable/sellable floor area) and reduce the requirement for a higher floor-to-floor height which is typically required for a centralized ventilation system. The in-suite ventilation also eliminates the requirement for fire-smoke dampers required by the BC Building Code, which reduces capital costs in a High-Rise archetype.

Table 1.7 (below) outlines some additional design components and suggested considerations when evaluating these Zero Emission Options. **Appendix C - Architectural Plant Considerations & Infographics** provides summary infographics of each baseline and Zero Emission Option, and their impact on roof and parkade areas, as well as outlining additional considerations.

HIGH-RISE ARCHITECTURAL DISTRIBUTION CONSIDERATIONS

Design Component	Suggested Consideration
Cast in place concrete structure	Planning of service risers requires detailed coordination with structural.
Typical floor to floor of 9’-3”	Is dependent on suite living area and typical corridor minimum celling height.
Typical corridor ceiling height 7’-6”	Needs to be carefully coordinated with mechanical and electrical services to ensure corridor ceiling height is achieved per design.
Typical suite minimum ceiling height 7’-3”	Mechanical and electrical services within suites requires close coordinate with structural so that height called for by the design is achieved without un-anticipated bulkheads.
Typical suite living space minimum ceiling height 8’-0”	Coordination with in-slab or dropped HVAC ductwork is required to ensure living space ceiling heights are achieved where HVAC intake/exhaust occurs on balcony soffits.
Electrical/communication closet area per floor	Locations need to be coordinated with mechanical to ensure cable routing does not conflict with mechanical service runs.
Heat Recovery Ventilator (HRV) direct connection to the exterior wall	HRV locations on exterior walls to be coordinated with the building envelope.
Rooftop Equipment	Screening is recommended to provide a shroud around the exposed equipment, and to provide noise attenuation from the equipment to the adjacent rooftop spaces.
Service Room Height	Electrical and Water room height should be coordinated. It has been identified that a typical 12 foot height is required throughout all of the Zero Emission Options.

Table 1.7: Design Components and Suggested Considerations



HIGH-RISE RESIDENTIAL BUILDING: CAPITAL COST/RESULTS

Table 1.8 and 1.9 (below), provides a breakdown of the capital costs relative to each Zero Emission Options and respective baseline option. The mechanical costs include all mechanical equipment, distribution (i.e. ductwork, piping) and the building costs include any requirement for architectural and structural (i.e. additional service spaces, screening of equipment etc.) related to these Zero Emission Options. The below noted column, "Total Cost ($/sq.ft.)" is noted as an estimate for the overall building construction costs. Refer to **Appendix E – Costing Details**, for a more detailed breakdown of the Class D costing completed for this report.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Mechanical Cost	Cost Relative to Baseline 1	Electrical Cost	Cost Relative to Baseline 1	Building Cost (Arch & Struct)	Cost Relative to Baseline 1	Total Cost	Cost Relative to Baseline 1	Total Cost ($/sq.ft.)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$2,161,300.00	-	$905,500.00	-	$344,800.00	-	$3,411,600.00	-	$325.00
Zero Emission Option 1: Baseboard + Electric DHW	$2,148,500.00	($12,800.00)	$986,200.00	$80,700.00	$349,800.00	$5,000.00	$3,484,500.00	$72,900.00	$325.32
Zero Emission Option 2: Baseboard + ASHP DHW	$2,301,400.00	$140,100.00	$985,600.00	$80,100.00	$429,800.00	$85,000.00	$3,716,800.00	$305,200.00	$326.33

Table 1.8: Cost Comparison to Baseline 1

HEATING & COOLING MECHANICAL OPTIONS

Option #	Mechanical Cost	Cost Relative to Baseline 2	Electrical Cost	Cost Relative to Baseline 2	Building Cost (Arch & Struct)	Cost Relative to Baseline 2	Total Cost	Cost Relative to Baseline 2	Total Cost ($/sq.ft.)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$6,401,500.00	-	$783,000.00	-	$634,800.00	-	$7,891,300.00	-	$343.00
Zero Emission Option 3: ASHP + ASHP DHW	$6,546,600.00	$145,100.00	$827,200.00	$44,200.00	$634,800.00	$0	$8,008,600.00	$189,300.00	$343.51
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$6,546,600.00	$145,100.00	$787,200.00	$4,200.00	$657,300.00	$22,500.00	$7,991,100.00	$171,800.00	$343.44
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$5,701,300.00	($700,200.00)	$846,000.00	$63,000.00	$477,300.00	($157,500.00)	$7,024,600.00	($794,700.00)	$339.22
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$5,672,000.00	($729,500.00)	$836,300.00	$53,300.00	$522,300.00	($112,500.00)	$7,030,600.00	($788,700.00)	$339.24
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$6,309,100.00	($92,400.00)	$831,700.00	$48,700.00	$512,800.00	($122,000.00)	$7,653,600.00	($165,700.00)	$341.96
Zero Emission Option 8: PTHP + Electric DHW	$4,797,800.00	($1,603,700.00)	$815,900.00	$32,900.00	$359,800.00	($275,000.00)	$5,973,500.00	($1,845,800.00)	$334.63

Table 1.9: Cost Comparison to Baseline 2

Exclusions:

- General Contractor's General Requirements, Overhead and Fees
- Design and Construction Contingencies
- Project Soft Costs

From the tables above, a few key points in regard to the capital cost implications of going to a Zero Emissions Option can be established.

For the Heating & Passive Cooling Zero Emission Option 2, there is a large increase in the mechanical equipment cost with slight increases in terms of Electrical and Building costs. This suggests that a typical baseline building is already being designed in a way that could accommodate a Zero Emissions Option with minimal implications on electrical or building systems.

For Heating & Cooling Zero Emission Options, most of the capital cost savings is shown coming from the Mechanical system, while some of the largest increases over Baseline 2 are identified for Zero Emission Options 3 and 4, that include an air-source heat pump (ASHP) for heating, cooling and domestic hot water, and the associated building costs (i.e. screening, roof area requirements) for these systems.

From Tables 1.8 and 1.9 we can see that switching to a Zero Emission Option only adds modest incremental costs, and that depending on the building's energy performance targets, ownership and tenure, either a simple Zero Emission Option (passively cooled), or a more complex system with lower GHGI and higher energy performance could be chosen.

HIGH-RISE RESIDENTIAL BUILDING: ENERGY PERFORMANCE RESULTS

Tables 1.10 and 1.11 below presents a breakdown of the results of the energy modelling analysis in terms of Energy Costs, Energy Savings, while identifying the GHGI's for all baselines and Zero Emission Options. The negative values indicate that there are either an increase to the energy usage or there are additional operational costs associated with the Zero Emission Options.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$212,204.95	$739.39	-	-	5.9
Zero Emission Option 1: Baseboard + Electric DHW	$256,136.69	$892.46	1%	-21%	1.2
Zero Emission Option 2: Baseboard + ASHP DHW	$223,293.63	$778.03	15%	-5%	1.0

Table 1.10: Energy Performance for Baselines and Options Without Mechanical Cooling

HEATING & COOLING MECHANICAL OPTIONS

Option #	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$207,520.20	$723.07	-	-	5.7
Zero Emission Option 3: ASHP + ASHP DHW	$210,150.32	$732.23	15%	-1%	1.0
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$217,373.77	$757.40	12%	-5%	1.0
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$269,810.74	$940.11	-11%	-30%	1.2
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$228,893.67	$797.54	7%	-10%	1.0
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$207,352.19	$722.48	16%	0%	0.9
Zero Emission Option 8: PTHP + Electric DHW	$242,656.42	$845.49	1%	-17%	1.1

Table 1.11: Energy Performance for Baselines and Options With Mechanical Cooling

From the tables above, there are a few key takeaways from this energy analysis and making the switch to a Zero Emission Option.

There are typically energy savings across the board for the Zero Emission Options, however due to the increased cost of electricity, we see an increase to the overall operational costs of these systems. As GHGI targets continue to be introduced through policies, these operating costs will become more commonplace. These operational costs, as estimated in this study, do not account for the future increases of the BC Carbon Tax, which is currently at $40 per tonne of emissions[7]. As such, the difference in energy costs between the higher GHGI baseline and the Zero Emission Options will reduce over time as carbon tax prices continue to increase.

Energy cost per suite ranges from $722.48 to $940.11 per year between all of the Baselines and Zero Emission Options. Most of the Zero Emission Options have energy savings against the baselines due to more energy efficient systems.

[7]https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax

However, the Zero Emission Options tend to have an energy cost premium compared to the baselines which is due to the electricity utility rates in BC. The energy cost per suite that have been identified and are pro-rated based on the yearly operation costs and divided by the number of suites, therefore these costs per suite are not specific to certain unit size or layout.

It should be noted that Baseline 2 and Zero Emission Options 3 through 7 have been modelled with a 15% space heating penalty, due to the lack of sub-metering at the suite level as per the CoV Energy Modelling Guidelines v2.0. Suite level sub-metering is possible for most of these options, however for the sake of this report were not included to provide a clearer picture of the cost implications to the specific systems, and not peripheral devices. Some building owners may opt to pursue suite-level sub-metering as this approach may encourage energy conservation and can lead to lower energy costs for residents.

HIGH-RISE RESIDENTIAL BUILDING: CAPITAL COST/ENERGY COST COMPARISONS

Tables 1.12 and 1.13 below, summarize the Zero Emission Options and respective baselines, in terms of total capital costs, operational costs and GHGI performance. This table allows the costs and GHGI performance metrics from the previous pages to be reviewed collectively. The negative values indicate that there are either an increase to the energy usage or that there are additional operational costs associated with the Zero Emission Options.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Total Cost	Cost Relative to Baseline 1	Energy Cost ($/yr)	Energy Cost Relative to Baseline 1	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$3,411,600.00	-	$212,204.95	-	5.9
Zero Emission Option 1: Baseboard + Electric DHW	$3,484,500.00	$72,900.00	$256,136.69	-21%	1.2
Zero Emission Option 2: Baseboard + ASHP DHW	$3,716,800.00	$305,200.00	$223,293.63	-5%	1.0

Table 1.12: Cost/Energy Performance Comparison to Baseline 1

HEATING & COOLING MECHANICAL OPTIONS

Option #	Total Cost	Cost Relative to Baseline 2	Energy Cost ($/yr/)	Energy Cost Relative to Baseline 2	GHGI ($kgCO_2e/m^2/yr$)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$7,891,300.00	-	$207,520.20	-	5.7
Zero Emission Option 3: ASHP + ASHP DHW	$8,008,600.00	$189,300.00	$210,150.32	-1%	1.0
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$7,991,100.00	$171,800.00	$217,373.77	-5%	1.0
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$7,025,400.00	($793,900.00)	$269,810.74	-30%	1.2
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$7,030,600.00	($788,700.00)	$228,893.67	-10%	1.0
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$7,653,600.00	($165,700.00)	$207,352.19	0%	0.9
Zero Emission Option 8: PTHP + Electric DHW	$5,973,500.00	($1,845,800.00)	$242,656.42	-17%	1.1

Table 1.13: Cost/Energy Performance Comparison to Baseline 2

There is a correlation between a reduced capital cost and the increase in overall operational cost of the Zero Emission Options and their respective baselines. Zero Emission Options 5, 6 and 8, have the lowest capital cost expenditures while also having some of the highest operational costs. Whereas the Zero Emission Options with the highest capital cost increases, as seen in Zero Emission Options 2, 3 & 4 typically show a lower operational cost, more in line with the respective baselines. These operational costs do not account for the future increases of the BC Carbon Tax, which is currently at $40 per tonne of emissions. As such, the difference in energy costs between the higher GHGI baseline and the Zero Emission Options will reduce over time as carbon tax prices continue to increase.

Including the GHGI allows the relationship between the energy performance with the capital and operating costs of these Zero Emission Options to be compared.

The tables show that Zero Emission Options 1 and 5, which have the highest operational cost also have the highest GHGI performance out of the remaining Zero Emission Options. Zero Emission Option 7, shows the lowest operational cost as well as the lowest GHGI performance.

Energy cost values, in Tables 1.12 and 1.13 are a static representation, and are based on current technologies and energy utility rates. To develop a more detailed cost evaluation the analysis could be developed to take into consideration inflation, overall life expectancy of equipment and net-present evaluations. These considerations were not part of the scope of any section of the report.

HIGH-RISE RESIDENTIAL BUILDING: ANALYSIS

Part 1 has identified eight (8) different Zero Emission Options that provide heating and hot-water for a High-Rise residential building archetype. These options were divided into Heating & Passive Cooling and Heating & Cooling mechanical options and evaluated with architectural considerations, capital costs, operating costs, and energy performance.

Due to the current limitations with BC Hydro's electrical infrastructure in Vancouver, all buildings modelled during this study, including the Baselines and Zero Emissions Options, require substations (i.e. Vista Switch). The costs and spatial requirements associated with this have been included for the costing of the Electrical equipment.

HEATING & PASSIVE COOLING ZERO EMISSION OPTIONS 1 AND 2

Between these two options, the only difference is that Zero Emission Option 2, utilizes an Air-Source Heat Pump (ASHP) to generate the domestic hot water. With this difference in mind, the key consideration and decision in going with one of the two options will depend on the spatial requirements, capital and operating costs that may be influenced by the type of building ownership (rental, condo, non-market).

When it comes to building considerations, as these two options are very similar, the difference lies with the mechanical roof area requirement for Zero Emission Option 2. ASHP’s are typically installed on roofs, and typical High-Rise residential buildings have a compact floor plate, the consideration for rooftop space with this reduced roof area may make it difficult to locate. Architectural screening is typically required around these ASHP’s to shroud the exposed equipment as well as to provide noise attenuation to adjacent rooftop spaces. Further to the shrouding of the ASHP’s, consideration of the rooftop location in respect to the suites below should be evaluated for potential sound attenuation. Another consideration for the overall building design is the total equivalent parking stalls occupied by service spaces, in this instance the baseline and both Zero Emission Options have the same number, nine (9).

Capital costs and operation costs for these two (2) Zero Emission Options may also be a consideration for the suitable option selection. Zero Emission Option 1 has a lower capital cost, however its operational costs are approximately 15% greater than Zero Emission Option 2. Included in the Zero Emission Options capital costs are the increase in the Electrical unit-substation from the Baseline. The increase in the substation size stem from the increase of the electrical loading from electrifying the mechanical system in the Zero Emission Options.

With both options being provided with a centralized domestic hot-water system, with energy payment (i.e. billing) likely through a pro-rated system based on the unit size is typical with other strata fees. These considerations between upfront capital costs or overall energy savings and operational costs likely are a decision that will be made based on the building ownership (rental, market, non-market etc.).

As outlined above, the type of building ownership will pay a role in consideration of these two (2) passive cooling Zero Emission Options. Rental and market buildings typically would look for solutions that reduce overall building maintenance and may be less concerned with the energy costs, as this would be redistributed through the unit residences by way of strata billings or increase rental costs. However, if the building was a non-market type that may be owned and operated by a non-profit society or a local municipality, the stakeholders may consider the overall energy costs over the reduced capital cost expenditures.

While both options provide a low cost Zero Emission Option, the lack of active cooling could encourage the evaluation of Zero Emissions Options 3 through 8, which provide heating and cooling to all the suites, which provides superior thermal comfort over the passively cooled Zero Emission Options.

HEATING & COOLING ZERO EMISSION OPTIONS 3 THROUGH 8

There are many differences between the Zero Emission Options, the key consideration and decision in selecting one of the options will depend on the spatial requirements, as well as the capital and operating costs that may be influenced by the type of building ownership (rental, condo, non-market).

When it comes to building considerations, the following need to be reviewed at the outset of the project to determine what Zero Emission Option may suit the buildings needs and goals: rooftop area for equipment, total equivalent parking stalls for service spaces and building floor to floor and finished ceiling heights.

Nearly all of the Zero Emission Options require equipment to be located on the building's roof, and typical High-Rise residential buildings have a compact floor plate, the consideration for rooftop space with this reduced roof area may make it difficult to locate. Architectural screening is also typically required around these ASHP's to hide the exposed equipment as well as to provide a form of noise attenuation. The one exception to the rooftop area requirement is Zero Emission Option 8, which provides heating and cooling through a PTAC unit, these units do however, require two (2) exterior wall penetrations for each unit installed (typically one per suite). This needs to be considered with respect to the overall building envelope, and the potential of thermal bridging and architectural expression of the building.

Another consideration for the overall building design is the total equivalent parking stalls occupied by service spaces. Baseline 2 requires a minimum of twelve (12) equivalent parking stalls, while the Zero Emission Options, range from ten (10) to a maximum of thirteen (13).

All of the Zero Emission Options consist of in-suite HRV's, and most will have a suite level terminal fan coil unit or heat pump, floor-to-floor considerations as well as final in-suite ceilings heights will need to be considered to incorporate the installation of these pieces of equipment. Fan coil units with ducting to each occupiable area will be provided for Zero Emission Options 3, 4, 5 and 7, these units typically can fit within a 9'-3" (2.8m) floor-to-floor height with a localized ceiling height of approximately 7'-6" (2.3m). Due to the finished ceiling heights, typically the fan coil and in-suite HRV's are located in washroom, storage or entrance areas of the unit, this will allow a more desirable and higher ceiling in the living room area.

Zero Emission Option 6 has been developed using a terminal heat pump installed within the suite. These heat pump units are typically larger than fan coils and will require additional ceiling height or floor space (i.e. mechanical closet) for a vertical heat pump arrangement. Similar to the fan coil units, these units should be located in the washroom, storage or entrance areas to allow for higher ceiling heights within the living spaces, as well as to help attenuate the noise from the heat pumps. Heat pumps have a compressor within the equipment casing, which is known for its noise when the unit is providing heating or cooling to the space.

Lastly, is Zero Emission Option 8, which is a Packaged Terminal Heat Pump system, commonly known as a PTAC unit. This unit is typically installed along a perimeter wall within the living room area to provide its connection to the outdoors. These units, similar to the heat pumps, do have a compressor located within the unit. While these units are significantly smaller than the heat pumps in Zero Emission Option 6, they will still attenuate noise to the living space. As these PTAC units are not installed within the ceiling, nor require any ducting from them, this allows ceiling spaces within the suite to be higher in nearly all spaces, with the exception of the ceiling location in which the HRV will reside.

Capital costs and operational costs for these Zero Emission Options may also be a driving factor for which option is best suited for the building. Zero Emission Options 3 and 4 stand out as the options that increase the overall capital cost expenditure, however when looking at the operational costs we see that these options are some of the best performing relative to the baseline. Conversely, Zero Emission Options 5, 6 and 8, show capital cost savings, over the baseline, in the range of approximately 2% to 24%, but along with these low capital costs we see that their operational costs typically increase as well.

Submetering of the heating and cooling for the Zero Emission Options can be provided, although the costs of additional suite-level meters have not been included in this study. These suite-level metering strategies for Zero Emission Options 3 through 7 would require the installation of a revenue-grade energy meter (BTU meter) on the heating and cooling piping (four pipes) serving each suite, in the case of Zero Emission Options 5 and 6 this would be across only two (2) pipes. These energy meters measure the flow and temperature across the supply and return piping (for both heating and cooling), to determine the amount of energy being utilized by the end user. Zero Emission Option 8 is a packaged heating and cooling system, which allows the energy cost of this option to be directly billed to the suite occupant through the suite-level electrical meter. With all options being provided with a centralized domestic hot-water system, the ability to sub-meter and charge the suite occupants is likely to be a pro-rated system based on the unit size is typical with other strata fees. These considerations along with sub-metering of the heating, cooling and hot-water systems need to be considered, and some of these decisions may be dependent on the type of building ownership (rental, market, non-market).

The type of building ownership will play a role in consideration of these six (6) mechanically cooled Zero Emission Options. Rental and market buildings typically would look for solutions that reduce overall building maintenance and may be less concerned with the energy costs, as this would be redistributed through the unit residences, however in order to pass these energy costs to the tenants for Zero Emission Options 3 through 7 it will require additional sub-metering infrastructure as noted above. That will need to be considered and accounted for as an additional capital cost investment as this has not been reviewed or incorporated in this study. Zero Emission Option 8 provides the simplest solution in terms of sub-metering the energy costs of heating and cooling as this is a standalone heating and cooling solution that would be connected to the suite’s electrical panel and suite meter. However, if the building was a non-market type of building that may be owned and operated by a non-profit society or a local municipality, the stakeholders may consider the overall energy costs over the reduced capital cost expenditures, as these suite-level energy costs may not be allowed to be passed down to the suite occupant. In this scenario, the Class D costing that has been provided will generate a more accurate depiction of the capital costing for these types of building operations.

There are many building specific details that may or may not allow the use of these Zero Emission Options for a particular project, and due to some of these considerations these options need to be reviewed at the outset of the project, with the design team (architectural, electrical, mechanical, and structural) to ensure that the floor-to-floor heights and dropped ceiling heights are optimized. These discussions, when they occur early in the building development stages, have been found to be highly successful in developing an economical strategy for the building owner or stakeholder when it comes to capital cost of the building.

LOW-RISE RESIDENTIAL BUILDING

The following section of this study will be broken down into four distinct parts as follows:

- Mechanical Options
- Building Considerations
- Costing
- Energy Results

As these Zero Emission Options and the respective baselines were developed to a schematic level of design with building considerations and area requirements, a Class D costing exercise was completed to provide additional insight to analyze the trade-offs, and rationale for choosing between the Zero Emission Options with respect to building ownership, building design and considerations, capital and operating costs, as well as peak energy demands. The costing was developed for the Zero Emission Options, with a total building cost per square foot to determine the overall cost differences of the Zero Emission Options compared to their respective baseline options.

The energy modelling for Part 1 was developed to determine the building energy performance targets, overheating hours, and GHGI performance that could be used to evaluate the Zero Emission Options relative to the associated baseline, as well as between options.

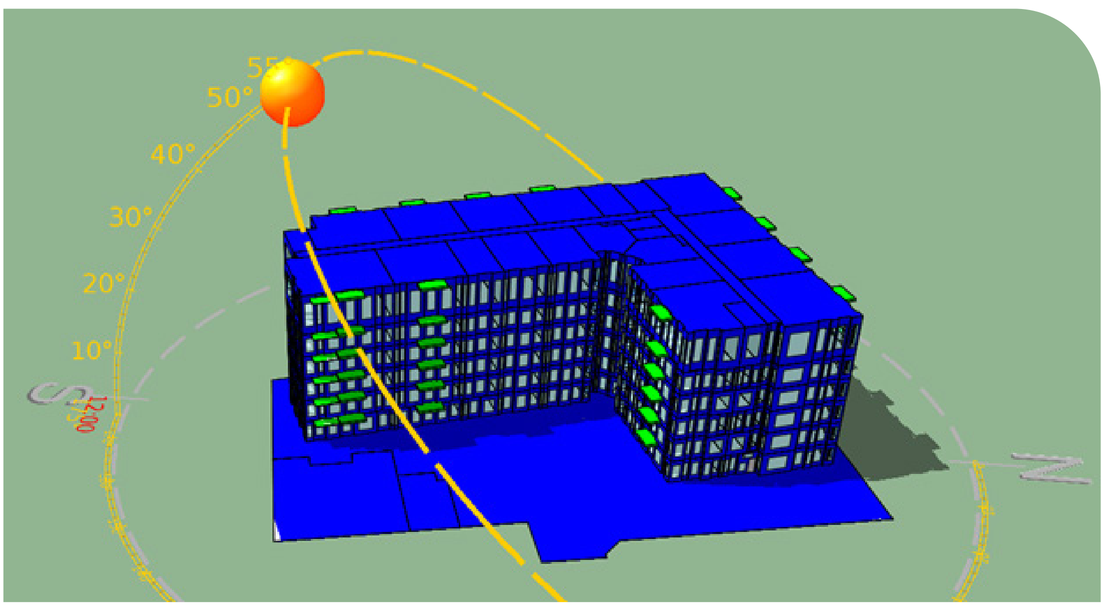


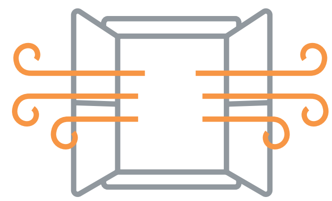
Figure 1.2: Low-Rise Residential Building Energy Model Geometry and Orientation

LOW-RISE RESIDENTIAL BUILDING: MECHANICAL OPTIONS

The Low-Rise Zero Emission Options were developed for energy-efficiency, thermal comfort abilities, operation, and maintenance as well as impact on building considerations. These options are provided with additional details, including energy performance, energy costs, and electrical requirements in **Appendix B – Mechanical Options**. The baselines were grouped according to the approach to cooling – passive and active cooling strategies. All Baselines and Zero Emission Options are provided with in-suite HRV providing suite ventilation.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

BASELINE 1: Electric baseboard heating with gas-fired hot water production and corridor ventilation system.



ZERO EMISSION OPTION 1: Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 2: Electric baseboard heating with an ASHP domestic hot water production system and electric resistance heating for the corridor ventilation system.

ZERO EMISSION OPTION 9: Electric baseboard heating with in-suite electrical resistance domestic hot water tank and for the corridor ventilation system.

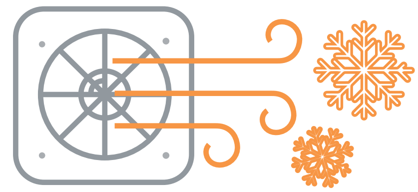
Option #	Heating Source	Cooling Source	Corridor Ventilation Heating Source	Suite Ventilation Strategy	Domestic Hot Water
Baseline 1	Electric Baseboard	N/A	Gas-Fired	In-Suite HRV	Centralized Gas-Fired
Zero Emission Option 1	Electric Baseboard	N/A	Electric Resistance	In-Suite HRV	Centralized Electric Resistance
Zero Emission Option 2	Electric Baseboard	N/A	Electric Resistance	In-Suite HRV	Centralized Air-Source Heat Pump
Zero Emission Option 9	Electric Baseboard	N/A	Electric Resistance	In-Suite HRV	In-Suite Electric Resistance

Table 1.14: Zero Emission Option Comparisons to Baseline 1

LOW-RISE RESIDENTIAL BUILDING MECHANICAL OPTIONS

HEATING & COOLING MECHANICAL OPTIONS

BASELINE 2: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.



ZERO EMISSION OPTION 3: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP domestic hot water production system and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 4: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and an ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 5: Air-cooled variable refrigerant flow heating/cooling system with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 6: 2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

ZERO EMISSION OPTION 7: 4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

ZERO EMISSION OPTION 8: Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

Option #	Heating Source	Cooling Source	Corridor Ventilation Heating Source	Suite Ventilation Strategy	Domestic Hot Water
Baseline 2	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Electric resistance	In-Suite HRV	Centralized Gas-Fired
Zero Emission Option 3	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized Air-Source Heat Pump
Zero Emission Option 4	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized Air-Source Heat Pump w/ Electric top up
Zero Emission Option 5	Air-cooled VRF	Air-cooled VRF	Electric resistance	In-Suite HRV	Centralized Electric Resistance
Zero Emission Option 6	2-Pipe Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Electric resistance	In-Suite HRV	Water to Water Heat Pump
Zero Emission Option 7	Air-Source Heat Pump w/ Back-up Electric Boiler	Air-Source Heat Pump	Hot water loop	In-Suite HRV	Centralized On-Demand DHW from Heating/Cooling System
Zero Emission Option 8	Packaged Terminal Heat Pump	Packaged Terminal Heat Pump	Electric resistance	In-Suite HRV	Centralized Electric Resistance

Table 1.15: Zero Emission Option Comparisons to Baseline 2

LOW-RISE RESIDENTIAL BUILDING: ARCHITECTURAL CONSIDERATIONS & DISTRIBUTION

The Low-Rise residential building is based on a real-world 6-storey stick frame wood construction building and the building envelope strategies were updated to reflect a Step Code 4 target. For Part 1 the Zero Emission Options were grouped according to the approach to cooling – passive and active cooling strategies.

Considerations from a TEDI perspective include the effective wall insulation level (R-13 - R-15) and a high performing double glazed system. One value that was kept consistent is the airtightness. A reduced airtightness value was used based on current CoV Energy Modelling Guidelines v2.0. The use of the lower airtightness value has been seen to be a cost-effective measure to achieve a TEDI target, however considerations to the quality assurance on the construction site will be required by the contractor. Table 1.16 (below) shows a summary of the values used for these two groupings; additional energy modelling inputs can be found in **Appendix A – Energy Modelling Inputs**.

Heating & Passively Cooled Baseline 1 and Zero Emission Options 1,2 & 9		Heating & Cooling Baseline 2 and Zero Emission Options 3-8	
Wall R-Value	R-13	**Wall R-Value**	R-15
Roof R-Value	R-40	**Roof R-Value**	R-40
Floor R-Value	R-15	**Floor R-Value**	R-15
WWR	30%	**WWR**	35%
Window Performance	U-0.27 (SHGC – 0.30) & U-0.29 (SHGC – 0.30)	**Window Performance**	U-0.27 (SHGC – 0.30)
Shading	Enhanced (Fixed Shading)	**Shading**	Standard (Balcony Overhangs)
Airtightness	0.1 L/s/m² of façade	**Airtightness**	0.1 L/s/m² of façade

Table 1.16: Building Envelope Performance

Each mechanical baseline and Zero Emission Option were evaluated for impact on roof and parkade areas, refer Table 1.17 (below), where these spaces impacted parkade areas the number of equivalent parking stalls have been provided and have been based 14 sq.m. (150 sq.ft.) per parking stall.

LOW-RISE PLANT DISTRIBUTION

Option #	Mechanical Room (sq.ft.)	Equivalent Parking Spaces	Water Room (sq.ft.)	Equivalent Parking Spaces	Electrical Room (sq.ft.)	Equivalent Parking Spaces	Generator Room (sq.ft.)	Equivalent Parking Spaces	Mech Outdoor Area (sq.ft.)	Total Equivalent Parking Spaces
Baseline 1: Baseboard + Gas DHW and Corridor Vent	N/A	0	135	1	646	4	228	2	N/A	7
Zero Emission Option 1: Baseboard + Electric DHW	N/A	0	180	1	646	4	228	2	N/A	7
Zero Emission Option 2: Baseboard + ASHP DHW	N/A	0	180	1	646	4	228	2	375	7
Zero Emission Option 9: Baseboard + Electric In-suite DHW	N/A	0	0	0	646	4	228	2	N/A	6
Baseline 2: ASHP + Gas DHW and Corridor Vent	400	3	135	1	646	4	228	2	420	10
Zero Emission Option 3: ASHP + ASHP DHW	400	3	180	1	646	4	228	2	795	10
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	400	3	252	2	646	4	228	2	420	11
Zero Emission Option 5: Air-Cooled VRF + Electric DHW	N/A	0	180	1	646	4	228	2	400	7
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	300	2	180	1	646	4	228	2	288	9
Zero Emission Option 7: ASHP + Heat Exchanger DHW	400	3	180	1	646	4	228	2	420	10
Zero Emission Option 8: PTHP + Electric DHW	N/A	0	180	1	646	4	228	2	N/A	7

Table 1.17: Low-Rise Zero Emission Option Spatial Considerations

The development of all Zero Emission Options requires coordination between the entire design team (architectural, structural, electrical and mechanical) at the outset of the project to indicate major mechanical and electrical room requirements, roof area required and/or the location of large shaft spaces needed throughout the building. The coordination required by the design team is crucial to determine overall building height, floor-to-floor heights, desired ceiling heights (where applicable), and usable floor area.

Design considerations include the location of the in-suite ventilation unit (i.e. ceiling space of the bathroom, storage rooms etc.), duct routing and the required envelope penetrations. The in-suite ventilation system option was chosen over a centralized option, as it has been found to reduce the complexity of running vertical duct shafts (which will reduce usable/sellable floor area) and while also reducing the requirement for a higher floor-to-floor height which is typically required for a centralized ventilation system. The in-suite ventilation also eliminates the requirement for fire-smoke dampers required by the BC Building Code, which reduces capital costs in a Low-Rise archetype.

Table 1.18 (below) outlines some additional design components and suggested considerations when evaluating these Zero Emission Options. **Appendix C - Architectural Plant Considerations & Infographics** provides summary infographics of each baseline and Zero Emission Option, and their impact on roof and parkade areas, as well as outlining additional considerations.

LOW-RISE DISTRIBUTION CONSIDERATIONS

Design Component	Suggested Consideration
Wood frame typical structure	Other types of structural framing will affect floor to floor distance.
Depth and location of structural beams	The ability to run services perpendicular to the public corridors needs careful coordination to avoid unplanned dropped bulkheads or structural upgrades.
Typical corridor ceiling height 7’-6”	Depending on the design floor to floor height, to achieving this ceiling height throughout careful coordination of the routing of the various systems within the corridor ceiling space is required.
Typical suite minimum ceiling height 7’-3”	This is bare minimum to be able to properly detail around door frames.
Typical suite living space minimum ceiling height 8’-0”	Coordination of mechanical access to exterior walls is needed to avoid bulkheads that block window head.
Rooftop Equipment	Screening is recommended to provide a shroud around the exposed equipment, and to provide noise attenuation from the equipment to the adjacent rooftop spaces.

Table 1.18: Design Components and Suggested Considerations

LOW-RISE RESIDENTIAL BUILDING: CAPITAL COST/ RESULTS

Table 1.19 and 1.20 below, provides a breakdown of the capital costs relative to each Zero Emission Option and respective baseline option. The mechanical costs include all mechanical equipment, distribution (i.e. ductwork, piping) and the building costs include any requirement for architectural and structural (i.e. additional service spaces, screening of equipment etc.) related to these Zero Emission Options. The below noted column, "Total Cost ($/sq.ft.)" is noted as an estimate for the overall building construction costs. Refer to **Appendix E – Costing Details**, for a more detailed breakdown of the Class D costing completed for this report.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Mechanical Cost	Cost Relative to Baseline 1	Electrical Cost	Cost Relative to Baseline 1	Building Cost (Arch & Struct)	Cost Relative to Baseline 1	Total Cost	Cost Relative to Baseline 1	Total Cost ($/sq.ft.)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$716,300.00	-	$369,800.00	-	$252,300.00	-	$1,338,400.00	-	$302.00
Zero Emission Option 1: Baseboard + Electric DHW	$714,400.00	($1,900.00)	$417,100.00	$47,300.00	$263,500.00	$11,200.00	$1,395,000.00	$56,600.00	$302.51
Zero Emission Option 2: Baseboard + ASHP DHW	$1,181,300.00	$465,000.00	$385,900.00	$16,100.00	$263,500.00	$11,200.00	$1,830,700.00	$492,300.00	$306.44
Zero Emission Option 9: Electric Baseboard Heating and In-suite Electric Hot Water Tank	$611,800.00	($104,500.00)	$499,900.00	$130,100.00	$364,100.00	$111,800.00	$1,475,800.00	$137,400.00	$303.24

Table 1.19: Cost Comparison to Baseline 1

HEATING & COOLING MECHANICAL OPTIONS

Option #	Mechanical Cost	Cost Relative to Baseline 2	Electrical Cost	Cost Relative to Baseline 2	Building Cost (Arch & Struct)	Cost Relative to Baseline 2	Total Cost	Cost Relative to Baseline 2	Total Cost ($/sq.ft.)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$2,126,200.00	-	$355,200.00	-	$394,300.00	-	$2,875,700.00	-	$317.00
Zero Emission Option 3: ASHP + ASHP DHW	$2,600,700.00	$474,500.00	$362,300.00	$7,100.00	$443,000.00	$48,700.00	$3,406,000.00	$530,300.00	$321.78
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$2,184,200.00	$58,000.00	$358,300.00	$3,100.00	$423,500.00	$29,200.00	$2,966,000.00	$90,300.00	$317.81
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$2,251,400.00	$125,200.00	$357,800.00	$2,600.00	$303,500.00	($90,800.00)	$2,912,700.00	$37,000.00	$317.33
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$1,818,600.00	($307,600.00)	$379,700.00	$24,500.00	$367,300.00	($27,000.00)	$2,565,600.00	($310,100.00)	$314.21
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$2,130,200.00	$4,000.00	$355,100.00	($100.00)	$405,500.00	$11,200.00	$2,890,800.00	$15,100.00	$317.14
Zero Emission Option 8: PTHP + Electric DHW	$1,541,400.00	($584,800.00)	$371,100.00	$15,900.00	$263,500.00	($130,800.00)	$2,176,000.00	($699,700.00)	$310.69

Table 1.20: Cost Comparison to Baseline 2

Exclusions:

- General Contractor's General Requirements, Overhead and Fees
- Design and Construction Contingencies
- Project Soft Costs

From the tables above, a few key points in regard to the capital cost implications of going to a Zero Emissions Option can be established.

For the Heating & Passive Cooling Zero Emission Options there is a large increase in the mechanical equipment cost, with slight increases in terms of Electrical and Building costs. Zero Emission Option 9 shows the contrary, with a large mechanical cost savings and an increase in the Electrical and Building costs. This suggests that a typical baseline building where centralized domestic hot-water use is being provided, the building is already designed in a way that could accommodate a Zero Emissions Option with minimal implications on the electrical or building systems. The modification to go to an in-suite domestic hot-water production system, adds additional Electrical costs for the increase in electricity demand, and the building costs to account for the sellable space (approximately 6 sq.ft. per suite) required to install these tanks within the suites.

For Heating & Cooling Zero Emission Options, the capital cost savings come from Zero Emission Options 6 and 8, while the largest increase in capital cost is Zero Emission Option 3, which includes an air-source heat pump (ASHP) for heating and domestic hot water, and the associated building costs (i.e. screening, roof area requirements) for this option.

From the Tables 1.19 and 1.20 (above), switching to a Zero Emission Option does not have to be cost prohibitive, and that depending on the building's energy performance targets, ownership and tenure, either a simple Zero Emission Option (passively cooled), or a more complex system with lower GHGI and higher energy performance could be chosen.

LOW-RISE RESIDENTIAL BUILDING: ENERGY PERFORMANCE RESULTS

Tables 1.21 and 1.22 (below) presents a breakdown of the results of the energy modelling analysis in terms of Energy Costs, Energy Savings, while identifying the GHGI's for all baselines and Zero Emission Options. The negative values in the tables indicated that there are either an increase to the energy usage or there are additional operational costs associated with the Zero Emission Options.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$79,312.86	$714.53	-	-	5.0
Zero Emission Option 1: Baseboard + Electric DHW	$95,395.25	$859.42	3%	-20%	0.9
Zero Emission Option 2: Baseboard + ASHP DHW	$82,685.93	$744.92	17%	-4%	0.8
Zero Emission Option 9: Baseboard + Electric In-suite DHW	$95,395.25	$859.42	3%	-20%	0.9

Table 1.21: Energy Performance Comparison to Baseline 1

HEATING & COOLING MECHANICAL OPTIONS

Option #	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$77,684.11	$699.86	-	-	4.7
Zero Emission Option 3: ASHP + ASHP DHW	$78,426.93	$706.55	16%	-1%	0.8
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$78,676.57	$708.80	16%	-1%	0.7
Zero Emission Option 5: Air-Cooled VRF + Electric DHW	$95,662.22	$861.82	-4%	-23%	0.9
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$90,373.18	$814.17	2%	-16%	0.9
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$75,358.55	$678.91	20%	3%	0.7
Zero Emission Option 8: PTHP + Electric DHW	$96,498.42	$869.36	-5%	-24%	0.9

Table 1.22: Energy Performance Comparison to Baseline 2

From the tables above, there are a few key takeaways from this energy analysis and making the switch to a Zero Emission Option.

There are typically energy savings across the board for the Zero Emission Options, however due to the increased cost of electricity, we see an increase to the overall operational costs of these systems. As GHGI targets continue to be introduced through policies, these operating costs will become more commonplace. These operational costs, as estimated in this study do not account for the future increases of the BC Carbon Tax, which is currently at $40 per tonne of emissions. As such, the difference in energy costs between the higher GHGI baseline and the Zero Emission Options will reduce over time as carbon tax prices continue to increase.

Energy cost per suite ranges from $678.91 to $869.36 per year between all of the Baselines and Zero Emission Options. Most of the Zero Emission Options have energy savings against the baselines due to more energy efficient systems. However, the Zero Emission Options tend to have an energy cost premium compared to the baselines which is due to the electricity utility rates in BC. The energy cost per suite that have been identified and are pro-rated based on the yearly operation costs and divided by the number of suites, therefore these costs per suite are not specific to certain unit size or layout.

It should be noted that Baseline 2 and Zero Emission Options 3 through 7 have been modelled with a 15% space heating penalty, due to the lack of sub-metering at the suite level as per the CoV Energy Modelling Guidelines v2.0. Suite level sub-metering is possible for most of these options, however for this report were not included to provide a clearer picture of the cost implications to the specific systems, and not peripheral devices. Some building owners may opt to pursue suite-level sub-metering as this approach may encourage energy conservation and can lead to lower energy costs for residents.

LOW-RISE RESIDENTIAL BUILDING: CAPITAL COST/ENERGY COST COMPARISON

Tables 1.23 and 1.24 below, summarize the Zero Emission Options and respective baselines, in terms of total capital costs, operational costs and GHGI performance. This table allows these costs and GHGI performance metrics from the previous pages to be reviewed collectively. The negative values indicate that there are either an increase to the energy usage or there are additional operational costs associated with the Zero Emission Options.

HEATING & PASSIVE COOLING MECHANICAL OPTIONS

Option #	Total Cost	Cost Relative to Baseline 1	Energy Cost ($/yr)	Energy Cost Savings Relative to Baseline 1	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$1,338,400.00	-	$79,312.86	-	5.0
Zero Emission Option 1: Baseboard + Electric DHW	$1,395,000.00	$56,600.00	$95,395.25	-20%	0.9
Zero Emission Option 2: Baseboard + ASHP DHW	$1,830,700.00	$492,300.00	$82,685.93	-4%	0.8
Zero Emission Option 9: Electric Baseboard Heating + In-suite Electric Hot Water Tank	$1,475,800.00	$137,400.00	$95,395.25	-20%	0.9

Table 1.23: Cost/Energy Performance Comparison to Baseline 1

HEATING & COOLING MECHANICAL OPTIONS

Option #	Total Cost	Cost Relative to Baseline 2	Energy Cost ($/yr)	Energy Cost Savings Relative to Baseline 2	GHGI ($kgCO_2e/m^2/yr$)
Baseline 2: ASHP + Gas DHW and Corridor Vent	$2,875,700.00	-	$77,684.11	-	4.7
Zero Emission Option 3: ASHP + ASHP DHW	$3,406,000.00	$530,300.00	$78,426.93	-1%	0.8
Zero Emission Option 4: ASHP + ASHP w/ Electric Top Up DHW	$2,966,00.00	$90,300.00	$78,676.57	-1%	0.7
Zero Emission Option 5: Water-Cooled VRF + Electric DHW	$2,912,700.00	$37,000.00	$77,143.96	1%	0.9
Zero Emission Option 6: 2-Pipe Loop w/ ASHP + WWHP DHW	$2,565,600.00	($310,100.00)	$90,373.18	-16%	0.9
Zero Emission Option 7: ASHP + Heat Exchanger DHW	$2,890,800.00	$15,100.00	$75,358.55	3%	0.7
Zero Emission Option 8: PTHP + Electric DHW	$2,176,000.00	($699,700.00)	$96,498.42	-24%	0.9

Table 1.24: Cost/Energy Performance Comparison to Baseline 2

There is a correlation between a reduced capital cost and the increase in overall operational cost of the Zero Emission Options and their respective baselines. Zero Emission Options 6 and 8, have the lowest capital cost expenditures while also having some of the highest operational costs. Whereas the Zero Emission Options with the highest capital cost increases, as seen in Zero Emission Options 2 & 3 typically show a lower operational cost, more in line with the respective baselines. These operational costs do not account for the future increases of the BC Carbon Tax, which is currently at $40 per tonne of emissions. As such, the difference in energy costs between the higher GHGI baseline and the Zero Emission Options will reduce over time as carbon tax prices continue to increase.

Including the GHGI allows the relationship between the energy performance with the capital and operating costs of these Zero Emission Options to be compared. The tables show that Zero Emission Options 1, 5, 6, 8 and 9, which have the highest operational cost also have the highest GHGI performance out of the remaining Zero Emission Options. Zero Emission Options 2, 3, 4 and 7 show some of the lowest operational costs as well as the lowest GHGI performance.

Energy cost values, in Tables 1.23 and 1.24 are a static representation, and are based on current technologies and energy utility rates. To develop a more detailed cost evaluation the analysis could be developed to take into consideration inflation, overall life expectancy of equipment and net-present evaluations. These considerations were not part of the scope of any section of the report.

LOW-RISE RESIDENTIAL BUILDING: ANALYSIS

Part 1 has identified nine (9) different Zero Emission Options that provide heating and hot-water for a Low-Rise residential building archetype. These options were divided into Heating & Passive Cooling and Heating & Cooling mechanical options and evaluated with architectural considerations, capital costs, operating costs, and energy performance.

Due to the current limitations with BC Hydro's electrical infrastructure in Vancouver, all buildings modelled during this study, including the Baselines and Zero Emissions Options, require substations (i.e. Vista Switch). The costs and spatial requirements associated with this have been included for the costing of the Electrical equipment.

HEATING & PASSIVE COOLING ZERO EMISSION OPTIONS 1, 2 AND 9

The key difference between these options is that Zero Emission Option 2 utilizes an Air-Source Heat Pump (ASHP) to generate the domestic hot water, and Zero Emission Option 9 modifies the domestic hot-water approach from a centralized to suite-by-suite. These different methodologies impact spatial requirements, capital and operating costs that may be influenced by the type of building ownership (rental, condo, non-market).

When it comes to building considerations, the difference lies with the mechanical area required for either the ASHP's from Zero Emission Option 2 or the in-suite spatial requirements needed for Zero Emission Option 9. ASHP's are typically installed on roofs, therefore consideration to the impact on roof amenity space is required. Architectural screening is typically required around these ASHP's to shroud the exposed equipment as well as to provide noise attenuation to adjacent rooftop spaces. Zero Emission Option 9 was developed with a fundamental change from a centralized domestic hot-water system to in-suite, this adds spatial considerations to be included within the boundaries of the suites. These spatial requirements need to be reviewed in detail as this will affect the sellable floor area.

Another consideration for the overall building design is the total equivalent parking stalls occupied by service spaces, in this instance Baseline 1 and both Zero Emission Options 1 and 2 have the same number, seven (7), while Zero Emission Option 9 only requires six (6) equivalent parking stalls.

Capital costs and operation costs for these three (3) Zero Emission Options may also be a consideration for the suitable option selection. Zero Emission Option 1 and 9 have a lower capital cost, their operational costs are approximately 15% greater than Zero Emission Option 2. Zero Emission Options 1 and 2 were developed to provide the building with a centralized domestic hot-water system with energy payment (i.e. billing) likely through a pro-rated system based on the unit size is typical with other strata fees. Zero Emission 9 eliminates the requirement for pro-rating the domestic hot-water energy usage and allows the energy cost of this option to be directly billed to the suite occupant through the suite-level electrical panel and meter. These considerations between upfront capital costs or overall energy savings and operational costs likely are a decision that will be made based on the building ownership (rental, market, non-market etc.).

As outlined above, the type of building ownership will pay a role in consideration of these three (3) passive cooling Zero Emission Options. Rental and market buildings typically would look for solutions that reduce overall building maintenance and may be less concerned with the energy costs, as this would be redistributed through the unit residences by way of strata billings or increase rental costs. Zero Emission Option 9 provides the simplest solution in terms of sub-metering the costs of the domestic hot-water system to the suite occupant as this is a standalone solution that would be connected to the suite's electrical panel and suite meter. However, if the building was a non-market type that may be owned and operated by a non-profit society or a local municipality, the stakeholders may consider the overall energy costs over the reduced capital cost expenditures.

