MORRISON HERSHFIELD

REPORT

Passive Cooling Measures for Multi-Unit Residential Buildings

Vancouver, BC

Presented to:

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City of Vancouver

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EXECUTIVE SUMMARY

Morrison Hershfield has conducted a study of passive cooling strategies using energy simulations to assess the reduction in overheated hours and maximum temperature in suites in multi-unit residential buildings simulated with a variety of passive cooling measures.

For multi-unit residential buildings complying with the City of Vancouver's 2016 Zero Emissions Building Plan with reduced window-to-wall ratio, improved wall and window thermal performance, suite HRVs, and an increase in airtightness, an increase in overheated hours is expected. This study considers worst typical case suites from a passive cooling perspective, with southwest facing suites at the high end of typical window to wall ratio.

Current baseline typical practice significantly overheats the suites, with up to 1000 overheated hours each year. The increase in overheated hours based on the strategies anticipated to comply with the City of Vancouver's 2016 Zero Emissions Building plan, without including passive cooling strategies in the design, ranges from approximately 100 to 1300 additional overheated hours depending on the suite type.

Southwest facing SRO and 1-bedroom suites and a southwest facing corner unit 2-bedroom suite were simulated. In general, the 2-bedroom corner suite has the highest number of overheated hours, and requires the most passive cooling design measures to reduce overheating to acceptable levels.

Levels of under 200 and under 20 overheated hours can be achieved using passive cooling for all of the suite types in the current climate conditions. To achieve the lowest levels of overheated hours, both natural ventilation and reductions in solar gains to the suite are required (using exterior fixed or movable shading or solar heat gain reduction measures for windows; specifics are discussed in Section 4.) Levels of below 200 overheated hours can be achieved at a cost savings compared to installing mechanical cooling, generally using natural ventilation and shading from balconies at no cost premium over current typical practice, as well as reduced SHGC using low-e window coatings.

The same passive cooling measures were also investigated for a 2050's climate weather file. Levels of under 200 overheated hours can still be achieved using passive design measures for all suite types, however for both the southwest facing 1-bedroom unit and the 2-bedroom corner suite, there is no combination of the passive cooling design measures investigated that bring the suites below 100 overheated hours. There are significantly fewer combinations that achieve a 200 overheated level of performance, and a suite designed using passive cooling measures for comfort currently will typically not meet comfort conditions in a 2050's climate.

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1. INTRODUCTION

Morrison Hershfield has conducted this study at the City of Vancouver's request to investigate the impact of the Zero Emissions Building Plan. This study uses energy simulation to look at the impacts of a number of passive cooling measures on occupant comfort, both now and in a future climate. EnergyPlus v8.6 software is used for energy simulation throughout the study.

The study models the impacts of fixed and operable exterior shading, HRV bypass and boosted flow, natural ventilation, night pre-cooling, window coatings, and switchable glazing. Both the maximum temperature within the suite and the number of overheated hours above ASHRAE 55's adaptive comfort model are shown. The cost premiums for each measure have been estimated, and are compared to the cost premium for adding mechanical cooling.

A parametric analysis has also been conducted, in Section 4, combining each of these passive cooling measures and assessing the impacts and cost premiums of these combinations.

In Section 5, the same parametric analysis is re-run using a 2050's weather file to investigate the effects of climate change on the effectiveness of these passive cooling measures and occupant comfort.

2. IMPACT OF THE 2016 ZERO EMISSIONS BUILDING PLAN

For this portion of the study, we have developed models of three typical suites: a southwest-facing SRO suite, a southwest-facing 1-bedroom rental suite, and a southwest corner 2-bedroom condo. These suites are chosen as typical worst-case suites from a cooling perspective. While 1- and 2-bedroom units are intended to represent a typical rental unit and typical condo unit respectively, they are representative of the form factor and window-to-wall ratio regardless of ownership. The layouts of all three suites are shown in Appendix A.

A baseline model representing typical current practice was compared with a proposed model typically meeting the 2016 Zero Emissions Building Plan (ZEBP.) The characteristics of both models, as outlined by the City of Vancouver in their RFP, are shown below.