While all options provide a relatively low cost Zero Emission Option, the lack of active cooling could encourage the evaluation of Zero Emissions Options 3 through 8, which provide heating and cooling to all the suites, which provides superior thermal comfort over the passively cooled Zero Emission Options.

HEATING & COOLING ZERO EMISSION OPTIONS 3 THROUGH 8

There are many differences between the Zero Emission Options, the key consideration and decision in selecting one of the options will depend on the spatial requirements, as well as the capital and operating costs that may be influenced by the type of building ownership (rental, condo, non-market).

When it comes to building considerations, the following need to be reviewed at the outset of the project to determine what Zero Emission Option may suit the buildings needs and goals: rooftop area for equipment, total equivalent parking stalls for service spaces and building floor to floor and finished ceiling heights.

Nearly all of the Zero Emission Options require equipment to be located on the building's roof, therefore consideration to the impact on roof amenity space is required. Architectural screening is typically required around these ASHP's to shroud the exposed equipment as well as to provide noise attenuation to adjacent rooftop spaces. The one exception to the rooftop area requirement is Zero Emission Option 8, which provides heating and cooling through a PTAC unit, these units do however, require two (2) exterior wall penetrations for each unit installed (typically one per suite). This needs to be considered with respect to the overall building envelope, and the potential of thermal bridging and architectural expression of the building.

Another consideration for the overall building design is the total equivalent parking stalls occupied by service spaces. Baseline 2 requires a minimum of ten (10) equivalent parking stalls, while the Zero Emission Options, range from as little as seven (7) to a maximum of eleven (11).

All of these Zero Emission Options consist of in-suite HRV's, and most will have a suite level terminal fan coil unit or heat pump, floor-to-floor considerations as well as final in-suite ceilings heights need will need to be considered to incorporate the installation of these pieces of equipment. Fan coil units with ducting to each occupiable area will be provided for Zero Emission Options 3, 4, 5 and 7, these units typically can fit within a 9'-3" (2.8m) floor-to-floor height with a localized ceiling height of approximately 7'-6" (2.3m). Due to the finished ceiling heights, typically the fan coil and in-suite HRV's are located in washroom, storage or entrance areas of the unit, this will allow a more desirable and higher ceiling in the living room area.

Zero Emission Option 6 has been developed using a terminal heat pump installed within the suite. These heat pump units are typically larger than fan coils and will require additional ceiling height or floor space (i.e. mechanical closet) for a vertical heat pump arrangement. Similar to the fan coil units, these units should be located in the washroom, storage or entrance areas to allow for higher ceiling heights within the living spaces, as well as to help attenuate the noise from the heat pumps. Heat pumps have a compressor within the equipment casing, which is known for its noise when the unit is providing heating or cooling to the space.

Lastly, is Zero Emission Option 8, which is a Packaged Terminal Heat Pump system, commonly known as a PTAC unit. This unit is typically installed along a perimeter wall within the living room area to provide its connection to the outdoors. These units, similar to the heat pumps, do have a compressor located within the unit. While these units are significantly smaller than the heat pumps in Zero Emission Option 6, they will still attenuate noise to the living space. As these PTAC units are not installed within the ceiling, nor require any ducting from them, this allows ceiling spaces within the suite to be higher in nearly all spaces, with the exception of the ceiling location in which the HRV will reside.

Capital costs and operational costs for these Zero Emission Options may also be a driving factor for which option is best suited for the building. Zero Emission Options 3 and 4 stand out as the couple of options which increase the overall capital cost expenditure, however when looking at the operational costs we see that these options are some of the best performing relative to the baseline. Conversely, Zero Emission Options 6 and 8 show a large capital cost savings over the baseline in the range of approximately 11% to 24%, but along with these low capital costs we see that the operational costs typically increase as well.

Submetering of the heating and cooling for the Zero Emission Options can be provided, although the costs of additional suite-level meters have not been included in this study. These suite-level metering strategies for Zero Emission Options 3 through 7 would require the installation of a revenue-grade energy meter (BTU meter) on the heating and cooling piping (four pipes) serving each suite, in the case of Zero Emission Options 5 and 6 this would be across only two (2) pipes. These energy meters measure the flow and temperature across the supply and return piping (for both heating and cooling), to determine the amount of energy being utilized by the end user. Zero Emission Option 8 is a packaged heating and cooling system which allows the energy cost of this option to be directly billed to the suite occupant through the suite-level electrical meter. With all options being provided with a centralized domestic hot-water system, the ability to sub-meter and charge the suite occupants is likely to be a pro-rated system based on the unit size is typical with other strata fees. These considerations along with sub-metering of the heating, cooling and hot-water systems need to be considered, and some of these decisions may be dependent on the type of building ownership (rental, market, non-market).

The type of building ownership will pay a role in consideration of these six (6) mechanically cooled Zero Emission Options. Rental and market buildings typically would look for solutions that reduce overall building maintenance and may be less concerned with the energy costs, as this would be redistributed through the unit residences, however in order to pass these energy costs to the tenants for Zero Emission Options 3 through 7 it will require additional sub-metering infrastructure as noted above. That will need to be considered and accounted for as an additional capital cost investment as this has not been reviewed or incorporated in this study. Zero Emission Option 8 provides the simplest solution in terms of sub-metering the energy costs of heating and cooling as this is a standalone heating and cooling solution that would be connected to the suite's electrical panel and suite meter. However, if the building was a non-market type of building that may be owned and operated by a non-profit society or a local municipality, the stakeholders may consider the overall energy costs over the reduced capital cost expenditures, as these suite-level energy costs may not be allowed to be passed down to the suite occupant. In this scenario, the Class D costing that has been provided will generate a more accurate depiction of the capital costing for these types of building operations.

There are many building specific details that may or may not allow the use of these Zero Emission Options for a particular project, and due to some of these considerations these options need to be reviewed at the outset of the project, with the design team (architectural, electrical, mechanical and structural) to ensure that the floor-to-floor heights and dropped ceiling heights are optimized. These discussions, when they occur early in the building development stages, have been found to be highly successful in developing an economical strategy for the building owner or stakeholder when it comes to capital cost of the building.

CONCLUSION

Part 1 has shown that for both High- and Low-Rise residential building archetypes, that there are many approaches to providing a Zero Emissions heating and hot-water solutions that meet the Step Code and GHGI performance targets, as well as the 200-hour overheating limitations. The Zero Emission Options analyzed are not comprehensive but provide a range of common solutions that are available to the local market. With these Zero Emission Options come a variety of considerations that should be studied at the outset of the project. These considerations include, building ownership, building design considerations (i.e. floor area, rooftop area, floor-to-floor heights etc.), capital and operating costs, as well as peak energy demands.

All of the Zero Emission Options studied were able to provide thermal comfort meeting a 200-hour overheating limitation for the current weather file (2016), Part 2 of this study provides a deeper look at the resiliency of these Zero Emission Options and how thermal comfort is met during future weather conditions and “shock events”.

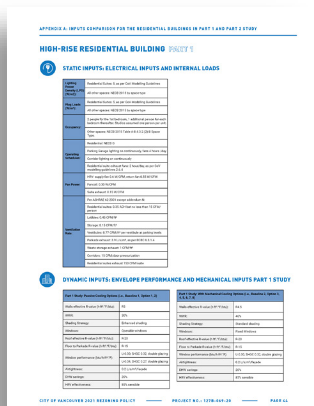
PART 2

CLIMATE RESILIENCE - OVERHEATING LIMITS & FUTURE WEATHER

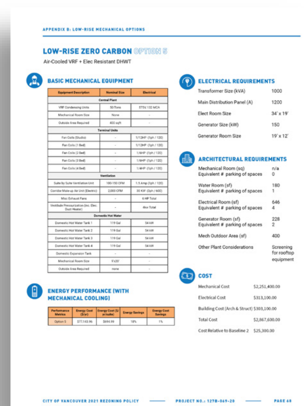
INTRODUCTION

In Part 2 Zero Emission Options for both the High- and Low-Rise residential building archetypes were studied to analyze the impact of the future 2050 weather conditions with a 20-hour overheating limit, and certain "shock events" (smoke events, increased internal loads, power outages). The main focus in Part 2, is based around occupant thermal comfort and resiliency, while placing these Zero Emission Options are under the stresses of a more stringent overheating limit or "shock events" using the future 2050 weather file.

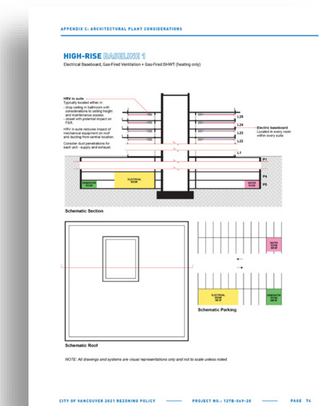
APPENDIX A



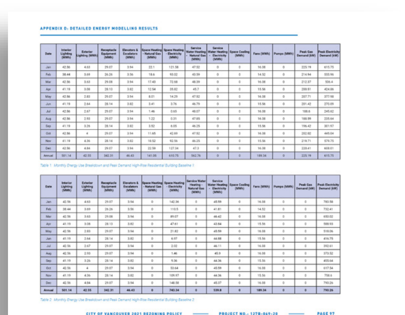
APPENDIX B



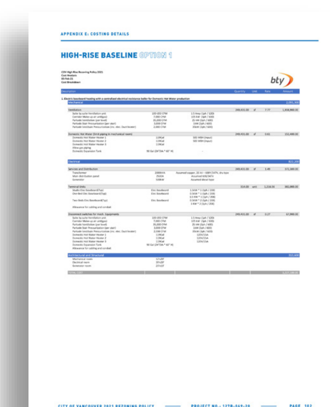
APPENDIX C



APPENDIX D



APPENDIX E



The noted appendices are to be read in conjunction with Part 2, these appendices provide additional information on the building inputs, Zero Emission Options infographics, energy modelling results and detailed costing breakdowns.

OVERHEATING STUDY METHODOLOGY

Part 2 of this report analyzes Zero Emission Options 1 (electric baseboard) and 3 (air-source heat pump with back-up electric boiler) from Part 1 and their resiliency in meeting a more stringent thermal comfort target of 20-hour overheating limits using the 2050 weather file. This stricter overheating limit currently aligns with the City of Vancouver Energy Modelling Guidelines[1] for buildings or spaces with vulnerable populations (i.e. seniors housing, supportive housing, daycares etc.).

The future weather file used for this Part of the report is the RCP-8.5[2] 2050's average weather file from the Pacific Climate Impacts Consortium (PCIC).

Figure 2.1 shows the dry-bulb comparison between the current weather file (2016; used in Part 1) and the 2050 weather file.

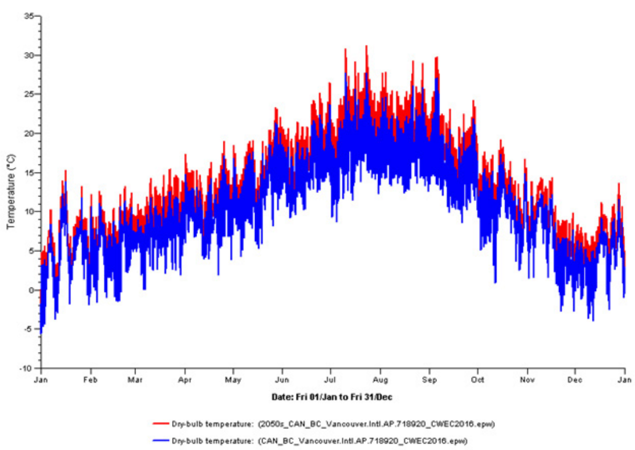


Figure 2.1: Dry-bulb Air Temperature for 2016 & 2050 Weather Files

	2016 Weather File		2050 Weather File	
Month	**Monthly Mean Outdoor Temperature (°C)**	**80% Acceptability Upper Limit (°C)**	**Monthly Mean Outdoor Temperature (°C)**	**80% Acceptability Upper Limit (°C)**
March	N/A	N/A	11.3	24.8
April	N/A	N/A	13.8	25.6
May	12.4	25.2	16.6	26.4
June	15.4	26.1	20.0	27.5
July	17.9	26.9	23.4	28.5
August	18.0	26.9	23.2	28.5
September	12.5	25.2	19.9	27.5
October	N/A	N/A	14.3	25.7
November	N/A	N/A	10.4	24.5

Table 2.1: 80% Acceptability Limits in Vancouver with RCP-8.5 2050 Average Weather File

Option #	Shading	Operable Window	WWR
Zero Emission Option 1: Baseboard + Electric DHW (Passively Cooled)	Fixed Exterior Shading	Yes	30%
Zero Emission Option 3: ASHP + ASHP DHW (Full Mechanical Cooled)	Balcony Overhangs	No[4]	46%

Table 2.2 – Zero Emission Passive Building Strategies

According to ASHRAE 55.1-2017[3], the 80% acceptability limit increases as the average outdoor air temperature increases, when the average monthly outdoor air is between 10˚C to 33.5˚C. With the 2016 Vancouver CWEC weather file, the months with acceptability limits are from May to September, while with the 2050 weather file from PCIC, the range extends from March to November, as listed in Table 2.1.

Zero Emission Option 1 (electric baseboard), was analyzed to review how a passively cooled design would perform, while Zero Emission Option 3 (air-source heat pump with back-up electric boiler) was reviewed for a fully cooled mechanical option.

Both options used within this Part of the study include the passive building strategies applied in Part 1 of this report (**Part 1 – Zero Emissions Heating & Hot Water**). These passive building strategies are outlined in Table 2.2.

The team enhanced the passive building strategies (lowering of WWR, increase glazing performance and increased shading elements) and found that these solutions were not feasible due to the significant impacts to the building façade.

Through an iterative process the passively cooled design option (Zero Emission Option 1) was modified to determine a simple and cost effective method to achieve the 20-hour overheating target, this new option has been labelled as Zero Emission Option 1a. For both residential buildings (High- and Low-Rise), a centralized ventilation system with a duct mounted cooling coil was studied. This system option was analyzed as a hybrid approach, that bridges the gap of a passively cooled option and a fully cooled mechanical option. When looking at this hybrid approach and the amount of cooling required to the suites, it was determined that the minimum ventilation being provided to the suite needed to be increased by approximately 10%-15% to achieve the overheating hour targets. This increase in ventilation was not significant in that it would affect the overall duct size being distributed to each unit.

[1]City of Vancouver Energy Modelling Guidelines Version 2.0 Section 4 Passively Cooled Buildings https://vancouver.ca/files/cov/guidelines-energy-modelling.pdf

[2]https://www.pacificclimate.org/data/weather-files

[3]ANSI/ASHRAE Standard 55-2017: Thermal Environmental Conditions for Human Occupancy

[4]Windows were modelled to be closed throughout this Report.

HIGH-RISE RESIDENTIAL BUILDING: OVERHEATING STUDY

As highlighted in the methodology section, the team went through an iterative process to design a practical, cost effective option that met the 20-hour overheating requirements modelled with a future 2050 weather file. In this Zero Emission (Option 1a) the suite ventilation system was changed from in-suite to centralized with a duct mounted cooling coil installed to provide partial cooling through the ventilation air. Through the analysis, it was found that due to the cooling requirements within all of the suites the overheating hours were unable to be achieved without providing an increase of approximately 10% to the ventilation airflow. This increase in ventilation airflow was found to have no impact at the suite level ducting and thus no effects on the floor-to-floor requirements. This new option has been labeled as Zero Emission Option 1a (additional details in **Appendix B – Mechanical Options**).

This new option demonstrates compliance to the 20-hour overheating limitations (see Table 2.4), however there are some challenges to the overall building design as the centralized nature of this ventilation system typically accounts for a rooftop mounted unit, horizontal ducting at the top floor, and vertical duct distribution through shafts to all suites. High-Rise building archetypes have a compact floor space where sellable floor area is at a premium. Table 2.5 identifies the architectural spatial considerations comparing the two Zero Emission Options (Option 1 and Option 1a) and the corresponding baseline. The largest impact is on the Outdoor space required with Zero Emission Option 1a, which is likely to be located on the roof with considerations on impact to roof amenity, acoustic and screening for rooftop equipment.

Space	Overheating Hours
L04 - Studio-West	13
L04 - Suite 1BR-South	80
L04 - Suite 2BR- Southwest	41
L25 - Studio-West	11
L25 - Suite 1BR-South	76
L25 - Suite 2BR-Southwest	38
Townhouse - West	33
Townhouse - Southwest	61

Table 2.3: Overheating Hours for Passively Cooled Zero Emission Option 1 (2050 Weather File)

Space	Overheating Hours
L04 - Studio-West	0
L04 - Suite 1BR-South	20
L04 - Suite 2BR- Southwest	11
L25 - Studio-West	0
L25 - Suite 1BR-South	19
L25 - Suite 2BR-Southwest	15
Townhouse - West	1
Townhouse - Southwest	20

Table 2.4 Overheating Hours for Partially Cooled Zero Emission Option 1a (2050 Weather File)

HIGH-RISE ARCHITECTURAL PLANT CONSIDERATIONS

Option #	Mechanical Room (sq.ft.)	Equivalent Parking Spaces	Water Room (sq.ft.)	Equivalent Parking Spaces	Electrical Room (sq.ft.)	Equivalent Parking Spaces	Generator Room (sq.ft.)	Equivalent Parking Spaces	Mech Outdoor Area (sq.ft.)	Total Equivalent Parking Spaces
Baseline 1: Baseboard + Gas DHW and Corridor Vent	N/A	0	300	2	780	5	299	2	N/A	9
Zero Emission Option 1: Baseboard + Electric DHW	N/A	0	300	2	800	5	299	2	N/A	9
Zero Emission Option 1a: Baseboard + Electric DHW	N/A	0	300	2	800	5	299	2	800	9

Table 2.5: High-Rise Zero Emission Option Spatial Considerations

Table 2.6 shows a comparison of the capital costs for the two Zero Emission Options (Option 1 and Option 1a) to corresponding baseline.

Zero Emission Option 1a cost is $229,200 more than the baseline, which is being driven by the centralized ventilation system and the need to have additional requirements of fire-smoke dampers as required in the Building Code. The fire-smoke dampers will also require yearly maintenance, this should be considered for future operational costs of the building.

Option #	Mechanical Cost	Cost Relative to Baseline 1	Electrical Cost	Cost Relative to Baseline 1	Building Cost (Arch & Struct)	Cost Relative to Baseline 1	Total Cost	Cost Relative to Baseline 1	Total Cost ($/sq.ft.)	Total Cost Relative to Baseline 1 ($/sq.ft.)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$2,161,300.00	-	$905,500.00	-	$344,800.00	-	$3,411,600.00	-	$325.00	-
Zero Emission Option 1: Baseboard + Electric DHW	$2,148,500.00	($12,800.00)	$986,200.00	$80,700.00	$349,800.00	$5,000.00	$3,484,500.00	$72,900.00	$325.32	+ $0.32
Zero Emission Option 1a: Baseboard + Electric DHW	$2,390,500.00	$229,200.00	$974,700.00	$69,200.00	$569,800.00	$225,500.00	$3,935,00.00	$523,400.00	$327.29	+$2.29

Table 2.6 – Cost Comparisons to Baseline 1

Exclusions:

- General Contractor's General Requirements, Overhead and Fees
- Design and Construction Contingencies
- Project Soft Costs

The capital costs, in Table 2.6, do not represent any increased costs associated with operational maintenance. There are additional requirements for maintenance of the fire-smoke dampers, however there may be overall savings with a centralized ventilation approach, as the regular maintenance (i.e. filter replacement) is now on a single piece of equipment situated in a location that does not require coordination with residences for access.

Table 2.7 shows the energy performance in terms of energy cost comparisons to the Baseline 1 and Zero Emission Options (Option 1 and Option 1a). Similarly, to Part 1 of this report, these energy costs have been evaluated based on the current BC Hydro and FortisBC utility rates, refer to **Appendix A – Energy Modelling Inputs** for rates used. Zero Emission Option 1a shows that there is a modest increase to the energy costs over Zero Emission 1, however this option provides cooling to the suite through the centralized ventilation system which provides resiliency and enhanced thermal comfort to the occupants. It should be noted that with Zero Emission Option 1a, metering the energy use per suite with a centralized HRV would be challenging and may not be suitable for certain building ownerships, such as rentals or market housing.

Option #	Total Cost	Energy Cost ($/yr)	Energy Cost ($/yr/Suite)	Relative Cost/ Suite	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$3,411,600.00	$194,044	$676	-	-	-	5.5
Zero Emission Option 1: Baseboard + Electric DHW	$3,484,500.00	$235,924	$822	$146	1%	-22%	1.1
Zero Emission Option 1a: Baseboard + Electric DHW	$3,935,00.00	$242,580	$845	$169	-2%	-25%	1.1

Table 2.7 – Cost/Energy Performance Comparison to Baseline 1 based on 2050 Weather Files

Energy cost values, in Table 2.7, are a static representation, and are based on the current technologies and energy utility rates. A more detailed evaluation should consider inflation, overall life expectancy of equipment and net-present evaluations and be specific to the building or project. The intent of this report was not to evaluate or create a full economic analysis of these options as these will vary from building to building.

HIGH-RISE RESIDENTIAL BUILDING: OVERHEATING ANALYSIS

The analysis of the High-Rise building found that providing a fully cooled building (Zero Emission Options 3 through 8) will achieve the stricter overheating limitations with the future 2050 weather file. The analysis also found that the passive building and mechanical strategies (i.e. Zero Emission Options 1 & 2) did not provide enough resiliency to the building and that in future weather conditions some form of mechanical cooling will need to be paired with these strategies to achieve the 20-hour overheating limits. It was found that a partially cooled centralized ventilation system provided an alternative approach between a passively cooled and fully cooled building.

Zero emission Option 1 was fundamentally changed from an in-suite to a centralized ventilation system. This revision, relabelled as Zero Emission Option 1a, poses some challenges for stakeholder and the design team. The following should be considerations to be reviewed:

- Additional rooftop equipment (screen and noise attenuation),
- Increased floor height on the topmost floor,
- Vertical mechanical shafts within suites,
- Requirements for fire-smoke dampers,
- Building ownership and tenure (rental, condo, non-market)

The additional rooftop equipment would include the space to accommodate the centralized ventilation system and cooling condensing unit. For High-Rise residential buildings, the rooftop area is typically small due to the compact floor plate and elevator overruns. Rooftop equipment will need careful considerations for maintenance, screening and acoustics.

The increase of the floor height on the topmost floor, will be required to allow larger duct mains from the centralized ventilation system, to distribute the partially cooled air to the vertical mechanical shafts and into the suites. This increase in floor height may have impacts surrounding the overall building heights and zoning restrictions.

Vertical mechanical shafts within the suites are used for the main distribution of the partially cooled ventilation air to the suites, these shafts take up potentially valuable sellable floor area, and depending on the municipality may not be excluded in floor-space ratio (FSR) calculations. Another duct distribution strategy would be to provide a main vertical duct shaft, with horizontal duct mains on a floor-by-floor basis, however while this may reduce the vertical duct shaft space located within suites, this approach will require additional floor to floor height throughout the entire High-Rise building.

The use of centralized ventilation system is more commonly seen within non-market residential projects, whereas market condo and rentals typically design to provide full cooling. While one main benefit to a centralized ventilation system is not requiring suite access to provide regular maintenance, considerations to the partial cooling design and its application need to be reviewed to ensure proper occupant comfort throughout the building. Some considerations include, zoning of centralized units based on suite orientation. Another consideration when reviewing this system, is regarding metering. Depending on the building ownership, the energy costs for operation of a centralized system, is likely to be a shared cost (i.e. square foot basis) from all building residences, or not charged at all.

Despite these considerations, which will have overall building design impacts, Zero Emission Option 1a provides an improvement to the energy savings, over the passively cooled Zero Emission Option 1, and provides enhanced thermal comfort and building resiliency at a significantly lower capital cost than the fully cooled Zero Emission Options (3 through 8). The range in capital cost savings from the lowest and highest full mechanical cooling Zero Emission Options (Zero Emission Options 3 and 8) to Zero Emission Option 1a is approximately $2,348,500 - $4,003,200. This range excludes the domestic hot water systems to highlight the capital cost savings specific to the mechanical heating and cooling and ventilation systems.

LOW-RISE RESIDENTIAL BUILDING: OVERHEATING STUDY

The team went through an iterative process to design a practical, cost effective option that met the 20-hour overheating requirements modelled with a future 2050 weather file. In this Zero Emission Option the suite ventilation system was changed from in-suite to a centralized system with a duct mounted cooling coil installed to provide partial cooling through the ventilation air. Through the analysis, it was found that due to the cooling requirements within the suites that the overheating hours were unable to be achieved without providing an increase of approximately 15% to the ventilation airflow. This increase in ventilation airflow was found to have no impact at the suite level ducting and therefore no effects on the floor-to-floor requirements This new option has been labelled as Zero Emission Option 1a (additional details in **Appendix B– Mechanical Options**).

This new option demonstrates compliance to the 20-hour overheating limitations (see Table 2.9), however there are some challenges to the overall building design. The centralized nature of this ventilation system typically accounts for a rooftop mounted unit, horizontal ducting at the top floor, and vertical duct distribution through shafts to all suites. Low-Rise building archetypes typically do not have as compact floor space as High-Rise residential buildings, therefore while these vertical shafts require floor area these considerations at the outset of the project will likely be easier to incorporate or determine if this solution is suitable for the project. Table 2.10 identifies the architectural spatial considerations comparing the two Zero Emission Options (Option 1 and Option 1a) and the corresponding baseline. The largest impact is on the Outdoor space required with Zero Emission Option 1a, which is likely to be located on the roof with considerations on impact to roof amenity, acoustic and screening for rooftop equipment.

Space	Overheating Hours
L2 - 2Bed - West	117
L2 - 3Bed - Southwest	45
L6 - Studio - South	34
L6 - 3Bed - Southeast	42
L6 - 3Bed - Southwest	55
L6 - 1 Bed - West	145

Table 2.8: Overheating Hours for Passively Cooled Zero Emission Option 1 (2050 Weather File)

Space	Overheating Hours
L2 - 2Bed - West	4
L2 - 3Bed - Southwest	3
L6 - Studio - South	0
L6 - 3Bed - Southeast	0
L6 - 3Bed - Southwest	12
L6 - 1 Bed - West	18

Table 2.9: Overheating Hours for Partially Cooled Zero Emission Option 1a (2050 Weather File)

LOW-RISE ARCHITECTURAL PLANT CONSIDERATIONS PART 2

Option #	Mechanical Room (sq.ft.)	Equivalent Parking Spaces	Water Room (sq.ft.)	Equivalent Parking Spaces	Electrical Room (sq.ft.)	Equivalent Parking Spaces	Generator Room (sq.ft.)	Equivalent Parking Spaces	Mech Outdoor Area (sq.ft.)	Total Equivalent Parking Spaces
Baseline 1: Baseboard + Gas DHW and Corridor Vent	N/A	0	135	1	646	4	228	2	N/A	7
Zero Emission Option 1: Baseboard + Electric DHW	N/A	0	180	1	646	4	228	2	N/A	7
Zero Emission Option 1a: Baseboard + Electric DHW	N/A	0	180	1	646	4	228	2	375	7

Table 2.10: Low-Rise Zero Emission Option Spatial Considerations

Along with the spatial considerations of this new Zero Emissions Option, there will be additional requirements to install fire-smoke dampers as outlined in the Building Code. These fire-smoke dampers will require regular yearly maintenance, along with capital costs to the project. Table 2.11 shows a comparison of the capital costs for the two Zero Emission Options (Option 1 and Option 1a) to their corresponding baseline.

Option #	Mechanical Cost	Cost Relative to Baseline 1	Electrical Cost	Cost Relative to Baseline 1	Building Cost (Arch & Struct)	Cost Relative to Baseline 1	Total Cost	Cost Relative to Baseline 1	Total ($/sq.ft.)	Total Cost Relative to Baseline 1 ($/sq.ft.)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$716,300.00	-	$369,800.00	-	$252,300.00	-	$1,338,400.00	-	$302.00	-
Zero Emission Option 1: Baseboard + Electric DHW	$714,400.00	($1,900.00)	$417,100.00	$47,300.00	$263,500.00	$11,200.00	$1,395,000.00	$56,600.00	$302.51	+$0.51
Zero Emission Option 1a: Baseboard + Electric DHW	$759,100.00	$42,800.00	$437,900.00	$68,100.00	$355,100.00	$102,800.00	$1,552,100.00	$213,700.00	$303.93	+$1.93

Table 2.11 – Costs Comparisons to Baseline 1

Exclusions:

- General Contractor's General Requirements, Overhead and Fees
- Design and Construction Contingencies
- Project Soft Costs

The capital costs, in Table 2.11, do not represent any increased costs associated with operational maintenance. There are additional requirements for maintenance of the fire-smoke dampers, however there may be overall savings with a centralized ventilation approach, as the regular maintenance (i.e. filter replacement) is now on a single piece of equipment situated in a location that does not require coordination with residences for access.

Table 2.12 shows the energy performance in terms of energy cost comparisons to the Baseline 1 and Zero Emission Option 1. Similarly, to Part 1 of this report, these energy costs have been evaluated based on the current BC Hydro and FortisBC utility rates, refer to **Appendix A – Energy Modelling Inputs** for rates used. Zero Emission Option 1a shows that there is an increase to the energy costs over Zero Emission 1, however this option provides cooling to the suite through the centralized ventilation system which provides resiliency and enhanced thermal comfort to the occupants. It should be noted that the cooling would not be charged based on usage but would be pro-rated based on unit size in line with other strata fees, for buildings with rentals or market housing type ownerships.

Option #	Total Cost	Energy Cost ($/yr)	Energy Cost ($/yr/Suite)	Relative Cost/ Suite	Energy Savings	Energy Cost Savings	GHGI ($kgCO_2e/m^2/yr$)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$1,338,400.00	$72,124	$650	-	-	-	4.6
Zero Emission Option 1: Baseboard + Electric DHW	$1,395,000.00	$88,122	$794	$144	2%	-22%	0.8
Zero Emission Option 1a: Baseboard + Electric DHW	$1,552,100.00	$93,605	$843	$193	-4%	-30%	0.9

Table 2.12 – Cost/Energy Performance Comparison to Baseline 1 based on 2050 Weather Files

Energy cost values, in Table 2.12 are a static representation, and are based on the current technologies and energy utility rates. A more detailed evaluation should consider inflation, overall life expectancy of equipment and net-present evaluations and be specific to the building or project. The intent of this report was not to evaluate or create a full economic analysis of these options as these will vary from building to building.

LOW-RISE RESIDENTIAL BUILDING: OVERHEATING ANALYSIS

The analysis of the Low-Rise building found that providing a fully cooled building (Zero Emission Options 3 through 8) will achieve the stricter overheating limitations with the future 2050 weather file. The analysis also found that the passive building and mechanical strategies (i.e. Zero Emission Options 1, 2 & 9) did not provide enough resiliency to the building and that in future weather conditions some form of mechanical cooling will need to be paired with these strategies to achieve the 20-hour overheating limits. It was found that a partially cooled centralized ventilation system provided an alternative approach between a passively cooled and a fully cooled building.

Zero Emission Option 1 was fundamentally changed from an in-suite to a centralized ventilation system. This revision, relabelled as Zero Emission Option 1a, poses some challenges for stakeholder and the design team. The following should be considerations to be reviewed:

- Additional rooftop equipment (screening and noise attenuation),
- Increased floor height on the topmost floor,
- Vertical mechanical shafts within suites,
- Requirements for fire-smoke dampers,
- Building Ownership and tenure (rental, condo, non-market).

The additional rooftop equipment would include the space to accommodate the centralized ventilation system and cooling condensing unit. For Low-Rise residential buildings, the rooftop area is commonly used as an outdoor amenity space, therefore rooftop equipment is not desirable but with careful considerations and screening can be integrated into the building's overall design.

The increase of the floor height on the topmost floor, will be required to allow larger duct mains from the centralized ventilation system, to distribute to partially cooled air the vertical mechanical shafts and to the suites. This increase in floor height may have impacts surrounding the overall building heights and zoning restrictions.

Vertical mechanical shafts within the suites are used for the main distribution of the partially cooled ventilation air to the suites, these shafts take up potentially valuable sellable floor area, and depending on the municipality may not be excluded in floor-space ratio (FSR) calculations. Another duct distribution strategy would be to provide a main vertical duct shaft, with horizontal duct mains on a floor-by-floor basis, however while this may reduce the vertical duct shaft space located within suites, this approach will require additional floor to floor height throughout the entire High-Rise building.

The use of centralized ventilation system is more commonly seen within non-market residential projects, whereas market condo and rentals typically design to provide full cooling. While one main benefit to a centralized ventilation system is not requiring suite access to provide regular maintenance, considerations to the partial cooling design and its application need to be reviewed to ensure proper occupant comfort throughout the building. Some considerations include, zoning of centralized units based on suite orientation. Another consideration when reviewing this system, is regarding metering. Depending on the building ownership, the energy costs for operation of a centralized system, is likely to be a shared cost (i.e. square foot basis) from all building residences, or not charged at all.

Despite these considerations, which will have overall building design impacts, Zero Emission Option 1a provides similar energy savings to the passively cooled Zero Emission Option 1, while providing enhanced thermal comfort and building resiliency, at a more economical capital cost than the fully cooled Zero Emission Options (3 through 8). The range in capital cost savings from the lowest and highest full mechanical cooling Zero Emission Options (Zero Emission Options 3 and 8) to Zero Emission Option 1a is approximately \$845,300 - \$1,439,700. This range excludes the domestic hot water systems to highlight the capital cost savings specific to the mechanical heating and cooling and ventilation systems.

OVERHEATING STUDY ANALYSIS

Throughout the overheating study conducted in this Part of the report there have been similarities identified with how the High- and Low-Rise buildings handle these more stringent 20-hour overheating limits in future 2050 weather conditions. A few key takeaways from this overheating study are as follows:

- Full mechanical cooling Zero Emission Options can achieve the more stringent overheating limitations, however, are capital cost intensive.
- Passive building strategies alone will not achieve thermal comfort limits for future weather conditions.
- Partial mechanical cooling Zero Emission Options can bridge the capital cost gap between passive cooling and full cooling, however, these options have building design implications that will require consideration at the project outset.

In this analysis we found that providing a fully cooled building (Zero Emission Options 3 through 8) for both the High- and Low-Rise buildings will achieve the stricter overheating limitations with the future 2050 weather file. Even without the passive building design strategies of Zero Emission Options 1 and 2, these options provide sufficient heating and cooling to maintain 0-hours of overheating, during the future 2050 weather conditions.

During this analysis it was found that both the High-Rise and Low-Rise buildings that included passive building strategies, Zero Emission Options 1 and 2, were unable to provide enough building resiliency that would achieve the 20-hour overheating limitations of the future weather condition, without some form of mechanical cooling. In Part 2, we evaluated a partial cooling strategy paired with an increase in the ventilation airflow rate (10-15%) to achieve the 20-hour overheating limits. This new partial cooling strategy was labelled as Zero Emission Option 1a.

The analysis shows throughout this overheating study that the implementation of passive building design strategies are valuable to thermal comfort of the occupants within the suite, however due to increasing climate conditions will not be able to maintain a more stringent overheating limit (20-hours). In the analysis, pairing these strategies with a partially cooled centralized ventilation system provided a hybrid solution that meets the overheating limits during future weather conditions. Other alternative methods and pathways, not reviewed as a part of this study, may be able to achieve these overheating limits, such as night-flushing, cross-flow ventilation through suites or electrochromatic glazing. While not reviewed as a part of this study these other methods could help reduce overheating hours and internal heat gains.

In this overheating study, the thermal comfort was reviewed with the more stringent overheating limitations during the future 2050 weather file, the next study in Part 2 of the study will review thermal comfort sensitivities in regards to potential “shock events” and how the fully mechanical cooled Zero Emission Option 3, and the partially cooled Zero Emission Option 1a manage in these scenarios.

SENSITIVITY STUDY METHODOLOGY

The second section to Part 2 is a continuation of the Thermal Comfort analysis and analyzes Zero Emissions Options 1a and 3 during individual “shock events”. The following “shock events” were used and analyzed individually as a part of this sensitivity study:

SCENARIO 1: SMOKE EVENTS

The smoke events scenario simulates a local wildfire limiting the occupant’s ability to open a window. This event will indicate potential stresses on the mechanical cooling (full or partial) systems and how they will respond in terms of thermal comfort and overheating. This has become a more regular experience in BC and the Lower Mainland, due to the increasing temperatures and longer periods of drought during the summer months which is expected to become more severe.

SCENARIO 2: HIGH INTERNAL HEAT GAINS

The high internal heat gains scenario will explore the influences of an increased lighting and plug load as well as an increased occupancy load on the mechanical cooling (full or partial) systems and thermal comfort. This scenario will review a 50% increase in lighting and plug loads and a 100% increase in occupancy, which would simulate a large gathering within the suite.

SCENARIO 3: LOSS OF POWER

The loss of power scenario will review a power outage throughout the whole building. While this would eliminate all internal heat gains produced by lighting and plug loads, it would also incapacitate the mechanical ventilation and cooling system.

These three (3) scenarios were studied using the future 2050 weather files, while focusing on the two (2) warmest weeks of the cooling season, the last two weeks of July. The outdoor air temperature for this two-week period are shown below in Figure 2.2, identified by the red line, while the ASHRAE 80% acceptability limit of 28.5˚C has been indicated by the straight black line. While ASHRAE is most commonly used in North America, there are also additional technical guidelines by the Chartered Institution of Building Services Engineers (CIBSE[5]), which focus on avoiding overheating.

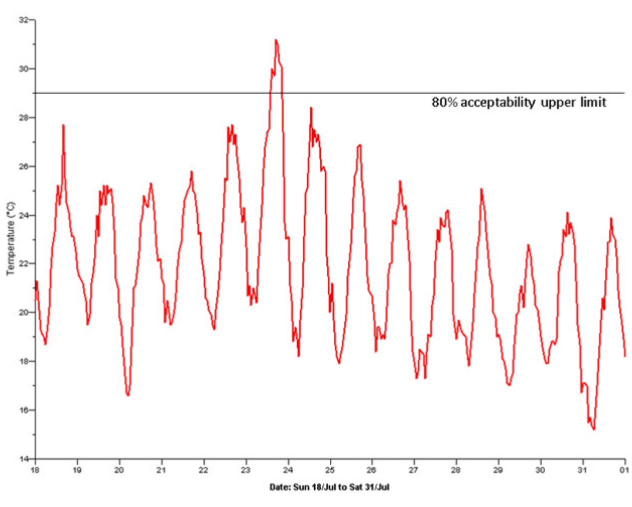


Figure 2.2: Outdoor Air Temperature, 2050 Weather File During the Last 2 Weeks of July

The purpose of this analysis is to review how the stresses of these individual “shock events” affect the occupant’s thermal comfort, while also providing insight on which building strategies may be practical to implement for projects of today and will have a lasting impact for the resiliency of the building and its occupants..

[5]CIBSE TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings

HIGH-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 1: SMOKE EVENTS

The study analyzed the High-Rise Residential building under a smoke event, where the windows were not operable for the Zero Emission Options 1a (partially cooled) and 3 (fully cooled). Due to Zero Emission Option 3 being a fully cooled systems, the smoke event and the implications of an inoperable window had no affect on the performance and the ability to maintain thermal comfort.

Figure 2.3 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line).

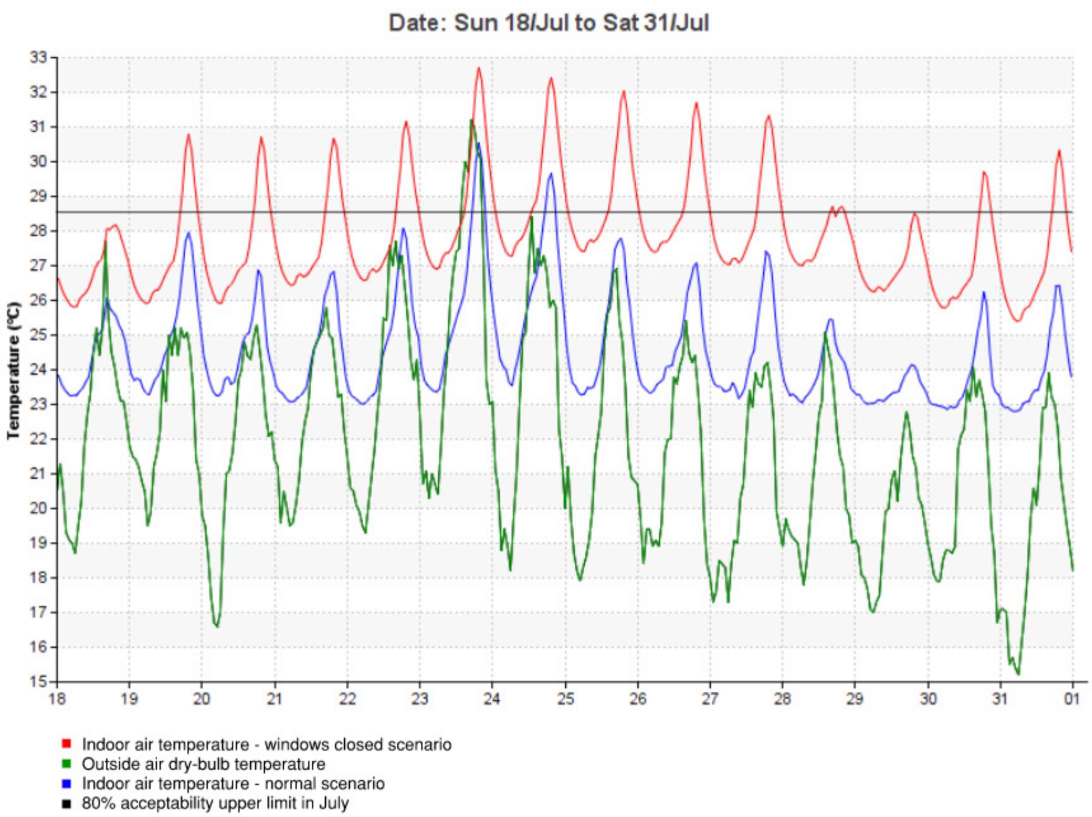


Figure 2.3: Indoor Air Temperature with Windows Closed Compared to the Normal Scenario for Zero Emission Option 1a

ANALYSIS

For the smoke event, the Zero Emission Option 1a (partial cooling) did not meet the occupant thermal comfort, with the indoor air temperature reaching 32.7˚C, which is 2.2˚C greater than normal operation. This study showed an overall increase of approximately 82 overheating hours over the normal operation (no smoke event) in a two-week span, this is due to the inability to open the window when the outdoor conditions were shown to be more optimal to provide “free cooling” (outdoor air temperature is lower than the temperature indoors). It should also be noted that the use of “free cooling” is also likely to be limited with the heat-island effect in urban areas. While this was not studied specifically, the energy model can be modified to study the impact through manipulating the exterior temperature.

This suggests that the passive building design solutions (i.e. operable windows and fixed shading), as well as a partially cooled mechanical systems have limitations on the ability to achieve occupant thermal comfort during these types of smoke events in the future.

HIGH-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 2: HIGH INTERNAL HEAT GAINS

The study analyzed the High-Rise Residential building for Zero Emission Options 1a (partially cooled) and 3 (fully cooled) with a 50% increase to the lighting and plug loads, and a 100% increase in occupant load to simulate a large gathering within the unit. As all of these "shock events" are being reviewed individually, the ability to open the operable window was utilized when applicable.

Due to Zero Emission Option 3 being a fully cooled system, with the ability to open the operable window there was no effect on the ability to maintain thermal comfort within the suite. Figure 2.4 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line).

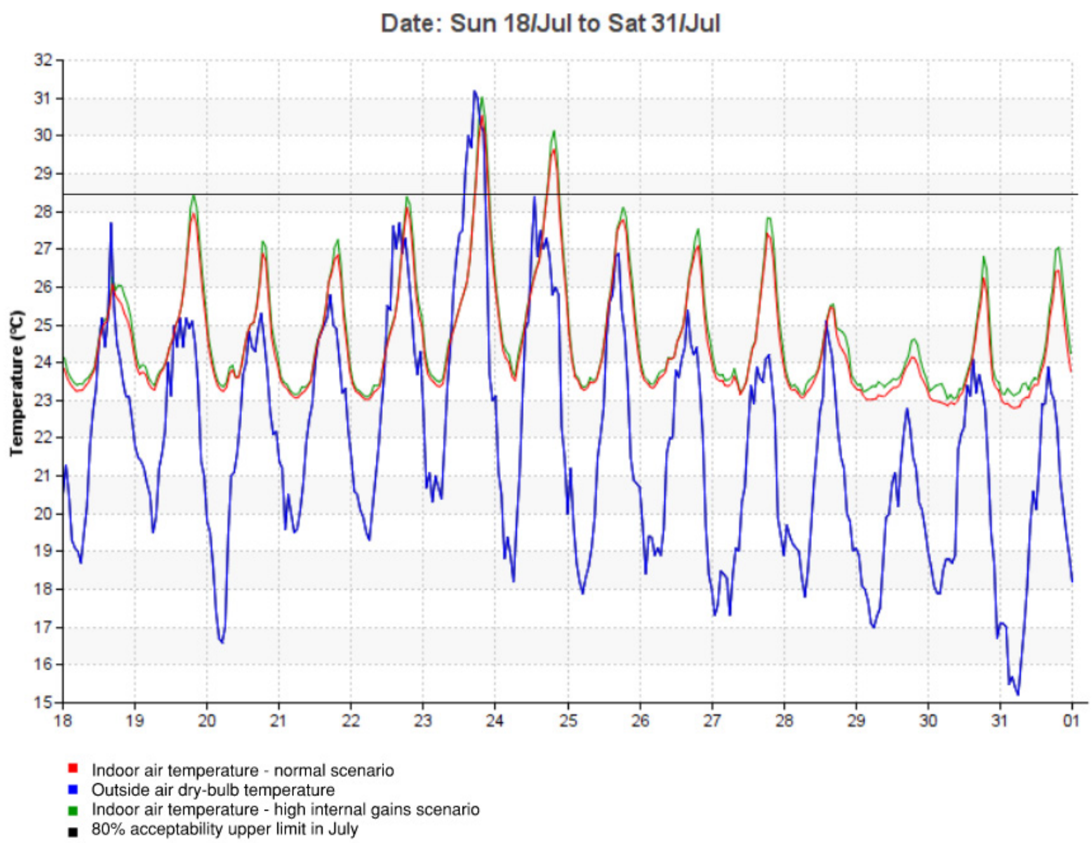


Figure 2.4: Indoor Air Temperature with High Internal Heat Gains Compared to the Normal Scenario for Zero Emission Option 1a

ANALYSIS

For the high internal heat gain "shock event" the Zero Emission Option 1a (partial cooling) was able to meet the occupant thermal comfort. Based on Figure 2.4 (above) and the modelling that was conducted, it was determined that over this two-week span, the peak internal temperature reached 31˚C, which is only a 0.5˚C increase from the normal operation. The use of the operable windows likely played a large role in Zero Emission Option 1a's ability to manage the increased heating loads. The modelling showed a total of approximately 9 overheating hours over this 2-week span.

This suggests that the operable windows implemented as a passive building design solution along with the fixed shading provide benefits in today's climate, as well in the future when it comes to increased internal loads. These fundamental strategies if adopted on new projects can provide building resiliency and allow for the building to operate comfortably with a partially cooled mechanical system (Zero Emission Option 1a), without the need of the capital cost intensive, fully cooled system.

HIGH-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 3: LOSS OF POWER

The study analyzed the High-Rise Residential building for Zero Emission Options 1a (partially cooled) and 3 (fully cooled) with a power outage that eliminates all electrical internal gains (lighting and plug loads), however this would also incapacitate the ventilation and mechanical heating and cooling. As all of these "shock events" are being reviewed individually, the ability to open the operable window was applied when applicable.

Figure 2.5 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line), for Zero Emission Option 1a (partial cooling).

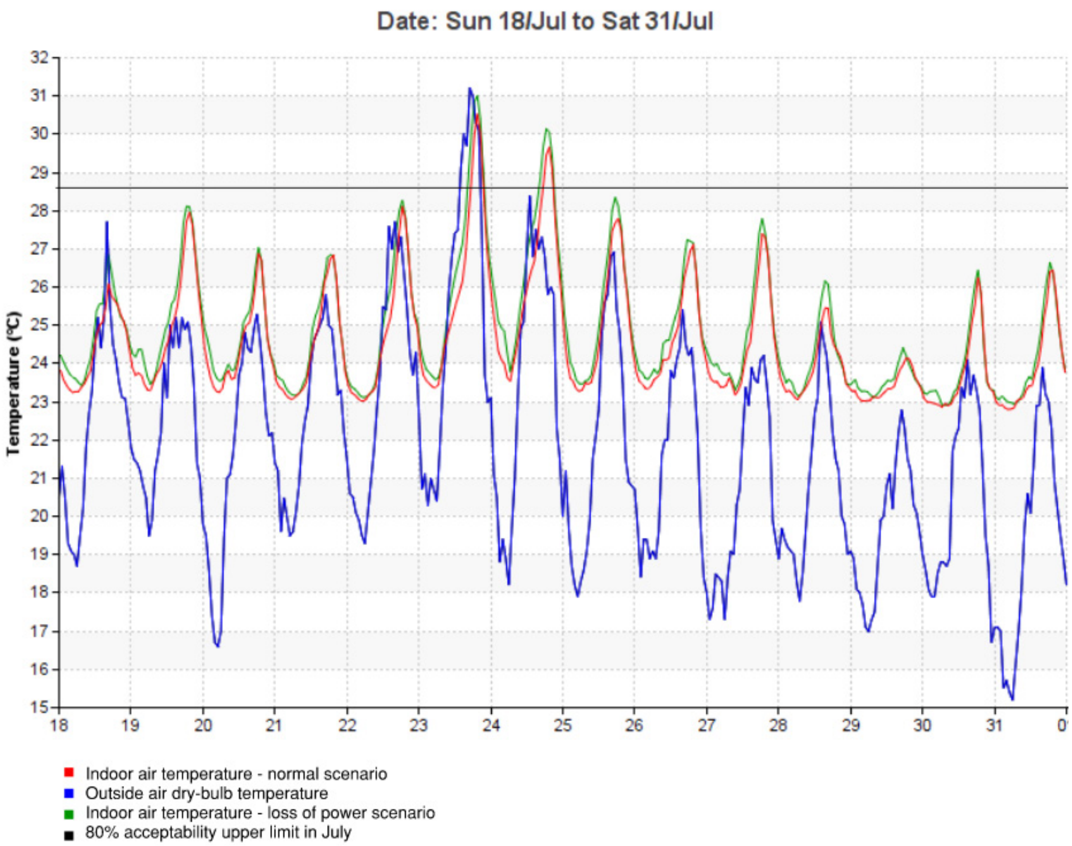


Figure 2.5: Indoor Air Temperature with Loss of Power Compared to the Normal Scenario for Zero Emission Option 1a

Figure 2.6 (on the following page) identifies the peak indoor air temperatures with Zero Emission Option 3 (full cooling). This shows a comparison between the power on versus the power outage and the ASHRAE 80% acceptability limit (indicated by the black line).

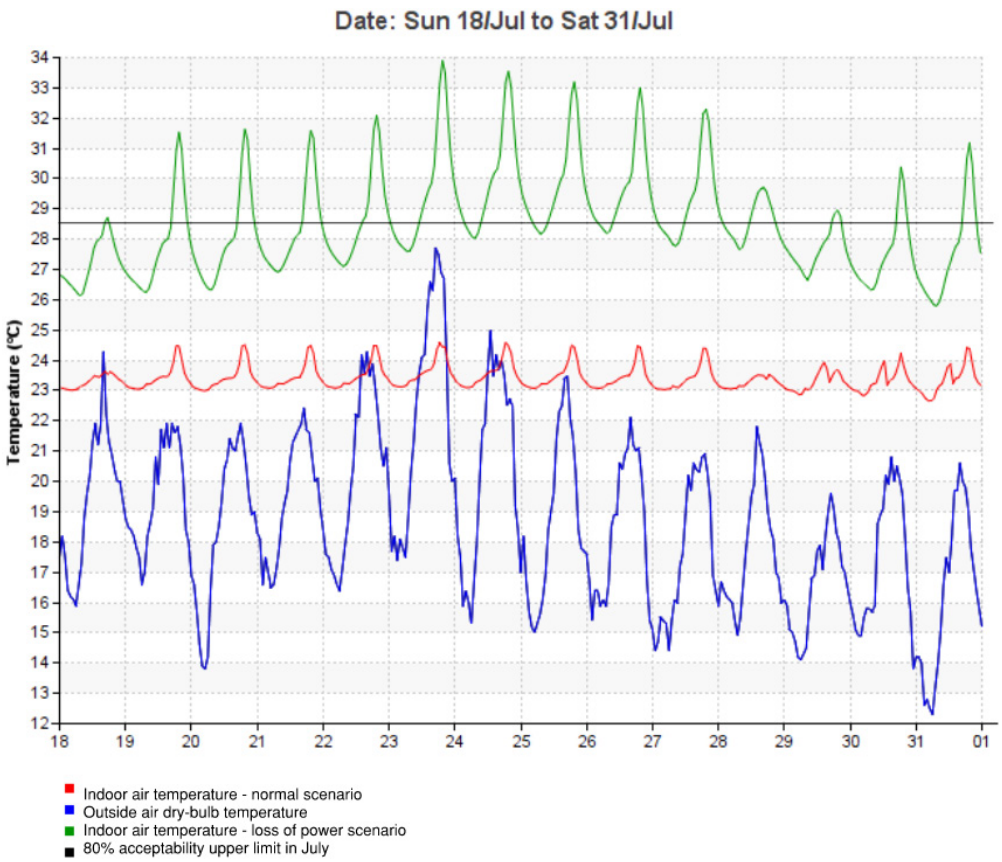


Figure 2.6: Indoor Air Temperature with Loss of Power Compared to the Normal Scenario for Zero Emission Option 3

ANALYSIS

Based on Figure 2.5 (previous page), for Zero Emission Option 1a, it was determined that over this two-week span, the peak internal temperature reached 31˚C, which is only a 0.5˚C increase from the normal operation. Based on this increase in the peak internal temperature the modelling showed a total of approximately 11- hours of overheating during this 2-week span, which is an increase of 2 overheating hours over normal operation. Similar to the other “shock events”, the Zero Emission Options that provided passive building design strategies indicate that these provide benefits for today’s buildings, future building and overall building resiliency.

Figure 2.6 (above) displays a significant increase in the indoor peak temperatures for this “shock event” for Zero Emission Option 3, which results in a significant increase of overheating hours. In total the Zero Emission Option 3 (fully cooled) resulted in approximately 143-hours of overheating during the 2-week span. That increase accounts for nearly 6-days of overheating. This increase is due to the Zero Emission Option 3 heavily relying on the mechanical means of cooling, rather than implementing any passive building design strategies (i.e. operable windows, fixed shading, reduced WWR). This highlights that for a level of true resiliency the design needs to be an integrated design with passive and active cooling strategies.

LOW-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 1: SMOKE EVENTS

The study analyzed the Low-Rise Residential building under a smoke event, where the windows were not operable for Zero Emission Options 1a (partially cooled) and 3 (fully cooled). Due to Zero Emission Option 3 being a fully cooled systems, the smoke event and the implications of an inoperable window had no affect on the building performance and the ability to maintain thermal comfort within the suite.

Figure 2.7 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line).

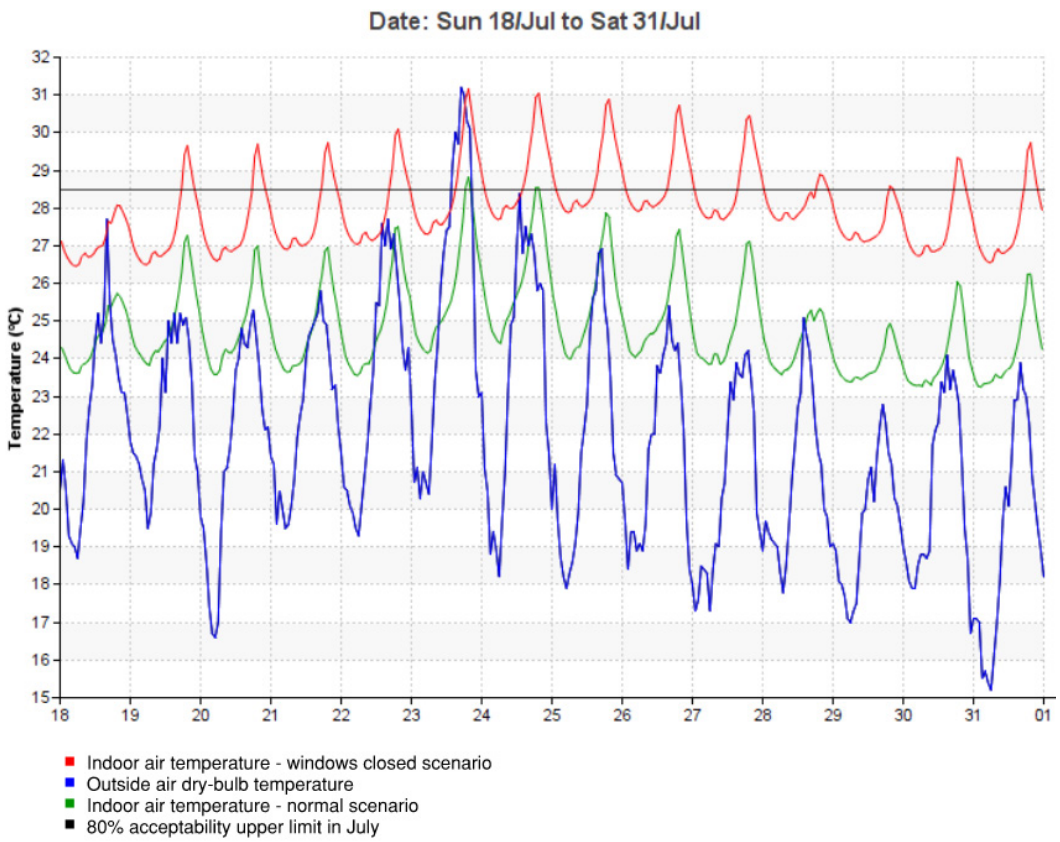


Figure 2.7: Indoor Air Temperature with Windows Closed Compared to the Normal Scenario for Zero Emission Option 1a

ANALYSIS

Zero Emission Option 1a (partial cooling) did not meet the occupant thermal comfort, with the indoor air temperature reaching 31.2˚C, which is 2.4˚C greater than normal operation. This study showed an overall increase of approximately 84 overheating hours over the normal operation (no smoke event) in a two-week span, this is due to the inability to open the window when the outdoor conditions were shown to be more optimal to provide "free cooling" (outdoor air temperature is lower than the temperature indoors). It should also be noted that the use of "free cooling" is also likely to be limited with the heat-island effect in urban areas. While this was not studied specifically, the energy model can be modified to study the impact through manipulating the exterior temperature.

This suggests that the passive building design solutions (i.e. operable windows and fixed shading), as well as a partially cooled mechanical systems have limitations on the ability to achieve occupant thermal comfort during these types of smoke events in the future.

LOW-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 2: HIGH INTERNAL HEAT GAINS

The study analyzed the Low-Rise Residential building for Zero Emission Options 1a (partially cooled) and 3 (fully cooled) with a 50% increase to the lighting and plug loads, and a 100% increase in occupant load to simulate a large gathering within the unit. As all of these "shock events" are being reviewed individually, the ability to open the operable window was utilized when applicable.

Due to Zero Emission Option 3 being a fully cooled systems, with the ability to open the operable window there was no effect on the ability to maintain thermal comfort within the suite. Figure 2.8 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line).

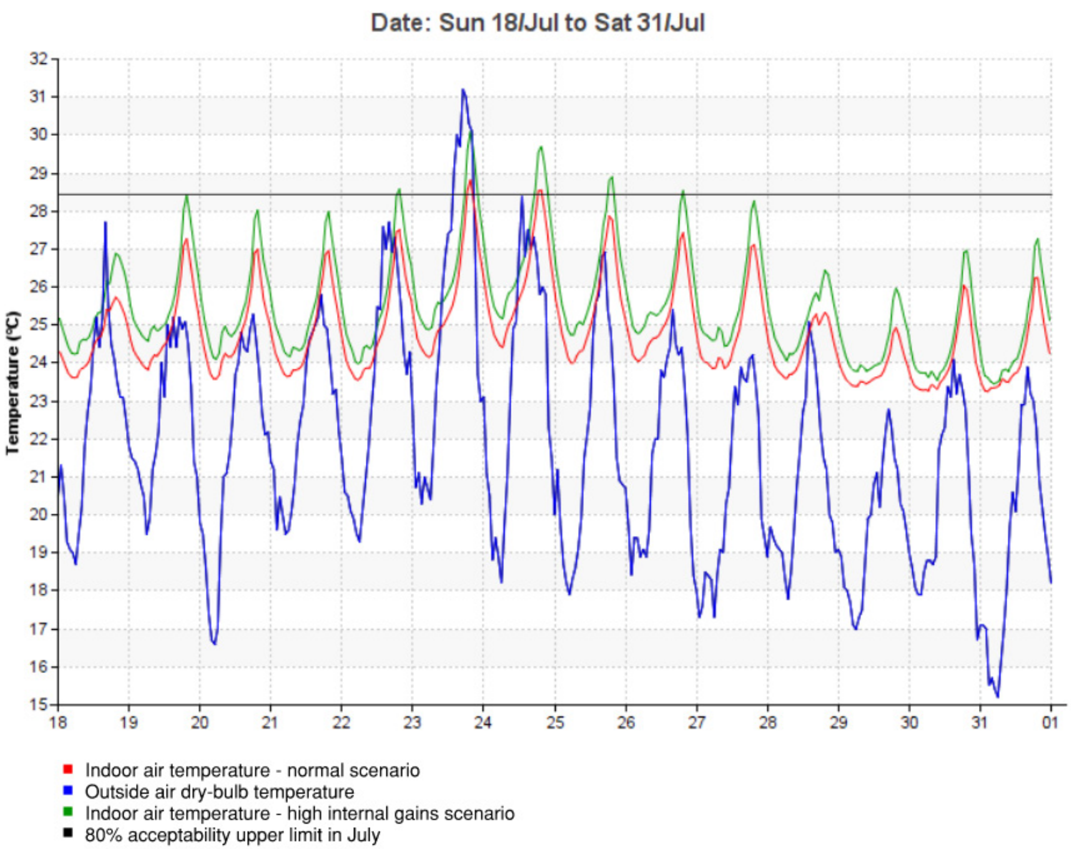


Figure 2.8: Indoor Air Temperature with High Internal Heat Gains Compared to the Normal Scenario for Zero Emission Option 1a

ANALYSIS

For the high internal heat gain, Zero Emission Option 1a (partial cooling) met the internal heat gains. Based on Figure 2.8 (above) and the modelling that was conducted, it was determined that over this two-week span, the peak internal temperature reached 30.1˚C, which is only a 1.3˚C increase from the normal operation. The use of the operable windows likely played a large role in Zero Emission Option 1a's ability to manage the increased heating loads. The modelling showed a total of approximately 9 overheating hours over the normal conditions during this 2-week span.

This suggests that the operable windows implemented as passive building design solutions along with the fixed shading provide benefits in today's climate, as well in the future when it comes to increased internal loads. These fundamental strategies if adapted on new projects can provide building resiliency and allow for the building to operate comfortably with a partially cooled mechanical system (Zero Emission Option 1a), without the need of the capital cost intensive, fully cooled system options.

LOW-RISE RESIDENTIAL BUILDING SENSITIVITY STUDY SCENARIO 3: LOSS OF POWER

The study analyzed the Low-Rise Residential building for Zero Emission Options 1a (partially cooled) and 3 (fully cooled) with a power outage, that eliminates all electrical internal gains (lighting and plug loads), however this would also incapacitate the ventilation and mechanical heating and cooling. As all of these "shock events" are being reviewed individually, the ability to open the operable window was applied when applicable.

Figure 2.9 (below) identifies the peak indoor air temperatures over the warmest two (2) weeks of the year, the outdoor air temperature and the ASHRAE 80% acceptability limit (as indicated by the black line), for Zero Emission Option 1a (partial cooling).

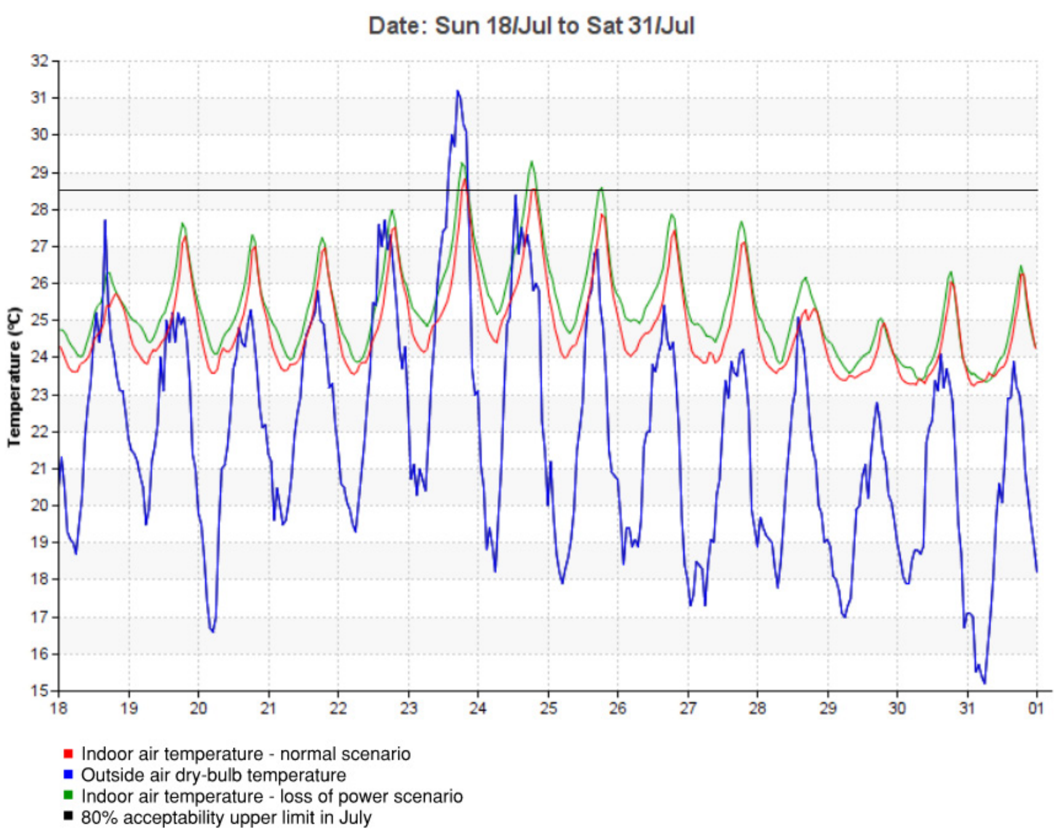


Figure 2.9: Indoor Air Temperature with Loss of Power Compared to the Normal Scenario for Zero Emission Option 1a

Figure 2.10 (on the following page) identifies the peak indoor air temperatures with Zero Emission Option 3 (full cooling). This shows a comparison between the power on versus the power outage and the ASHRAE 80% acceptability limit (indicated by the black line).

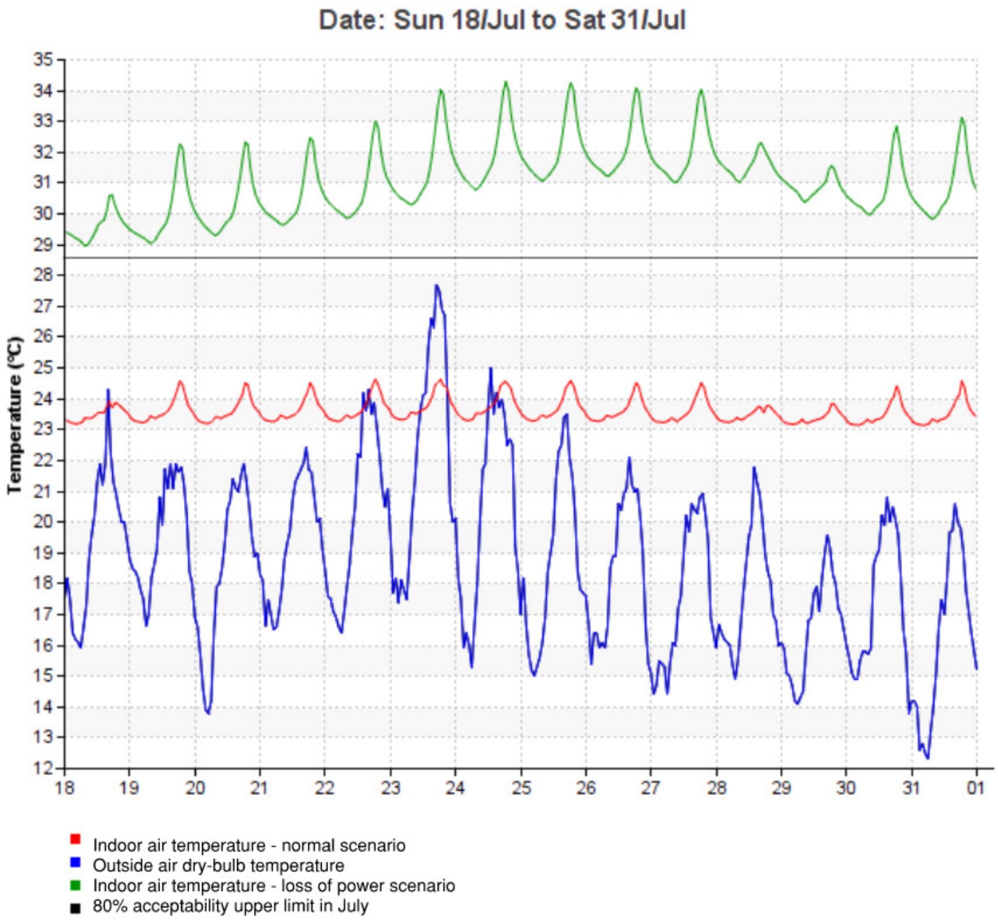


Figure 2.10: Indoor Air Temperature with Loss of Power Compared to the Normal Scenario for Zero Emission Option 3

ANALYSIS

Based on Figure 2.9 (previous page) for Zero Emission Option 1a, it was determined that over this two-week span, the peak internal temperature reached 29.3˚C, which is only a 0.5˚C increase from the normal operation. Based on this increase in the peak internal temperature the modelling showed a total of approximately 11 hours of overheating during this 2-week span. Similar to the other "shock events", the Zero Emission Options that provided passive building design strategies indicate that these provide benefits for today's buildings, future building and overall building resiliency.

Figure 2.10 (above) displays a significant increase in the indoor peak temperatures for this "shock event" for Zero Emission Option 3, which results in a significant increase of overheating hours. In total the Zero Emission Option 3 (fully cooled) resulted in approximately 336-hours of overheating during the 2-week span. That increase accounts for all 14-days of overheating. This increase is due to the Zero Emission Option 3 heavily relying on the mechanical means of cooling, rather than implementing any passive building design strategies (i.e. operable windows, fixed shading, reduced WWR). This highlights that for a level of true resiliency the design needs to be an integrated design with passive and active cooling strategies.

SENSITIVITY STUDY ANALYSIS

Throughout the Sensitivity Study conducted similarities have been identified with how High- and Low-Rise buildings handle “shock events” during future weather conditions. A couple key takeaways of this Sensitivity Study are as follows:

- Passive building design strategies work well in mitigating overheating, especially operable windows. It should be noted that the use of operable windows will not be possible during fire events, and that consideration to heat island effect and the impact on “free cooling” in more dense urban environments.
- Reliance on a Zero Emission Option with full cooling does not mean resiliency for all “shock events”, as there is significant overheating when there is a power outage through the summer months when the design has not considered any passive cooling strategies.

The passive building strategies on the three scenarios in the Sensitivity Study all play a role in providing the High- and Low-Rise residential buildings with resiliency when it comes occupant thermal comfort in future climate conditions. The analysis shows that the most important passive strategy is operable windows (when possible). The windows allow the occupants to open during desirable temperature ranges, in order to provide free-cooling, which in the event of high internal heat gains, or a power outage were the main factors that Zero Emission Option 1a (High- and Low-Rise) was able to maintain a reasonable number of overheating hours. However, during the Smoke Event the inability to open the window provided challenges for the partially cooled Zero Emission Option. Another consideration when it comes to operable windows should be the Urban Heat Island effect, which is likely to negatively impact the amount of “free cooling” hours in an urban environment.

Providing a fully cooled building does meet overheating metrics with some of the “shock events” (smoke events, high internal heat gains), however full cooling falls short when it comes to a power outage. The big takeaway with the Zero Emission Options that provided full cooling (3 through 8), was that no passive building design strategies were implemented. The impacts of this approach during a power outage for both the High- and Low-Rise buildings were substantial when it relates to the overall resiliency and occupant thermal comfort of this system option. Therefore, consideration to passive cooling strategies, such as operable windows should be considered with fully cooled buildings.

With the findings of this study, any developer or building stakeholder could potentially provide a building which provides resiliency for future weather, and the “shock events” identified in this study, however these solutions will come with an increased capital cost. The level of building resiliency will need to be considered at the early stages of design, and solutions such as fixed shading, and WWR will require the Architect to design these features into the building façade.

Another solution, that will have less effect on upfront capital costs, is the potential of “future-proofing” the building. A couple examples could be providing exterior wall penetrations at each suite for the installation of a PTAC unit, or providing an allowable area on suite patios for future installation of mini-split air conditioning unit. These two examples are potential low-cost solutions if building stakeholders or developers are looking for ways to provide resiliency without the upfront capital costs. These options will have Architectural considerations whether it is thermal bridging implications of penetrations or screening for the future condensing units located on the patios.

CONCLUSION

Part 2 has reviewed the Zero Emission Options for both the High- and Low-Rise residential building archetypes, as outlined and developed in Part 1. These Zero Emission Options were studied in respect to thermal comfort and resiliency on how they would react to future 2050 weather conditions, a 20-hour overheating limitation, and the impact of certain “shock events”.

While the full mechanical cooling Zero Emission Options 3 through 8 displayed no issues achieving the more stringent overheating limitations of 20-hours, the Heating and Passive cooling Zero Emission Options 1, 2 and 9 (Low-Rise only) for both building archetypes, were unable to reach this target and were therefore modified in order to achieve this target. The result of the modifications allowed for a partially cooled Zero Emission Option 1a to achieve the 20-hour overheating limitation, while providing a capital cost friendly solution, rather than going to a full mechanical cooling option. This study highlighted the benefits of the passive building design strategies to the occupant thermal comfort, although alone these strategies are unable to achieve the more stringent overheating limitations using the future 2050 weather file.

In the “shock event” study, three (3) scenarios were analyzed while using the future 2050 weather file: Smoke Events, High Internal Heat Gains, and Loss of Power. Zero Emission Options 3 through 8 typically were able to maintain thermal comfort in the “shock events” which allowed the system to operate, however when there was a loss of power, these options without being provided with passive building strategies saw a significant increase in the number of overheating hours in a two-week span. Zero Emission Option 1a, with its passive building design strategies implemented was able to reduce the amount of overheating hours throughout these shock events, however, showed some difficulty when there was an inability to utilize the operable windows in the Smoke Event scenario. Through this study, it was highlighted again, that passive building design strategies played a large role in reducing the impacts to the occupant thermal comfort and overheating limitations.

In the next part of the report, the full mechanical cooling Baseline 2 and Zero Emission Options 3 through 8, for both the High- and Low-Rise residential building archetypes are analyzed to review the potential of implementing a Cooling Energy Demand Intensity (CEDI) target, and what implications this performance metric may have on the building design strategies.

PART 3

CLIMATE RESILIENCE - COOLING DEMAND

INTRODUCTION

Part 3 of the report analyzes the full mechanical cooling Baseline and Zero Emission Options, for both the High- and Low-Rise residential building archetypes, to review the potential of implementing a Cooling Energy Demand Intensity (CEDI) performance targets. Under consideration are setting these CEDI targets that match Step Code 3 or 4 TEDI equivalent as outlined in Table 3.1. In addition, the study will review a High-Rise Office building and the potential of implementing a CEDI target. The target used for this study has been selected to meet the VBBL Office occupancies TEDI performance target. For the three archetypes the study will review building design implications in setting and meeting these CEDI performance targets to further understand the potential effects this may have on the overall building.

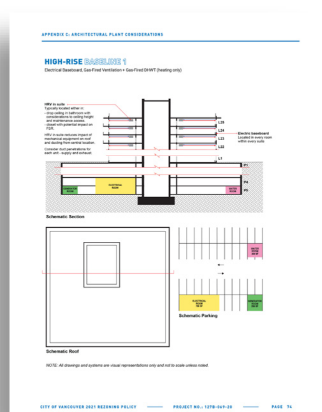
Building Archetype	Step Code	TEDI (kWh/m²/yr)	CEDI (kWh/m²/yr)
High-Rise Residential	3	30	30
Low-Rise Residential	4	15	15
High-Rise Office	N/A	30	30

Table 3.1: CEDI Performance Targets for Part 3

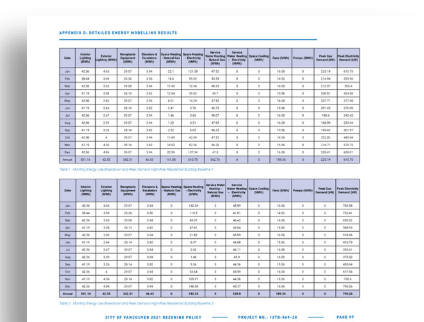
CEDI performance targets have not yet been introduced by Municipalities or the BC Building Code, but these performance metrics will become more prominent with increasing design temperatures and a need to meet occupant's thermal comfort with energy efficient design solutions.

Part 3 studies the impacts of these potential CEDI targets, for the current weather files (2016 CWEC) as well as the future 2050 weather files to outline considerations in the next steps in responding to changing climate within the local building archetypes.

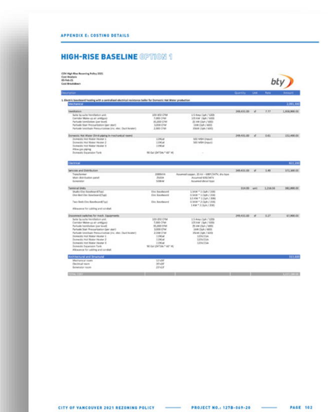
APPENDIX C



APPENDIX D



APPENDIX E



The noted appendices are to be read in conjunction with Part 3, these appendices provide Zero Emission Options infographics, energy modelling results and detailed costing breakdowns.

METHODOLOGY

Part 3 takes the High- and Low-Rise residential building archetypes and analyzes how these buildings perform against the CEDI targets that match the Step Code TEDI performance targets. The High-Rise residential building has been analyzed against a CEDI target of 30 kWh/m²/yr, which aligns with a Step Code 3 TEDI target. The Low-Rise residential building was analyzed against a CEDI target of 15 kWh/m²/yr, which aligns with a Step Code 4 TEDI target. Both the High- and Low-Rise residential building archetypes were modelled using the mechanically cooled Zero Emission Options (Baseline 2, and Zero Emission Options 3 through 8). Part 3 of the study also examines a High-Rise Office building, using a CEDI target that matches the Vancouver Building By-Law (VBBL) Office Occupancies TEDI target of 30 kWh/m²/yr.

No modifications to either the High- or Low-Rise residential building archetypes were made to the overall building designs and any passive building design strategies from Part 1 of this report. As such, these findings can be correlated to the associated costs and energy performances from Part 1 and summarized in **Appendix B – Mechanical Options**.

The High-Rise Office building with a fully mechanically cooled system was analyzed against a CEDI target of 30 kWh/m²/yr, which aligns with the VBBL Office Occupancies TEDI target. The High-Rise Office building has 25-storeys with five (5) levels of below-grade parking, and the building envelope values used are identified in Table 3.2 below, with additional details outlined in **Appendix A – Energy Modelling Inputs**.

Through this analysis, both current (2016 CWEC) and future 2050 weather files were utilized, to review how policies or decisions made today may affect future buildings. Similar to Part 2 of this report, the future 2050 weather files used were the RCP-8.5 2050 average weather file from the PCIC.

High-Rise Office Building Envelope	
Overall Roof R-Value (˚F·ft²/BTU/hr)	R-40
Overall Exterior Opaque Wall R-Value (˚F·ft²/BTU/hr)	R-9
Floor R-Value (˚F·ft²/BTU/hr)	R-15
Window-to-Wall Ratio	60%
Overall Window U-Valye & SHGC (BTU/hr/˚F·ft²)	U-0.33, SHGC – 0.25
Infiltration Rate (L/s/m² of façade)	0.2

Table 3.2: High-Rise Office Building Envelope Values

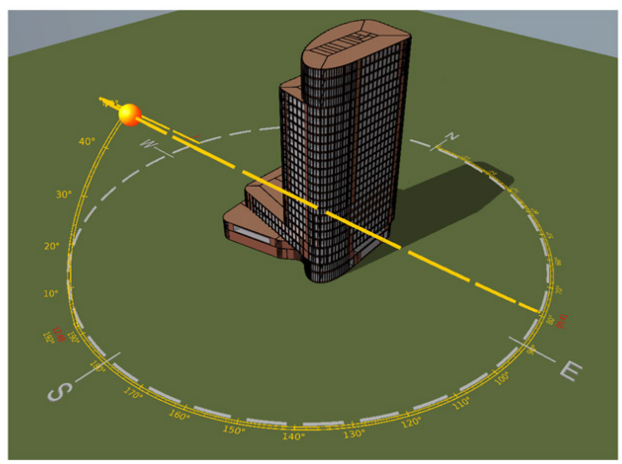


Figure 3.1: High-Rise Office Building

HIGH-RISE RESIDENTIAL BUILDING ANALYSIS

The High-Rise residential building mechanically cooled Baseline 2 and Zero Emission Options 3 through 8 are able to achieve the CEDI performance target without any modifications to the original building design, which had a 46% WWR, fixed windows and standard shading from balcony overhangs, for both the current and future weather files. The performance for both weather files (current and future) are considerably lower than the CEDI target of 30 kWh/m²/yr target (Table 3.3).

The CEDI performance can be further reduced by implementing operable shading. During the analysis a 100% operable shading option was implemented and the result is a CEDI performance of 16.8 kWh/m²/yr under the 2050 future weather file, as shown in Table 3.3. In current modelling practice, NECB 2015 does not allow for manually operated devices such as shading, and the CoV Modelling Guideline does not provide a detailed methodology on modelling operable shading. For this analysis, it was assumed that when the solar power density is below 150 W/m², the operable shading is not utilized (i.e., 0%). When the solar power density is above 300 W/m², the operable shading is fully utilized (i.e., 100%), and when the solar power density falls between 150 to 300 W/m², the operable shading usage is linearly interpolated. This modelling approach allows for solar gains in the winter while reducing solar gains on hot summer days, however, real-world performance of operable shading will vary based on occupant behaviour.

Energy Modelling Scenario	2016-CEDI (kWh/m²/yr)	2050 CEDI (kWh/m²/yr)
46% WWR, Standard Shading	13.8	22.3
30% WWR, Enhanced Shading	11.2	18.9
46% WWR, 100% Operable Shading	N/A	16.8

Table 3.3: CEDI Performance for the High-Rise Residential Building

A second modelling scenario was analyzed to understand how CEDI performance is affected by the enhanced shading strategies such as those used in the Passively Cooled Baseline 1 and Zero Emission Options 1 & 2 (which consists of lower WWR and fixed shading). These strategies are shown to further decrease CEDI values under current and future weather as shown in Table 3.3 (identified as the "30% WWR, Enhanced Shading" scenario). While this option may seem less desirable from a developer or building owner standpoint due to the reduced WWR, this analysis shows that passive strategies can reduce the CEDI performance for today's and future climate.

Based on the above analysis, it can be concluded that a CEDI target of 30kWh/m²/yr is achievable for High-Rise Residential building archetypes. This CEDI target maintains a reasonable degree of flexibility for building stakeholders and design teams for certain designs elements such as façade, WWR and shading (operable or fixed).

According to the 'UBC – Building Design Strategies for Future Climate' [7] report, in the 2080s time frame there will be further increase in energy demand for cooling systems due to the continual increase of global temperatures. Based on the findings in this report, it can be assumed that the building envelope components identified (Wall R-Value and Airtightness) along with additional passive building design strategies (reduction of WWR, fixed or operable shading, or operable windows) will continue to support the reduction of the overall building cooling energy demand and provide additional resilience to the building stock.

[7] https://sustain.ubc.ca/sites/default/files/Designing%20Future%20Climate_Nov%202020-small.pdf

LOW-RISE RESIDENTIAL BUILDING ANALYSIS

The Low-Rise residential building mechanically cooled Baseline 2 and Zero Emission Options 3 through 8 are able to achieve the CEDI performance target of 15 kWh/m²/yr without any modifications to the original building design under the current weather file (2016 CWEC). However they are unable to meet the CEDI performance target (Table 3.4) for the future weather file unless further passive cooling strategies are taken.

A second modelling scenario was analyzed using the enhanced shading strategies taken in the passively cooled Baseline 1 and Zero Emission Options 1, 2 & 9, which includes a lower WWR, fixed shading and operable windows. These passive building design options are shown to reduce CEDI performance under current and future weather conditions, however, the CEDI performance target still could not be met for the future 2050 weather file.

Further analysis was completed to identify which measures would be required to achieve the CEDI performance target of 15 kWh/m²/yr under the 2050 future climate. The combination of lower SHGC windows and 100% operable shading are necessary for the low-rise residential building to achieve the CEDI performance target (Table 3.4). The operable shading modelling methodology is outlined in the High-Rise Residential Analysis section.

Energy Modelling Scenario	2016 CEDI (kWh/m²/yr)	2050 CEDI (kWh/m²/yr)
35% WWR, Standard Shading	14	21.8
30% WWR, Enhanced Shading	13.2	20.6
35% WWR, 100% Operable Shading	N/A	16.8
35% WWR, 100% Operable Shading, Lower SHGC from 0.30 to 0.20	N/A	15.0

Table 3.4: CEDI Performance for the Low-Rise Residential Building

Based on the above modelling analysis, it can be concluded that a CEDI target of 15 kWh/m²/yr for the Low-Rise Residential building archetypes may be too aggressive when future weather conditions are considered. The results show that under the current weather files, all three (3) iterations of the model can meet the performance target, however as future climate files are analyzed it can be seen that the CEDI target is not met.

Low-Rise residential buildings built to either the Vancouver Building By-law or BC Energy Step Code, have higher performance walls and lower airtightness requirements when compared to its High-Rise counterpart. These two building envelope aspects appear to have major impacts on the CEDI performance of the building. In Vancouver, there is significant time in which the interior spaces are warmer than the outside air conditions. In these conditions higher wall insulation values combined with a more airtight envelope negatively affects CEDI performance, because the building retains warm interior temperatures and does not allow heat to escape through conduction or air leakage to the outdoors.

While the higher wall performance and reduced infiltration rates reduces the overall building TEDI, these factors increase the CEDI performance. A balance between TEDI and CEDI performance will need to be considered as a part of future building designs if a CEDI performance target is implemented through policy or building code.

According to the 'UBC – Building Design Strategies for Future Climate' report, in the 2080s timeframe there will be further increases in energy demand for cooling systems due to the continual increase of global temperatures. For Low-Rise residential buildings, in order to further reduce the CEDI performance in future climate conditions, a mix of passive building design strategies (reduction of WWR, fixed or operable shading, operable windows, lower wall performance, less airtight construction) as well as some potential building operations strategies (nighttime air flushing, heat recovery ventilator by-pass) may be required to achieve performance targets.

HIGH-RISE OFFICE BUILDING ANALYSIS

The High-Rise Office Building was modelled with a typical low-carbon mechanically cooled system option, which consists of a high-efficiency heat recovery chiller, and cooling tower, refer to **Appendix A – Energy Modelling** Inputs for additional details. This High-Rise Office archetype is adapted from a current office tower that is in the design stage and consists of a high-performance building envelope (walls and windows), high WWR, and no passive design strategies such as fixed or operable shading. It should be noted that the modelled building has a district energy system providing heating, which will not impact CEDI performance. The focus of the analysis is on the building envelope design and looking at the resiliency of a typical High-Rise Office archetype to achieve a CEDI performance target of 30 kWh/m²/yr (based on the VBBL target prior to June 2021). Modelling results show that the Office Building is able to achieve the CEDI performance target under the current weather conditions but is unable to achieve this target using the future 2050 weather file, as shown in Table 3.5 below.

	TEUI (kWh/m²/yr)	TEDI (kWh/m²/yr)	CEDI (kWh/m²/yr)
VBBL Office Occupancies Targets (Prior to June 2021)	130	30	N/A
BC Energy Step Code (Step 3 Target)	100	20	N/A
Proposed Design (2016 Weather File)	87	15	27
Proposed Design (2050 Weather File)	87	11	35
Proposed Design with Electrochromic Glass (2050 Weather File)	84.7	14	28.4

Table 3.5: Energy Performance Compared to VBBL and BC Energy Step Code

A third energy model was run with the addition of Electrochromic Glass to determine whether the building can meet the CEDI performance target under 2050 future weather conditions. Electrochromic glass is an emerging technology that is tintable through the use of low-voltage power. This allows the glazing to transition from a clear and opaque surface to tinted in order to reduce the amount of solar heat gain into the building.

The TEDI performance of the proposed design meets both the VBBL and the BC Energy Step code targets; this would suggest that the building envelope performance could be reviewed and modified in order to assist reducing the CEDI target. While these changes in the building envelope may assist in reducing the CEDI performance to achieve the targets using today's weather files, these changes alone will likely not be able to reduce the overall performance to provide a level of resilience for the future 2050 weather without incorporating further measures. Analysis with further building envelope revisions, alongside passive building design strategies (i.e. reduced WWR, fixed shading) were not completed as a part of this report.

ANALYSIS

Part 3 analysis evaluates the CEDI performance of fully mechanically cooled Baseline and Zero Emission Options to understand the design implications of implementing CEDI performance targets that match TEDI targets for three (3) building archetypes; High-Rise Residential, Low-Rise Residential, and High-Rise Office Building. As CEDI performance targets have not been introduced by Municipalities or the BC Building Code, the aim of Part 3 is to assist policy makers and stakeholders in determining the feasibility of CEDI performance targets and provide some insight on the resiliency in respect to the future 2050 weather conditions.

The High-Rise residential building analysis shows that the current design strategies for all Zero Emission Options from Part 1 are able to achieve the CEDI performance target of 30 kWh/m²/yr, which matches the Step Code 3 TEDI target, for both current and future 2050 weather files. This shows that this CEDI target may be too lenient or that the building modelled during this report had an overall suitable design approach that balances the TEDI and CEDI performances while not having major impacts on the overall building design.

The Low-Rise residential building analysis shows that current design strategies for the mechanically cooled Baseline 2 and Zero Emissions Options 3-8 was just able to achieve a CEDI performance target of 15 kWh/m²/yr, which matches the Step 4 TEDI target, for the current weather conditions but not for future weather. After making further modifications to the overall building design (reducing WWR, including operable shading and lower SHGC windows) the building model was able to meet the CEDI target under the future weather conditions.

In reviewing the High-Rise and Low-Rise Residential Building results, the key role of the building envelope insulation and airtightness in overall energy performance can be seen. Designing highly efficient buildings with a focus on reducing the overall heating demand (TEDI) can result in making CEDI performance targets more challenging to achieve. The high-performing building envelope and an increase in the airtightness of the building to achieve TEDI targets appears to negatively affect the CEDI performance. These building elements make the transfer of the interior heat gains to the exterior more difficult as the rate of heat transfer (conduction) through the wall is reduced due to the added insulation, and air leakage is reduced through a more airtight envelope system.

The High-Rise office building model was able to achieve a CEDI performance target of 30 kWh/m²/yr using the current weather files but the target cannot be achieved under future weather conditions. Further to this, the High-Rise office building was unable to achieve a CEDI performance target of 20 kWh/m²/yr under current or future weather conditions. Additional analysis indicates that in addition to the building envelope insulation values and airtightness, the performance of the glazing system is likely another significant factor in the CEDI performance of a building. Typically, High-Rise office buildings utilize a curtain wall system to allow for the higher WWR desired for this archetype, however this system typically uses windows with lower performance than those windows used in the residential building archetypes. This means that more heat is being introduced to the interior spaces through solar transmission. Due to the lower performing glazing system, the use of a passive building strategy such as fixed shading is likely to provide a reduction in the CEDI, without having to review the overall building design that may include reduction to WWRs.

INTERPRETATION/FUTURE QUESTIONS

Key takeaways from Part 3:

- Setting a CEDI target that matches the building archetype's TEDI performance target is suitable in some instances, however for the Low-Rise residential building this appears to be too aggressive.
- Designing buildings for today's weather conditions does not necessarily create resiliency or lower CEDI performance in future weather conditions.

The analysis suggests that using a BC Energy Step Code TEDI equivalent for a CEDI performance target may be reasonable for a High-Rise residential building archetype, however this would be too aggressive for the Low-Rise residential building and High-Rise office buildings when looking at building resiliency and utilizing future weather files.

The TEDI performance targets introduced into Building Codes and Policies have prioritized the need of reducing heating energy being consumed, which has prompted the industry to shift towards electrification and zero emission solutions and away from greenhouse gas emitting energy sources. The implementation of a CEDI performance target, especially if evaluated under future climate conditions, will likely create a shift in the industry's design approaches to one that is more holistic and looks at creating a balance between the TEDI and CEDI performance rather than outweighing one metric over the other. This balanced design approach would need to evaluate high-performance building envelope, airtightness, WWR's, and external shading (fixed or operable) with both of these performance metrics in mind.

If cooling demands are not addressed through Building Codes or Policies there may be significant impacts on existing electrical infrastructure, which may result in significant changes to the delivery of electricity, by means of load shedding (rolling blackouts), utility rate restructuring (i.e. time-of-use rates) or some other means implemented by BC Hydro or other local utility companies.

OVERALL STUDY CONCLUSION

STUDY CONCLUSION

The three (3) parts of the CoV Rezoning Policy Study reviewed Zero Emission heating and hot water solutions, these options were then studied for how they perform in terms of thermal comfort and resiliency, and how the building archetypes performed against potential CEDI performance targets.

Part 1 of this study presented various Zero Emission Options heating and hot water solutions for High- and Low-Rise residential building archetypes, all of which will achieve the current Policy and Building Code energy and GHGI performance targets as well was the overheating limitations. There are numerous ways to achieve a suitable Zero Emission Option for buildings, the options provided as a part of this study highlighted some of the most common solutions using the current technologies available, while considering overall design implications and building ownership.

Part 2 continued investigations of the Zero Emission Options developed in Part 1 to study the impact of occupant thermal comfort while using the 2050 future climate data. In the second section of Part 2 occupant thermal comfort was analyzed under the same weather files during three (3) different types of "shock events".