Table 1. Model Inputs

Variable Type	Variable	SRO	1-Bed Rental	2-Bed Condo
Program	Area	300 ft^2	650 ft^2	850 ft^2
	Occupants	1 person	2 people	3 people
	Suite Base Ventilation Rate	30 cfm	50 cfm	80 cfm
Typical Baseline Design	Suite Window-to-Wall Ratio	50%	60%	70%
	Wall True Effective R-Value	4 hr-ft^2-F/Btu		
	Window Effective U-Value	0.35 Btu/hr-ft^2-F		
	Average Airtightness	0.3 ACH @ 5 Pa		
Typical Proposed Design	Suite Window-to-Wall Ratio	40%	50%	60%
	Wall True Effective R-Value	9 hr-ft^2-F/Btu		
	Window Effective U-Value	0.25 Btu/hr-ft^2-F		
	Average Airtightness	0.2 ACH @ 5 Pa		

In order to evaluate the differences between typical current practice and a building typically meeting the ZEBP, the model has been run with no heating system activated, with outdoor (untempered) air provided directly to all spaces within the suite, and no mechanical cooling system. Operable windows with restrictors operating to maintain openings at a maximum of 4 inches are modeled in both cases, with occupants assumed to open windows when the indoor temperature reaches 23˚C. Manually operated shading, such as interior blinds, are modeled, with shades controlled by occupants during periods of high solar gain on the window. Interior doors (between bedrooms and living rooms) are modeled as closed as a worst-case scenario; if interior doors are open, additional cross ventilation can occur, reducing overheated hours and peak temperatures, with a peak difference of approximately 0.5˚C. Interior gains for lighting and plug loads are modeled using 5 W/m^2 each, as per the City of Vancouver's draft energy modeling guidelines. An HRV with 70% effectiveness is modeled in the proposed, with no HRV in the typical current practice baseline.

The suite is considered to be overheated for hours when the 80% acceptability limit outlined in ASRHAE 55-2010 Section 5.3 is not met. This method only applies when the mean monthly outdoor temperature is between 10˚C and 33.5˚C. Using Vancouver's CWEC (typical year) hourly weather data, the mean monthly temperature is between these limits from May through September.

In determining the acceptability limits, we have delineated the acceptability limit by calendar month rather than re-calculating the mean temperature of the previous 30 days for each simulated day, for clarity and simplicity.

The temperatures within the suites based on these characteristics are shown in the figures below. Each figure compares the baseline (typical current practice) with the proposed (typically meeting the ZEBP.)

The overheated hours and peak temperatures are intended for quantitative comparison between options, and are based on the standardized inputs outlined above. Actual temperatures in new buildings or those built to meet the ZEBP will vary depending on the design.