Part 3 studied the impacts of the residential building archetypes and how they performed against a CEDI performance target, based on TEDI (heating demand) targets currently implemented Policy or Building Code. Further to the review of the High- and Low-Rise residential building archetypes, a High-Rise office building was also studied in Part 3.

Throughout this study some main factors were identified that provided different successes and shortfalls, however, there appear to be some interrelated themes that happen to appear throughout. The main successful factors that show up throughout the three (3) Parts are: passive building design strategies, high-performance building envelope and airtightness, and mechanical cooling.

These main factors are connected throughout the three (3) Parts of the CoV Rezoning Policy Options Study. From Part 1, the passive building design strategies along with the high-performance building envelope, allowed the development of Heating and Passive cooling Zero Emission Options that follow current Policy and Building Code performance targets and overheating limitations. In this instance, the utilization of passive building design strategies and the high-performing building envelope reduced the heating demand and assisted in providing the thermal comfort required under today’s climate conditions.

In Part 2, as the focus of these studies were based around occupant thermal comfort, here it was determined that in order to meet the 20-hour overheating limitations while using future 2050 weather files, that some means of mechanically cooling will be required. The passive building design strategies (i.e. reduced WWR, fixed shading and operable windows), influenced the amount of mechanical cooling required to meet the 20-hour overheating limitations. It was found that a partial cooling Zero Emission Option, achieved the overheating limitations, while providing a capital cost friendly approach to introduce mechanical cooling to the building. These factors continued through the second part of the analysis for Part 2, “shock events”. The “shock events” added stressors to the building archetypes, and Zero Emission Options (partially and fully cooled), to analyze their resiliency. Through this part of the study, it was found that passive building designs alleviated some of the strains produced by the three (3) “shock events”, while the type of Zero Emission Option aided in providing the occupant thermal comfort.

Part 3 concentrates on the potential implementation of a CEDI performance target, which is the measurement of the annual cooling energy needed to maintain the building’s interior temperatures. As such, the passive building design strategies and the high-performance building envelope and airtightness played a large role. To this point of the report, the building archetypes were designed with the current Policy and Building Code requirements, which focus on reducing the TEDI performance. The passive building design strategies, assisted in reducing the CEDI performance, but those alone will not achieve these performance targets.

It was found that some of these high-performing building envelope and airtightness practices add some challenges in achieving the CEDI performance targets. By creating a well-insulated, airtight building, which assists in reducing TEDI performance by utilizing these passive heat gains to offset heating demand, appears to also negatively affect the CEDI performance for these exact reasons.

In order to create a Zero Emission building, that encourages occupant thermal comfort, overall building resiliency and the potential introduction of a CEDI performance metric, the building design will need to take a more holistic approach at evaluating these main factors to provide the proper solution for the project. This report provides numerous considerations and factors, which can be used to aid in making specific design decisions to achieve project goals.

APPENDIX A

ENERGY MODELLING INPUTS

HIGH-RISE RESIDENTIAL BUILDING PART 1

STATIC INPUTS: ELECTRICAL INPUTS AND INTERNAL LOADS

Lighting Power Density (LPD) (W/m²):	Residential Suites: 5, as per CoV Modelling Guidelines
	All other spaces: NECB 2015 by space type
Plug Loads (W/m²):	Residential Suites: 5, as per CoV Modelling Guidelines
	All other spaces: NECB 2015 by space type
Occupancy:	2 people for the 1st bedroom, 1 additional person for each bedroom thereafter. Studios assumed one person per unit.
	Other spaces: NECB 2015 Table A-8.4.3.2.(2)-B Space Type.
Operating Schedules:	Residential: NECB G
	Parking Garage lighting on continuously, fans 4 hours /day
	Corridor lighting on continuously
	Residential suite exhaust fans: 2 hour/day, as per CoV modelling guidelines 2.6.4
Fan Power:	HRV: supply fan 0.6 W/CFM, return fan 0.55 W/CFM
	Fancoil: 0.30 W/CFM
	Suite exhaust: 0.15 W/CFM
Ventilation Rate:	Per ASHRAE 62-2001 except addendum N:
	Residential suites: 0.35 ACH but no less than 15 CFM/person
	Lobbies: 0.45 CFM/ft²
	Storage: 0.15 CFM/ft²
	Vestibules: 0.77 CFM/ft² per vestibule at parking levels
	Parkade exhaust: 0.75 CFM/ft², as per BCBC 6.3.1.4
	Waste storage exhaust: 1.0 CFM/ft²
	Corridors: 15 CFM/door pressurization
	Residential suites exhaust 150 CFM/suite

GENERAL INPUTS

Modelling Software	IES VE 2018.2.0
Energy Modelling Guidelines	City of Vancouver Modelling Guidelines V2.0; NECB 2015
Modelled floor area	22,636 m²
Climate Zone	Climate Zone 4 as per NECB 2015
Weather File	CAN_BC_Vancouver.Intl.AP.718920_CWEC2016.epw
Utility costs	Electricity rate $0.117/kWh; Natural gas $0.0391/kWh
Emission factors	Electricity 0.011 kgCO₂e/kWh; Natural gas 0.185 kgCO₂e/kWh

DYNAMIC INPUTS: ENVELOPE PERFORMANCE AND MECHANICAL INPUTS

Part 1 Study: Passive Cooling Options (i.e., Baseline 1, Option 1, 2)	
Walls effective R-value (h·ft².°F/btu):	R-5
WWR:	30%
Shading Strategy:	Enhanced shading (Fixed exterior shading)
Windows:	Operable windows
Roof effective R-value (h·ft².°F/btu):	R-20
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.30, SHGC 0.32, double glazing
	U-0.34, SHGC 0.27, double glazing
Airtightness:	0.2 L/s/m² of façade
DHW savings:	20%
HRV effectiveness:	85% sensible

Part 1 Study: With Mechanical Cooling Options (i.e., Baseline 2, Zero Emission Options 3, 4, 5, 6, 7, 8)	
Walls effective R-value (h·ft².°F/btu):	R-4.5
WWR:	46%
Shading Strategy:	Standard shading (Balcony overhangs)
Windows:	Fixed Windows (Windows were modelled to be closed throughout this Report)
Roof effective R-value (h·ft².°F/btu):	R-20
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.30, SHGC 0.32, double glazing
Airtightness:	0.2 L/s/m² of façade
DHW savings:	20%
HRV effectiveness:	85% sensible

LOW-RISE RESIDENTIAL BUILDING PART 1

STATIC INPUTS: ELECTRICAL INPUTS AND INTERNAL LOADS

Lighting Power Density (LPD) (W/m²):	Residential Suites: 5, as per CoV Modelling Guidelines
	All other spaces: NECB 2015 by space type
Plug Loads (W/m²):	Residential Suites: 5, as per CoV Modelling Guidelines
	All other spaces: NECB 2015 by space type
Occupancy:	2 people for the 1st bedroom, 1 additional person for each bedroom thereafter. Studios assumed one person per unit.
Other Spaces:	NECB 2015 Table A-8.4.3.2.(2)-B Space Type.
Operating Schedules:	Residential: NECB G
	Parking Garage lighting on continuously, fans 4 hours /day
	Corridor lighting on continuously
	Residential suite exhaust fans: 2 hour/day, as per CoV modelling guidelines 2.6.4
Fan Power:	HRV: supply fan 0.6 W/CFM, return fan 0.55 W/CFM
	Fancoil: 0.30 W/CFM
	Suite exhaust: 0.15 W/CFM
Ventilation Rate:	Per ASHRAE 62-2001 except addendum N:
	Residential suites: 0.35 ACH but no less than 15 CFM/person
	Corridors: 15 CFM/door pressurization
	Lobbies: 0.45 CFM/ft²
	Storage: 0.15 CFM/ft²
	Vestibules: 0.77 CFM/ft² per vestibule at parking levels
	Parkade exhaust: 0.75 CFM/ft², as per BCBC 6.3.1.4
	Waste storage exhaust: 1.0 CFM/ft²
	Residential suites exhaust 150 CFM/suite

GENERAL INPUTS

Modelling Software	IES VE 2018.2.0
Energy Modelling Guidelines	City of Vancouver Modelling Guidelines V2.0; NECB 2015
Modelled floor area	10,308 m²
Climate Zone	Climate Zone 4 as per NECB 2015
Weather File	CAN_BC_Vancouver.Intl.AP.718920_CWEC2016.epw
Utility costs	Electricity rate $0.117/kWh; Natural gas $0.0391/kWh
Emission factors	Electricity 0.011 $kgCO_2e$/kWh; Natural gas 0.185 $kgCO_2e$/kWh

DYNAMIC INPUTS: ENVELOPE PERFORMANCE AND MECHANICAL INPUTS

Part 1 Study: Passive Cooling Options (i.e., Baseline 1, Zero Emission Options 1, 2 & 9)	
Walls effective R-value (h·ft².°F/btu):	R-13
WWR:	30%
Shading Strategy:	Enhanced shading (Fixed exterior shading)
Windows:	Operable windows
Roof effective R-value (h·ft².°F/btu):	R-40
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.27, SHGC 0.30, double glazing
	U-0.29, SHGC 0.30, double glazing
Airtightness:	0.1 L/s/m² of façade
DHW savings:	30%
HRV effectiveness:	85% sensible

Part 1 Study: With Mechanical Cooling Options (i.e., Baseline 2, Zero Emission Options 3, 4, 5, 6, 7, 8)	
Walls effective R-value (h·ft².°F/btu):	R-15
WWR:	35%
Shading Strategy:	Standard shading (Balcony overhangs)
Windows:	Fixed Windows (Windows were modelled to be closed throughout this Report)
Roof effective R-value (h·ft².°F/btu):	R-40
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.27, SHGC 0.30, double glazing
Airtightness:	0.1 L/s/m² of façade
DHW savings:	30%
HRV effectiveness:	85% sensible

HIGH-RISE RESIDENTIAL BUILDING PART 2

DYNAMIC INPUTS: ENVELOPE PERFORMANCE AND MECHANICAL INPUTS

Part 2 Study: Partial Cooling Options (i.e., Baseline 1, Zero Emission Options 1a)	
Walls effective R-value (h·ft².°F/btu):	R-5
WWR:	30%
Shading Strategy:	Enhanced shading (Fixed exterior shading)
Windows:	Operable windows, 20% operable area
Roof effective R-value (h·ft².°F/btu):	R-20
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.30, SHGC 0.32, double glazing
	U-0.34, SHGC 0.32, double glazing
Airtightness:	0.2 L/s/m² of façade
DHW savings:	20%
HRV effectiveness:	85% sensible
Partial cooling:	Cool OA to 12.8ºC, 10% fan boost

LOW-RISE RESIDENTIAL BUILDING PART 2

DYNAMIC INPUTS: ENVELOPE PERFORMANCE AND MECHANICAL INPUTS

Part 2 Study: Partial Cooling Options (i.e., Baseline 1, Zero Emission Options 1a)	
Walls effective R-value (h·ft².°F/btu):	R-13
WWR:	30%
Shading Strategy:	Enhanced shading (Fixed exterior shading)
Windows:	Operable windows, 20% operable area
Roof effective R-value (h·ft².°F/btu):	R-40
Floor to Parkade R-value (h·ft².°F/btu):	R-15
Window performance (btu/h ft².°F):	U-0.27, SHGC 0.30, double glazing
	U-0.29, SHGC 0.30, double glazing
Airtightness:	0.1 L/s/m² of façade
DHW savings:	30%
HRV effectiveness:	85% sensible
Partial cooling:	Cool OA to 12.8ºC, 15% fan boost

HIGH-RISE OFFICE BUILDING PART 3

STATIC INPUTS: ELECTRICAL INPUTS AND INTERNAL LOADS

Lighting Power Density (LPD) (W/sq.ft.)	Parkade: 0.14 W/ ft² Office: 0.79 W/ ft²
Plug Loads (W/sq.ft.)	Per NECB 2015 by space type
Occupancy	Per NECB 2015 by space type
Service Hot Water	4,117,452 litre/year With condenser heat recovery, only up to 50% of the load, with DES top up
Operating schedules	NECB 2011 Schedule A

GENERAL INPUTS

Modelling Software	IES VE 2018.2.0
Energy Modelling Guidelines	City of Vancouver Modelling Guidelines V2.0; NECB 2015
Modelled Floor Area	53,568 m^2
Climate Zone	Climate Zone 4 as per NECB 2015
Weather File	CAN_BC_Vancouver.Intl.AP.718920_CWEC2016.epw

DYNAMIC INPUTS: ENVELOPE PERFORMANCE AND MECHANICAL INPUTS

	Proposed Design
Overall Roof R-value (°F·ft²/btu/h)	R-40
Overall Exterior Opaque Wall R-value (°F·ft²/btu/h)	R-9
Floor R-value (ground floor and parkade) (°F·ft²/btu/h)	R-15
Window to Wall percentage (%)	60%
Overall Window U-value including frame (btu/h/°F·ft²) and Solar Heat Gain Coefficient (SHGC)	U-0.33, SHGC-0.25
Infiltration Rate (L/s/m^2 of façade)	0.2
Mechanical System	4-pipe fan coil High efficiency central HRV with 91.6% sensible effectiveness at winter conditions Heat recovery chillers, and DES connection for heating Cooling tower, 2 fans, 20 bhp per fan, VSD, water side economizer 300-ton heat recovery chiller, COP=4 500-ton SMARDT cooling chiller, rated COP=6.67 900-ton SMARDT cooling chiller, rated COP=6.67

APPENDIX B

MECHANICAL OPTIONS

HIGH-RISE BASELINE 1

Electric baseboard heating with gas-fired hot water production and corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Elec Baseboard	Elec Baseboard	479 kW Total
Ventilation		
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Make-up air unit (Gas-fired)	7,000 CFM	410 MBH [Input] (3ph / 600 - 10HP)
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (per stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 3 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (240 sq.ft.)	12'x20'	-
Outside Area Required	none	-

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Baseline 1	$212,204.95	$739.39	N/A	N/A	5.9

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	780
Equivalent parking spaces	5
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft)	N/A
Total Equivalent Parking Spaces	9

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2000
Main Distribution Panel (A)	2500
Elect Room Size	39' x 20' (780 sq.ft)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$2,161,300.00
Electrical Cost	$905,500.00
Building Cost (Arch & Struct)	$344,800.00
Total Cost	$3,411,600.00
Cost Relative to Baseline Option 1	-
Total Cost ($/sq.ft.)	$325.00

HIGH-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Elec Baseboard	Elec Baseboard	479 kW Total
Ventilation		
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up air unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (per stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (300 sq.ft.)	25'x12'x12' (LxWxH)	-
Outside Area Required	none	-

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 1	$256,136.69	$892.46	1%	-21%	1.2

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft)	300
Equivalent parking spaces	2
Electrical Room (sq.ft)	800
Equivalent parking spaces	5
Generator Room (sq.ft)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft)	N/A
Total Equivalent Parking Spaces	9

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft)

COST

Mechanical Cost	$2,148,500.00
Electrical Cost	$986,200.00
Building Cost (Arch & Struct)	$349,800.00
Total Cost	$3,484,500.00
Cost Relative to Baseline Option 1	$72,900.00
Total Cost ($/sq.ft.)	$325.32

HIGH-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 10% increase in airflow.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
DX Cool in Centralized HRV	65 Tons	600V, 142A MCA
Terminal Units		
Elec Baseboard	Elec Baseboard	479 kW Total
Ventilation		
Centralized HRV	13,300 CFM	208/3/60 - 55A MCA
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (300 sq.ft.)	25'x12'x12' (LxWxH)	-
Outside Area Required (800 sq.ft.)	40'x20' (LxW)	-

ENERGY PERFORMANCE (PARTIAL MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 1a	$223,293.63	$845.00	7%	14%	1.1

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	800
Equivalent parking spaces	5
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	800
Total Equivalent Parking Spaces	9

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$2,390,500.00
Electrical Cost	$974,700.00
Building Cost (Arch & Struct)	$569,800.00
Total Cost	$3,935,00.00
Cost Relative to Baseline Option 1	$523,400.00
Total Cost ($/sq.ft.)	$327.29

HIGH-RISE ZERO EMISSION OPTION 2

Electric baseboard heating with an Air-Source Heat Pump (ASHP) domestic hot water production system and electric resistance heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
DX Cool in Centralized HRV	65 Tons	600V, 142A MCA
Terminal Units		
Elec Baseboard	Elec Baseboard	479 kW Total
Ventilation		
Centralized HRV	13,300 CFM	208/3/60 - 55A MCA
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1	900 Gal	-
Domestic Hot Water Tank 2	900 Gal	-
Domestic Hot Water Tank 3	900 Gal	-
Domestic Hot Water Tank 4	900 Gal	-
Swing Tank	120 Gal	49 kW (3ph / 600)
Heat Pumps	NRK0600	62.2 kW (3ph / 460)
Water Room Size (300 sq.ft.)	25'x12'x12' (LxWxH)	-
Outside Area Required (800 sq.ft.)	40'x20' (LxW)	-

ENERGY PERFORMANCE (PARTIAL MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 2	$223,293.63	$778.03	15%	-5%	1.0

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	800
Equivalent parking spaces	5
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	800
Total Equivalent Parking Spaces	9

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft)

COST

Mechanical Cost	$2,301,400.00
Electrical Cost	$985,600.00
Building Cost (Arch & Struct)	$429,800.00
Total Cost	$3,716,800.00
Cost Relative to Baseline Option 1	$305,200.00
Total Cost ($/sq.ft.)	$326.33

HIGH-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	150 Tons & 1650MBH Htg	1@ 600/3/60 - 145A MCA, 1@ 600/3/60 - 275A MCA
Electrical Boiler (Back-up)	1,650 MBH Heating	479kW (3ph / 600)
Heating Distribution Pump 1	165 GPM (Duty)	15 HP (3ph / 600)
Heating Distribution Pump 2	165 GPM (Standby)	15 HP (3ph / 600)
Expansion Tank 1	-	-
Air Seperator 1	-	-
Chilled Distribution Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Chilled Distribution Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Expansion Tank 2	-	-
Air Seperator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Terminal Units		
Studio Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
One-Bed Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
Two-Beds Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Hydronic)	7,000 CFM	10HP (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 3 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (300 sq.ft.)	40'x20'x12' (LxWxH)	
Mechanical Room Size (500 sq.ft.)	12'x20'	-
Outside Area Required (1600 sq.ft.)	40'x40' (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	500
Equivalent parking spaces	3
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	800
Equivalent parking spaces	5
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	1600
Total Equivalent Parking Spaces	12

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft)

COST

Mechanical Cost	$6,401,500.00
Electrical Cost	$783,000.00
Building Cost (Arch & Struct)	$634,800.00
Total Cost	$7,891,300.00
Total Cost Relative to Baseline Option 2	-
Total Cost ($/sq.ft.)	$343.00

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Baseline 2	$207,520.20	$723.07	-	-	5.7

HIGH-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP Domestic hot water production system and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-source Heat Pump	150 Tons & 1650MBH Htg	1@ 600/3/60 - 145A MCA, 1@ 600/3/60 - 275A MCA
Electrical Boiler (Back-up)	1,650 MBH Heating	479 kW (3ph / 600)
Heating Distribution Pump 1	165 GPM (Duty)	15 HP (3ph / 600)
Heating Distribution Pump 2	165 GPM (Stanby)	15 HP (3ph / 600)
Expansion Tank 1	-	-
Air Seperator 1	-	-
Chilled Distribution Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Chilled Distribution Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Expansion Tank 2	-	-
Air Seperator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Terminal Units		
Studio Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
One-Bed Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
Two-Beds Fancoil Unit (Typ)	Fancoil Unit (Ducted)	1/12HP * 1 (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1	900 Gal	-
Domestic Hot Water Tank 2	900 Gal	-
Domestic Hot Water Tank 3	900 Gal	-
Domestic Hot Water Tank 4	900 Gal	-
Swing Tank	120 Gal	49 kW (3ph / 600)
Heat Pumps	NRK0600	62.2 kW (3ph / 460)
Water Room Size (300 sq.ft.)	40'x20'x12' (LxWxH)	-
Mechanical Room Size (500 sq.ft.)	20'x25'(LxW)	-
Outside Area Required (1600 sq.ft.)	40'x40' (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	500
Equivalent parking spaces	3
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	800
Equivalent parking spaces	5
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	1600
Total Equivalent Parking Spaces	12

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft)

COST

Mechanical Cost	$6,546,600.00
Electrical Cost	$827,200.00
Building Cost (Arch & Struct)	$634,800.00
Total Cost	$8,008,600.00
Total Cost Relative to Baseline Option 2	$189,300.00
Total Cost ($/sq.ft.)	$343.51

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Zero Emission Option 3	$210,150.32	$732.23	15%	-1%	1.0

HIGH-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	150 Tons & 1650MBH Htg	1@ 600/3/60 - 145A MCA, 1@ 600/3/60 - 275A MCA
Electrical Boiler (Full Back-up)-TBD	1,650 MBH Heating	479 kW (3ph / 600)
Heating Distribution Pump 1	165 GPM (Duty)	15 HP (3ph / 600)
Heating Distribution Pump 2	165 GPM (Stanby)	15 HP (3ph / 600)
Expansion Tank 1	-	-
Air Seperator 1	-	-
Chilled Distribution Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Chilled Distribution Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Expansion Tank 2	-	-
Air Seperator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Terminal Units		
Studio Fancoil Unit (Typ)	Fancoil unit(Ducted)	1/12HP * 1 (1ph / 120)
One-Bed Fancoil Unit (Typ)	Fancoil unit(Ducted)	1/12HP * 1 (1ph / 120)
Two-Beds Fancoil Unit (Typ)	Fancoil unit(Ducted)	1/12HP * 1 (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1	900 Gal	-
Domestic Hot Water Tank 2	900 Gal	-
Domestic Hot Water Tank 3	900 Gal	-
Domestic Hot Water Tank 4	900 Gal	-
Swing Tank	120 Gal	49 kW (3ph / 600)
Heat Pumps	NRL0750	60 kW (3ph / 460)
Water Room Size (300 sq.ft.)	45'x12'x12' (LxWxH)	-
Mechanical Room Size (550 sq.ft.)	35.5'x15'(LxW)	-
Outside Area Required (1600 sq.ft.)	40'x40' (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.) Equivalent parking spaces	550 4
Water Room (sq.ft.) Equivalent parking spaces	300 2
Electrical Room (sq.ft.) Equivalent parking spaces	800 5
Generator Room (sq.ft.) Equivalent parking spaces	299 2
Mech Outdoor Area (sq.ft.)	1600
Total Equivalent Parking Spaces	13

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	2500
Main Distribution Panel (A)	3000
Elect Room Size	40' x 20' (800 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$6,546,600.00
Electrical Cost	$787,200.00
Building Cost (Arch & Struct)	$657,300.00
Total Cost	$7,991,100.00
Total Cost Relative to Baseline Option 2	$171,800.00
Total Cost ($/sq.ft.)	$343.44

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 4	$217,373.77	$757.40	12%	-5%	1.0

HIGH-RISE ZERO EMISSION OPTION 5

Water-cooled variable refrigerant flow heating/cooling system (consisting of cooling tower and electric boilers) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
VRF Condensing Units	One Condensing Unit (Per Floor)	15.05 kW *28 (3ph / 208)
Electric Boiler	1,650 MBH Heating	479 kW (3ph / 600)
Cooling Tower	150 Tons	15 HP (3ph / 600)
Ambient Loop Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Ambient Loop Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Terminal Units		
Studio AC Unit (Typ)	Indoor AC Unit (Ducted)	0.09 kW * 1 (1ph / 208)
One-Bed AC Unit (Typ)	Indoor AC Unit (Ducted)	0.09 kW * 1 (1ph / 208)
Two-Beds AC Unit (Typ)	Indoor AC Unit (Ducted)	0.17 kW * 1 (1ph / 208)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (300 sq.ft.)	25'x12'x12' (LxWxH)	-
Mechanical Room Size (150 sq.ft.)	15'x10' (LxW)	-
Outside Area Required (800 sq.ft.)	40'x20' (LxW)	-

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Zero Emission Option 5	$269,810.74	$940.11	-11%	-30%	1.2

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	150
Equivalent parking spaces	1
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	840
Equivalent parking spaces	6
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	800
Total Equivalent Parking Spaces	11

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	3000
Main Distribution Panel (A)	4000
Elect Room Size	40' x 20' (800 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$5,701,300.00
Electrical Cost	$846,000.00
Building Cost (Arch & Struct)	$477,300.00
Total Cost	$7,025,400.00
Total Cost Relative to Baseline Option 2	($793,900.00)
Total Cost ($/sq.ft.)	$339.22

HIGH-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air Source Heat Pump	150 Tons & 1650MBH Htg	1@ 600/3/60 - 145A MCA, 1@ 600/3/60 - 275A MCA
Electrical Boiler (Full Back-up)	1,650 MBH Heating	479 kW (3ph / 600)
Buffer Tank	-	-
Air Seperator	-	-
Ambient Loop Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Ambient Loop Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Expansion Tank	-	-
Terminal Units		
Studio Heat Pump Unit (Typ)	Heat Pump Unit (Ducted)	1.1 kW * 1 (1ph / 208)
One-Bed Heat Pump Unit (Typ)	Heat Pump Unit (Ducted)	1.1 kW * 1 (1ph / 208)
Two-Beds Heat Pump Unit (Typ)	Heat Pump Unit (Ducted)	2.2 kW * 1 (1ph / 208)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Tank 1	750 Gal	-
Domestic Hot Water Tank 2	750 Gal	-
Domestic Hot Water Tank 3	750 Gal	-
Domestic Hot Water Tank 4	750 Gal	-
Swing Tank	120 Gal	49 kW (3ph / 600)
Heat Pumps (x10)	Nyle C540WM	200 Amps(LRA) (3ph / 600)
Domestic Expansion Tank	90 Gal (24”DIA * 60” H)	-
Water Room Size (350 sq.ft.)	29x12’x12’ (LxWxH)	-
Mechanical Room Size (250 sq.ft.)	25’x10’(LxW)	-
Outside Area Required (800 sq.ft.)	40’x20’ (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	250
Equivalent parking spaces	2
Water Room (sq.ft.)	350
Equivalent parking spaces	2
Electrical Room (sq.ft.)	840
Equivalent parking spaces	6
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	800
Total Equivalent Parking Spaces	12

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	3000
Main Distribution Panel (A)	4000
Elect Room Size	40’ x 20’ (800 sq.ft)
Generator Size (kW)	500
Generator Room Size	23’ x 13’ (299 sq.ft)

COST

Mechanical Cost	$5,672,000.00
Electrical Cost	$836,300.00
Building Cost (Arch & Struct)	$522,300.00
Total Cost	$7,030,600.00
Total Cost Relative to Baseline Option 2	($788,700.00)
Total Cost ($/sq.ft.)	$339.24

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Zero Emission Option 6	$228,893.67	$797.54	7%	-10%	1.0

HIGH-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	150 Tons & 1650MBH Htg	1@ 600/3/60 - 145A MCA, 1@ 600/3/60 - 275A MCA
Electrical Boiler	1,650 MBH Heating	479 kW (3ph / 600)
Boiler Pump 1	-	-
Boiler Pump 2	-	-
Heating Distribution Pump 1	165 GPM (Duty)	15 HP (3ph / 600)
Heating Distribution Pump 2	165 GPM (Standby)	15 HP (3ph / 600)
Expansion Tank 1	-	-
Air Separator 1	-	-
Chilled Distribution Pump 1	360 GPM (Duty)	20 HP (3ph / 600)
Chilled Distribution Pump 2	360 GPM (Standby)	20 HP (3ph / 600)
Expansion Tank 2	-	-
Air Separator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Mechanical Room Size	10'x40'	-
Outside Area Required	15'x28'	-
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 bed)	-	1/12HP (1ph / 120)
Fan Coils (2 bed)	-	1/6HP (1ph / 120)
Fan Coils (3 bed)	-	1/6HP (1ph / 120)
Fan Coils (4 bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	-
Domestic Hot Water Tank 2	119 Gal	-
Domestic Hot Water Tank 3	119 Gal	-
Domestic Hot Water Tank 4	119 Gal	-
Heat Exchanger	468 kW - 160 GPM	-
Domestic Expansion Tank	-	-
Circulator Pump	160 GPM	-
Water Room Size (252 sq.ft.)	9'x28' (LxW)	-
Mechanical Room Size (400 sq.ft.)	10'x40' (LxW)	-
Outside Area Required	none	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	400
Equivalent parking spaces	3
Water Room (sq.ft.)	252
Equivalent parking spaces	2
Electrical Room (sq.ft.)	840
Equivalent parking spaces	6
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	800
Total Equivalent Parking Spaces	13

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	3000
Main Distribution Panel (A)	4000
Elect Room Size	42' x 20' (840 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$6,309,100.00
Electrical Cost	$831,700.00
Building Cost (Arch & Struct)	$512,800.00
Total Cost	$7,653,600.00
Total Cost Relative to Baseline Option 2	($165,700.00)
Total Cost ($/sq.ft.)	$341.96

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 7	$207,352.19	$722.48	16%	0%	0.9

HIGH-RISE ZERO EMISSION OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Suite by Suite PTAC Unit	1 per suite	208/1/60 - 15A Circuit
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	7,000 CFM	105 kW (3ph / 600)
Parkade Ventilation (Per Level)	35,000 CFM	25 kW (3ph / 600)
Parkade Stair Pressurization (Per Stair)	3,000 CFM	1 kW (3ph / 600)
Parkade Vestibule Pressurization (inc. Elec. Duct Heater)	2,000 CFM	35 kW (3ph / 600)
Domestic Hot Water		
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-
Water Room Size (300 sq.ft.)	25'x12'x12' (LxWxH)	-
Outside Area Required	None	-

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 8	$242,656.42	$845.49	1%	-17%	1.1

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	300
Equivalent parking spaces	2
Electrical Room (sq.ft.)	840
Equivalent parking spaces	6
Generator Room (sq.ft.)	299
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	N/A
Total Equivalent Parking Spaces	10

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	3000
Main Distribution Panel (A)	4000
Elect Room Size	42' x 20' (840 sq.ft.)
Generator Size (kW)	500
Generator Room Size	23' x 13' (299 sq.ft.)

COST

Mechanical Cost	$4,797,800.00
Electrical Cost	$815,900.00
Building Cost (Arch & Struct)	$359,800.00
Total Cost	$5,973,500.00
Total Cost Relative to Baseline Option 2	($1,845,800.00)
Total Cost ($/sq.ft.)	$334.63

LOW-RISE BASELINE 1

Electric baseboard heating with gas-fired hot water production and corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Elec Baseboard	-	145 kW Total
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Gas-Fired)	2,000 CFM	120 MBH [Input] (3ph / 208 - 5 HP)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water (Gas-Fired)		
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Expansion Tank	-	-
Water Room Size (135 sq.ft.)	9'x15' (LxW)	-
Outside Area Required	none	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	135
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	N/A
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	750
Main Distribution Panel (A)	1000
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Baseline 1	$79,312.86	$714.53	-	-	5.0

COST

Mechanical Cost	$716,300.00
Electrical Cost	$369,800.00
Building Cost (Arch & Struct)	$252,300.00
Total Cost	$1,338,400.00
Total Cost Relative to Baseline Option 1	-
Total Cost ($/sq.ft.)	$302.00

LOW-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Elec Baseboard	-	145 kW Total
Ventilation		
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up air unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. elec. Duct heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Expansion Tank	-	-
Water Room Size (180 sq.ft.)	9'x20' (LxW)	-
Outside Area Required	none	-

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 1	$95,395.25	$859.42	3%	-20%	0.9

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	N/A
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1250
Main Distribution Panel (A)	1600
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$714,400.00
Electrical Cost	$417,100.00
Building Cost (Arch & Struct)	$263,500.00
Total Cost	$1,395,000.00
Total Cost Relative to Baseline Option 1	$56,600.00
Total Cost ($/sq.ft.)	$302.51

LOW-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 15% increase in airflow.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
DX Cool in Centralized HRV	30 Tons	575V, 70 MCA
Terminal Units		
Elec Baseboard	-	145 kW Total
Ventilation		
Centralized HRV	6,400 CFM	208/3/60 - 40A MCA
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Expansion Tank	-	-
Water Room Size (180 sq.ft.)	9'x20' (LxW)	-
Outside Area Required	25' x 15' (LxW) (375 sq.ft.)	-

ENERGY PERFORMANCE (PARTIAL MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 1a	$95,395.25	$859.42	3%	-20%	0.9

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	375 sq.ft.
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$759,100.00
Electrical Cost	$437,900.00
Building Cost (Arch & Struct)	$355,100.00
Total Cost	$1,552,100.00
Total Cost Relative to Baseline Option 1	$213,700.00
Total Cost ($/sq.ft.)	$303.93

LOW-RISE ZERO EMISSION OPTION 2

Electric baseboard heating with an ASHP domestic hot water production system and electric resistance heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Elec Baseboard	-	145 kW Total
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	-
Domestic Hot Water Tank 2	119 Gal	-
Domestic Hot Water Tank 3	119 Gal	-
Domestic Hot Water Tank 4	119 Gal	-
Domestic Expansion Tank	-	-
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)
Water Room Size (180 sq.ft.)	9'x20' (LxW)	-
Outside Area Required (375 sq.ft.)	25'x15' (LxW)	-

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 2	$82,685.93	$744.92	17%	-4%	0.8

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	375
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$1,181,300.00
Electrical Cost	$385,900.00
Building Cost (Arch & Struct)	$263,500.00
Total Cost	$1,830,700.00
Total Cost Relative to Baseline Option 1	$492,300.00
Total Cost ($/sq.ft.)	$306.44

LOW-RISE ZERO EMISSION OPTION 9

Electric baseboard heating with in-suite electrical resistance domestic hot water tank and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
DX Cool in Centralized HRV	30 Tons	
Terminal Units		
Elec Baseboard	-	145 kW Total
Ventilation		
Centralized HRV	6,400 CFM	208/3/60 - 40A MCA
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	20 Gal (each)	4 kW (each) (1ph / 208)
Domestic Expansion Tank	-	-
Water Room Size	none	-
Outside Area Required	none	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	0
Equivalent parking spaces	0
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	N/A
Total Equivalent Parking Spaces	6

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1250
Main Distribution Panel (A)	1600
Elect Room Size	34’ x 19’ (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19’ x 12’ (228 sq.ft.)

ENERGY PERFORMANCE (WITHOUT MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 9	$95,395.25	$859.42	3%	-20%	0.9

COST

Mechanical Cost	$611,800.00
Electrical Cost	$499,900.00
Building Cost (Arch & Struct)	$364,100.00
Total Cost	$1,475,800.00
Total Cost Relative to Baseline Option 1	$137,400.00
Total Cost ($/sq.ft.)	$303.24

LOW-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	50 Tons	575V, 145 MCA
Electrical Boiler	-	75 kW
Electrical Boiler	-	75 kW
Boiler Pump 1	-	-
Boiler Pump 2	-	-
Heating Distribution Pump 1	50 GPM	-
Heating Distribution Pump 2	50 GPM	-
Expansion Tank 1	-	-
Air Separator 1	-	-
Chilled Distribution Pump 1	40 GPM	-
Chilled Distribution Pump 2	40 GPM	-
Expansion Tank 2	-	-
Air Separator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Mechanical Room Size (400 sq.ft.)	10'x40' (LxW)	-
Outside Area Required (420 sq.ft.)	15'x28' (LxW)	-
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 Bed)	-	1/12HP (1ph / 120)
Fan Coils (2 Bed)	-	1/6HP (1ph / 120)
Fan Coils (3 Bed)	-	1/6HP (1ph / 120)
Fan Coils (4 Bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Hydronic)	2,000 CFM	5 HP (3ph / 208)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water (Gas-Fired)		
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)
Domestic Expansion Tank	-	-
Water Room (135 sq.ft.)	9'x15' (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	400
Equivalent parking spaces	3
Water Room (sq.ft.)	135
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	420
Total Equivalent Parking Spaces	10

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34' x 21.6' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$2,126,200.00
Electrical Cost	$355,200.00
Building Cost (Arch & Struct)	$394,300.00
Total Cost	$2,875,700.00
Total Cost Relative to Baseline Option 2	-
Total Cost ($/sq.ft.)	$317.00

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Baseline 2	$77,684.11	$699.86	-	-	4.7

LOW-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP domestic hot water production system and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	50 Tons	575V, 145 MCA
Electrical Boiler	-	75 kW
Electrical Boiler	-	75 kW
Boiler Pump 1	-	-
Boiler Pump 2	-	-
Heating Distribution Pump 1	50 GPM	-
Heating Distribution Pump 2	50 GPM	-
Expansion Tank 1	-	-
Air Separator 1	-	-
Chilled Distribution Pump 1	40 GPM	-
Chilled Distribution Pump 2	40 GPM	-
Expansion Tank 2	-	-
Air Separator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Mechanical Room Size (400 sq.ft.)	10’x40’ (LxW)	--
Outside Area Required (420 sq.ft.)	15’x28’ (LxW)	
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 Bed)	-	1/12HP (1ph / 120)
Fan Coils (2 Bed)	-	1/6HP (1ph / 120)
Fan Coils (3 Bed)	-	1/6HP (1ph / 120)
Fan Coils (4 Bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	-
Domestic Hot Water Tank 2	119 Gal	-
Domestic Hot Water Tank 3	119 Gal	-
Domestic Hot Water Tank 4	119 Gal	-
Domestic Expansion Tank	-	-
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)
Water Room (180 sq.ft.)	9’x20’ (LxW)	-
Outside Area Required (375 sq.ft.)	25’x15’ (LxW)	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	400
Equivalent parking spaces	3
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	795
Total Equivalent Parking Spaces	10

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34’ x 21.6’ (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19’ x 12’ (228 sq.ft.)

COST

Mechanical Cost	$2,600,700.00
Electrical Cost	$362,300.00
Building Cost (Arch & Struct)	$443,000.00
Total Cost	$3,406,000.00
Total Cost Relative to Baseline Option 2	$530,300.00
Total Cost ($/sq.ft.)	$321.78

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Zero Emission Option 3	$78,426.93	$706.55	16%	-1%	0.8

LOW-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and an ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	50 Tons	575V, 145 MCA
Electrical Boiler	-	75 kW
Electrical Boiler	-	75 kW
Boiler Pump 1	-	-
Boiler Pump 2	-	-
Heating Distribution Pump 1	50 GPM	-
Heating Distribution Pump 2	50 GPM	-
Expansion Tank 1	-	-
Air Separator 1	-	-
Chilled Distribution Pump 1	40 GPM	-
Chilled Distribution Pump 2	40 GPM	-
Expansion Tank 2	-	-
Air Separator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Mechanical Room Size (400 sq.ft.)	10'x40' (LxW)	-
Outside Area Required (420 sq.ft.)	15'x28' (LxW)	-
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 Bed)	-	1/12HP (1ph / 120)
Fan Coils (2 Bed)	-	1/6HP (1ph / 120)
Fan Coils (3 Bed)	-	1/6HP (1ph / 120)
Fan Coils (4 Bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Hot Water Tank 5	119 Gal	-
Domestic Hot Water Tank 6	119 Gal	-
Heat Exchanger	25 GPM	-
Domestic Expansion Tank	-	-
Circulator Pump	25 GPM	-
Water Room (255 sq.ft.)	9'x28' (LxW)	-
Outside Area Required	None	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	400
Equivalent parking spaces	3
Water Room (sq.ft.)	252
Equivalent parking spaces	2
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	420
Total Equivalent Parking Spaces	11

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$2,184,200.00
Electrical Cost	$358,300.00
Building Cost (Arch & Struct)	$423,500.00
Total Cost	$2,966,00.00
Total Cost Relative to Baseline Option 2	$90,300.00
Total Cost ($/sq.ft.)	$317.81

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI (kwCO₂e/m²/yr)
Zero Emission Option 4	$78,676.57	$708.80	16%	-1%	0.7

LOW-RISE ZERO EMISSION OPTION 5

Air-cooled variable refrigerant flow heating/cooling system with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
VRF Condensing Units	50 Tons	575V, 132 MCA
Mechanical Room Size	None	-
Outside Area Required (400 sq.ft.)	20' x 20' (LxW)	-
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 Bed)	-	1/12HP (1ph / 120)
Fan Coils (2 Bed)	-	1/6HP (1ph / 120)
Fan Coils (3 Bed)	-	1/6HP (1ph / 120)
Fan Coils (4 Bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Expansion Tank	-	-
Water Room Size (180 sq.ft.)	9'x20' (LxW)	-
Outside Area Required	none	-

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 5	$77,143.96	$694.99	18%	1%	0.9

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	400
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$2,251,400.00
Electrical Cost	$357,800.00
Building Cost (Arch & Struct)	$303,500.00
Total Cost	$2,912,700.00
Total Cost Relative to Baseline Option 2	$37,000.00
Total Cost ($/sq.ft.)	$317.33

LOW-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air Source Heat Pump 1	25 Ton	575V, 139 MCA
Air Source Heat Pump 2	25 Ton	575V, 139 MCA
Electric Boiler		75 kW
Electric Boiler		75 kW
Buffer Tank	400 Gal	-
Air Separator	-	-
Ambient Loop Pump 1	60 GPM	-
Ambient Loop Pump 2	60 GPM	-
Expansion Tank	-	-
Mechanical Room Size (300 sq.ft.)	10'x30'(LxW)	-
Outside Area Required (288 sq.ft.)	18'x16'(LxW)	-
Terminal Units		
Heat Pumps (Studio)	-	1.1 kW
Heat Pumps (1 Bed)	-	1.1 kW
Heat Pumps (2 Bed)	-	2.2 kW
Heat Pumps (3 Bed)	-	2.2 kW
Heat Pumps (4 Bed)	-	3.3 kW
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Expansion Tank	-	-
Water Room Size (180 sq.ft.)	9'x20'(LxW)	-
Outside Area Required (229 sq.ft.)	None	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	300
Equivalent parking spaces	2
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	288
Total Equivalent Parking Spaces	9

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1250
Main Distribution Panel (A)	1600
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$1,818,600.00
Electrical Cost	$379,700.00
Building Cost (Arch & Struct)	$367,300.00
Total Cost	$2,565,600.00
Total Cost Relative to Baseline Option 2	($310,100.00)
Total Cost ($/sq.ft.)	$314.21

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 6	$90,373.18	$814.17	2%	-16%	0.9

LOW-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
Air-Source Heat Pump	50 Tons	575V, 145 MCA
Electrical Boiler	-	75 kW
Electrical Boiler	-	75 kW
Boiler Pump 1	-	-
Boiler Pump 2	-	-
Heating Distribution Pump 1	50 GPM	-
Heating Distribution Pump 2	50 GPM	-
Expansion Tank 1	-	-
Air Separator 1	-	-
Chilled Distribution Pump 1	40 GPM	-
Chilled Distribution Pump 2	40 GPM	-
Expansion Tank 2	-	-
Air Separator 2	-	-
Buffer Tank 1	-	-
Buffer Tank 2	-	-
Mechanical Room Size (400 sq.ft.)	10'x40' (LxW)	-
Outside Area Required (420 sq.ft.)	15'x28' (LxW)	-
Terminal Units		
Fan Coils (Studio)	-	1/12HP (1ph / 120)
Fan Coils (1 Bed)	-	1/12HP (1ph / 120)
Fan Coils (2 Bed)	-	1/6HP (1ph / 120)
Fan Coils (3 Bed)	-	1/6HP (1ph / 120)
Fan Coils (4 Bed)	-	1/4HP (1ph / 120)
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	-
Domestic Hot Water Tank 2	119 Gal	-
Domestic Hot Water Tank 3	119 Gal	-
Domestic Hot Water Tank 4	119 Gal	-
Heat Exchanger	216 kW - 80 GPM	-
Domestic Expansion Tank	-	-
Circulator Pump	80 GPM	-
Water Room Size (180 sq.ft.)	9'x20 (LxW)	-
Outside Area Required	none	-

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	400
Equivalent parking spaces	3
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	420
Total Equivalent Parking Spaces	10

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1250
Main Distribution Panel (A)	1250
Elect Room Size	34' x 19' (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19' x 12' (228 sq.ft.)

COST

Mechanical Cost	$2,130,200.00
Electrical Cost	$355,100.00
Building Cost (Arch & Struct)	$405,500.00
Total Cost	$2,890,800.00
Total Cost Relative to Baseline Option 2	$15,100.00
Total Cost ($/sq.ft.)	$317.14

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 7	$75,358.55	$678.91	20%	3%	0.7

LOW-RISE ZERO CARBON OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

BASIC MECHANICAL EQUIPMENT

Equipment Description	Nominal Size	Electrical
Central Plant		
No Plant Equipment	-	-
Terminal Units		
Suite by Suite PTAC Unit	1 per suite	208/1/60 - 15A Circuit
Ventilation		
Suite by Suite Ventilation Unit	100-150 CFM	1.5 Amp (1ph / 120)
Corridor Male-up Air Unit (Electric)	2,000 CFM	30 kW (3ph / 600)
Misc Exhaust Fans	-	6 HP Total
Vestibule Pressurization (inc. Elec. Duct Heater)	-	4 kW Total
Domestic Hot Water		
Domestic Hot Water Tank 1	119 Gal	54 kW
Domestic Hot Water Tank 2	119 Gal	54 kW
Domestic Hot Water Tank 3	119 Gal	54 kW
Domestic Hot Water Tank 4	119 Gal	54 kW
Domestic Expansion Tank	-	-
Water Room Size (180 sq.ft.)	9’x20’ (LxW)	-
Outside Area Required	none	-

ENERGY PERFORMANCE (WITH MECHANICAL COOLING)

Performance Metrics	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings	GHGI ($kwCO_2e/m^2/yr$)
Zero Emission Option 8	$96,498.42	$869.36	-5%	-24%	0.9

ARCHITECTURAL REQUIREMENTS

Mechanical Room (sq.ft.)	N/A
Equivalent parking spaces	0
Water Room (sq.ft.)	180
Equivalent parking spaces	1
Electrical Room (sq.ft.)	646
Equivalent parking spaces	4
Generator Room (sq.ft.)	228
Equivalent parking spaces	2
Mech Outdoor Area (sq.ft.)	0
Total Equivalent Parking Spaces	7

ELECTRICAL REQUIREMENTS

Transformer Size (kVA)	1000
Main Distribution Panel (A)	1200
Elect Room Size	34’ x 21.6’ (646 sq.ft.)
Generator Size (kW)	150
Generator Room Size	19’ x 12’ (228 sq.ft.)

COST

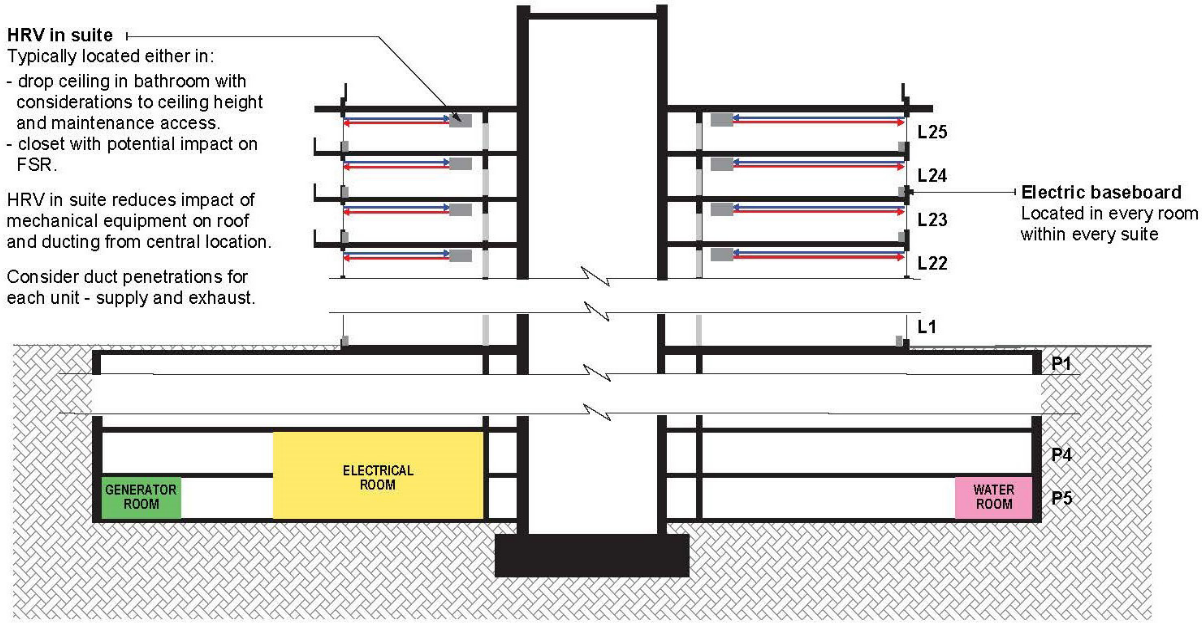
Mechanical Cost	$1,541,400.00
Electrical Cost	$371,100.00
Building Cost (Arch & Struct)	$263,500.00
Total Cost	$2,176,000.00
Total Cost Relative to Baseline Option 2	($699,700.00)
Total Cost ($/sq.ft.)	$310.69

APPENDIX C

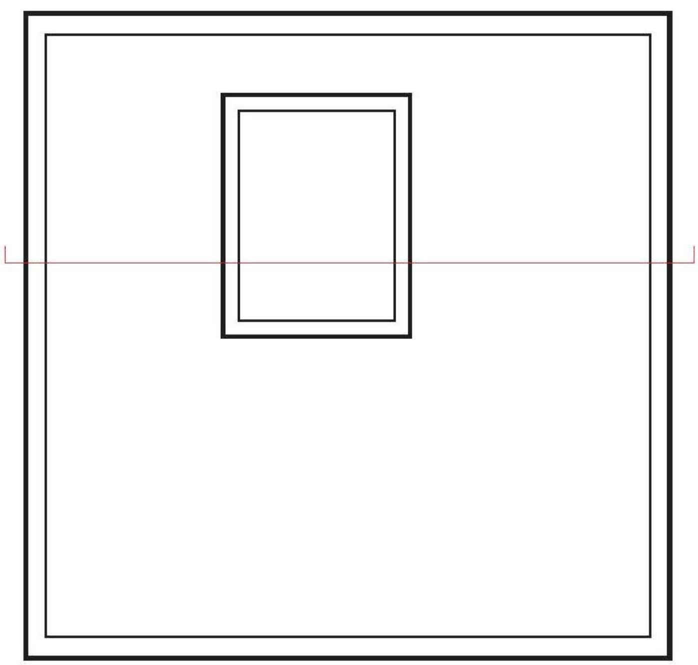
ARCHITECTURAL PLANT CONSIDERATIONS AND INFOGRAPHICS

HIGH-RISE BASELINE 1

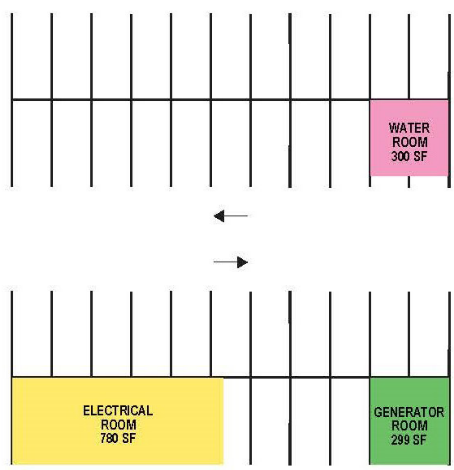
Electric baseboard heating with gas-fired hot water production and corridor ventilation system.



Schematic Section



Schematic Roof

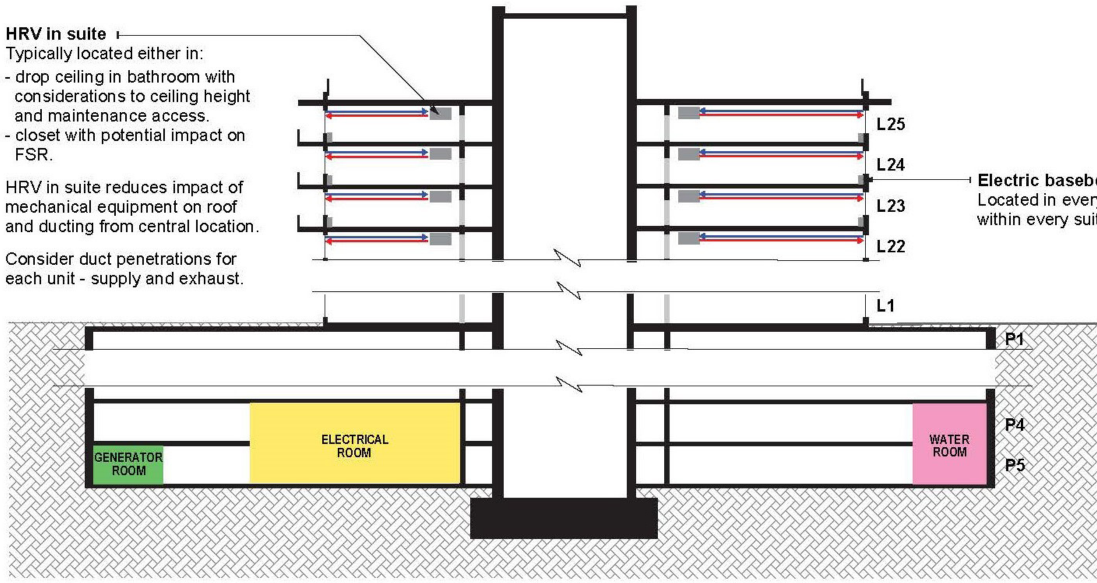


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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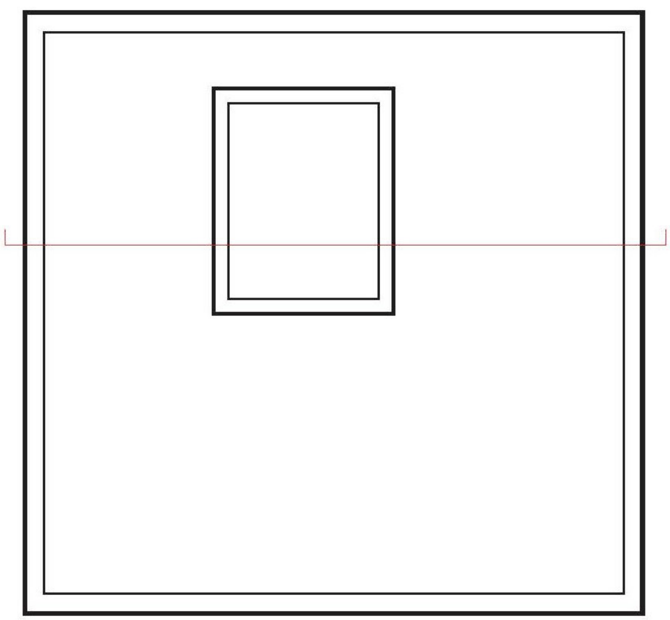

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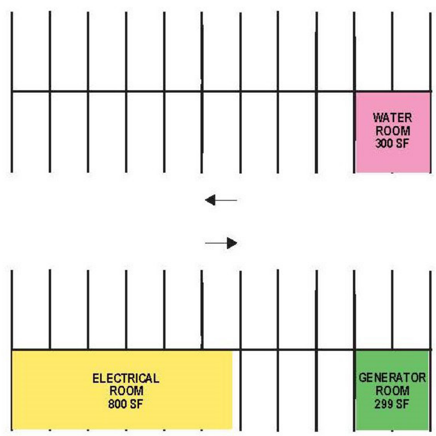
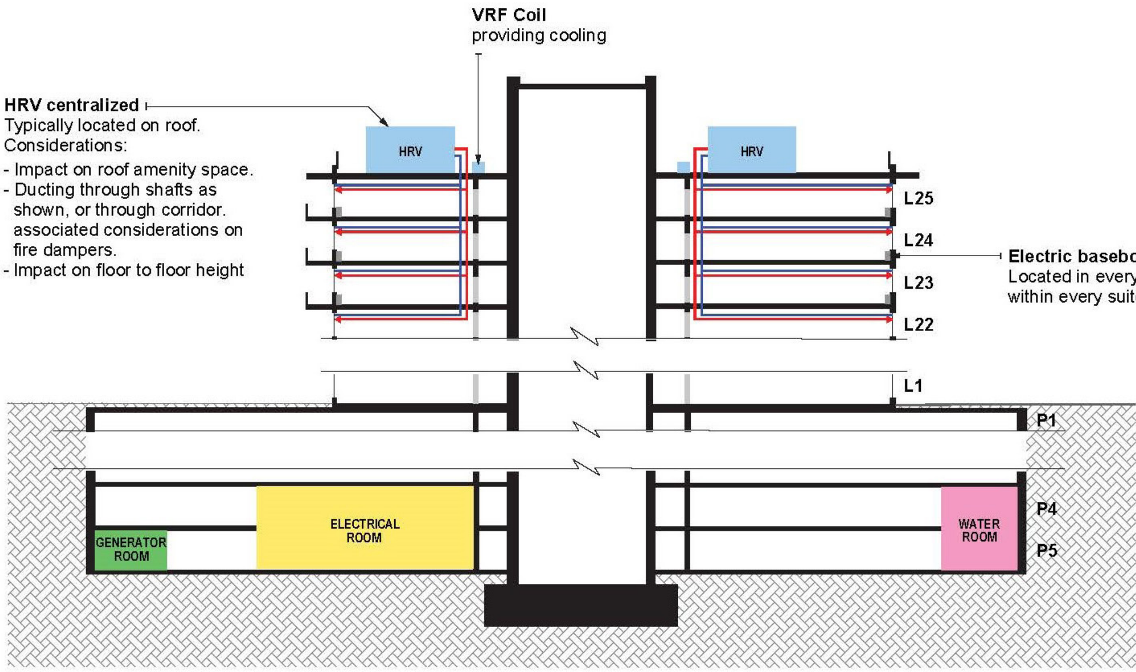


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 10% increase in airflow.



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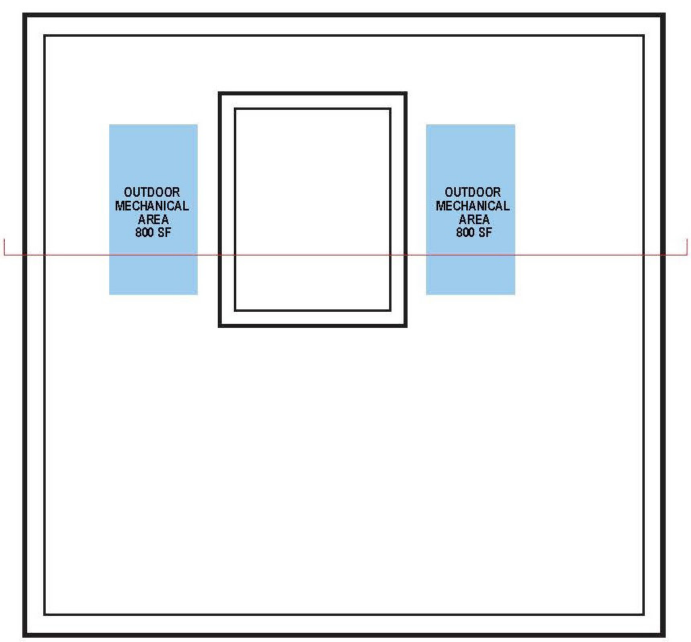
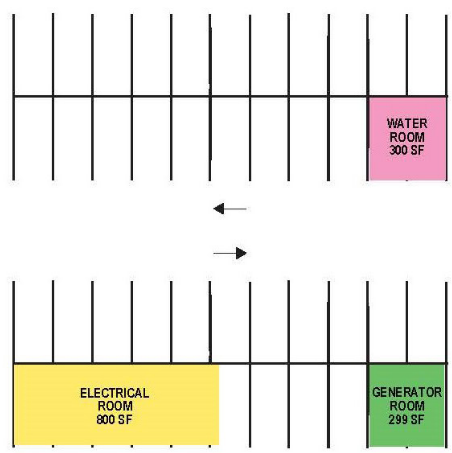


Schematic Roof

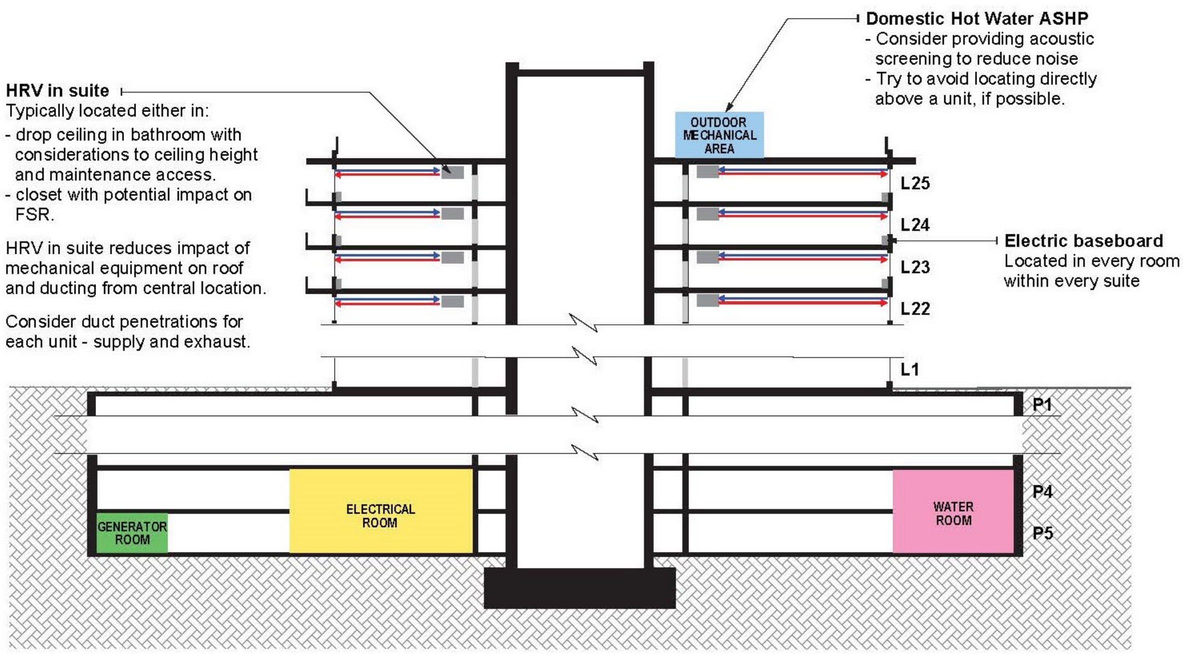


Schematic Parking

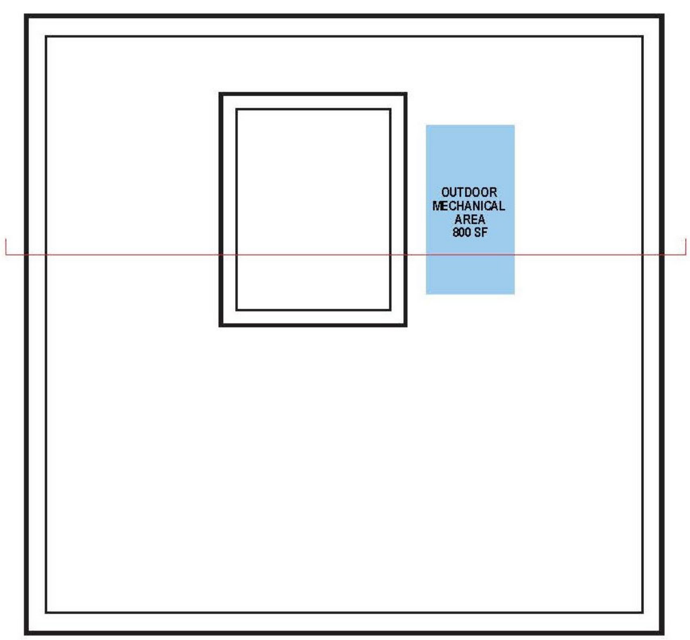
NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 2

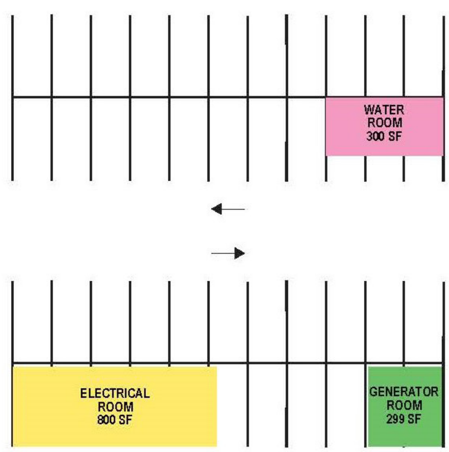
Electric baseboard heating with an Air-Source Heat Pump (ASHP) domestic hot water production system and electric resistance heating for the corridor ventilation system.



Schematic Section



Schematic Roof

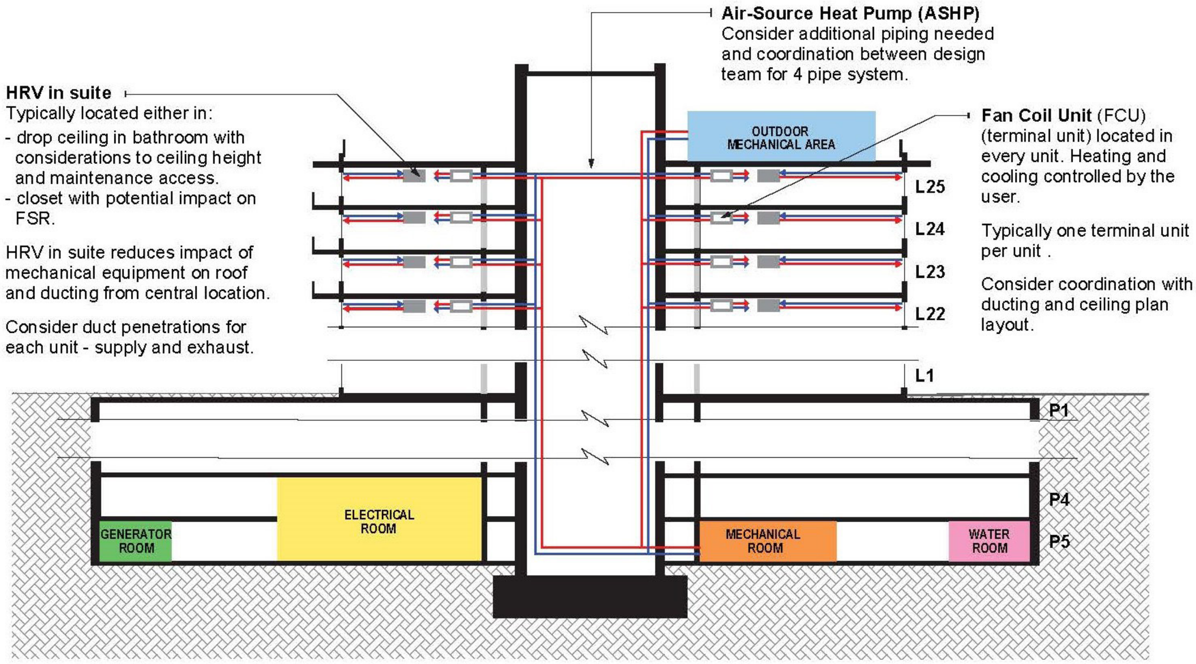


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.



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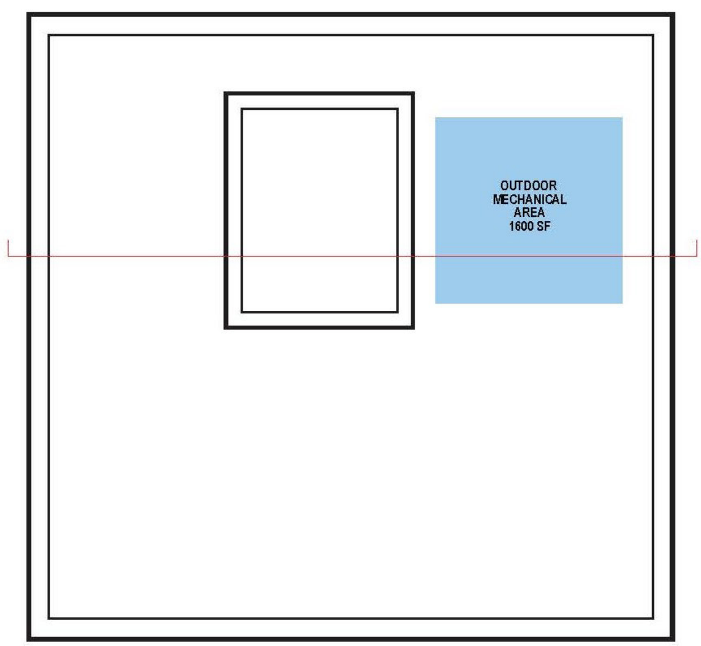

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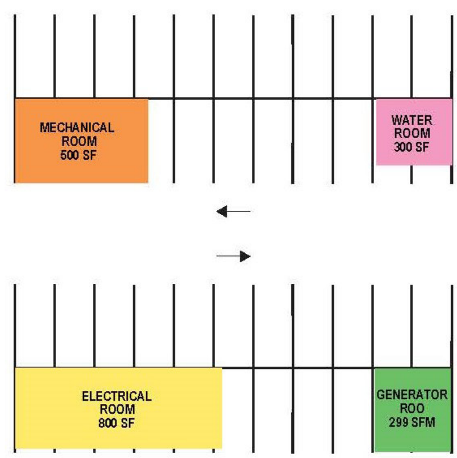
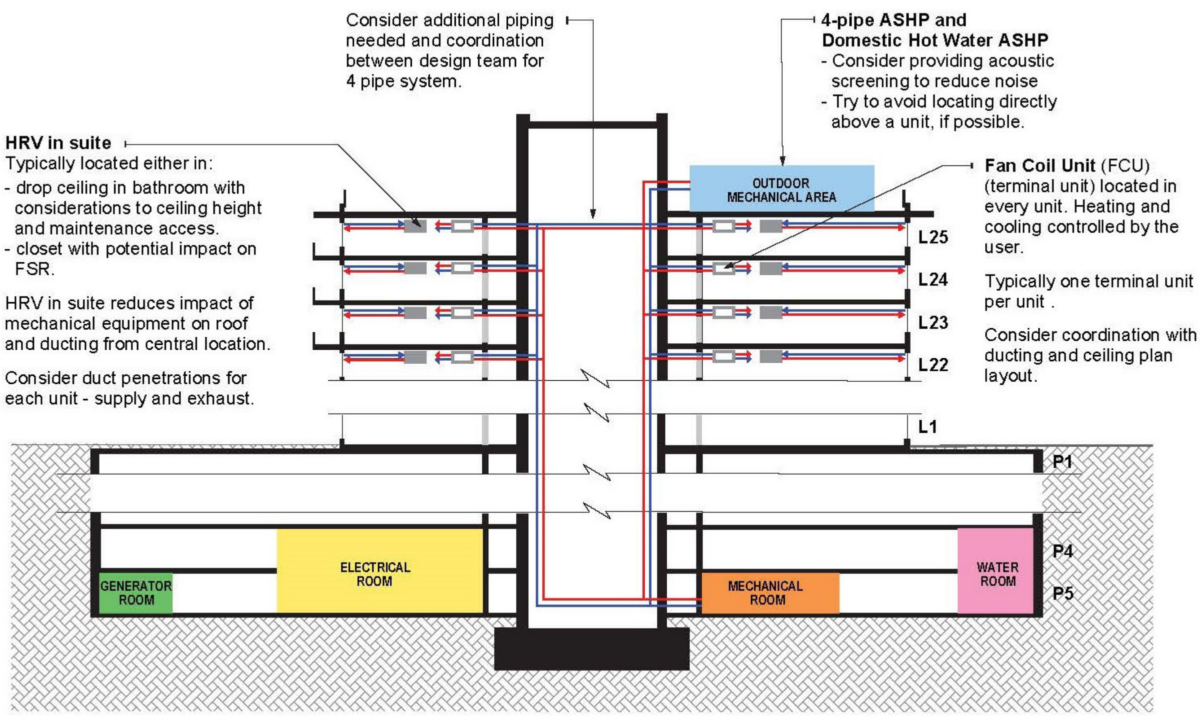


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP Domestic hot water production system and hydronic heating for the corridor ventilation system.



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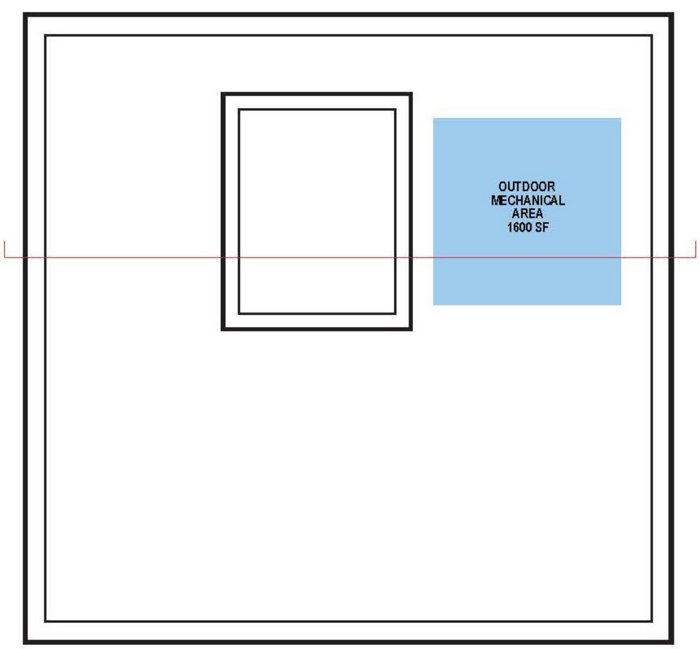

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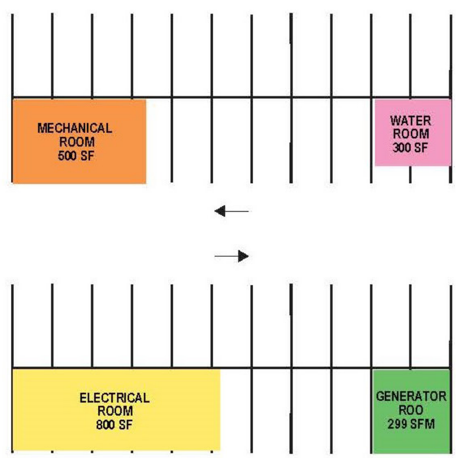
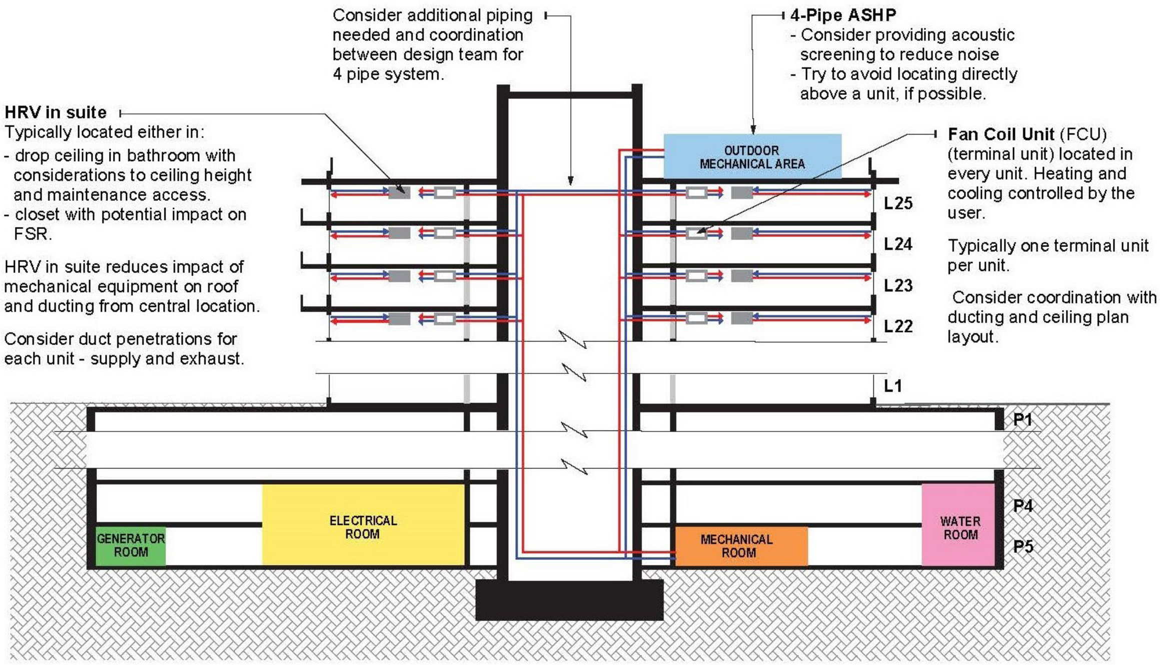


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.



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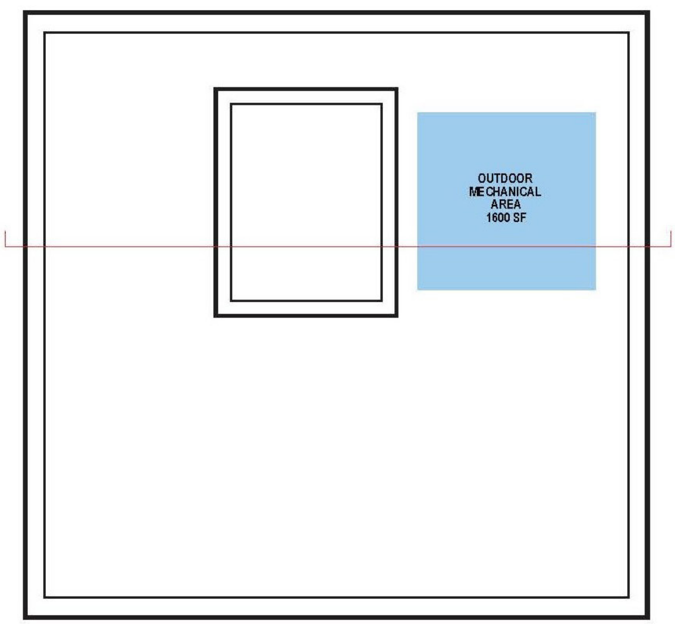
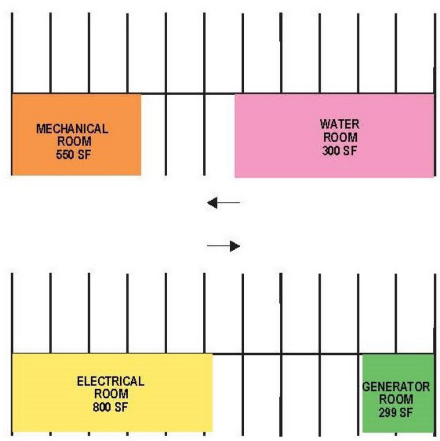




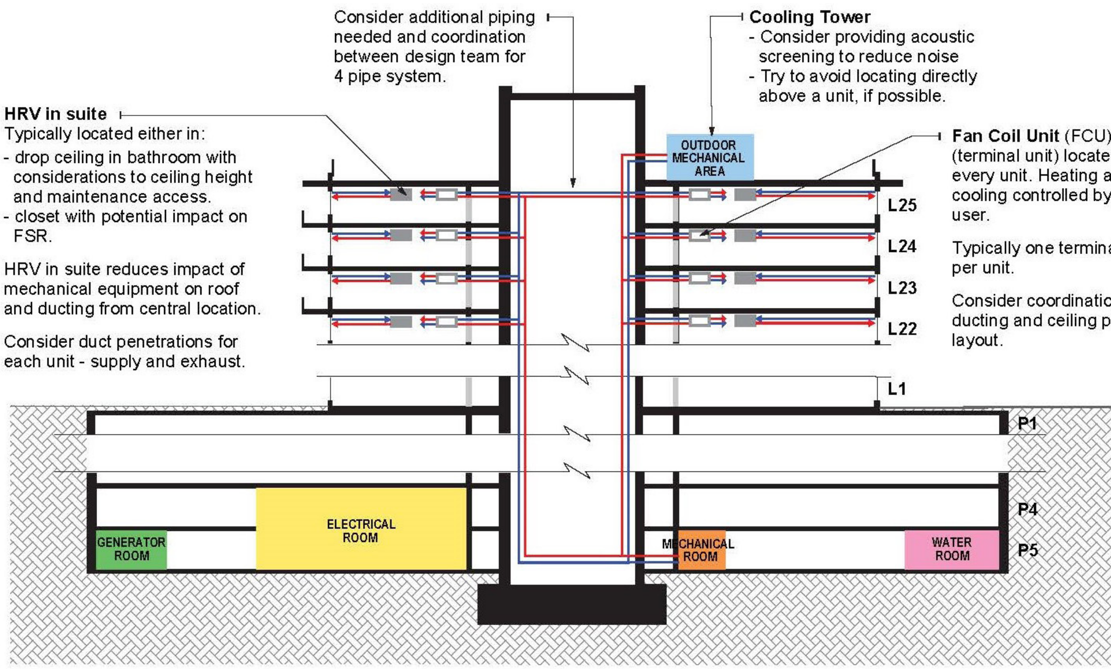
Schematic Parking

Schematic Roof

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 5

Water-cooled variable refrigerant flow heating/cooling system (consisting of cooling tower and electric boilers) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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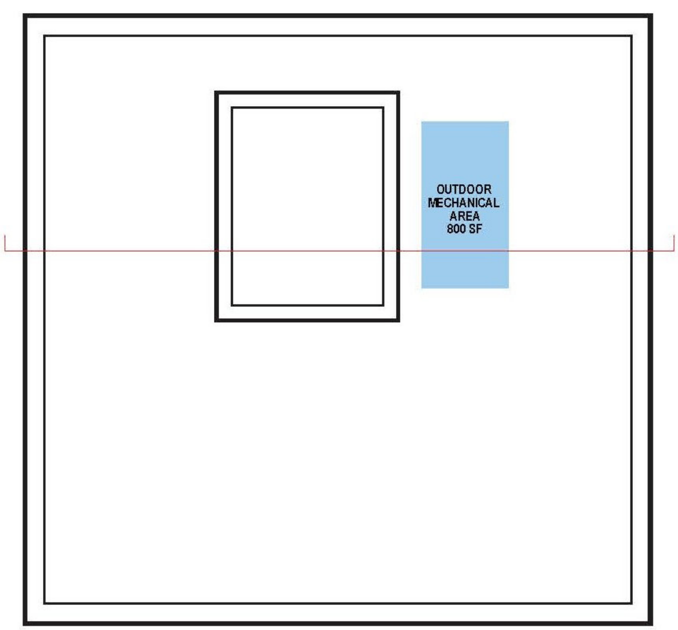

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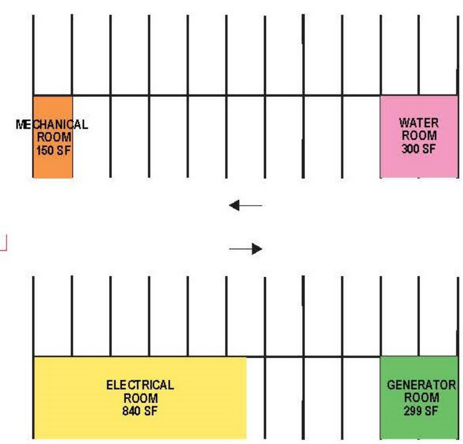
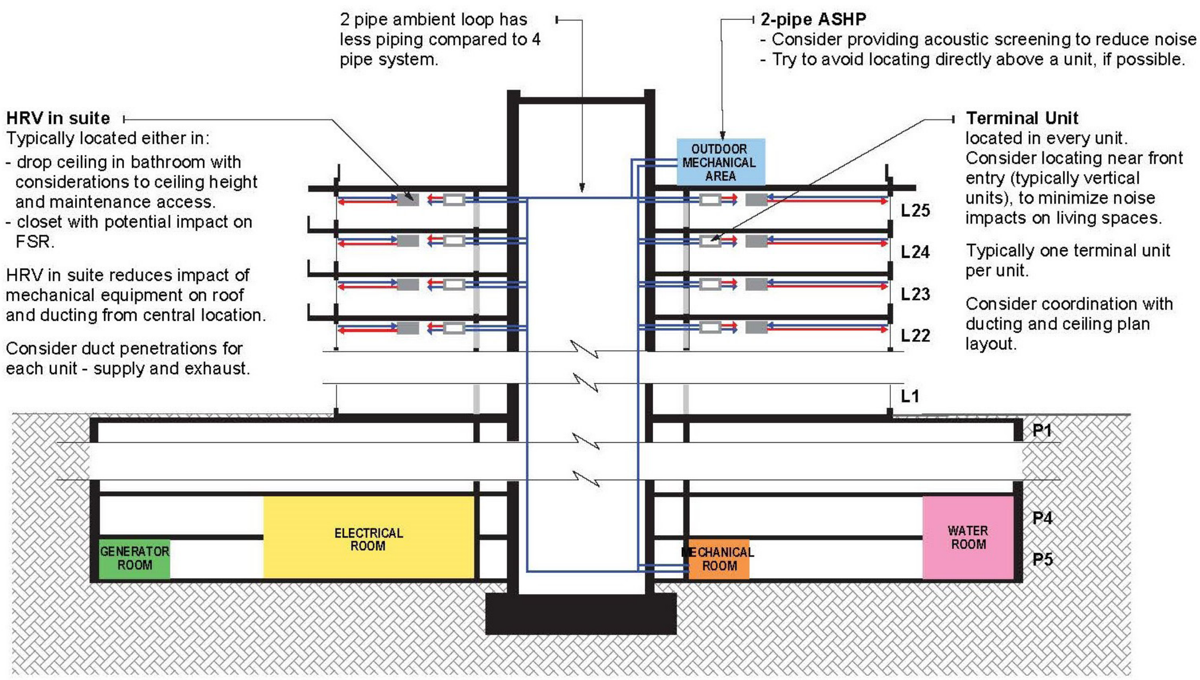


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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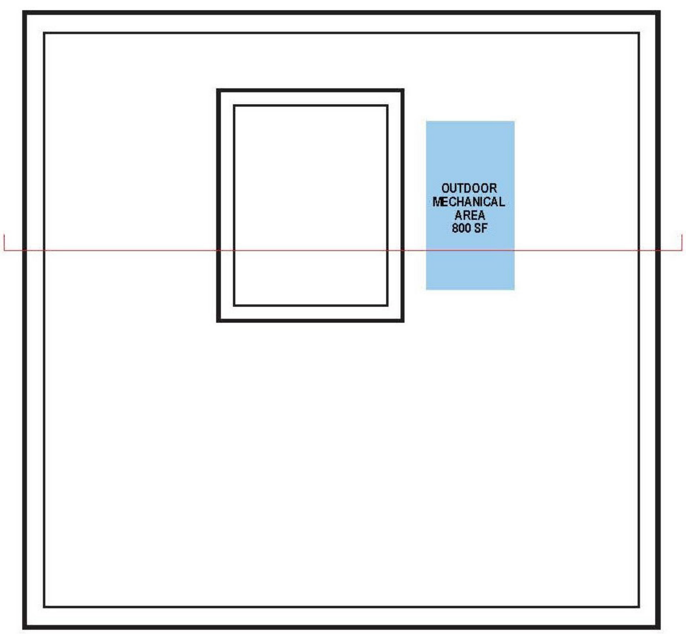

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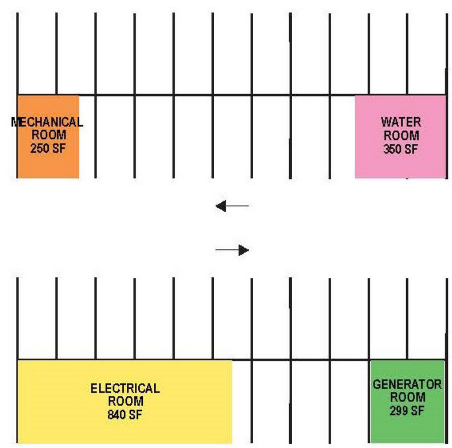
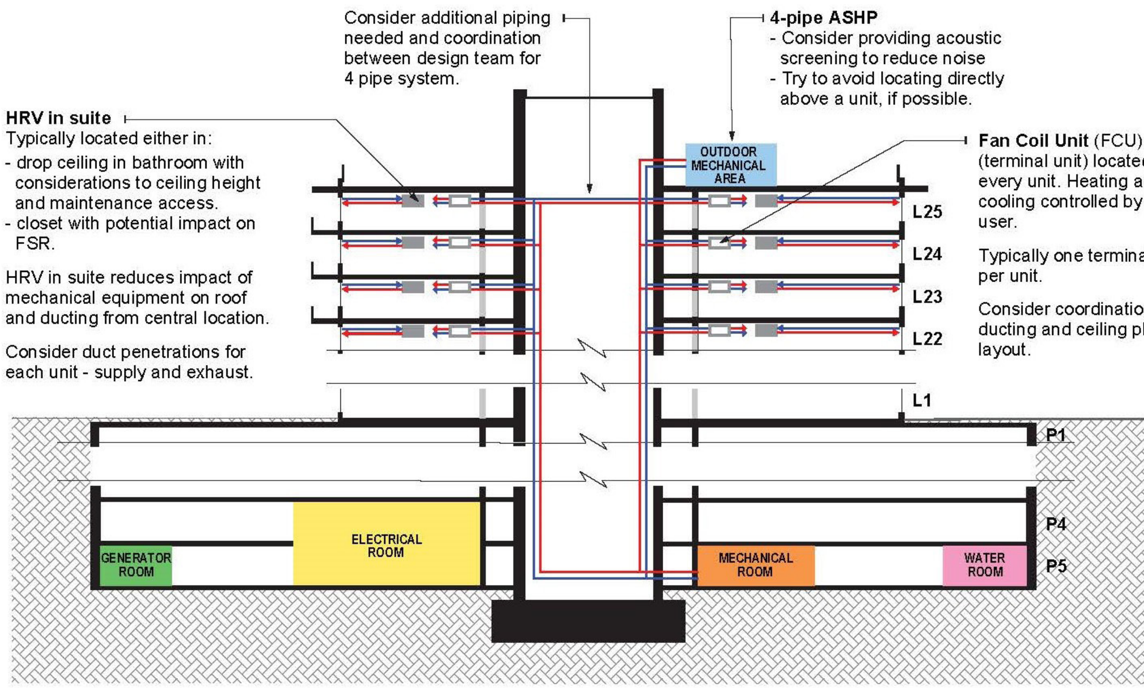


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.



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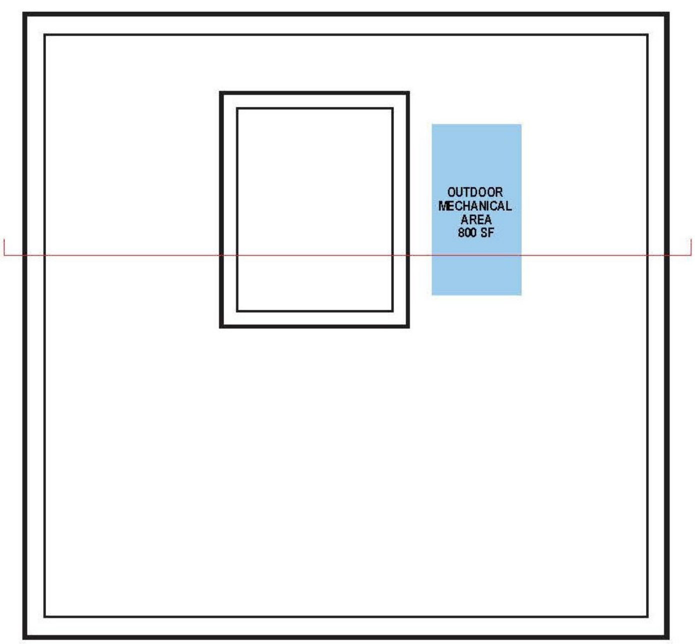

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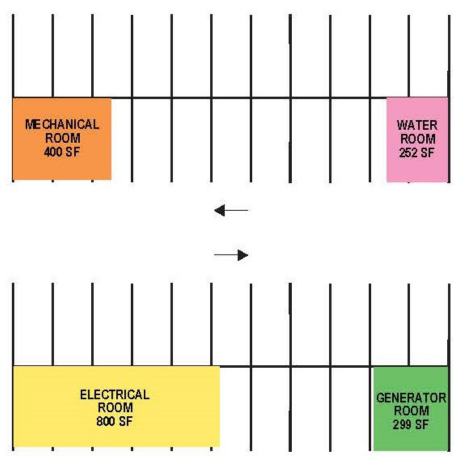
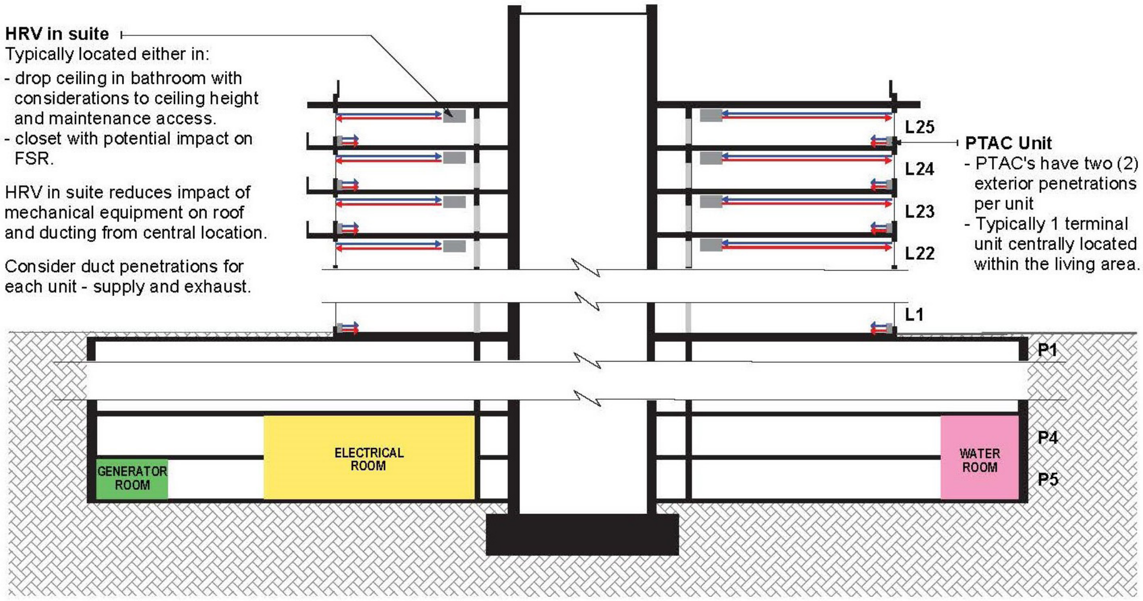


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

HIGH-RISE ZERO EMISSION OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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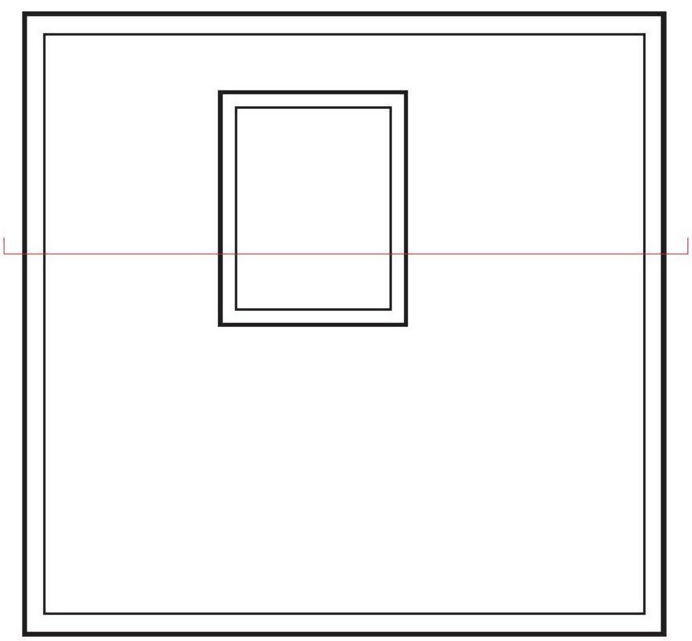

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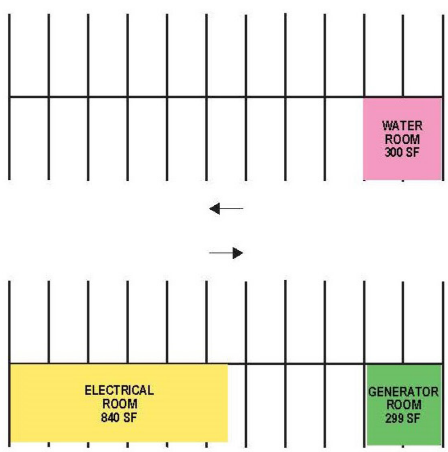
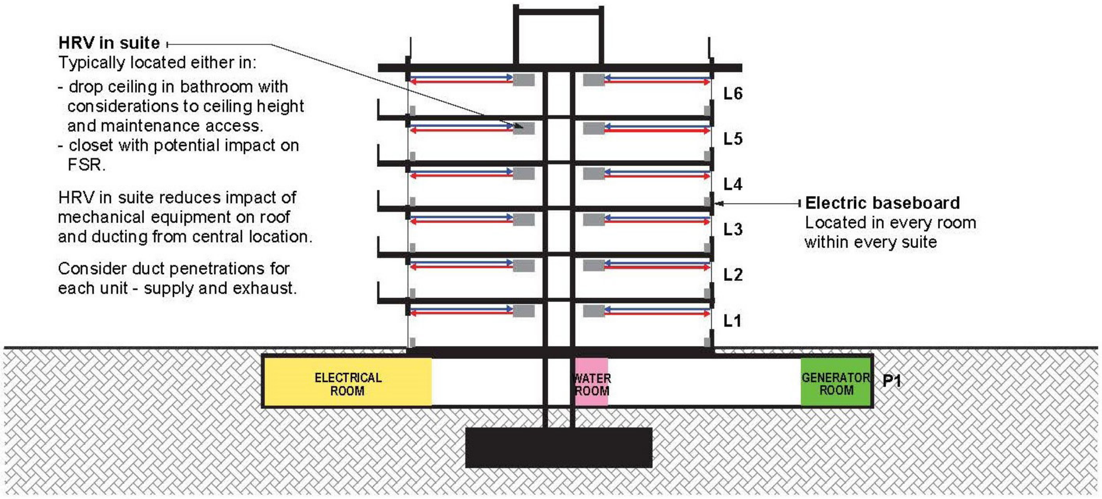


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE BASELINE 1

Electric baseboard heating with gas-fired hot water production and corridor ventilation system.