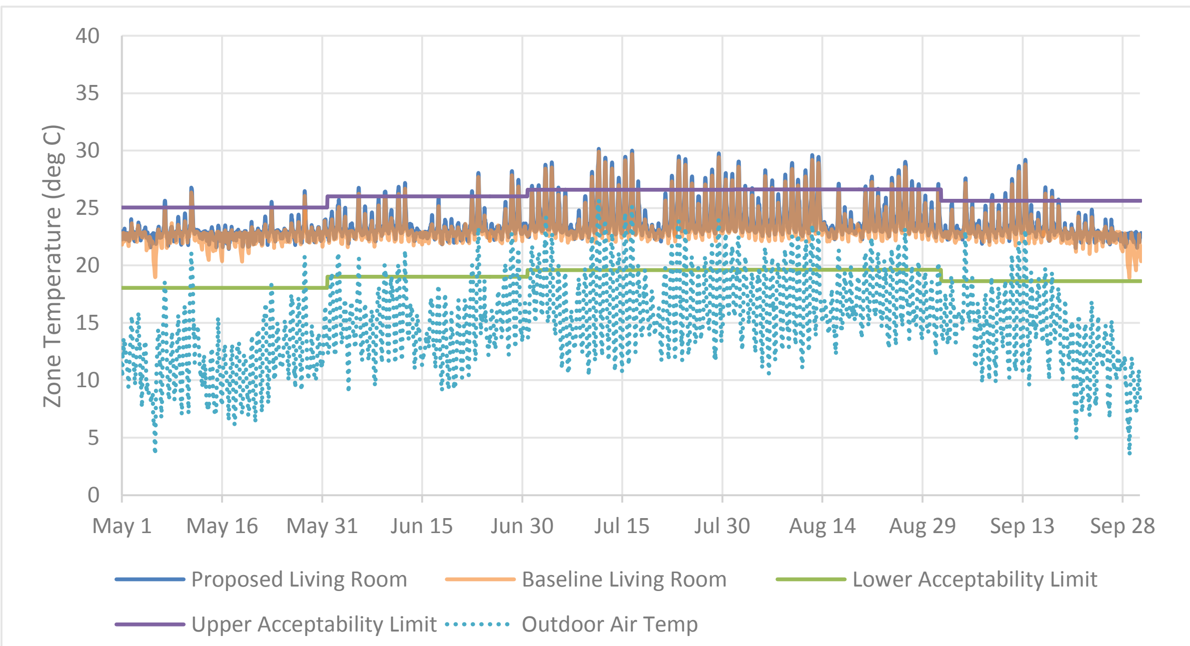


Figure 1. Suite temperature of a southwest facing SRO

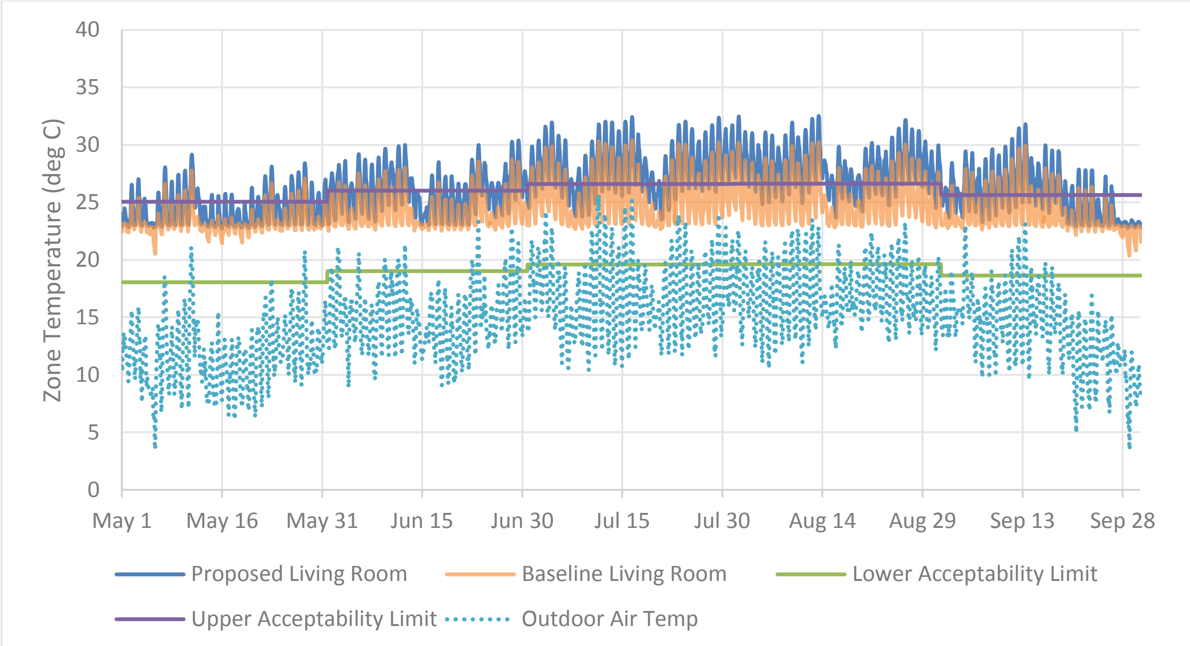


Figure 2. Suite temperature of a southwest facing 1-bedroom rental unit

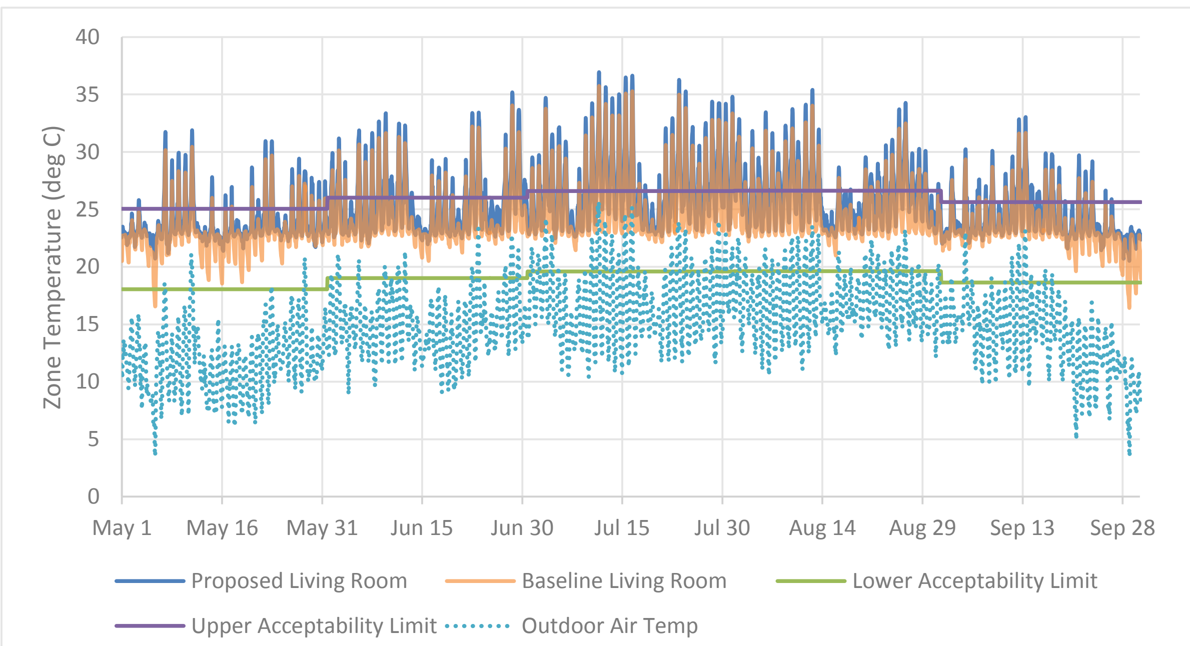


Figure 3. Suite temperature of a southwest corner 2-bedroom condo unit

From the above figures, we can see that the suites typically meeting the ZEBP have more overheated hours and higher peak temperatures than would be expected for suites built using current typical practices. The number of hours outside the 80% acceptability limits and the peak modeled temperatures are shown below.

Table 2. Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
Baseline (Typical Current)	190	29.9 ˚C	637	30.4 ˚C	927	36.3 ˚C
Proposed (ZEBP)	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C

In order to mitigate the number of overheated hours in the proposed suites typically meeting the ZEBP, a number of passive cooling strategies are explored in Section 3, below.

Passive House limits the number of hours over 25˚C to 10% of the year, or 876 hours. However, Passive House recommends a target well below this, of 1% to 5%. This constitutes a higher number of hours than is considered elsewhere in this report, but a lower overheating temperature than what is determined using ASHRAE 55. In general, the ASHRAE 55 acceptability limits will be discussed throughout this report, however to provide some context, the hours over Passive House targets for the baseline and ZEBP scenarios are compared below. As can be seen, due to the differences in target temperatures, the number of overheated hours cannot be readily converted between the two, though in general the increase in overheated hours from the baseline to the proposed is similar using either metric.

Table 3. Overheated Hours Calculated for Passive House compared to ASHRAE 55