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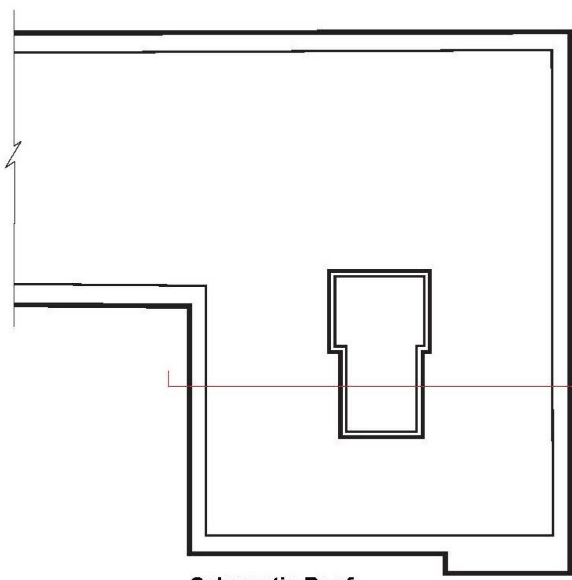

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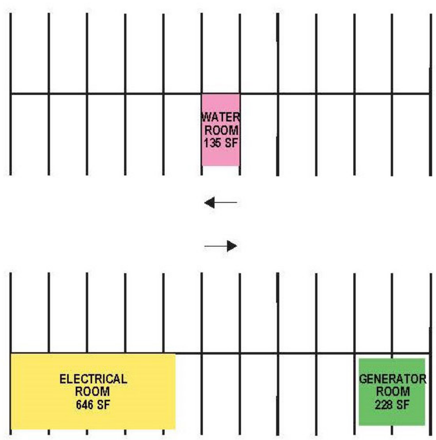
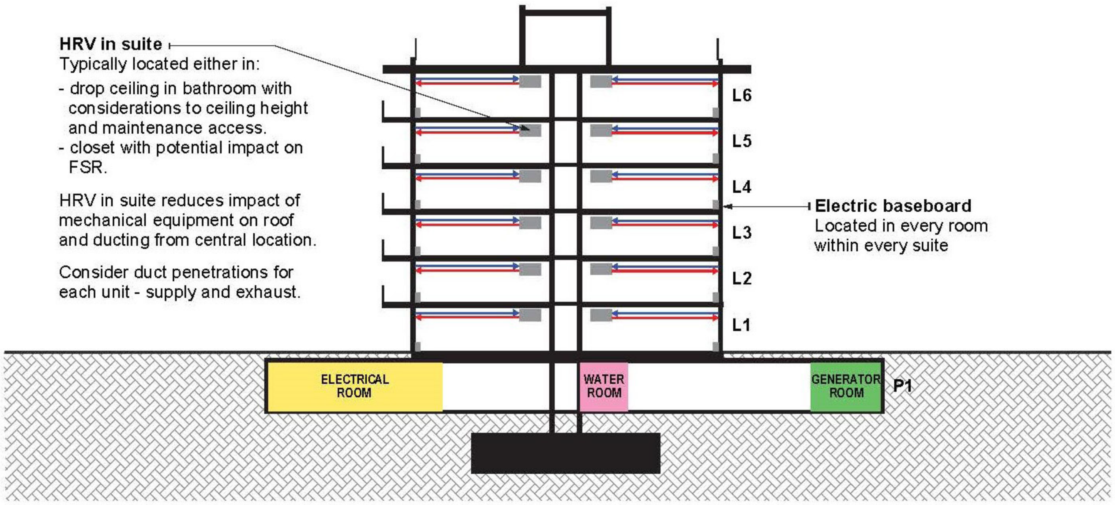


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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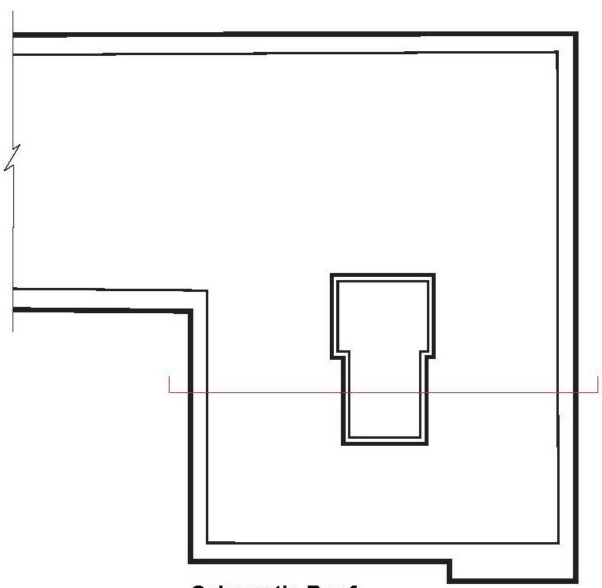

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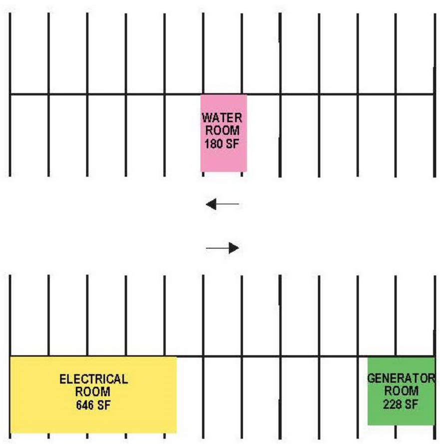
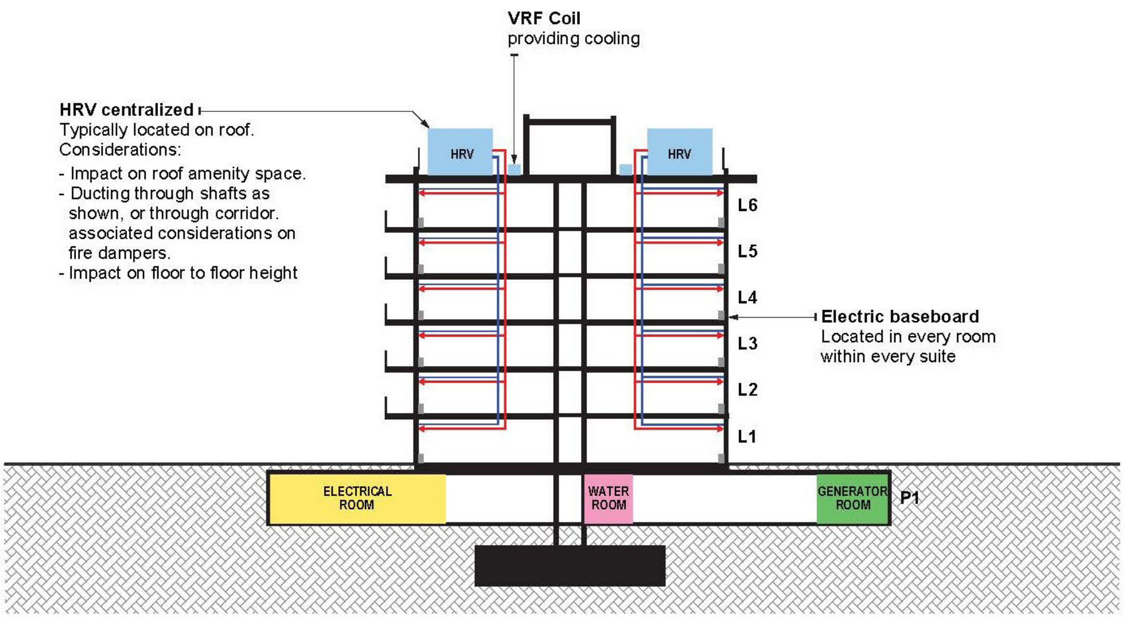


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 15% increase in airflow.



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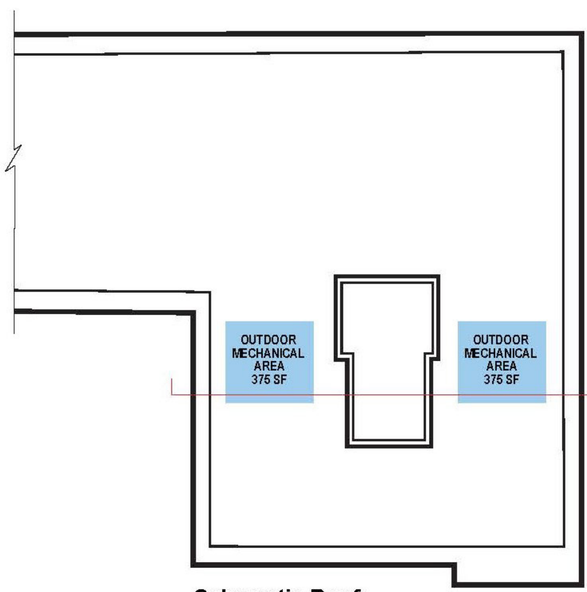

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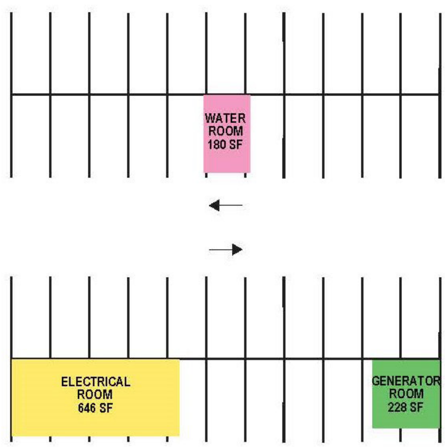
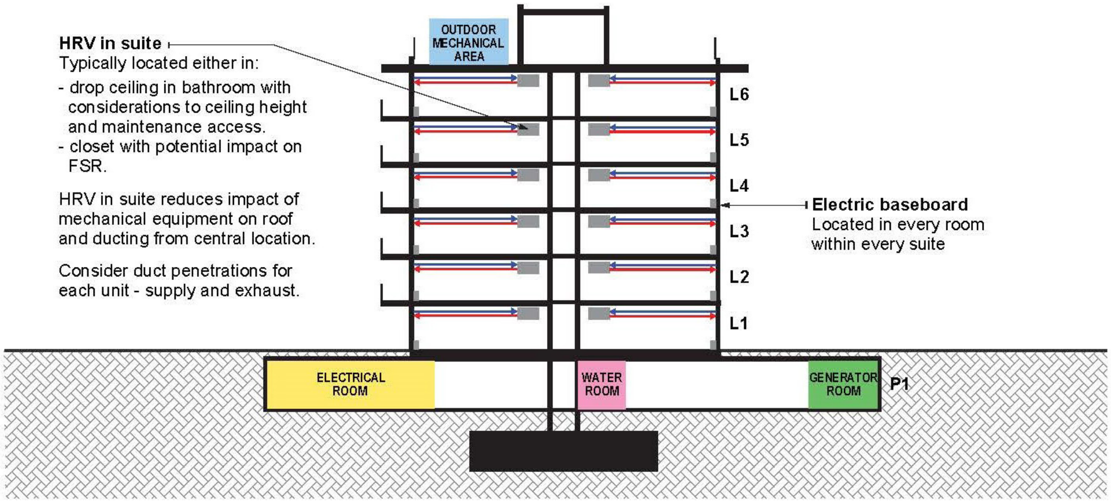


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 2

Electric baseboard heating with an ASHP domestic hot water production system and electric resistance heating for the corridor ventilation system.



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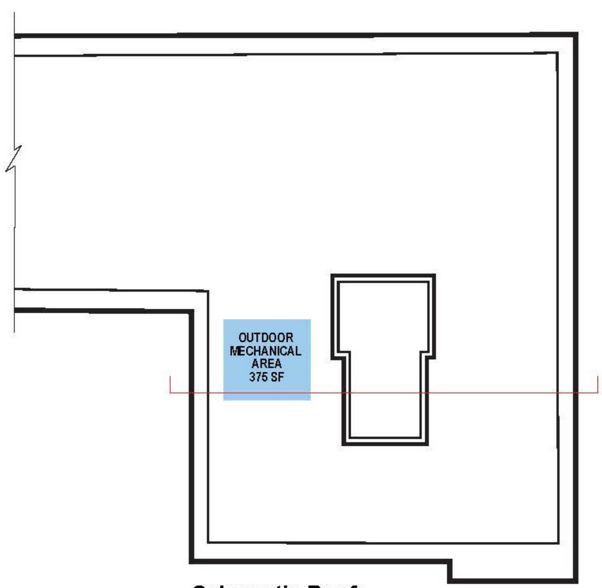

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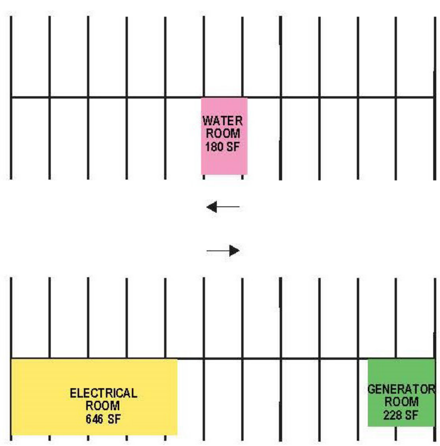
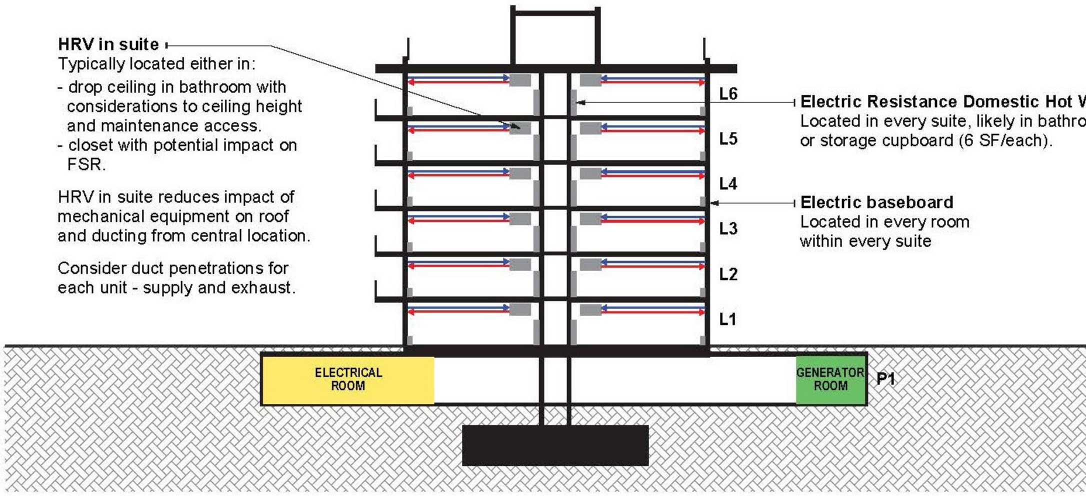


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 9

Electric baseboard heating with in-suite electrical resistance domestic hot water tank and for the corridor ventilation system.



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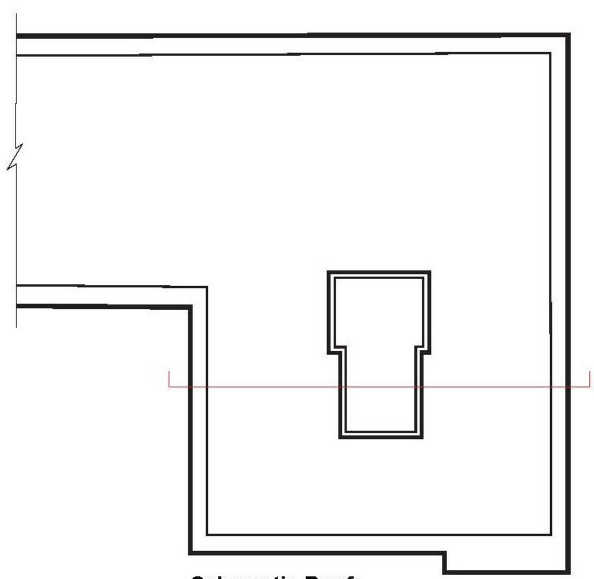

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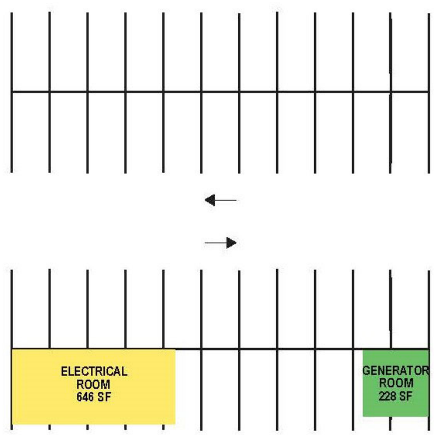
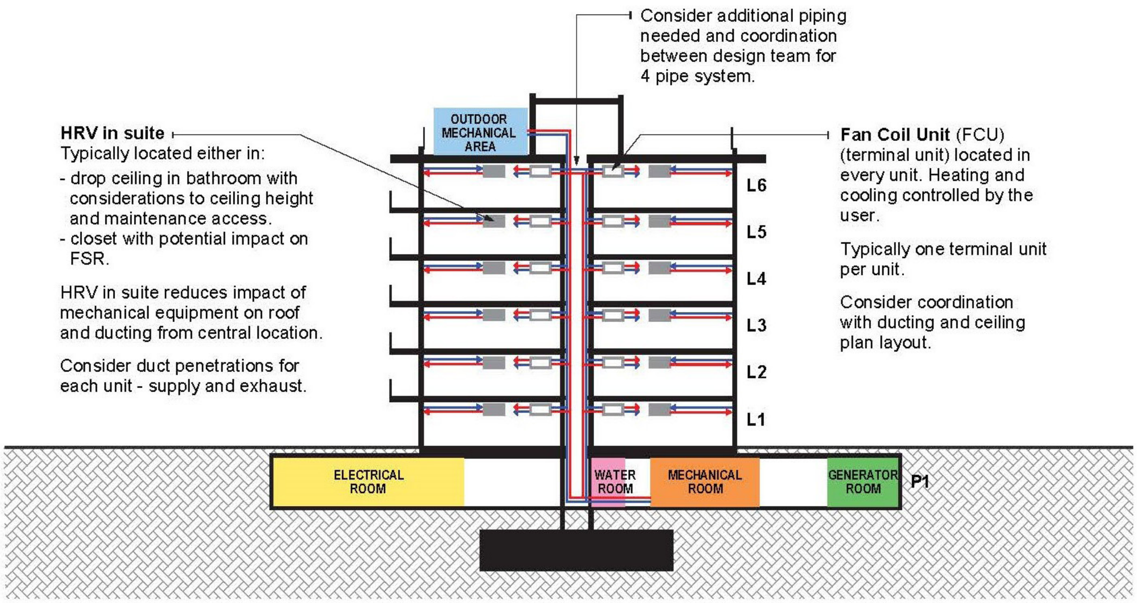


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.



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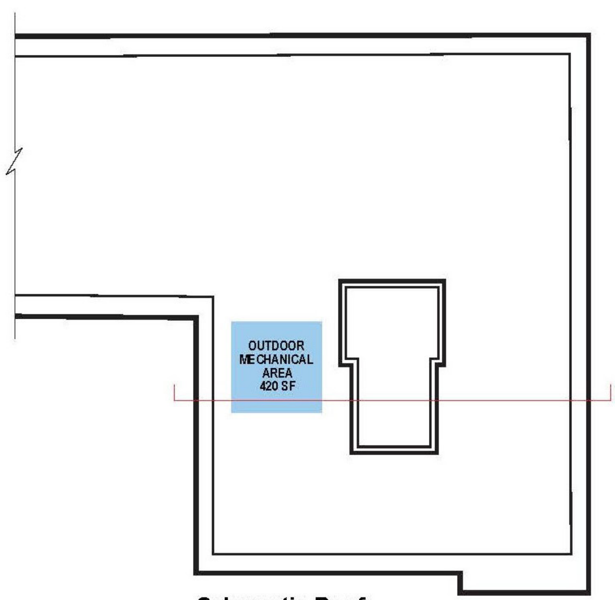

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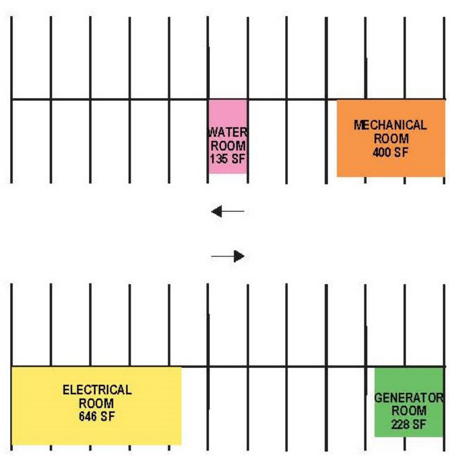
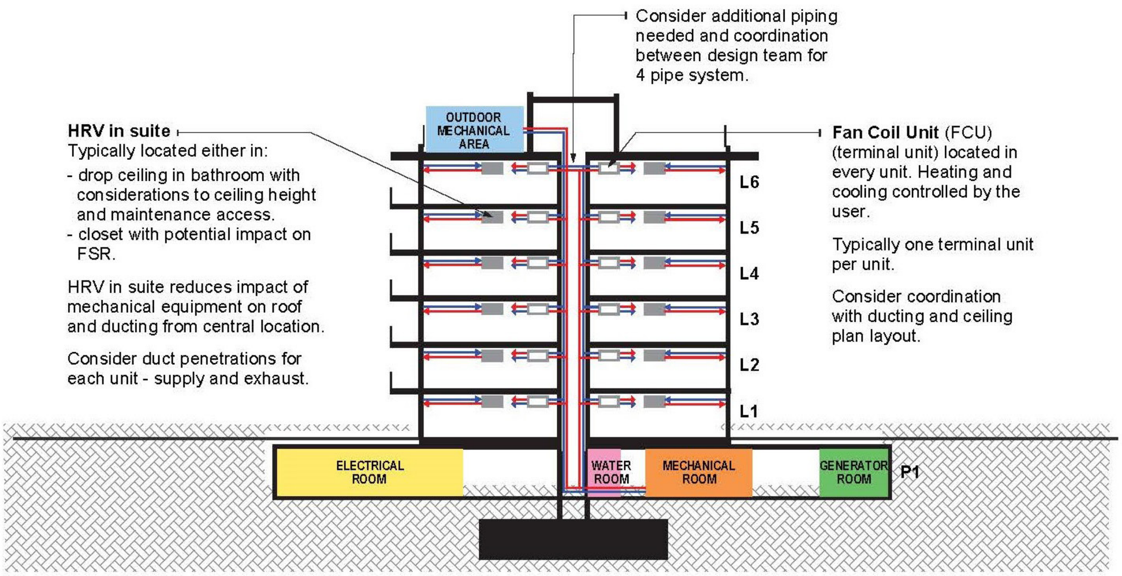


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP domestic hot water production system and hydronic heating for the corridor ventilation system.



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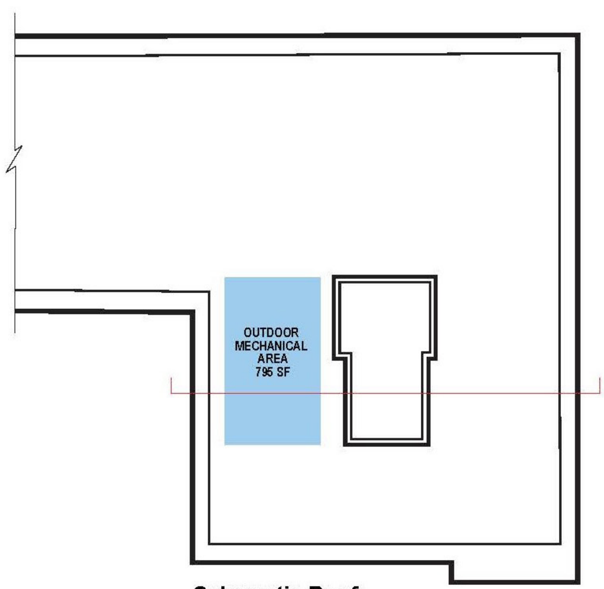

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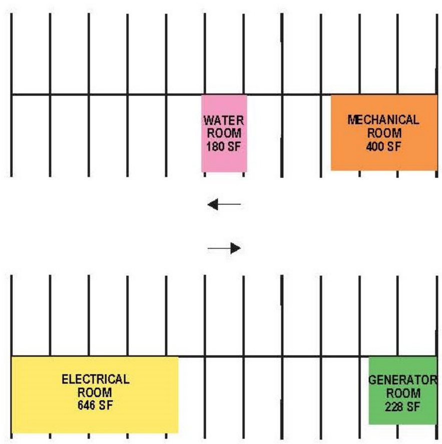
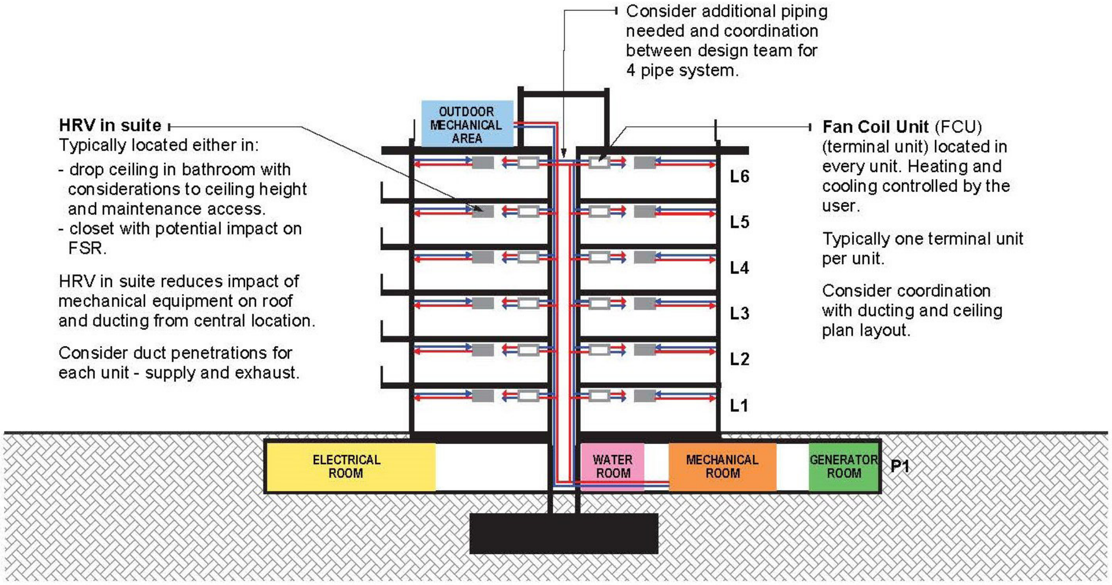


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and an ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.



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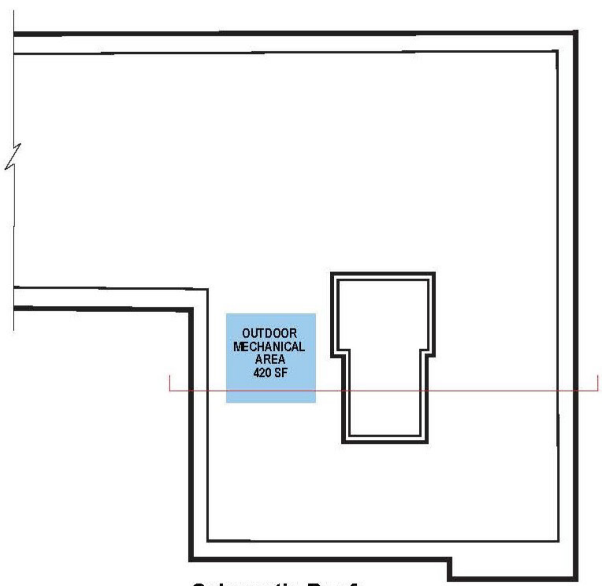

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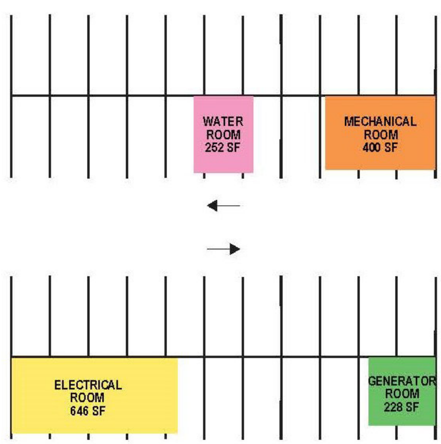
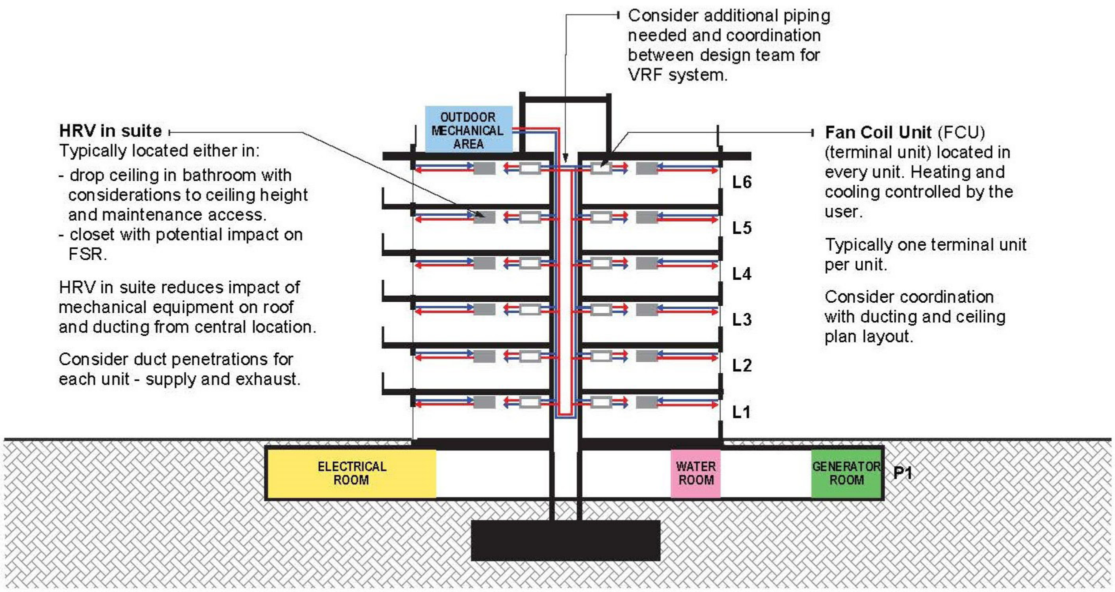


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 5

Air-cooled variable refrigerant flow heating/cooling system with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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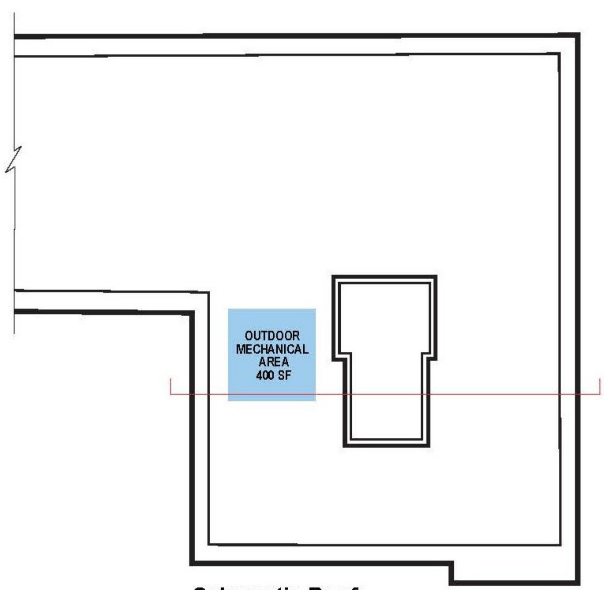

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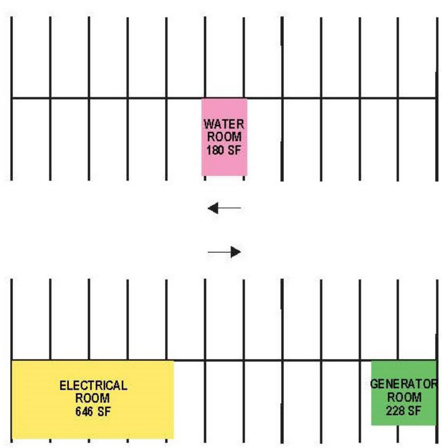
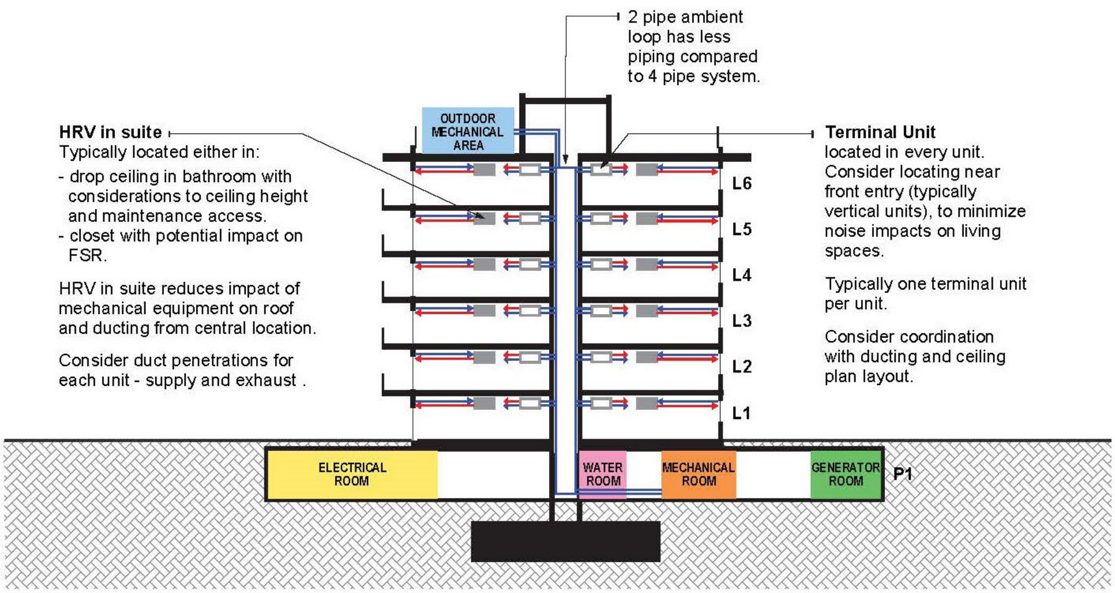


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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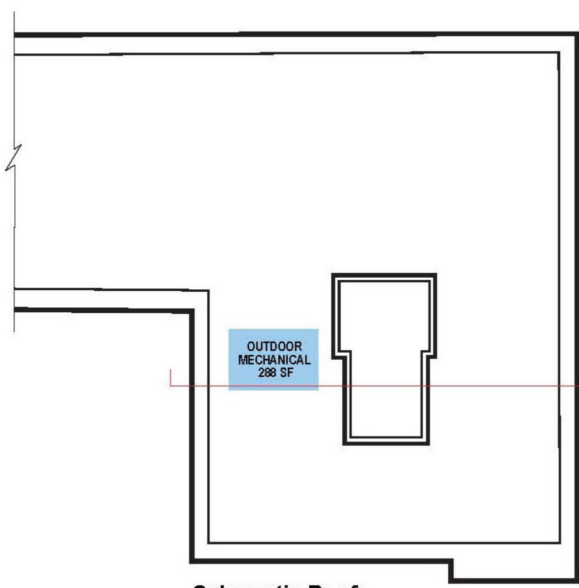

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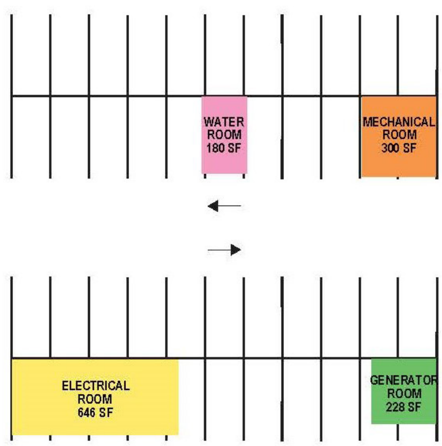
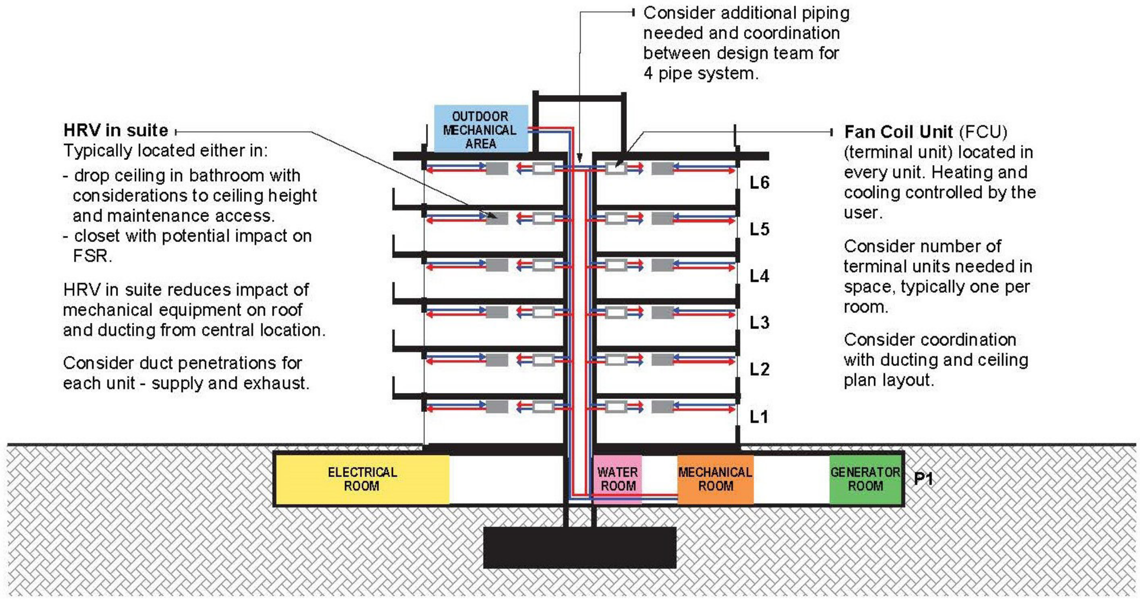


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.



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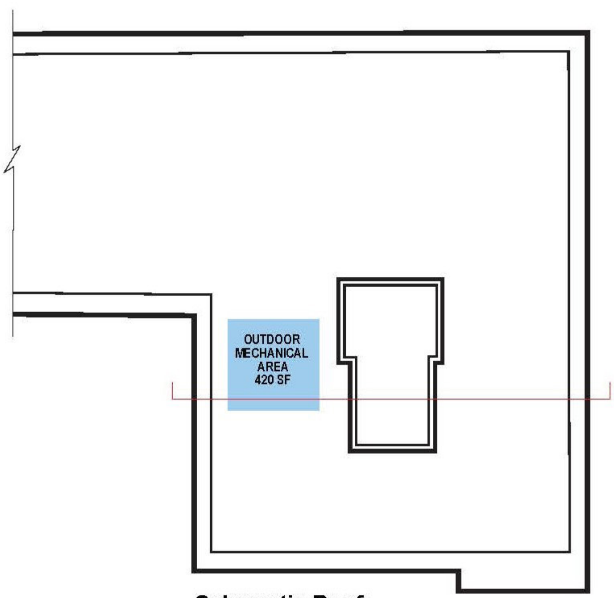

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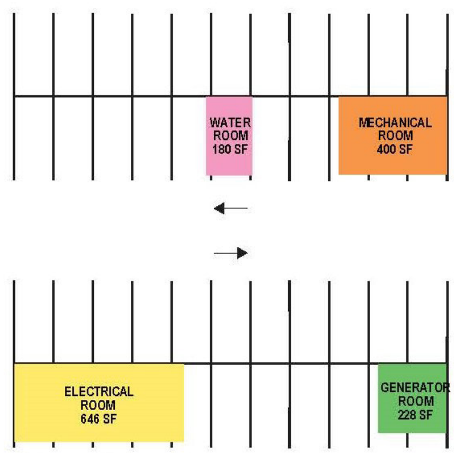
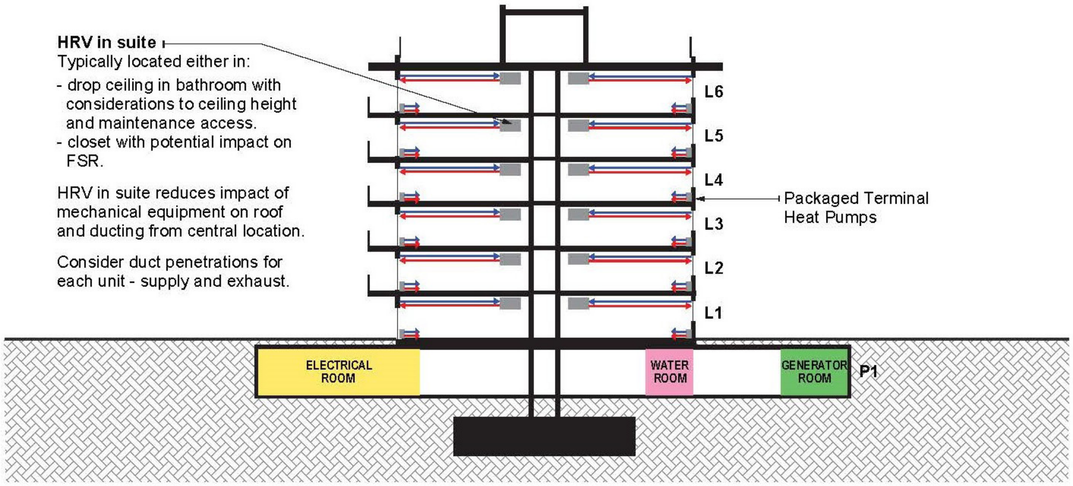


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

LOW-RISE ZERO EMISSION OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.



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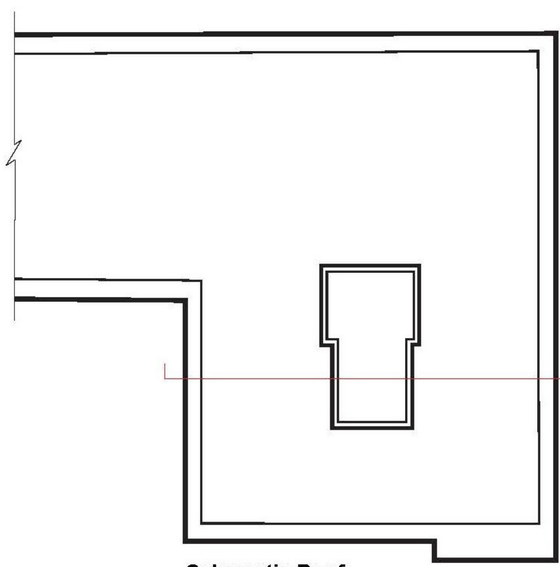

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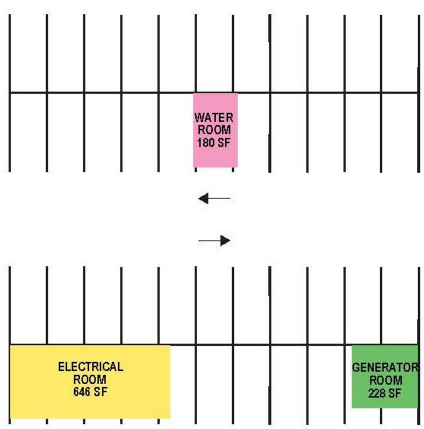


Schematic Parking

NOTE: All drawings and systems are visual representations only and not to scale unless noted.