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	ASHRAE Over-heated Hours	Passive House Over-heated Hours	ASHRAE Over-heated Hours	Passive House Over-heated Hours	ASHRAE Over-heated Hours	Passive House Over-heated Hours
Baseline (Typical Current)	190	396	637	1107	927	994
Proposed (ZEBP)	292	564	1942	2522	1763	2009

3. PASSIVE COOLING MEASURES

To address the overheating of the proposed models, a number of passive cooling measures have been explored.

3.1 Shading

3.1.1 Overhangs

Overhangs including balconies or brise-soleils are modeled, with 1.2m projection at the slab height above the suite. We also tested projections of half and 1.5x that measurement to test the practical bounds of the effects and the sensitivity to projection length. Any of these fixed shading lengths reduced the number of overheated hours, with greater effects at greater projection lengths for those values.

The analysis below assumes that interior shades and operable windows with restrictors are still included in the typical design, consistent with the analysis of overheated hours above.

Table 4. Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
No Shading	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
0.6m Projection	250	29.8 ˚C	1782	32.2 ˚C	1556	38.0 ˚C
1.2m Projection	142	28.9 ˚C	1487	31.4 ˚C	1297	37.0 ˚C
1.8m Projection	72	28.1 ˚C	1252	30.6 ˚C	1085	35.6 ˚C

The 1.2m projection is anticipated to be the most practical and likely to be applied on projects, therefore this projection length is used when testing combined packages of shading measures.

3.1.2 Vertical Shading

Vertical shading has been modeled using 0.3m (1 ft) projections spanning the full height of the windows. Two scenarios have been tested:

1) Vertical shading on each side of each window only, tested at 0.3m (1 ft) and 0.6m (2 ft) projection lengths.

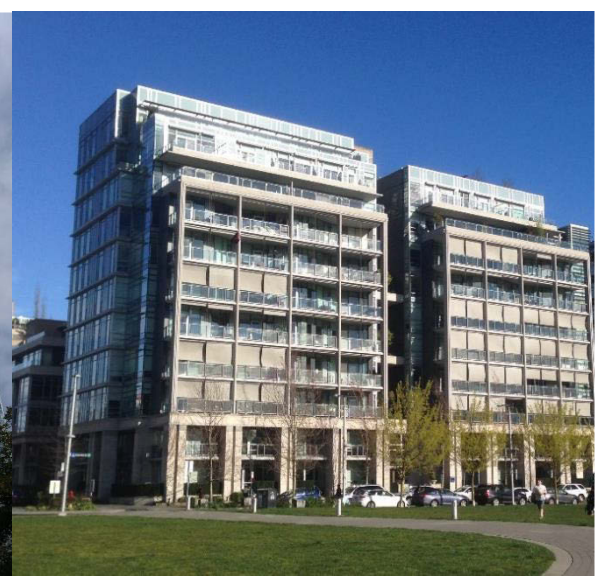
2) Vertical fins, at 0.3m (1 ft) spacing across the window

Vertical shading on each side of windows has limited benefits, with additional projection length providing only minor additional reductions in overheated hours and peak temperature. Regularly spaced vertical fins are the most effective of the vertical shading scenarios tested, and are among the most effective of the fixed exterior shading solutions tested (along with the longest overhang shading measure.)

Table 5. Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
No Shading	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Vertical Sides Only 1ft	253	29.8 ˚C	1765	32.1 ˚C	1517	37.9 ˚C
Vertical Sides Only 2ft	211	29.4 ˚C	1620	31.8 ˚C	1386	37.4 ˚C
Vertical Fins 1ft	140	28.6 ˚C	1288	30.9 ˚C	1190	36.4 ˚C

3.1.3 Operable Exterior Shading (Screens and Blinds)

Operable exterior shading is modeled based on movable screens or exterior blinds. Both are modeled using the same modeling methods, as we are assuming that in the case of occupant controlled shading, occupants operate shading devices optimally to minimize cooling, which would be expected to be similar control to an automatic sensor control.

Table 6. Operable Exterior Shading Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
No Shading	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Operable Exterior Shading	55	27.8 ˚C	993	29.5 ˚C	512	30.0 ˚C

3.2 Increased Ventilation

3.2.1 HRV Bypass & Boosted Flow

In order to avoid overheating caused by an HRV providing warmer air than required, a bypass is modeled, providing outdoor air directly to the zone without passing through the heat exchanger core.

In addition, we also tested a boosted flow, with an increase in ventilation rates (i.e. oversizing the HRV). We modeled boosted flow both with and without bypass.

Table 7. HRV Boosted Flow Rates

	Proposed HRV Flow	Boosted HRV Flow
SRO	30 cfm	50 cfm
1-bedroom	50 cfm	80 cfm
2-bedroom	80 cfm	100 cfm

Table 8. HRV Bypass and Boosted Flow Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
Proposed	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Boosted Flow	280	30.1 ˚C	1689	32.2 ˚C	1770	38.5 ˚C
Boosted Flow With Bypass	171	29.5 ˚C	729	30.3 ˚C	1311	37.3 ˚C
HRV Bypass	217	29.7 ˚C	1076	31.2 ˚C	1305	37.4 ˚C

3.2.2 Natural Ventilation

Our proposed case assumes that there are operable windows, with restrictors limiting openings to 4 inches. This passive cooling measure increases the size of openings to approximately 1 foot open area over the full (approx. 3 ft) width of the window. Using an opening half this width is also shown.

The windows are controlled to be fully open anytime the indoor temperature is over 23˚C. Interior shades are still used.

The SRO has 2 operable windows. The 1-bedroom has 3, and the condo has 8 (2 in the master bedroom and 1 in the second bedroom, 4 along one living room façade, and 2 along the other living room façade.) We have also tested a run with one window per room (one per façade in the condo living room to allow cross-ventilation in the corner unit.)

Table 9. Natural Ventilation Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	**Peak Temp.**	**Overheated Hours**	**Peak Temp.**	**Overheated Hours**	**Peak Temp.**
Proposed	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Natural Ventilation Full Width	38	28.3 ˚C	319	29.5 ˚C	623	34.2 ˚C
Natural Ventilation Half Width	133	29.4 ˚C	831	30.7 ˚C	1075	36.3 ˚C
Natural Ventilation Fewer Openings	143	29.4 ˚C	327	29.9 ˚C	1094	35.9 ˚C

3.3 Night Ventilation

3.3.1 Night Pre-cooling

In this passive cooling measure, the natural ventilation measure described in Section 3.2.2 is active overnight from 10 pm – 7 am anytime the indoor temperature is greater than 16˚C. This strategy is intended to precool the space overnight to delay overheating during the day. During the day, windows are open anytime the indoor temperature rises above 23˚C.