TYPICAL FLOOR SECTIONS

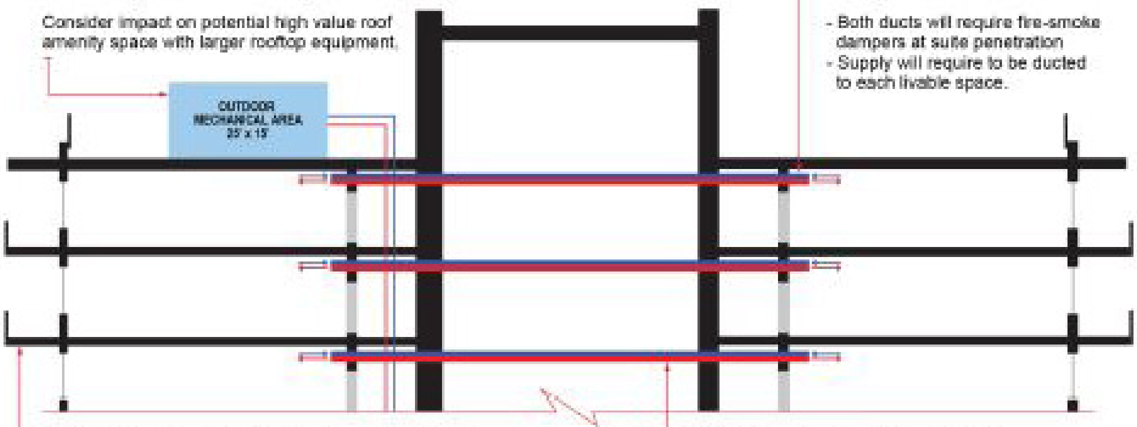
With Balconies

Centralized HRV
with Cooling Coil, and condensing unit.

Consider impact on potential high value roof amenity space with larger rooftop equipment.

Supply and Exhaust
ducting from each suite.

- Both ducts will require fire-smoke dampers at suite penetration
- Supply will require to be ducted to each livable space.



For study balconies set at 1.8m for the southern facade.

Early design to evaluate shading, including analysis to optimize size and shape.

Consider shading device capital cost, access to local solutions, access for maintenance of system and window cleaning, wind and snow load.

Distribution shown here through corridor

Consider impact on floor to floor height of centralized system

Coordination with design professionals to minimize impact on height early in the process.

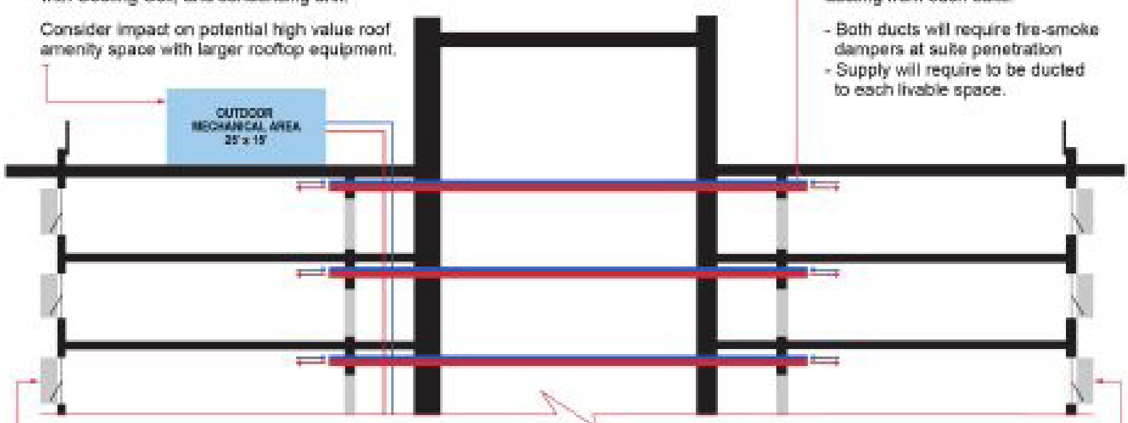
With Operable Windows and Shading

Centralized HRV
with Cooling Coil, and condensing unit.

Consider impact on potential high value roof amenity space with larger rooftop equipment.

Supply and Exhaust
ducting from each suite.

- Both ducts will require fire-smoke dampers at suite penetration
- Supply will require to be ducted to each livable space.



Operable windows for natural ventilation and cooling. Consider negative impact during fire events through the summer months.

Vertical shading for energy model set at 0.3m and used on east and west elevations.

Early design to evaluate shading, including analysis to optimize size and shape.

Consider shading device capital cost, access to local solutions, access for maintenance of system and window cleaning, wind and snow load.

APPENDIX D

DETAILED ENERGY MODELLING RESULTS

HIGH-RISE RESIDENTIAL BUILDING BASELINE 1

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	22.10	121.58	47.52	0.00	0.00	16.08	0.00	225.19	615.75
Feb	38.44	3.69	26.26	3.56	18.60	93.02	43.59	0.00	0.00	14.52	0.00	214.94	555.96
Mar	42.56	3.63	29.08	3.94	17.43	72.68	48.39	0.00	0.00	16.08	0.00	212.37	506.40
Apr	41.19	3.08	28.13	3.82	12.54	35.82	45.70	0.00	0.00	15.56	0.00	200.51	424.86
May	42.56	2.83	29.07	3.94	8.01	14.29	47.52	0.00	0.00	16.08	0.00	207.71	377.98
Jun	41.19	2.64	28.14	3.82	3.41	3.76	46.79	0.00	0.00	15.56	0.00	201.42	270.09
Jul	42.56	2.67	29.07	3.94	1.46	0.65	48.07	0.00	0.00	16.08	0.00	188.60	245.62
Aug	42.56	2.93	29.07	3.94	1.22	0.31	47.85	0.00	0.00	16.08	0.00	188.59	235.64
Sep	41.19	3.26	28.14	3.82	3.52	6.05	46.25	0.00	0.00	15.56	0.00	196.42	301.97
Oct	42.56	4.00	29.07	3.94	11.65	42.69	47.52	0.00	0.00	16.08	0.00	202.02	445.04
Nov	41.19	4.36	28.14	3.82	18.52	92.56	46.25	0.00	0.00	15.56	0.00	219.71	579.75
Dec	42.56	4.84	29.07	3.94	22.59	127.34	47.30	0.00	0.00	16.08	0.00	220.41	608.01
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**141.05**	**610.75**	**562.76**	**0.00**	**0.00**	**189.34**	**0.00**	**225.19**	**615.75**

Table D.1: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 1

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	142.36	0.00	45.59	0.00	16.08	0.00	0.00	780.58
Feb	38.44	3.69	26.26	3.56	0.00	110.50	0.00	41.81	0.00	14.52	0.00	0.00	732.41
Mar	42.56	3.63	29.08	3.94	0.00	89.07	0.00	46.42	0.00	16.08	0.00	0.00	650.02
Apr	41.19	3.08	28.13	3.82	0.00	47.61	0.00	43.84	0.00	15.56	0.00	0.00	588.93
May	42.56	2.83	29.07	3.94	0.00	21.82	0.00	45.59	0.00	16.08	0.00	0.00	518.06
Jun	41.19	2.64	28.14	3.82	0.00	6.97	0.00	44.88	0.00	15.56	0.00	0.00	416.75
Jul	42.56	2.67	29.07	3.94	0.00	2.02	0.00	46.11	0.00	16.08	0.00	0.00	392.61
Aug	42.56	2.93	29.07	3.94	0.00	1.46	0.00	45.90	0.00	16.08	0.00	0.00	373.52
Sep	41.19	3.26	28.14	3.82	0.00	9.36	0.00	44.36	0.00	15.56	0.00	0.00	455.64
Oct	42.56	4.00	29.07	3.94	0.00	53.64	0.00	45.59	0.00	16.08	0.00	0.00	617.54
Nov	41.19	4.36	28.14	3.82	0.00	109.97	0.00	44.36	0.00	15.56	0.00	0.00	758.60
Dec	42.56	4.84	29.07	3.94	0.00	148.58	0.00	45.37	0.00	16.08	0.00	0.00	790.26
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**743.34**	**0.00**	**539.80**	**0.00**	**189.34**	**0.00**	**0.00**	**790.26**

Table D.2: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 2

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	142.36	0.00	19.61	0.00	16.08	0.00	0.00	727.31
Feb	38.44	3.69	26.26	3.56	0.00	110.50	0.00	17.70	0.00	14.52	0.00	0.00	674.66
Mar	42.56	3.63	29.08	3.94	0.00	89.07	0.00	19.65	0.00	16.08	0.00	0.00	598.22
Apr	41.19	3.08	28.13	3.82	0.00	47.61	0.00	18.80	0.00	15.56	0.00	0.00	519.84
May	42.56	2.83	29.07	3.94	0.00	21.82	0.00	19.65	0.00	16.08	0.00	0.00	452.91
Jun	41.19	2.64	28.14	3.82	0.00	6.97	0.00	19.38	0.00	15.56	0.00	0.00	351.98
Jul	42.56	2.67	29.07	3.94	0.00	2.02	0.00	19.91	0.00	16.08	0.00	0.00	327.84
Aug	42.56	2.93	29.07	3.94	0.00	1.46	0.00	19.81	0.00	16.08	0.00	0.00	308.75
Sep	41.19	3.26	28.14	3.82	0.00	9.36	0.00	19.15	0.00	15.56	0.00	0.00	390.87
Oct	42.56	4.00	29.07	3.94	0.00	53.64	0.00	19.58	0.00	16.08	0.00	0.00	555.44
Nov	41.19	4.36	28.14	3.82	0.00	109.97	0.00	18.92	0.00	15.56	0.00	0.00	703.08
Dec	42.56	4.84	29.07	3.94	0.00	148.58	0.00	19.28	0.00	16.08	0.00	0.00	738.10
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**743.34**	**0.00**	**231.43**	**0.00**	**189.34**	**0.00**	**0.00**	**738.10**

Table D.3: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING BASELINE 2

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0	83.65	47.53	0	0.13	24.41	2.56	188.59	531.61
Feb	38.44	3.69	26.26	3.56	0	62.46	43.59	0	0.22	21.61	1.70	188.59	460.94
Mar	42.56	3.63	29.08	3.94	0	47.86	48.39	0	0.98	22.92	1.24	188.59	423.67
Apr	41.19	3.08	28.13	3.82	0	22.74	45.70	0	3.17	20.71	0.61	188.59	354.40
May	42.56	2.83	29.07	3.94	0	7.42	47.53	0	8.83	20.77	0.40	188.59	351.23
Jun	41.19	2.65	28.14	3.82	0	1.27	46.79	0	17.81	21.56	0.44	188.59	387.24
Jul	42.56	2.67	29.07	3.94	0	0.24	48.07	0	35.89	24.91	0.82	188.59	439.75
Aug	42.56	2.93	29.08	3.94	0	0.01	47.85	0	35.49	24.88	0.80	188.59	417.82
Sep	41.19	3.26	28.14	3.82	0	2.05	46.25	0	17.23	21.59	0.45	188.59	413.51
Oct	42.56	4.00	29.07	3.94	0	25.55	47.53	0	1.37	21.73	0.72	188.59	377.99
Nov	41.19	4.36	28.14	3.82	0	61.66	46.25	0	0.25	22.95	1.82	188.59	483.82
Dec	42.56	4.84	29.07	3.94	0	86.10	47.31	0	0.11	24.49	2.71	188.59	509.91
Annual	**501.14**	**42.55**	**342.30**	**46.43**	**0**	**401.01**	**562.76**	**0**	**121.47**	**272.53**	**14.27**	**188.59**	**531.61**

Table D.4: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 3

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	83.65	0.00	19.61	0.13	24.41	2.56	0.00	574.54
Feb	38.44	3.69	26.26	3.56	0.00	62.46	0.00	17.70	0.22	21.61	1.70	0.00	528.42
Mar	42.56	3.63	29.08	3.94	0.00	47.86	0.00	19.65	0.98	22.92	1.24	0.00	469.72
Apr	41.19	3.08	28.13	3.82	0.00	22.74	0.00	18.80	3.17	20.71	0.61	0.00	411.68
May	42.56	2.83	29.07	3.94	0.00	7.42	0.00	19.65	8.83	20.77	0.39	0.00	411.97
Jun	41.19	2.64	28.14	3.82	0.00	1.27	0.00	19.38	17.81	21.56	0.44	0.00	447.98
Jul	42.56	2.67	29.07	3.94	0.00	0.24	0.00	19.91	35.89	24.91	0.82	0.00	500.49
Aug	42.56	2.93	29.07	3.94	0.00	0.01	0.00	19.81	35.49	24.88	0.80	0.00	478.56
Sep	41.19	3.26	28.14	3.82	0.00	2.05	0.00	19.15	17.23	21.59	0.45	0.00	474.25
Oct	42.56	4.00	29.07	3.94	0.00	25.55	0.00	19.58	1.37	21.73	0.72	0.00	440.87
Nov	41.19	4.36	28.14	3.82	0.00	61.66	0.00	18.92	0.25	22.95	1.82	0.00	551.97
Dec	42.56	4.84	29.07	3.94	0.00	86.10	0.00	19.28	0.11	24.49	2.71	0.00	580.74
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**401.00**	**0.00**	**231.43**	**121.47**	**272.53**	**14.27**	**0.00**	**580.74**

Table D.5: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 4

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	83.65	0.00	25.36	0.13	24.41	2.56	0.00	595.03
Feb	38.44	3.69	26.26	3.56	0.00	62.46	0.00	22.88	0.22	21.61	1.70	0.00	548.25
Mar	42.56	3.63	29.08	3.94	0.00	47.86	0.00	25.41	0.98	22.92	1.24	0.00	483.27
Apr	41.19	3.08	28.13	3.82	0.00	22.74	0.00	24.30	3.17	20.71	0.61	0.00	428.42
May	42.56	2.83	29.07	3.94	0.00	7.42	0.00	25.42	8.83	20.77	0.39	0.00	429.77
Jun	41.19	2.64	28.14	3.82	0.00	1.27	0.00	25.06	17.81	21.56	0.44	0.00	465.79
Jul	42.56	2.67	29.07	3.94	0.00	0.24	0.00	25.74	35.89	24.91	0.82	0.00	518.29
Aug	42.56	2.93	29.07	3.94	0.00	0.01	0.00	25.62	35.49	24.88	0.80	0.00	496.37
Sep	41.19	3.26	28.14	3.82	0.00	2.05	0.00	24.77	17.23	21.59	0.45	0.00	492.05
Oct	42.56	4.00	29.07	3.94	0.00	25.55	0.00	25.31	1.37	21.73	0.72	0.00	459.34
Nov	41.19	4.36	28.14	3.82	0.00	61.66	0.00	24.46	0.25	22.95	1.82	0.00	571.97
Dec	42.56	4.84	29.07	3.94	0.00	86.10	0.00	24.92	0.11	24.49	2.71	0.00	601.47
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**401.00**	**0.00**	**299.25**	**121.47**	**272.53**	**14.27**	**0.00**	**601.47**

Table D.6: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 5

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	144.39	0.00	45.58	0.05	24.40	1.62	0.00	840.23
Feb	38.44	3.69	26.26	3.56	0.00	108.25	0.00	41.81	0.08	21.61	1.40	0.00	771.84
Mar	42.56	3.63	29.08	3.94	0.00	83.39	0.00	46.42	0.37	22.92	1.37	0.00	713.37
Apr	41.19	3.08	28.13	3.82	0.00	36.79	0.00	43.84	1.55	20.71	0.78	0.00	636.36
May	42.56	2.83	29.07	3.94	0.00	11.34	0.00	45.58	5.20	20.77	0.68	0.00	515.21
Jun	41.19	2.64	28.14	3.82	0.00	3.68	0.00	44.88	10.64	21.56	1.34	0.00	480.64
Jul	42.56	2.67	29.07	3.94	0.00	1.46	0.00	46.11	21.09	24.91	1.74	0.00	511.51
Aug	42.56	2.93	29.07	3.94	0.00	1.21	0.00	45.90	20.69	24.89	1.75	0.00	499.80
Sep	41.19	3.26	28.14	3.82	0.00	4.12	0.00	44.36	10.24	21.59	1.23	0.00	497.67
Oct	42.56	4.00	29.07	3.94	0.00	46.05	0.00	45.58	0.61	21.73	1.12	0.00	663.89
Nov	41.19	4.36	28.14	3.82	0.00	109.55	0.00	44.36	0.09	22.95	1.54	0.00	811.29
Dec	42.56	4.84	29.07	3.94	0.00	150.64	0.00	45.37	0.04	24.48	1.60	0.00	847.47
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**700.88**	**0.00**	**539.79**	**70.67**	**272.52**	**16.19**	**0.00**	**847.47**

Table D.7: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 6

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	105.50	0.00	26.63	0.06	24.40	1.62	0.00	621.57
Feb	38.44	3.69	26.26	3.56	0.00	80.89	0.00	24.26	0.11	21.61	1.40	0.00	577.60
Mar	42.56	3.63	29.08	3.94	0.00	64.54	0.00	26.92	0.52	22.92	1.37	0.00	515.60
Apr	41.19	3.08	28.13	3.82	0.00	33.46	0.00	24.03	2.93	20.71	0.78	0.00	468.85
May	42.56	2.83	29.07	3.94	0.00	13.76	0.00	19.44	10.39	20.77	0.68	0.00	393.55
Jun	41.19	2.64	28.14	3.82	0.00	4.50	0.00	12.65	22.54	21.56	1.34	0.00	452.91
Jul	42.56	2.67	29.07	3.94	0.00	1.72	0.00	7.38	45.46	24.91	1.74	0.00	523.72
Aug	42.56	2.93	29.07	3.94	0.00	1.43	0.00	7.57	44.62	24.89	1.75	0.00	492.51
Sep	41.19	3.26	28.14	3.82	0.00	5.26	0.00	12.98	21.55	21.59	1.23	0.00	494.61
Oct	42.56	4.00	29.07	3.94	0.00	36.55	0.00	26.45	1.09	21.73	1.12	0.00	494.80
Nov	41.19	4.36	28.14	3.82	0.00	80.20	0.00	25.91	0.12	22.95	1.54	0.00	601.45
Dec	42.56	4.84	29.07	3.94	0.00	109.36	0.00	26.32	0.05	24.48	1.60	0.00	626.13
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**537.18**	**0.00**	**240.56**	**149.43**	**272.52**	**16.19**	**0.00**	**626.13**

Table D.8: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 7

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	84.82	0.00	23.04	0.13	24.41	0.02	0.00	582.69
Feb	38.44	3.69	26.26	3.56	0.00	63.29	0.00	20.73	0.23	21.61	0.03	0.00	536.15
Mar	42.56	3.63	29.08	3.94	0.00	48.96	0.00	22.19	1.01	22.92	0.11	0.00	473.66
Apr	41.19	3.08	28.13	3.82	0.00	23.68	0.00	18.87	3.25	20.71	0.28	0.00	418.31
May	42.56	2.83	29.07	3.94	0.00	8.29	0.00	14.71	9.05	20.77	0.77	0.00	365.71
Jun	41.19	2.64	28.14	3.82	0.00	1.91	0.00	9.60	18.13	21.56	1.29	0.00	389.01
Jul	42.56	2.67	29.07	3.94	0.00	0.47	0.00	4.32	36.19	24.91	2.19	0.00	435.67
Aug	42.56	2.93	29.07	3.94	0.00	0.29	0.00	4.50	35.84	24.88	2.16	0.00	416.38
Sep	41.19	3.26	28.14	3.82	0.00	2.62	0.00	9.54	17.54	21.59	1.28	0.00	412.75
Oct	42.56	4.00	29.07	3.94	0.00	26.33	0.00	21.68	1.40	21.73	0.13	0.00	448.47
Nov	41.19	4.36	28.14	3.82	0.00	62.55	0.00	22.15	0.26	22.95	0.03	0.00	559.73
Dec	42.56	4.84	29.07	3.94	0.00	87.29	0.00	22.66	0.11	24.49	0.02	0.00	589.10
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**410.51**	**0.00**	**193.99**	**123.14**	**272.53**	**8.30**	**0.00**	**589.10**

Table D.9: Monthly Energy Use Breakdown and Peak Demand

HIGH-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 8

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	42.56	4.63	29.07	3.94	0.00	81.47	0.00	45.59	0.09	24.40	0.00	0.00	564.01
Feb	38.44	3.69	26.26	3.56	0.00	62.60	0.00	41.81	0.18	21.61	0.00	0.00	546.57
Mar	42.56	3.63	29.08	3.94	0.00	50.59	0.00	46.42	0.89	22.92	0.00	0.00	506.17
Apr	41.19	3.08	28.13	3.82	0.00	27.21	0.00	43.84	2.87	20.71	0.00	0.00	479.86
May	42.56	2.83	29.07	3.94	0.00	12.01	0.00	45.59	8.28	20.77	0.00	0.00	459.56
Jun	41.19	2.64	28.14	3.82	0.00	3.97	0.00	44.88	16.44	21.56	0.00	0.00	491.90
Jul	42.56	2.67	29.07	3.94	0.00	1.52	0.00	46.11	30.80	24.91	0.00	0.00	532.27
Aug	42.56	2.93	29.07	3.94	0.00	1.25	0.00	45.90	30.46	24.88	0.00	0.00	513.14
Sep	41.19	3.26	28.14	3.82	0.00	4.68	0.00	44.36	15.82	21.59	0.00	0.00	511.81
Oct	42.56	4.00	29.07	3.94	0.00	28.43	0.00	45.59	1.28	21.73	0.00	0.00	493.76
Nov	41.19	4.36	28.14	3.82	0.00	61.62	0.00	44.36	0.18	22.95	0.00	0.00	556.76
Dec	42.56	4.84	29.07	3.94	0.00	84.03	0.00	45.37	0.08	24.48	0.00	0.00	565.78
Annual	**501.14**	**42.55**	**342.31**	**46.43**	**0.00**	**419.38**	**0.00**	**539.80**	**107.36**	**272.51**	**0.00**	**0.00**	**565.78**

Table D.10: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING BASELINE 1

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	9.69	28.77	19.15	0	0	7.51	0	92.02	200.71
Feb	15.75	1.79	12.70	1.78	8.16	20.47	17.56	0	0	6.79	0	87.53	178.76
Mar	17.44	1.76	14.06	1.97	7.64	13.10	19.50	0	0	7.51	0	86.41	154.55
Apr	16.88	1.49	13.60	1.91	5.50	3.44	18.41	0	0	7.27	0	81.95	126.03
May	17.44	1.37	14.05	1.97	3.51	0.64	19.15	0	0	7.51	0	84.36	113.92
Jun	16.88	1.28	13.61	1.91	1.50	0.08	18.85	0	0	7.27	0	81.60	112.60
Jul	17.44	1.29	14.06	1.97	0.64	0.01	19.37	0	0	7.51	0	75.98	112.32
Aug	17.44	1.42	14.06	1.97	0.53	0.00	19.28	0	0	7.51	0	75.97	112.30
Sep	16.88	1.58	13.60	1.91	1.54	0.24	18.63	0	0	7.27	0	79.41	113.71
Oct	17.44	1.94	14.05	1.97	5.11	5.25	19.15	0	0	7.51	0	82.61	135.15
Nov	16.88	2.11	13.60	1.91	8.12	19.37	18.63	0	0	7.27	0	89.62	188.29
Dec	17.44	2.35	14.05	1.97	9.91	30.72	19.06	0	0	7.51	0	89.93	193.97
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**61.86**	**122.08**	**226.71**	**0**	**0**	**88.47**	**0**	**92.02**	**200.71**

Table D.11: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 1

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	37.88	0	18.00	0	7.51	0	0	268.69
Feb	15.75	1.79	12.70	1.78	0	28.14	0	16.51	0	6.79	0	0	251.21
Mar	17.44	1.76	14.06	1.97	0	20.28	0	18.33	0	7.51	0	0	215.72
Apr	16.88	1.49	13.60	1.91	0	8.60	0	17.31	0	7.27	0	0	193.06
May	17.44	1.37	14.05	1.97	0	3.94	0	18.00	0	7.51	0	0	175.05
Jun	16.88	1.28	13.61	1.91	0	1.49	0	17.72	0	7.27	0	0	172.19
Jul	17.44	1.29	14.06	1.97	0	0.61	0	18.20	0	7.51	0	0	169.01
Aug	17.44	1.42	14.06	1.97	0	0.50	0	18.12	0	7.51	0	0	167.84
Sep	16.88	1.58	13.60	1.91	0	1.69	0	17.51	0	7.27	0	0	172.10
Oct	17.44	1.94	14.05	1.97	0	10.06	0	18.00	0	7.51	0	0	200.38
Nov	16.88	2.11	13.60	1.91	0	27.00	0	17.51	0	7.27	0	0	261.81
Dec	17.44	2.35	14.05	1.97	0	40.04	0	17.91	0	7.51	0	0	268.98
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**180.23**	**0**	**213.11**	**0**	**88.47**	**0**	**0**	**268.98**

Table D.12: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 2

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	37.88	0	8.84	0	7.51	0	0	245.27
Feb	15.75	1.79	12.70	1.78	0	28.14	0	7.94	0	6.79	0	0	227.49
Mar	17.44	1.76	14.06	1.97	0	20.28	0	8.31	0	7.51	0	0	192.44
Apr	16.88	1.49	13.60	1.91	0	8.60	0	7.37	0	7.27	0	0	164.40
May	17.44	1.37	14.05	1.97	0	3.94	0	7.27	0	7.51	0	0	142.78
Jun	16.88	1.28	13.61	1.91	0	1.49	0	6.88	0	7.27	0	0	139.09
Jul	17.44	1.29	14.06	1.97	0	0.61	0	6.81	0	7.51	0	0	135.09
Aug	17.44	1.42	14.06	1.97	0	0.50	0	6.78	0	7.51	0	0	133.22
Sep	16.88	1.58	13.60	1.91	0	1.69	0	6.79	0	7.27	0	0	138.66
Oct	17.44	1.94	14.05	1.97	0	10.06	0	7.59	0	7.51	0	0	172.98
Nov	16.88	2.11	13.60	1.91	0	27.00	0	8.27	0	7.27	0	0	238.49
Dec	17.44	2.35	14.05	1.97	0	40.04	0	8.92	0	7.51	0	0	245.50
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**180.23**	**0**	**91.78**	**0**	**88.47**	**0**	**0**	**245.50**

Table D.13: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 9

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	37.88	0	18.00	0	7.51	0	0	268.69
Feb	15.75	1.79	12.70	1.78	0	28.14	0	16.51	0	6.79	0	0	251.21
Mar	17.44	1.76	14.06	1.97	0	20.28	0	18.33	0	7.51	0	0	215.72
Apr	16.88	1.49	13.60	1.91	0	8.60	0	17.31	0	7.27	0	0	193.06
May	17.44	1.37	14.05	1.97	0	3.94	0	18.00	0	7.51	0	0	175.05
Jun	16.88	1.28	13.61	1.91	0	1.49	0	17.72	0	7.27	0	0	172.19
Jul	17.44	1.29	14.06	1.97	0	0.61	0	18.20	0	7.51	0	0	169.01
Aug	17.44	1.42	14.06	1.97	0	0.50	0	18.12	0	7.51	0	0	167.84
Sep	16.88	1.58	13.60	1.91	0	1.69	0	17.51	0	7.27	0	0	172.10
Oct	17.44	1.94	14.05	1.97	0	10.06	0	18.00	0	7.51	0	0	200.38
Nov	16.88	2.11	13.60	1.91	0	27.00	0	17.51	0	7.27	0	0	261.81
Dec	17.44	2.35	14.05	1.97	0	40.04	0	17.91	0	7.51	0	0	268.98
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**180.23**	**0**	**213.11**	**0**	**88.47**	**0**	**0**	**268.98**

Table D.15: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING BASELINE 2

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	22.46	19.15	0	0.00	9.58	0.62	75.97	187.13
Feb	15.75	1.79	12.70	1.78	0	15.95	17.56	0	0.03	8.43	0.44	75.97	164.86
Mar	17.44	1.76	14.06	1.97	0	10.31	19.50	0	0.26	8.98	0.33	75.97	145.95
Apr	16.88	1.49	13.60	1.91	0	2.79	18.41	0	1.29	8.64	0.27	75.97	131.02
May	17.44	1.37	14.05	1.97	0	0.50	19.15	0	2.93	9.47	0.36	75.97	134.66
Jun	16.88	1.28	13.61	1.91	0	0.04	18.85	0	4.43	9.85	0.42	75.97	152.44
Jul	17.44	1.29	14.06	1.97	0	0.02	19.37	0	7.84	10.82	0.57	75.97	169.73
Aug	17.44	1.42	14.06	1.97	0	0.01	19.28	0	7.70	10.87	0.56	75.97	157.97
Sep	16.88	1.58	13.60	1.91	0	0.05	18.63	0	4.15	9.73	0.40	75.97	153.85
Oct	17.44	1.94	14.05	1.97	0	3.52	19.15	0	0.67	8.77	0.23	75.97	130.76
Nov	16.88	2.11	13.60	1.91	0	14.68	18.63	0	0.02	8.96	0.44	75.97	172.50
Dec	17.44	2.35	14.05	1.97	0	23.58	19.06	0	0	9.66	0.66	75.97	178.44
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**93.91**	**226.71**	**0**	**29.32**	**113.77**	**5.29**	**75.97**	**187.13**

Table D.14: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 3

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	22.46	0	8.84	0.00	9.58	0.62	0	211.43
Feb	15.75	1.79	12.70	1.78	0	15.95	0	7.94	0.03	8.43	0.44	0	196.68
Mar	17.44	1.76	14.06	1.97	0	10.31	0	8.31	0.26	8.98	0.33	0	167.94
Apr	16.88	1.49	13.60	1.91	0	2.79	0	7.37	1.29	8.64	0.27	0	149.27
May	17.44	1.37	14.05	1.97	0	0.50	0	7.27	2.93	9.47	0.36	0	155.68
Jun	16.88	1.28	13.61	1.91	0	0.04	0	6.88	4.43	9.85	0.42	0	172.24
Jul	17.44	1.29	14.06	1.97	0	0.02	0	6.81	7.84	10.82	0.57	0	188.51
Aug	17.44	1.42	14.06	1.97	0	0.01	0	6.78	7.70	10.87	0.56	0	177.34
Sep	16.88	1.58	13.60	1.91	0	0.05	0	6.79	4.15	9.73	0.40	0	172.99
Oct	17.44	1.94	14.05	1.97	0	3.52	0	7.59	0.67	8.77	0.23	0	155.72
Nov	16.88	2.11	13.60	1.91	0	14.68	0	8.27	0.02	8.96	0.44	0	204.71
Dec	17.44	2.35	14.05	1.97	0	23.58	0	8.92	0	9.66	0.66	0	210.52
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**93.91**	**0**	**91.78**	**29.32**	**113.77**	**5.29**	**0**	**211.43**

Table D.16: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 4

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	22.46	0	11.07	0.00	9.58	0.62	0	212.26
Feb	15.75	1.79	12.70	1.78	0	15.95	0	9.81	0.03	8.43	0.44	0	197.50
Mar	17.44	1.76	14.06	1.97	0	10.31	0	9.56	0.26	8.98	0.33	0	168.51
Apr	16.88	1.49	13.60	1.91	0	2.79	0	7.14	1.29	8.64	0.27	0	149.88
May	17.44	1.37	14.05	1.97	0	0.50	0	5.82	2.93	9.47	0.36	0	156.23
Jun	16.88	1.28	13.61	1.91	0	0.04	0	5.25	4.43	9.85	0.42	0	172.75
Jul	17.44	1.29	14.06	1.97	0	0.02	0	5.68	7.84	10.82	0.57	0	188.99
Aug	17.44	1.42	14.06	1.97	0	0.01	0	5.68	7.70	10.87	0.56	0	177.84
Sep	16.88	1.58	13.60	1.91	0	0.05	0	5.28	4.15	9.73	0.40	0	173.49
Oct	17.44	1.94	14.05	1.97	0	3.52	0	7.49	0.67	8.77	0.23	0	156.37
Nov	16.88	2.11	13.60	1.91	0	14.68	0	10.08	0.02	8.96	0.44	0	205.54
Dec	17.44	2.35	14.05	1.97	0	23.58	0	11.28	0	9.66	0.66	0	211.35
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**93.91**	**0**	**94.16**	**29.32**	**113.77**	**5.29**	**0**	**212.26**

Table D.17: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 5

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	27.76	0	18.00	0.00	9.58	0.47	0	237.70
Feb	15.75	1.79	12.70	1.78	0	20.94	0	16.51	0.02	8.43	0.30	0	222.72
Mar	17.44	1.76	14.06	1.97	0	15.61	0	18.33	0.24	8.98	0.20	0	199.47
Apr	16.88	1.49	13.60	1.91	0	7.23	0	17.31	1.23	8.64	0.17	0	189.22
May	17.44	1.37	14.05	1.97	0	3.84	0	18.00	2.81	9.47	0.34	0	193.89
Jun	16.88	1.28	13.61	1.91	0	1.62	0	17.72	4.49	9.85	0.55	0	209.03
Jul	17.44	1.29	14.06	1.97	0	0.69	0	18.20	8.32	10.82	1.04	0	219.98
Aug	17.44	1.42	14.06	1.97	0	0.58	0	18.12	8.20	10.87	1.02	0	212.65
Sep	16.88	1.58	13.60	1.91	0	1.67	0	17.51	4.14	9.73	0.51	0	208.36
Oct	17.44	1.94	14.05	1.97	0	7.54	0	18.00	0.59	8.77	0.12	0	193.10
Nov	16.88	2.11	13.60	1.91	0	19.66	0	17.51	0.03	8.96	0.31	0	230.56
Dec	17.44	2.35	14.05	1.97	0	28.96	0	17.91	0	9.66	0.51	0	237.47
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**136.09**	**0**	**213.11**	**30.08**	**113.77**	**5.55**	**0**	**237.70**

Table D.18: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 6

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	33.44	0	10.73	0.00	9.58	0.48	0	237.93
Feb	15.75	1.79	12.70	1.78	0	25.07	0	9.77	0.02	8.43	0.42	0	220.79
Mar	17.44	1.76	14.06	1.97	0	18.28	0	10.88	0.24	8.98	0.34	0	189.53
Apr	16.88	1.49	13.60	1.91	0	8.02	0	9.77	1.89	8.64	0.30	0	170.56
May	17.44	1.37	14.05	1.97	0	4.01	0	6.88	6.54	9.47	0.52	0	168.94
Jun	16.88	1.28	13.61	1.91	0	1.63	0	4.50	11.33	9.85	0.53	0	200.73
Jul	17.44	1.29	14.06	1.97	0	0.69	0	2.66	21.18	10.83	0.55	0	224.02
Aug	17.44	1.42	14.06	1.97	0	0.58	0	2.50	20.87	10.88	0.55	0	210.53
Sep	16.88	1.58	13.60	1.91	0	1.72	0	4.45	10.62	9.74	0.53	0	204.07
Oct	17.44	1.94	14.05	1.97	0	8.88	0	10.78	0.71	8.77	0.29	0	176.54
Nov	16.88	2.11	13.60	1.91	0	23.80	0	10.44	0.01	8.96	0.44	0	229.82
Dec	17.44	2.35	14.05	1.97	0	34.99	0	10.60	0	9.66	0.48	0	237.49
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**161.09**	**0**	**93.95**	**73.39**	**113.78**	**5.42**	**0**	**237.93**

Table D.19: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 7

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0	22.47	0	6.36	0.00	9.58	0.93	0	205.42
Feb	15.75	1.79	12.70	1.78	0	15.96	0	5.62	0.03	8.43	0.79	0	189.93
Mar	17.44	1.76	14.06	1.97	0	10.41	0	5.52	0.26	8.98	0.8	0	163.06
Apr	16.88	1.49	13.60	1.91	0	3.15	0	4.23	1.29	8.64	0.78	0	142.31
May	17.44	1.37	14.05	1.97	0	0.88	0	3.61	2.93	9.47	0.90	0	147.19
Jun	16.88	1.28	13.61	1.91	0	0.22	0	3.28	4.43	9.85	0.97	0	163.52
Jul	17.44	1.29	14.06	1.97	0	0.09	0	3.30	7.84	10.82	1.13	0	179.97
Aug	17.44	1.42	14.06	1.97	0	0.07	0	3.27	7.70	10.87	1.12	0	168.75
Sep	16.88	1.58	13.60	1.91	0	0.26	0	3.28	4.15	9.73	0.94	0	164.97
Oct	17.44	1.94	14.05	1.97	0	3.76	0	4.52	0.67	8.77	0.74	0	148.73
Nov	16.88	2.11	13.60	1.91	0	14.70	0	5.78	0.02	8.96	0.82	0	198.36
Dec	17.44	2.35	14.05	1.97	0	23.60	0	6.48	0	9.66	0.95	0	204.72
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0**	**95.55**	**0**	**55.27**	**29.32**	**113.77**	**10.86**	**0**	**205.42**

Table D.20: Monthly Energy Use Breakdown and Peak Demand

LOW-RISE RESIDENTIAL BUILDING ZERO EMISSION OPTION 8

Date	Interior Lighting (MWh)	Exterior Lighting (MWh)	Receptacle Equipment (MWh)	Elevators & Escalators (MWh)	Space Heating - Natural Gas (MWh)	Space Heating - Electricity (MWh)	Service Water Heating - Natural Gas (MWh)	Service Water Heating - Electricity (MWh)	Space Cooling (MWh)	Fans (MWh)	Pumps (MWh)	Peak Gas Demand (kW)	Peak Electricity Demand (kW)
Jan	17.44	2.24	14.05	1.97	0.13	24.63	0	18.00	0	9.67	0	0	234.88
Feb	15.75	1.79	12.70	1.78	0.02	18.71	0	16.51	0.03	8.53	0	0	221.08
Mar	17.44	1.76	14.06	1.97	0.00	14.11	0	18.33	0.37	9.07	0	0	200.90
Apr	16.88	1.49	13.60	1.91	0	6.79	0	17.31	2.09	8.71	0	0	194.51
May	17.44	1.37	14.05	1.97	0	3.49	0	18.00	5.42	9.54	0	0	201.46
Jun	16.88	1.28	13.61	1.91	0	1.42	0	17.72	8.50	9.94	0	0	216.95
Jul	17.44	1.29	14.06	1.97	0	0.60	0	18.20	13.71	10.96	0	0	230.37
Aug	17.44	1.42	14.06	1.97	0	0.50	0	18.12	13.74	11.02	0	0	221.63
Sep	16.88	1.58	13.60	1.91	0	1.49	0	17.51	7.95	9.82	0	0	217.54
Oct	17.44	1.94	14.05	1.97	0	7.10	0	18.00	0.99	8.84	0	0	194.20
Nov	16.88	2.11	13.60	1.91	0.03	17.65	0	17.51	0.02	9.05	0	0	229.71
Dec	17.44	2.35	14.05	1.97	0.06	25.82	0	17.91	0	9.75	0	0	237.17
Annual	**205.34**	**20.62**	**165.50**	**23.21**	**0.24**	**122.30**	**0**	**213.11**	**52.81**	**114.90**	**0**	**0**	**237.17**

Table D.21: Monthly Energy Use Breakdown and Peak Demand

APPENDIX E

COSTING DETAILS

HIGH-RISE BASELINE 1

Electric baseboard heating with gas-fired hot water production and corridor ventilation system.

COV High Rise Rezoning Policy 2021
Cost Analysis
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Cost Breakdown

Description			Quantity	Unit	Rate	Amount
B1) Electrical Baseboard, Gas-Fired Ventilation + Gas-Fired DHWT (HEATING ONLY)						
Mechanical						**2,161,300**
Ventilation			**249,431.00**	**sf**	**7.77**	**1,938,900.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(gas)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water (limit piping in mechanical room)			**249,431.00**	**sf**	**0.89**	**222,400.00**
Domestic Hot Water Heater 1	119Gal	500 MBH (Input)				
Domestic Hot Water Heater 2	119Gal	500 MBH (Input)				
Domestic Hot Water Heater 3	119Gal	500 MBH (Input)				
Allow gas piping						
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						**905,500**
Services and Distribution			**249,431.00**	**sf**	**1.49**	**372,300.00**
Transformer	2000kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	2500A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Terminal Units			**314.00**	**unit**	**1,216.56**	**382,000.00**
Studio Elec Baseboard(Typ)	Elec Baseboard	1.5KW * 1 (1ph / 208)				
One-Bed Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 1 (1ph / 208) 1.5 KW * 1 (1ph / 208)				
Two-Beds Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 2 (1ph / 208) 1 KW * 2 (1ph / 208)				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**249,431.00**	**sf**	**0.61**	**151,200.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(gas)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water Heater 1	119Gal	120V/15A				
Domestic Hot Water Heater 2	119Gal	120V/15A				
Domestic Hot Water Heater 3	119Gal	120V/15A				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)					
Allowance for cabling and conduit						
Architectural and Structural						**344,800**
Mechanical room	None					
Water room	300 SF					
Mechanical outdoor area	None					
Electrical room	780 SF					
Generator room	299 SF					
TOTAL COST						3,411,600.00

HIGH-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

COV High Rise Rezoning Policy 2021
Cost Analysis
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Cost Breakdown

Description			Quantity	Unit	Rate	Amount
1. Electric baseboard heating with a centralized electrical resistance boiler for Domestic Hot Water production						
Mechanical						2,148,500
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	0.86	214,600.00
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						986,200
Services and Distributions			249,431.00	sf	1.71	427,100.00
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Terminal Units			314.00	unit	1,300.00	408,200.00
Studio Elec Baseboard(Typ)	Elec Baseboard	1.5KW * 1 (1ph / 208)				
One-Bed Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 1 (1ph / 208) 1.5 KW * 1 (1ph / 208)				
Two-Beds Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 2 (1ph / 208) 1 KW * 2 (1ph / 208)				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			249,431.00	sf	0.60	150,900.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Allowance for cabling and conduit						
Architectural and Structural						349,800
Mechanical room	None					
Water room	300 SF					
Mechanical outdoor area	0 SF					
Electrical room	800 SF					
Generator room	299 SF					
TOTAL COST						3,484,500.00

HIGH-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 10% increase in airflow.

COV High Rise Rezoning Policy 2021
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Cost Breakdown

Description			Quantity	Unit	Rate	Amount
1a. Electric baseboard heating with a centralized electrical resistance boiler for Domestic Hot Water production Partial Cooling						
Mechanical						**2,390,500**
Ventilation			**249,431**	**sf**	**6.60**	**1,646,500**
Centralized HRV	13,300 CFM					
Corridor Make-up air unit(electric)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Fire smoke dampers			**249,431**	**sf**	**1.21**	**301,900.00**
Fire smoke dampers						
Domestic Hot Water (limit piping in mechanical room)			**249,431**	**sf**	**0.86**	**214,600.00**
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Partial Cooling			**249,431**	**sf**	**0.91**	**227,500.00**
DX Cool in centralized HRV	65 Tons					
Electrical						**974,700**
Services and Distribution			**249,431**	**sf**	**1.71**	**427,100.00**
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Terminal Units			**314**	**unit**	**1,300.00**	**408,200.00**
Studio Elec Baseboard(Typ)	Elec Baseboard	1.5KW * 1 (1ph / 208)				
One-Bed Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 1 (1ph / 208) 1.5 KW * 1 (1ph / 208)				
Two-Beds Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 2 (1ph / 208) 1 KW * 2 (1ph / 208)				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**249,431**	**sf**	**0.10**	**24,400.00**
DX Cool in centralized HRV	65 Tons					
Centralized HRV	13,300 CFM					
Corridor Make-up air unit(elect)	7,000 CFM	105 kW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Allowance for cabling and conduit						
Fire smoke devices into FACP			**249,431**	**sf**	**0.46**	**115,000.00**
Fire smoke devices into FACP						
Architectural and Structural						**569,800**
Water room	300 SF					
Mechanical outdoor area	800 SF					
Electrical room	800 SF					
Generator room	299 SF					
Shaft Risers	24SF x 28 Floors					
TOTAL COST						3,935,000

HIGH-RISE ZERO EMISSION OPTION 2

Electric baseboard heating with an Air-Source Heat Pump (ASHP) domestic hot water production system and electric resistance heating for the corridor ventilation system.

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Cost Analysis
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Cost Breakdown

Description			Quanity	Unit	Rate	Amount
2. Electric baseboard heating with an air-source heat pump domestic hot water system						
Mechanical						**2,301,400**
Ventilation			**249,431.00**	**sf**	**7.75**	**1,933,900.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	7,000 CFM	105 KW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water (limit piping in mechanical room)			**249,431.00**	**sf**	**1.47**	**367,500.00**
Domestic Hot Water Tank 1	900 Gal	-				
Domestic Hot Water Tank 2	900 Gal	-				
Domestic Hot Water Tank 3	900 Gal	-				
Domestic Hot Water Tank 4	900 Gal	-				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRK0600	62.2 kW (3ph / 460)				
Electrical						**985,600**
Services and Distributions			**249,431.00**	**sf**	**1.71**	**427,100.00**
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Terminal Units			**314.00**	**unit**	**1300.00**	**408,200.00**
Studio Elec Baseboard(Typ)	Elec Baseboard	1.5KW * 1 (1ph / 208)				
One-Bed Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 1 (1ph / 208) 1.5 KW * 1 (1ph / 208)				
Two-Beds Elec Baseboard(Typ)	Elec Baseboard	0.5KW * 2 (1ph / 208) 1 KW * 2 (1ph / 208)				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**249,431.00**	**sf**	**0.60**	**150,300.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	7,000 CFM	105 KW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRK0600	62.2 kW (3ph / 460)				
Allowance for cabling and conduit						
Architectural and Structural						**429,800**
Mechanical room	None					
Water room	300 SF					
Mechanical outdoor area	800 SF					
Electrical room	800 SF					
Generator room	299 SF					
TOTAL COST						3,716,800.00

HIGH-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.

COV High Rise Rezoning Policy 2021
Cost Analysis
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Cost Breakdown

Description			Quantity	Unit	Rate	Amount
B2) 4-pipe Air-source heating/cooling system (consisting of ASHP, Electric Boiler) + Gas-Fired DHWT						
Mechanical						**6,401,500**
Central Plant			249,431.00	sf	4.15	1,034,000.00
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Expansion Tank 1						
Air Seperator 1						
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Expansion Tank 2						
Air Seperator 2						
Buffer Tank 1						
Buffer Tank 2						
Terminal Units			314.00	unit	10,226.75	3,211,200.00
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM					
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	0.89	222,400.00
Domestic Hot Water Heater 1	119Gal	500 MBH (Input)				
Domestic Hot Water Heater 2	119Gal	500 MBH (Input)				
Domestic Hot Water Heater 3	119Gal					
Allow gas piping						
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						**783,000**
Services and Distribution			249,431.00	sf	1.71	427,100.00
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			249,431.00	sf	1.43	355,900.00
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water Heater 1	119Gal	120V/15A				
Domestic Hot Water Heater 2	119Gal	120V/15A				
Domestic Hot Water Heater 3	119Gal	120V/15A				
Allowance for cabling and conduit						
Architectural and Structural						**634,800**
Mechanical room	500 SF					
Water room	300 SF					
Mechanical outdoor area	1600 SF					
Electrical room	800 SF					
Generator room	299 SF					
TOTAL COST						7,819,300.00

HIGH-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP Domestic hot water production system and hydronic heating for the corridor ventilation system.