Table 10. Night Ventilation Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	**Peak Temp.**	**Overheated Hours**	**Peak Temp.**	**Overheated Hours**	**Peak Temp.**
Proposed	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Natural Ventilation	38	28.3 ˚C	319	29.5 ˚C	623	34.2 ˚C
Night Natural Ventilation	0	26.3 ˚C	198	28.8 ˚C	529	33.8 ˚C

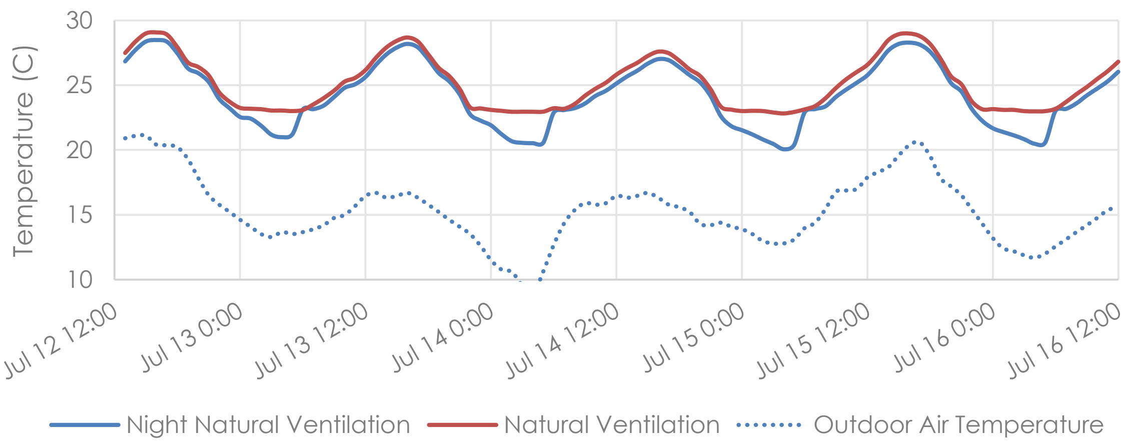


Figure 4. Suite Air Temperature with Natural Ventilation and Night Pre-cool

3.4 Reduced Glazing SHGC

3.4.1 Coatings

Reducing the SHGC from 0.4 to 0.2 using a coating would increase the required heating energy but would decrease overheated hours as shown in the table below.

3.4.2 Switchable Glazing

Switchable glazing is one means of reducing the SHGC of a window on demand, allowing heat to enter when it is needed during heating season but reducing the solar gains during summer, reducing overheated hours.

Table 11. Reduced Glazing SHGC Overheated Hours and Peak Temperatures

	SRO		1-Bedroom Rental		2-Bedroom Condo	
	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.	Overheated Hours	Peak Temp.
Proposed	292	30.2 ˚C	1942	32.5 ˚C	1763	38.5 ˚C
Coatings	142	28.9 ˚C	1300	30.7 ˚C	1039	33.7 ˚C
Switchable Glazing	49	27.7 ˚C	927	29.2 ˚C	410	30.1 ˚C

3.5 Estimated Cost Summary

The estimated costs of adding mechanical cooling and the costs of the passive cooling measures outlined above are also compared.

In some cases, passive cooling measures may already be incorporated into the design and in those cases there would be no additional cost premium for passive cooling. Balconies are assumed to be included at zero additional cost to the project, as these are commonly included on projects and we consider it unlikely these will be added to the design primarily as a passive cooling measure. Balconies and glazing are assumed to be well located to provide shading. Operable windows are assumed to typically be included in residential applications that do not have mechanical cooling, and no cost premium is included. Other passive cooling features may be included in projects for reasons other than passive cooling, for example switchable glazing and movable exterior screens may be installed for privacy reasons, however these strategies are less common and a cost premium is accounted for.

Table 12. Summary of Cost Estimates

		Estimated Unit Cost	Description of Estimate
3.1.1	Balcony	No cost premium	Assumed to be included in typical practice.
3.1.2	Vertical Shading - Fins	$90/ft of shading device	Vertical aluminum fins 12" deep at 1' spacing
3.1.3	Operable Exterior Shading – Exterior Roller Blinds	$31/ft^2 of shading device	Exterior roller blinds with automatic sensor operation; deduction of $5/ft^2 for interior blinds
3.2.1	HRV Bypass	$1000/suite	Including controls connections
3.2.1	HRV Boosted Flow	$100/suite	Includes increase in HRV size and duct size
3.2.2	Natural Ventilation	No cost premium	Typical practice assumed to include operable windows.
3.3.2	Night Pre-cool (Natural Ventilation)	Same as 3.2.2	
3.4.1	Low-e	$6.5/ft^2 of window	Window wall double glazing premium from approx. 0.39 to 0.23
3.4.2	Switchable Glazing	$81.9/ft^2 of window	Dynamic glass window wall
-	Mechanical Cooling	$4/ft^2 suite area	Premium for ASHP system over electric baseboard, for 100,000 ft^2 building

4. COMBINED PASSIVE COOLING MEASURES

Since none of the passive cooling measures investigated lead to acceptable outcomes individually for all of the suite types, a parametric analysis has been developed showing various combinations of passive cooling measures.

The various combinations of the measures listed in Section 3 yield a total of over 17,000 simulations. These are presented using MH's Building Energy Performance Mapping tool. The performance map shows each parameter tested as one column. The columns are connected with curved lines representing a specific simulation with a particular set of parameters.

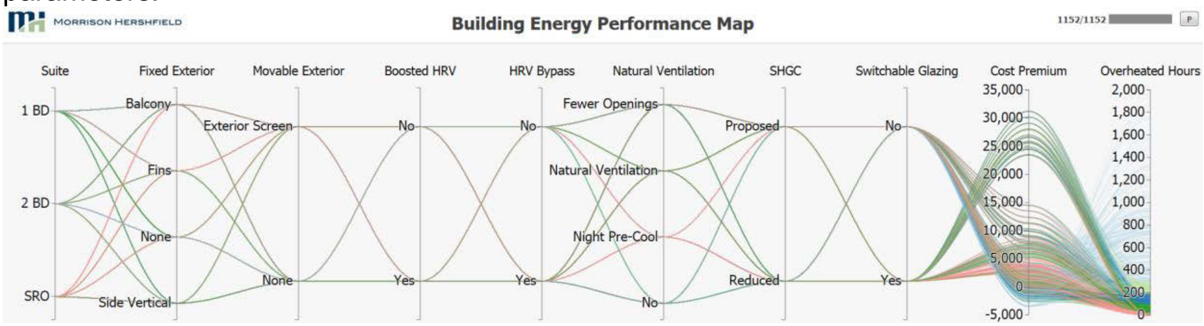


Figure 5. Combined Passive Cooling Measures Building Energy Performance Map

Several possible scenarios are presented below; these are not the only combinations leading to reduced overheated hours. The 2-bedroom corner unit has the highest costs and highest overheated hours in general, so design measures are shown for this suite type as it is typically the most stringent requirement. 200 overheated hours has been used as a threshold for this exercise, as there is a natural break around this area in the performance map and there are solutions that are likely to be achievable for most projects at this level. We have also shown design solutions to get the project below 20 hours for comparison in Section 4.2.

The likely project solutions, which minimize the overall cost premium, are summarized in the table below.

Table 13. Summary of Likely Project Solutions

		Description	Cost Premium	Overheated Hours	Peak Temperature
<20 Hours	SRO	Night pre-cool and exterior screen	$250	0	25.2 ˚C
	1-bedroom		$500	0	26.4 ˚C
	2-bedroom		$7,000	15	27.0 ˚C
<200 Hours	SRO	Natural ventilation, reduced SHGC, balconies	$900 Savings	5	27.0 ˚C
	1-bedroom		$1,850 Savings	100	28.2˚C
	2-bedroom		$1,250 Savings	190	29.7 ˚C

The cost premiums shown in the results are calculated based on a premium over installing a mechanical cooling (ASHP) system; in some cases a cost savings (negative premium) are shown. Cost premiums are per suite.

4.1 Less than 200 Overheated Hours (2-Bedroom)

4.1.1 Likely Project Solution - Minimizes Cost Premium

Has: Minimizes overall cost premium, with a cost savings over installing mechanical cooling.

Excludes: N/A

Needs: Natural ventilation, reduced SHGC, and balconies

Other Suites: Under this scenario, the 1-bedroom and SRO have approximately $0 cost premium and <100 overheated hours.