COV High Rise Rezoning Policy 2021
Cost Analysis
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Cost Breakdown

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Description			Quantity	Unit	Rate	Amount
3. 4-pipe Air-source heating/cooling system (consisting of ASHP, Electric Boiler), and a dedicated air-source heat pump domestic hot water system						
Mechanical						6,546,600
Central Plant			249,431.00	sf	4.15	1,034,000.00
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Expansion Tank 1						
Air Seperator 1						
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Expansion Tank 2						
Air Seperator 2						
Buffer Tank 1						
Buffer Tank 2						
Terminal Units			314.00	unit	10,226.75	3,211,200.00
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM					
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	1.47	367,500.00
Domestic Hot Water Tank 1	900 Gal	-				
Domestic Hot Water Tank 2	900 Gal	-				
Domestic Hot Water Tank 3	900 Gal	-				
Domestic Hot Water Tank 4	900 Gal	-				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRK0600	62.2 kW (3ph / 460)				
Electrical						827,200
Services and Diistribution			249,431.00	sf	1.87	467,100.00
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			249,431.00	sf	1.44	360,100.00
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRK0600	62.2 kW (3ph / 460)				
Allowance for cabling and conduit						
Architectural and Structural						634,800
Mechanical room	500 SF					
Water room	300 SF					
Mechanical outdoor area	1600 SF					
Electrical room	800 SF					
Generator room	299 SF					
TOTAL COST						8,008,600.00

HIGH-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

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Description			Quantity	Unit	Rate	Amount
4. 4-pipe Air-source heating/cooling system (consisting of ASHP, Electric Boiler), and electric resistance top up for domestic hot water production						
Mechanical						**6,546,600**
Central Plant			**249,431.00**	**sf**	**4.15**	**1,034,000.00**
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Expansion Tank 1						
Air Separator 1						
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Expansion Tank 2						
Air Separator 2						
Buffer Tank 1						
Buffer Tank 2						
Terminal Units			**314.00**	**unit**	**10226.75**	**3,211,200.00**
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Ventilation			**249,431.00**	**sf**	**7.75**	**1,933,900.00**
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM					
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water (limit piping in mechanical room)			**249,431.00**	**sf**	**1.47**	**367,500.00**
Domestic Hot Water Tank 1	900 Gal	-				
Domestic Hot Water Tank 2	900 Gal	-				
Domestic Hot Water Tank 3	900 Gal	-				
Domestic Hot Water Tank 4	900 Gal	-				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRL0750	60 kW (3ph / 460)				
Electrical						**787,200**
Services and Diistribution			**249,431.00**	**sf**	**1.71**	**427,100.00**
Transformer	2500kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	3000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			**249,431.00**	**sf**	**1.44**	**360,100.00**
Air-source Heat Pump	150 Tons & 1650MBH Htg					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRL0750	60 kW (3ph / 460)				
Allowance for cabling and conduit						
Architectural and Structural						**647,300**
Mechanical room	550 SF					
Water room	300 SF					
Mechanical outdoor area	1600 SF					
Electrical room	800 SF					
Generator room	299 SF					
TOTAL COST						7,981,100

HIGH-RISE ZERO EMISSION OPTION 5

Water-cooled variable refrigerant flow heating/cooling system (consisting of cooling tower and electric boilers) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description			Quantity	Unit	Rate	Amount
5. Water-cooled variable refrigerant flow heating/cooling system with a centralized electrical resistance boiler for Domestic Hot Water production						
Mechanical						**5,701,300**
Central Plant			249,431.00	sf	3.22	802,100.00
VRF Condensing Units	One condensing unit per floor	15.05KW *28 (3ph / 208)				
Electric Boiler	1,650 MBH Heating	479kW (3ph / 600)				
Cooling tower	150 Tons	15HP (3ph / 600)				
Ambient Loop pump 1	360 GPM (Duty)	20 HP (3ph / 600)				
Ambient Loop pump 2	360 GPM (Standby)	20 HP (3ph / 600)				
Terminal Units			314.00	unit	8572.93	2,691,900.00
Studio AC unit (typ)	Indoor AC unit(Ducted)	0.09 KW * 1 (1ph / 208)				
One-Bed AC unit (typ)	Indoor AC unit(Ducted)	0.09 KW * 1 (1ph / 208)				
Two-Beds AC unit (typ)	Indoor AC unit(Ducted)	0.17 KW * 1 (1ph / 208)				
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	7,000 CFM	105 KW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	1.10	273,400.00
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						**846,800**
Services and Distribution			249,431.00	sf	1.91	477,100.00
Transformer	3000kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	4000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			249,431.00	sf	1.48	369,700.00
VRF Condensing Units	One condensing unit per floor	15.05KW *28 (3ph / 208)				
Electric Boiler	1,650 MBH Heating	479kW (3ph / 600)				
Cooling tower	150 Tons	15HP (3ph / 600)				
Ambient Loop pump 1	360 GPM (Duty)	20 HP (3ph / 600)				
Ambient Loop pump 2	360 GPM (Standby)	20 HP (3ph / 600)				
Studio AC unit (typ)	Indoor AC unit(Ducted)	0.09 KW * 1 (1ph / 208)				
One-Bed AC unit (typ)	Indoor AC unit(Ducted)	0.09 KW * 1 (1ph / 208)				
Two-Beds AC unit (typ)	Indoor AC unit(Ducted)	0.17 KW * 1 (1ph / 208)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Allowance for cabling and conduit						
Architectural and Structural						**477,300**
Mechanical room	150 SF					
Water room	300 SF					
Mechanical outdoor area	800 SF					
Electrical room	840 SF					
Generator room	299 SF					
TOTAL COST						7,025,400

HIGH-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description			Quantity	Unit	Rate	Amount
6. 2-pipe heating/cooling system (consisting of ASHP and Electric back-up Boiler) with a centralized Water-to-Water heat Pump for Domestic Hot Water production						
Mechanical						**5,672,000**
Central Plant			**249,431.00**	**sf**	**3.92**	**979,000.00**
Air Source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (Full back-up)-TBD	1,650 MBH Heating					
Buffer tank	165 GPM (Duty)					
Air Separator	165 GPM (Stanby)					
Ambient Loop pump 1						
Ambient Loop pump 2						
Expansion Tank	360 GPM (Duty)					
	360 GPM (Standby)					
Terminal Units			**314.00**	**unit**	**7464.01**	**2,343,700.00**
Studio Heat Pump unit (typ)	Heat Pump Unit(Ducted)	1.1 KW * 1 (1ph / 208)				
One-Bed Heat Pump unit (typ)	Heat Pump Unit(Ducted)	1.1 KW * 1 (1ph / 208)				
Two-Beds Heat Pump unit (typ)	Heat Pump Unit(Ducted)	2.2 KW * 1 (1ph / 208)				
Ventilation			**249,431.00**	**sf**	**7.75**	**1,933,900.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	7,000 CFM	105 KW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Domestic Hot Water (limit piping in mechanical room)			**249,431.00**	**sf**	**1.67**	**415,400.00**
Domestic Hot Water Tank 1	750 Gal	-				
Domestic Hot Water Tank 2	750 Gal	-				
Domestic Hot Water Tank 3	750 Gal	-				
Domestic Hot Water Tank 4	750 Gal	-				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	Nyle C540WM	200 Amps(LRA) (3ph / 600)				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						**836,300**
Services and Distribution			**249,431.00**	**sf**	**1.91**	**477,100.00**
Transformer	3000kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	4000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			**249,431.00**	**sf**	**1.44**	**359,200.00**
Air Source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (Full back-up)-TBD	1,650 MBH Heating					
Ambient Loop pump 1	360 GPM (Duty)	20 HP (3ph / 600)				
Ambient Loop pump 2	360 GPM (Standby)	20 HP (3ph / 600)				
Studio Heat Pump unit (typ)	Heat Pump Unit(Ducted)	1.1 KW * 1 (1ph / 208)				
One-Bed Heat Pump unit (typ)	Heat Pump Unit(Ducted)	1.1 KW * 1 (1ph / 208)				
Two-Beds Heat Pump unit (typ)	Heat Pump Unit(Ducted)	2.2 KW * 1 (1ph / 208)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM	25 kW (3ph / 600)				
Parkade Stair Pressurization (per stair)	3,000 CFM	1kW (3ph / 600)				
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM	35kW (3ph / 600)				
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	Nyle C540WM	200 Amps(LRA) (3ph / 600)				
Allowance for cabling and conduit						
Architectural and Structural						**522,300**
Mechanical room	250 SF					
Water room	350 SF					
Mechanical outdoor area	800 SF					
Electrical room	840 SF					
Generator room	299 SF					
TOTAL COST						7,030,600

HIGH-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

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Description			Quantity	Unit	Rate	Amount
7. 4-pipe Air-source heating/cooling system + HX DHW Generation						
Mechanical						**6,309,100**
Central Plant			249,431.00	sf	4.15	1,034,000.00
Air source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Expansion Tank 1						
Air Seperator 1						
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Expansion Tank 2						
Air Seperator 2						
Buffer Tank 1						
Buffer Tank 2						
Terminal Units			314.00	unit	10226.75	3,211,200.00
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM					
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	0.52	130,000.00
Domestic Hot Water Tank 1	119 Gal					
Domestic Hot Water Tank 2	119 Gal					
Domestic Hot Water Tank 3	119 Gal					
Domestic Hot Water Tank 4	119 Gal					
Heat Exchanger	468kW - 160 GPM	-				
Domestic Expansion Tank						
Circulator Pump	160 GPM					
Electrical						**831,700**
Services and Distribution			249,431.00	sf	1.91	477,100.00
Transformer	3000kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	4000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			249,431.00	sf	1.42	354,600.00
Air-source Heat Pump	150 RT Cooling & 2,500 MBH Heating					
Electrical Boiler (back-up)	1,650 MBH Heating					
Heating Distribution Pump 1	165 GPM (Duty)					
Heating Distribution Pump 2	165 GPM (Stanby)					
Chilled Distribution Pump 1	360 GPM (Duty)					
Chilled Distribution Pump 2	360 GPM (Standby)					
Studio Fancoil unit (typ)	Fancoil unit(Ducted)					
One-Bed Fancoil unit (typ)	Fancoil unit(Ducted)					
Two-Beds Fancoil unit (typ)	Fancoil unit(Ducted)					
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(gas)	7,000 CFM	10HP (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Swing Tank	120 Gal	49 kW (3ph / 600)				
Heat Pumps	NRK0600	62.2 kW (3ph / 460)				
Allowance for cabling and conduit						
Architectural and Structural						**527,800**
Mechanical room	400 SF					
Water room	252 SF					
Mechanical outdoor area	800 SF					
Electrical room	840 SF					
Generator room	299 SF					
TOTAL COST						7,668,600.00

HIGH-RISE ZERO EMISSION OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description			Quantity	Unit	Rate	Amount
8. PTAC + Elec Resistant DHWT						
Mechanical						4,797,800
Terminal Units			314.00	unit	8,250.00	2,590,500.00
PTAC						
Ventilation			249,431.00	sf	7.75	1,933,900.00
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(Electric)	7,000 CFM					
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water (limit piping in mechanical room)			249,431.00	sf	1.10	273,400.00
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
Domestic Expansion Tank	90 Gal (24"DIA * 60" H)	-				
Electrical						815,900
Services and Distribution			249,431.00	sf	1.91	477,100.00
Transformer	3000kVA	Assumed copper, 25 kV – 600Y/347V, dry type				
Main distribution panel	4000A	Assumed 600/347V				
Generator	500kW	Assumed diesel type				
Disconnect switches for mech. Equipments			249,431.00	sf	1.36	338,800.00
Suite by suite Ventilation unit	100-150 CFM					
Corridor Make-up air unit(gas)	7,000 CFM	105 KW (3ph / 600)				
Parkade Ventilation (per level)	35,000 CFM					
Parkade Stair Pressurization (per stair)	3,000 CFM					
Parkade Vestibule Pressurization (inc. elec. Duct heater)	2,000 CFM					
Domestic Hot Water Heater 1	1250 Gal	234 kW (3ph / 208)				
Domestic Hot Water Heater 2	1250 Gal	234 kW (3ph / 208)				
PTAC						
Allowance for cabling and conduit						
Architectural and Structural						359,800
Mechanical room	None					
Water room	300 SF					
Mechanical outdoor area	None					
Electrical room	840 SF					
Generator room	299 SF					
TOTAL COST						5,973,500

LOW-RISE BASELINE 1

Electric baseboard heating with gas-fired hot water production and corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
B1) Electrical Baseboard, Gas-Fired Ventilation + Gas-Fired						
HVAC + DHWT						**716,300**
Ventilation			**103,072**	**sf**	**5.98**	**616,300.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(gas)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**0.97**	**100,000.00**
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)				
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)				
Allow gas piping						
Domestic Expansion Tank		-				
Electrical						**369,800**
Services and Distribution			**103,072**	**sf**	**1.88**	**194,000.00**
Transformer Size (kVA)		750kVA				
Main Distribution Panel (A)		1000A				
Generator Size (kW)		150kW				
Terminal Units			**110**	**unit**	**1,114.55**	**122,600.00**
Elec Baseboard		145 kW Total				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**103,072**	**sf**	**0.52**	**53,200.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(gas)	2,000 CFM					
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)				
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)				
Allowance for cabling and conduit						
Architectural and Structural						**252,300**
Mechanical Room	0 SF					
Water Room	135 SF					
Mechanical Outdoor Area	none					
Electrical Room	646 SF					
Generator Room	228 SF					
						1,338,400.00

LOW-RISE ZERO EMISSION OPTION 1

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
1) Electrical Baseboard + ELEC Resistant DHWT						
HVAC + DHWT						**714,400**
Ventilation			**103,072**	**sf**	**5.94**	**611,800.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit (Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**1.00**	**102,600.00**
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Expansion Tank		-				
Electrical						**417,100**
Services and Distribution			**103,072**	**sf**	**2.30**	**237,000.00**
Transformer Size (kVA)		1250kVA				
Main Distribution Panel (A)		1600 A				
Generator Size (kW)		150kW				
Terminal Units			**110**	**unit**	**1,114.55**	**122,600.00**
Elec Baseboard		145 kW Total				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**103,072**	**sf**	**0.56**	**57,500.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Allowance for cabling and conduit						
Architectural and Structural						**263,500**
Building Services area						
Mechanical Room	None					
Water Room	180 SF					
Mechanical Outdoor Area	None					
Electrical Room	646 SF					
Generator Room	228 SF					
						1,395,000.00

LOW-RISE ZERO EMISSION OPTION 1A

Electric baseboard heating with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system. Partial cooling is provided through a centralized HRV with a 15% increase in airflow.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
1a. Electric baseboard heating with a centralized electrical resistance boiler for Domestic Hot Water production Partial Cooling						
HVAC + DHWT						**759,100**
Ventilation			103,072	sf	4.98	513,800.00
Centralized HRV	30T					
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Fire smoke dampers			103,072	sf	0.75	77,700.00
Fire smoke dampers						
Domestic Hot Water			103,072	sf	1.00	102,600.00
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Expansion Tank		-				
Partial Cooling			103,072	sf	0.63	65,000.00
DX Cool in centralized HRV		575V, 70 MCA				
Electrical						**411,900**
Services and Distribution			103,072	sf	2.05	211,000.00
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200kVA				
Generator Size (kW)		150kW				
Terminal Units			110	unit	1,114.55	122,600.00
Elec Baseboard		145 kW Total				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			103,072	sf	0.33	33,900.00
DX Cool in centralized HRV						
Centralized HRV						
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Allowance for cabling and conduit						
Fire smoke dampers			103,072	sf	0.43	44,400.00
Fire smoke devices tie into FACP						
Architectural and Structural						**355,100**
Water Room	180 SF					
Mechanical Outdoor Area	646 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
Shaft Risers	24 SF x 6 FL					
						1,526,100.00

LOW-RISE ZERO EMISSION OPTION 2

Electric baseboard heating with an ASHP domestic hot water production system and electric resistance heating for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
2) Electrical Baseboard + ELEC Heat Pump DHWT						
HVAC + DHWT						**1,181,300**
Ventilation			**103,072**	**sf**	**5.94**	**611,800.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor MaKe-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**5.53**	**569,500.00**
Domestic Hot Water Tank 1	119 Gal	-				
Domestic Hot Water Tank 2	119 Gal	-				
Domestic Hot Water Tank 3	119 Gal	-				
Domestic Hot Water Tank 4	119 Gal	-				
Domestic Expansion Tank		-				
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)				
Electrical						**393,900**
Services and Distribution			**103,072**	**sf**	**2.05**	**211,000.00**
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Terminal Units			**110**	**unit**	**1,114.55**	**122,600.00**
Elec Baseboard		145 kW Total				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**103,072**	**sf**	**0.59**	**60,300.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)				
Allowance for cabling and conduit						
Architectural and Structural						**263,500**
Mechanical Room	None					
Water Room	180 SF					
Mechanical Outdoor Area	0 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						1,838,700.00

LOW-RISE ZERO EMISSION OPTION 9

Electric baseboard heating with in-suite electrical resistance domestic hot water tank and for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
9) Electrical Baseboard + Individual DHWT						
HVAC + DHWT						**743,800**
Ventilation			**103,072**	**sf**	**5.94**	**611,800.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**1.28**	**132,000.00**
Domestic Hot Water Tank	20Gal	4kW				
Electrical						**499,900**
Services and Distribution			**103,072**	**sf**	**2.30**	**237,000.00**
Transformer Size (kVA)		1250kVA				
Main Distribution Panel (A)		1600A				
Generator Size (kW)		150kW				
Terminal Units			**110**	**unit**	**1,114.55**	**122,600.00**
Elec Baseboard		145 kW Total				
Allowance for cabling and conduit						
Disconnect switches for mech. Equipments			**103,072**	**sf**	**1.36**	**140,300.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water	20 Gal	4kw Total				
Allowance for cabling and conduit						
Architectural and Structural						**364,100**
Building Services area						
DHWT Closet (assume 6sf per unit)	6SF x 110 unit					
Water Room	none					
Electrical Room	646 SF					
Generator Room	228 SF					
						1,607,800.00

LOW-RISE BASELINE 2

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler) and gas-fired hot water production and corridor ventilation.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
B2) 4-pipe Air-source heating/cooling system (consisting of ASHP, Electric Boiler) + Gas DHWT						
HVAC + DHWT						**2,126,200**
Central Plant			**103,072**	**sf**	**3.83**	**395,200.00**
Air-source Heat Pump	50 Tons	575V, 280 MCA				
Electrical Boiler		75 kW				
Electrical Boiler		75kW				
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Expansion Tank 1		-				
Air Seperator 1		-				
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Expansion Tank 2		-				
Air Seperator 2		-				
Buffer Tank 1		-				
Buffer Tank 2		-				
Terminal Units			**110**	**unit**	**9,310.91**	**1,024,200.00**
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Ventilation			**103,072**	**sf**	**5.94**	**611,800.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**0.92**	**95,000.00**
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)				
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)				
Allow gas piping						
Domestic Expansion Tank		-				
Electrical						**355,200**
Services and Distribution			**103,072**	**sf**	**2.05**	**211,000.00**
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200kVA				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			**103,072**	**sf**	**1.40**	**144,200.00**
Air-source Heat Pump	50 Tons	575V, 145 MCA				
Electrical Boiler		75 kW				
Electrical Boiler		75kW				
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(gas)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal	500 MBH (Input)				
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal	500 MBH (Input)				
Allowance for cabling and conduit						
Architectural and Structural						**394,300**
Mechanical Room	400 SF					
Water Room	135 SF					
Mechanical Outdoor Area	420 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,875,700.00

LOW-RISE ZERO EMISSION OPTION 3

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a dedicated ASHP domestic hot water production system and hydronic heating for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
3) 4-Pipe ASHP + Heat Pump DHWT						
HVAC + DHWT						2,600,700
Central Plant			103,072	sf	3.83	395,200.00
Air-source Heat Pump	50T	575V, 280 MCA				
Electrical Boiler		75 kW				
Electrical Boiler		75 kW				
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Expansion Tank 1		-				
Air Seperator 1		-				
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Expansion Tank 2		-				
Air Seperator 2		-				
Buffer Tank 1		-				
Buffer Tank 2		-				
Terminal Units			110	unit	9,310.91	1,024,200.00
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Ventilation			103,072	sf	5.94	611,800.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			103,072	sf	5.53	569,500.00
Domestic Hot Water Tank 1	119 Gal	-				
Domestic Hot Water Tank 2	119 Gal	-				
Domestic Hot Water Tank 3	119 Gal	-				
Domestic Hot Water Tank 4	119 Gal	-				
Domestic Expansion Tank		-				
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)				
Electrical						362,300
Services and Distribution			103,072	sf	2.05	211,000.00
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			103,072	sf	1.47	151,300.00
Air-source Heat Pump	50 Tons	575V, 145 MCA				
Electrical Boiler		75 kW				
Electrical Boiler		75kW				
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Heat Pumps (x10)	CxA15	15 HP (x10) (11.2 kW)				
Allowance for cabling and conduit						
Architectural and Structural						443,000
Mechanical Room	400 SF					
Water Room	180 SF					
Mechanical Outdoor Area	795 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						3,406,000.00

LOW-RISE ZERO EMISSION OPTION 4

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and an ASHP with electric resistance top up for domestic hot water production and hydronic heating for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
4) 4-Pipe ASHP + Elec Resistant DHWT						
HVAC + DHWT						**2,184,200**
Central Plant			103,072	sf	3.83	395,200.00
Air-source Heat Pump	50T	575V, 280 MCA				
Electrical Boiler						
Electrical Boiler						
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Expansion Tank 1		-				
Air Seperator 1		-				
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Expansion Tank 2		-				
Air Seperator 2		-				
Buffer Tank 1		-				
Buffer Tank 2		-				
Terminal Units			110	units	9,310.91	1,024,200.00
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Ventilation			103,072	sf	5.94	611,800.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			103,072	sf	1.48	153,000.00
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Hot Water Tank 5	119 Gal	-				
Domestic Hot Water Tank 6	119 Gal	-				
Heat Exchanger	25 GPM	-				
Domestic Expansion Tank		-				
Circulator Pump	25 GPM					
Electrical						**358,300**
Services and Distribution			103,072	sf	2.05	211,000.00
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			103,072	sf	1.43	147,300.00
Air-source Heat Pump	50 Tons	575V, 280 MCA				
Electrical Boiler						
Electrical Boiler						
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Circulator Pump	25 GPM					
Allowance for cabling and conduit						
Architectural and Structural						**423,500**
Mechanical Room	400 SF					
Water Room	252 SF					
Mechanical Outdoor Area	420 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,966,000.00

LOW-RISE ZERO EMISSION OPTION 5

Air-cooled variable refrigerant flow heating/cooling system with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
5) Air-Cooled VRF + Elec Resistant DHWT						
HVAC + DHWT						**2,251,400**
Central Plant			**103,072**	**sf**	**5.04**	**519,000.00**
VRF Condensing Units						
Terminal Units			**103,072**	**sf**	**9.94**	**1,024,200.00**
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Ventilation			**103,072**	**sf**	**5.94**	**611,800.00**
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			**103,072**	**sf**	**0.94**	**96,400.00**
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Expansion Tank						
Electrical						**357,800**
Services and Distribution			**103,072**	**sf**	**2.05**	**211,000.00**
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			**103,072**	**sf**	**1.42**	**146,800.00**
VRF Condensing Units						
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Allowance for cabling and conduit						
Architectural and Structural						**303,500**
Mechanical Room	None					
Water Room	180 SF					
Mechanical Outdoor Area	400 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,912,700.00

LOW-RISE ZERO EMISSION OPTION 6

2-pipe ambient loop heating/cooling system (consisting of ASHP with an electric back-up boiler, and terminal heat pumps in each suite) with a centralized electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
6. ASHP, 2-Pipe Condesner system Terminal Heat pump + Electric Resistance DHWT						
HVAC + DHWT						**1,818,600**
Central Plant			103,072	sf	3.29	339,600.00
Air Source Heat Pump 1	25 Ton	575V 120A				
Air Source Heat Pump 2	25 Ton	575V 120A				
Buffer tank	400 Gal	-				
Air Seperator		-				
Ambient Loop pump 1	60 GPM					
Ambient Loop pump 2	60 GPM					
Expansion Tank		-				
Terminal Units			110	unit	6,950.91	764,600.00
Heat Pumps (studio)		1.1 kW				
Heat Pumps (1 Bed)		1.1 kW				
Heat Pumps (2 Bed)		2.2 kW				
Ventilation			103,072	sf	5.94	611,800.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			103,072	sf	1.00	102,600.00
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Expansion Tank		-				
Electrical						**379,700**
Services and Distribution			103,072	sf	2.30	237,000.00
Transformer Size (kVA)		1250kVA				
Main Distribution Panel (A)		1600 A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			103,072	sf	1.38	142,700.00
Air Source Heat Pump 1	25 Ton	575V 120A				
Air Source Heat Pump 2	25 Ton	575V 120A				
Ambient Loop pump 1	60 GPM					
Ambient Loop pump 2	60 GPM					
Heat Pumps (studio)		1.1 kW				
Heat Pumps (1 Bed)		1.1 kW				
Heat Pumps (2 Bed)		2.2 kW				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Allowance for cabling and conduit						
Architectural and Structural						**367,300**
Mechanical Room	300 SF					
Water Room	180 SF					
Mechanical Outdoor Area	288 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,565,600.00

LOW-RISE ZERO EMISSION OPTION 7

4-pipe air-source heating/cooling system (consisting of ASHP with an electric back-up boiler), and a double-walled heat exchanger for on-demand domestic hot water production and hydronic heating for the corridor ventilation system.

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
7) 4-Pipe ASHP + HX DHWT Generation						
HVAC + DHWT						**2,130,200**
Central Plant			103,072.00	sf	3.83	395,200.00
Air-source Heat Pump	50T	575V, 280 MCA				
Electrical Boiler						
Electrical Boiler						
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Expansion Tank 1		-				
Air Seperator 1		-				
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Expansion Tank 2		-				
Air Seperator 2		-				
Buffer Tank 1		-				
Buffer Tank 2		-				
Terminal Units			110.00	unit	9,310.91	1,024,200.00
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Ventilation			103,072.00	sf	5.94	611,800.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			103,072.00	sf	0.96	99,000.00
Domestic Hot Water Tank 1 (Gas-Fired)	119 Gal					
Domestic Hot Water Tank 2 (Gas-Fired)	119 Gal					
Domestic Hot Water Tank 3	119 Gal					
Domestic Hot Water Tank 4	119 Gal					
Heat Exchanger	216kW - 80 GPM	-				
Domestic Expansion Tank		-				
Circulator Pump	80 GPM	-				
Electrical						**355,100**
Services and Distribution			103,072.00	sf	2.05	211,000.00
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			103,072.00	sf	1.40	144,100.00
Air-source Heat Pump	50T	575V, 280 MCA				
Electrical Boiler						
Electrical Boiler						
Boiler pump 1						
Boiler Pump 2						
Heating Distribution Pump 1	50 GPM					
Heating Distribution Pump 2	50 GPM					
Chilled Distribution Pump 1	40 GPM					
Chilled Distribution Pump 2	40 GPM					
Fan Coils (Studio)		1/12HP (1ph / 120)				
Fan Coils (1 bed)		1/12HP (1ph / 120)				
Fan Coils (2 bed)		1/6HP (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Circulator Pump	25 GPM					
Allowance for cabling and conduit						
Architectural and Structural						**405,500**
Mechanical Room	400 SF					
Water Room	180 SF					
Mechanical Outdoor Area	288 SF					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,890,800.00

LOW-RISE ZERO EMISSION OPTION 8

Packaged Terminal Heat Pumps (PTHP) heating/cooling system with electrical resistance boiler for domestic hot water production and for the corridor ventilation system.

COV Low Rise Rezoning Policy 2021
Cost Analysis
Tuesday, March 30, 2021
Cost Breakdown

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Description	Nominal Size	Electrical	Quantity	Unit	Rate	Amount
8) PTAC + Elec Resistant DHW						
HVAC + DHWT						**1,541,400**
Central Plant			103,072	sf	8.00	825,000.00
PTAC						
Ventilation			103,072	sf	5.94	611,800.00
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Male-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water			103,072	sf	1.01	104,600.00
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Domestic Expansion Tank		-				
Electrical						**371,100**
Services and Distribution			103,072	sf	2.05	211,000.00
Transformer Size (kVA)		1000kVA				
Main Distribution Panel (A)		1200A				
Generator Size (kW)		150kW				
Disconnect switches for mech. Equipments			103,072	sf	1.55	160,100.00
PTAC	100-150 CFM	1.5 Amp (1ph / 120)				
Suite by suite Ventilation unit	100-150 CFM	1.5 Amp (1ph / 120)				
Corridor Make-up air unit(Electric)	2,000 CFM	30 KW (3ph / 600)				
Misc Exhaust Fans		6 HP Total				
Vestibule Pressurization (inc. elec. Duct heater)		4kw Total				
Domestic Hot Water Tank 1	119 Gal	54 kW				
Domestic Hot Water Tank 2	119 Gal	54 kW				
Domestic Hot Water Tank 3	119 Gal	54 kW				
Domestic Hot Water Tank 4	119 Gal	54 kW				
Circulator Pump	25 GPM					
Allowance for cabling and conduit						
Architectural and Structural						**263,500**
Mechanical Room	None					
Water Room	180 SF					
Mechanical Outdoor Area	None					
Electrical Room	646 SF					
Generator Room	228 SF					
						2,176,000.00

HIGH-RISE OFFICE BUILDING ZERO EMISSION OPTION (PART 3)

COV High Rise Rezoning Policy 2021
Cost Analysis for High Rise Office Building
February 2, 2021

Description		Quantity	Unit	Rate	Amount
Roof R-40					
	Concrete suspended roof slab with concrete beams & columns	842	m²	454.50	382,700
	SBS two ply roofing	842	m²	83.50	70,300
	Rigid insulation R7.5	842	m²	23.50	19,800
	Rigid insulation 100mm R20 - 2 layers	1,684	m²	50.00	84,200
	Sloped rigid insulation 25mm min.	842	m²	31.00	26,100
	Asphalt impreg. fibreboard 12mm	842	m²	20.00	16,800
	Drain mat	842	m²	46.50	39,200
	Filter fabric	842	m²	6.70	5,600
	Gravel Ballast 75mm thick	842	m²	21.50	18,100
					0
	General requirements & fee		15%		99,400
	Total Unit Cost for Roof R-40	842	m	905.23	$762,200
Floor to Parkade R-15					
	Concrete suspended floor slab with concrete beams & columns	14,292	m²	540.00	7,717,400
	5" max spray thermal insulation (R15)	14,292	m²	65.00	929,000
					0
	General requirements & fee		15%		1,297,000
	Total Unit Cost for Floor to Parkade R-15	14,292	m²	695.75	$9,943,400
Partitions around Heated Spaces					
	16mm drywall	14,434	m²	31.30	451,800
	92mm metal stud	14,434	m²	54.50	786,700
	3 1/2" batt mineral wool insulation	14,434	m²	18.50	267,000
	16mm drywall	14,434	m²	31.30	451,800
					0
	General requirements & fee		15%		293,600
	Total Unit Cost for Partitions around Heated Spaces	14,434	m²	155.94	2,250,900
Curtain Wall U Values = 0.33, SHGC = 0.25					
	Aluminum frame curtain wall - double glazing	13,910	m²	1,100.00	15,301,400
					0
	General requirements & fee		15%		2,295,200
	Total Unit Cost for Curtain Wall U Values = 0.33, SHGC = 0.25	13,910	m²	1,265.00	$17,596,600

COV High Rise Rezoning Policy 2021
Cost Analysis for High Rise Office Building
February 2, 2021

Description		Quantity	Unit	Rate	Amount
Wall R9					
	Aluminum composite panel	9,274	m²	537.80	4,987,300
	50mm z-girt	9,274	m²	17.40	161,400
	Membrane air/vapour barrier	9,274	m²	43.00	398,800
	Rigid insulation R9	9,274	m²	25.00	231,800
	Concrete wall 200mm thick with sealer	9,274	m²	315.70	2,927,700
	64mm steel furring	9,274	m²	26.91	249,600
	16mm drywall	9,274	m²	31.30	290,300
					0
	General requirements & fee		15%		1,387,000
	Total Unit Cost for Wall R9	9,274	m²	1,146.69	$10,633,900

APPENDIX F

VANCOUVER BUILDING BY-LAW 2014 BASELINE MODEL RESULTS

INTRODUCTION

This appendix includes energy performance and energy cost analysis of two scenarios that have been modified from Part 1 of the study. These scenarios are as follows:

- 2014 Code Compliant Baseline: Utilizes the building geometries (High- and Low-Rise Residential) from Part 1 of the study and modifies the building modelling inputs to simulate a building baseline that met 2014 Vancouver Building By-Law (VBBL).
- Zero Emissions Option 1b: Simulates a building that uses a gas-fired make-up air (MUA) system for corridor ventilation, instead of an electric MUA as in Zero Emissions Option 1, for both High- and Low-Rise Residential Building archetypes.

METHODOLOGY - 2014 CODE COMPLIANT BASELINE

The 2014 Code Compliant analysis was completed to represent the type of High- and Low-Rise Residential buildings that would have complied with the 2014 VBBL (i.e. ASHRAE 90.1-2010). This additional analysis follows the methodology of Part 1 Study. The model inputs for the 2014 code compliant building are summarized in Table F.1 and Table F.2 for the High and Low-Rise Residential Buildings, respectively. Modelling inputs for the 2017 Rezoning Baseline from Part 1 of the study are shown strictly for comparison, however were not used in this additional analysis.

Inputs	2017 Rezoning Baseline	2014 Code Compliant Building
Walls Effective R-value (h·ft²·°F/btu)	R-5	R-3, window walls
WWR	30%	55%
Shading Strategy	Enhanced shading (Fixed exterior shading)	Standard shading (Balcony overhangs)
Windows	Operable windows	Operable windows
Roof Effective R-value (h·ft²·°F/btu)	R-20	R-20
Floor to Parkade R-value (h·ft²·°F/btu)	R-15	R-12
Window Performance (btu/h ft²·°F)	U-0.30, SHGC 0.32, double glazing U-0.34, SHGC 0.27, double glazing	U-0.39, SHGC 0.35, metal frame windows
Airtightness	0.2 L/s/m² of façade	0.25 L/s/m²/façade, as per NECB 2011 A-8.4.3.4.(3)
DHW Savings	20%	None
HRV Effectiveness	85% sensible	None
Mechanical System	Baseboard + Gas DHW and Corridor Ventilation. No Cooling.	Gas boiler for space heating, DHW heating, and Corridor ventilation. No cooling. Gas boiler efficiency: 92% efficiency
Corridor Pressurization	15 CFM/door	30 CFM/door

Table F.1: High-Rise Residential 2014 Code Compliant Building Model Inputs Compared to 2017 Rezoning Baseline

Inputs	2017 Rezoning Baseline	2014 Code Compliant Building
Walls Effective R-value (h·ft²·°F/btu)	R-13	R-10
WWR	30%	40%
Shading Strategy	Enhanced shading (Fixed exterior shading)	Standard shading (Balcony overhangs)
Windows	Operable windows	Operable windows
Roof Effective R-value (h·ft²·°F/btu)	R-40	R-20
Floor to Parkade R-value (h·ft²·°F/btu)	R-15	R-10, wood frame walls
Window Performance (btu/h ft²·°F)	U-0.27, SHGC 0.30, double glazing U-0.29, SHGC 0.30, double glazing	U-0.39, SHGC 0.35, metal frame windows
Airtightness	0.1 L/s/m² of façade	0.25 L/s/m²/façade, as per NECB 2011 A-8.4.3.4.(3)
DHW Savings	30%	None
HRV Effectiveness	85% sensible	None
Mechanical System	Baseboard + Gas DHW and Corridor Ventilation. No Cooling.	Gas boiler for space heating, DHW heating, and Corridor ventilation. No cooling. Gas boiler efficiency: 84% efficiency
Corridor Pressurization	15 CFM/door	20 CFM/door

Table F.2: Low-Rise Residential 2014 Code Compliant Building Model Inputs Compared to 2017 Rezoning Baseline

METHODOLOGY - GAS-FIRED MAKE-UP AIR FOR CORRIDOR VENTILATION (ZERO EMISSIONS OPTION 1B)

In this additional analysis, Zero Emission Option 1 was modified from an electric MUA for corridor ventilation to a gas-fired system. The difference between Zero Emission Option 1 and 1b is shown in Table F.3 below.

	Zero Emission Option 1	Zero Emission Option 1b
Corridor Ventilation	Electric MUA	Natural Gas MUA

Table F.3: Difference Between Zero Emission Option 1 and Zero Emission Option 1b

RESULTS AND ANALYSIS

The energy performance and energy costs results for the 2014 Baseline and Zero Emission Option 1b compared to 2017 Rezoning Baseline 1 and Zero Emission Options 1 & 2 are summarized below.

Performance Metrics	TEUI (kWh/m²/yr)	TEDI (kWh/m²/yr)	GHGI (kgCO2e/m²/yr)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2014 Code Baseline	162.5	69.9	19.6	$229,838.00	$801	-	-
2017 Rezoning Baseline 1	108.4	28.9	5.9	$212,205.00	$739	33%	8%
Zero Emission Option 1	106.9	28.9	1.2	$256,137.00	$892	34%	-11%
Zero Emission Option 1b	107.3	28.9	1.3	$247,534.00	$862	34%	-8%
Zero Emissions Option 2	92.4	28.9	1.0	$223,294.00	$778	43%	3%

Table F.4: Energy Performance Results of the 2014 Baseline High-Rise Residential Building

Performance Metrics	TEUI (kWh/m²/yr)	TEDI (kWh/m²/yr)	GHGI (kgCO2e/m²/yr)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2014 Code Baseline	152.4	54.2	17.7	$105,061.00	$947	-	-
2017 Rezoning Baseline 1	84.2	12.9	5.0	$76,910.00	$693	45%	27%
Zero Emission Option 1	82.4	12.9	0.9	$93,903.00	$846	46%	11%
Zero Emission Option 1b	82.7	12.9	1.2	$90,233.00	$831	46%	14%
Zero Emissions Option 2	70.6	12.9	0.8	$81,194.00	$731	54%	23%

Table F.5: Energy Performance Results of the 2014 Baseline Low-Rise Residential Building

The 2014 Code Compliant Baseline shows much higher TEUI, TEDI, and GHGI values than the 2017 Rezoning Baseline 1 and Zero Emission Options for both the High and Low-Rise Residential Buildings. This identifies that the Baseline and Zero Emission Options developed and used in Part 1 of this Study use significantly less energy, have lower energy costs, and emit fewer carbon emissions compared to the 2014 Code Compliant Building. The resulting energy cost savings between the 2014 Baseline and the 2017 Rezoning Baseline 1 are 8% and 27% for the High- and Low-Rise Residential Buildings, as seen in Tables F.4 and F.5 above.

Compared to Zero Emissions Option 1, Zero Emission Option 1b shows a small increase in GHGI due to the use of gas-fired make-up air unit for corridor ventilation. In the CoV Modelling Guidelines, adjustments to the TEDI or GHGI performance targets are allowed for corridor ventilation, depending on what fuel source is utilized (electric or gas). Zero Emission Option 1b uses a gas-fired MUA, which allows for a higher adjustment which results in a lower GHGI increase between the Zero Emission Options.

Due to the lower gas utility rates in BC, the energy costs for Zero Emission Option 1b are lower than Zero Emission Option 1. The energy costs for Zero Emission Option 1b in the High and Low-Rise Residential Buildings are lower by 3.4% and 3.9% from Zero Emissions Option 1.

APPENDIX G

ALTERNATIVE LOW-RISE RESIDENTIAL MODEL RESULTS AND COSTING

INTRODUCTION

In this appendix, the Low-Rise Residential Building in the Part 1 Study has been reduced to a smaller building with a total of 41 suites (model floor area: 3954 m²), to represent a 2-6 storey development in a more densely occupied part of town. This size of the reduces residential building can be typically be supported by a pad mounted transformer for its electrical loads, which differs from the other Low-Rise Residential Building in Part 1. Figure G.1 shows a rendering of the building from the energy model software.

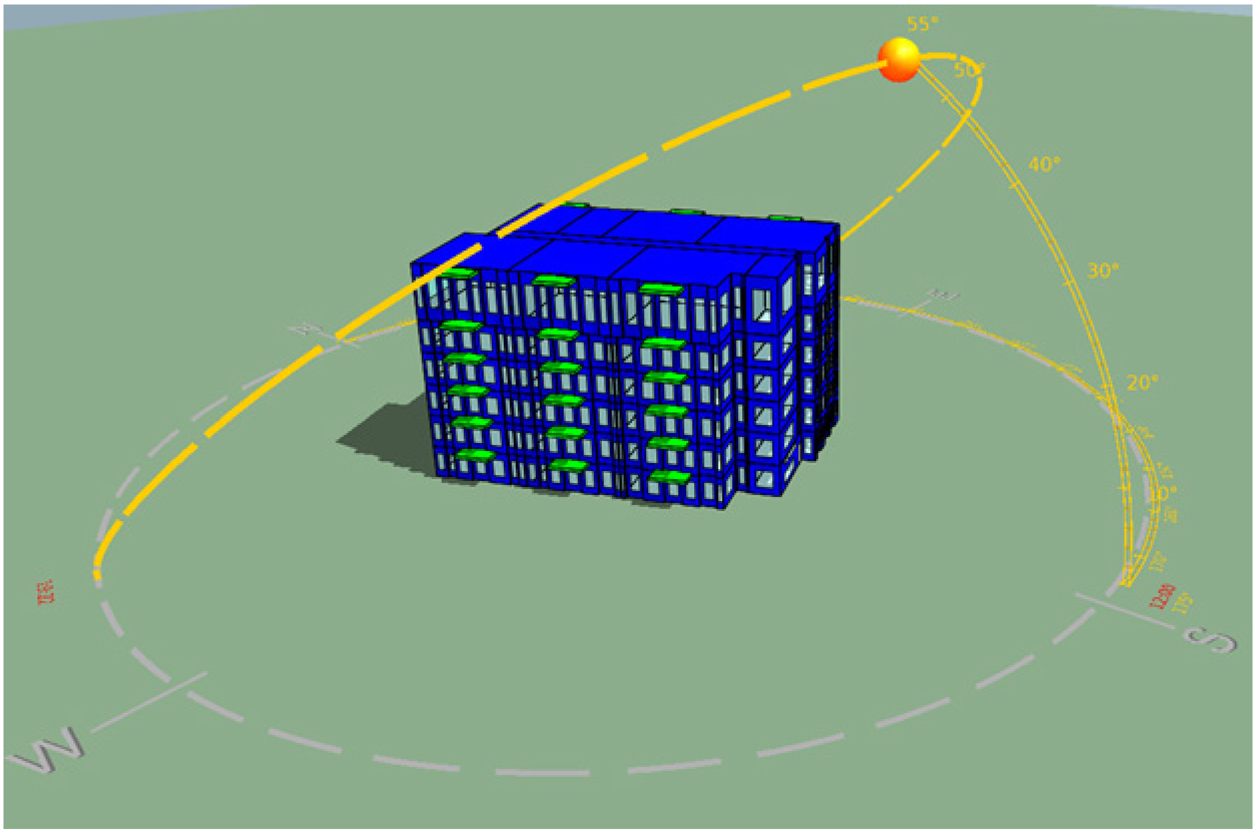

Figure G.1: Energy Model Geometry and Orientation

METHODOLOGY

The building envelope and mechanical inputs were modified to meet Step 4 of the BC Energy Step Code, GHGI target from the current Green Building Policy of Rezoning, and the City of Vancouver Modelling Guidelines' 200-hour overheating limit. The revised inputs are shown below in Table G.1.

Inputs	Smaller Low-Rise Residential Building
Wall R-value	R-15
Roof R-Value	R-40
Floor to Parkade R-Value	R-15
WWR	30%
Window Performance	U-0.27, SHGC-0.30, double glazing for fixed windows U-0.29, SHGC-0.30, double glazing for operable windows
Operable Windows	20% operable area of windows
Shading	Standard shading (balcony overhangs)
Airtightness	0.1 L/s/m² façade
DHW savings	36%
HRV efficiency	85% sensible

Table G.1: Envelope and Mechanical Inputs for the Smaller Low-Rise Residential Building

Using these inputs, the analysis was completed using the same Zero Emission Options as in Part 1 of this study:

- 2017 Rezoning Baseline 1: Baseboard + Gas DHW and Corridor Vent
- Zero Emissions Option 1: Baseboard + Electric DHW and Corridor Vent
- Zero Emissions Option 2: Baseboard + ASHP DHW + Electric Corridor Vent

RESULTS AND ANALYSIS

Energy performance results are shown in Table G.2. The maximum overheating hours is 83 hour/yr.

Performance Metrics	TEUI (Target 100)	TEDI (Target 15)	GHGI (Target 5)	Energy Cost ($/yr)	Energy Cost ($/yr/suite)	Energy Savings	Energy Cost Savings
2017 Rezoning Baseline 1	86.2	14.6	4.8	$30,601.00	$746	-	-
Zero Emission Option 1	84.6	14.6	0.9	$36,903.00	$900	2%	-21%
Zero Emissions Option 2	73.3	14.6	0.8	$32,225.00	$786	15%	-5%

Table G.2: Energy Performance Results for the Smaller Low-Rise Residential Building

Similar to what was seen in the Low-Rise Residential Building in the Part 1 Study, the GHGI results of the Zero Emission Options are significantly lower than the Baseline due to electrification of ventilation heating and DHW heating. However, energy costs for the Zero Emission Options compared to the 2017 Rezoning Baseline due to the low cost of gas utility rates in BC. The energy cost ranges from $746 to $900 per suite/year through all of the options reviewed.

Table G.3 below provides a breakdown of the capital costs relative to each Baseline and Zero Emission Option. The mechanical costs include all mechanical equipment, distribution (i.e. ductwork, piping) and the building costs include any requirement for architectural and structural (i.e. additional service spaces, screening of equipment etc.) related to these Zero Emission Options.

Option #	Mechanical Cost	Cost Relative to Baseline 1	Electrical Cost	Cost Relative to Baseline 1	Building Cost (Arch & Struct)	Cost Relative to Baseline 1	Total Cost	Cost Relative to Baseline 1	Total Cost ($/sq.ft.)	Cost Relative to Baseline 1 ($/sq.ft.)
Baseline 1: Baseboard + Gas DHW and Corridor Vent	$355,800.00	-	$205,800.00	-	$90,000.00	-	$651,600.00	-	$15.31	-
Zero Emission Option 1: Baseboard + Electric DHW	$385,600.00	$29,800.00	$208,800.00	$3,000.00	$101,300.00	$11,300.00	$695,700.00	$44,100.00	$16.35	$1.04
Zero Emissions Option 2 : Baseboard + ASHP DHW	$638,300.00	$282,500.00	$212,900.00	$7,100.00	$145,500.00	$55,500.00	$996,700.00	$345,100.00	$23.42	$8.11

Table G.3: Cost Comparison to Baseline 1

Exclusions:

- General Contractor's General Requirements, Overhead and Fees
- Design and Construction Contingencies
- Project Soft Costs

Compared to the Low-Rise Residential Building in Part 1 of the Study, the electrical cost is significantly reduced in this building. For example, the electrical cost of Baseline 1 decreased from $369.8k to $205.8k, with the main factor being that the building used in Part 1 of the Study requires the use of a Vista switch (unit substation), while the Small Low-Rise Residential Building based on the electrical demand can utilize a pad mounted transformer (PMT). With the use of the PMT, there are additional cost reductions for electrical services and distribution as shown in Table G.4.

Building	Electrical Services and Distribution Cost
Low-Rise Residential Building in Part 1	$194,000.00
Smaller Low-Rise Residential Building	$107,100.00

Table G.4: Cost Comparison of Electrical Services and Distribution

AME Consulting Group Ltd.
200 - 638 Smithe St
Vancouver, BC V6B 1E3
P: 604 684 5995

ZGF Architects Inc.
355 Burrard St #350,
Vancouver, BC V6C 2G8
P: 604 558 8390

AES Engineering Ltd.
505 Burrard Street #950,
Vancouver, BC V7X 1M4
P: 604 569 6500

BTY Consultancy Group Inc.
2288 Manitoba St,
Vancouver, BC V5Y 4B5
P: 604 734 3126