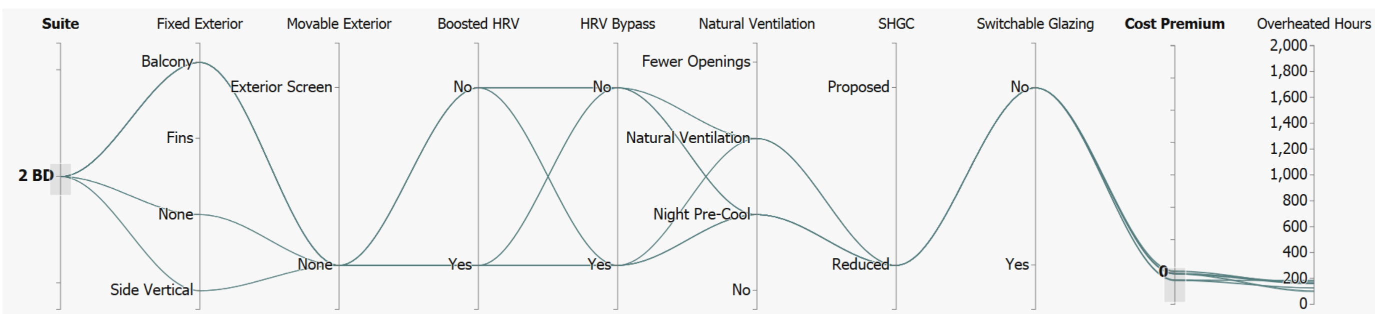


Figure 6. Likely Project Solution <200 Overheated Hours

4.1.2 Natural Ventilation

Has: Natural Ventilation

Excludes: Reduced SHGC, switchable glazing

Needs: Exterior screen

Other Suites: Under this scenario, the 1-bedroom and SRO have between $0 and $5,000 cost premium and <200 overheated hours.

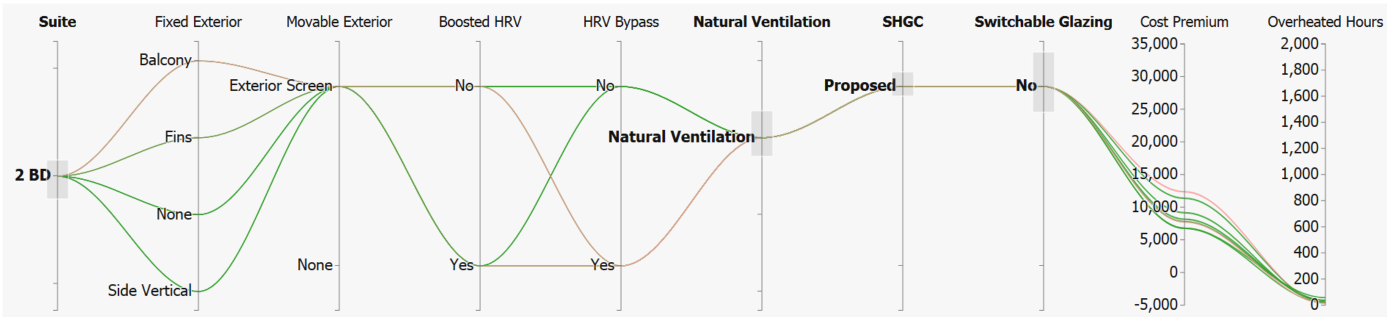


Figure 7. Natural Ventilation <200 Overheated Hours

4.1.3 Boosted HRV with Bypass

Has: Boosted HRV with bypass

Excludes: Natural ventilation, switchable glazing

Needs: Exterior movable shading and either balcony or fins fixed exterior shading combined with proposed SHGC, or a reduced SHGC combined with either those shading or a smaller amount of shading provided by side vertical fins.

Other Suites: Under this scenario, the 1-bedroom and SRO have between $0 and $4,000 cost premium and <200 overheated hours.

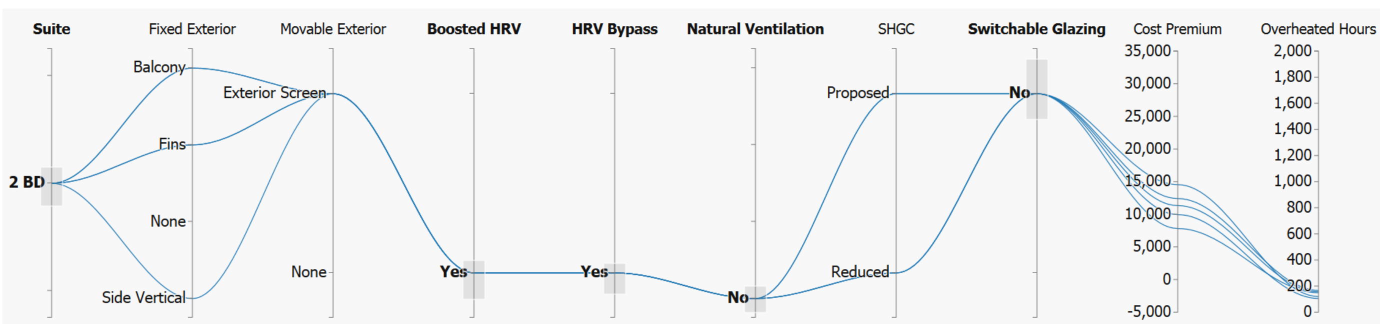


Figure 8. Boosted HRV with Bypass <200 Overheated Hours

4.1.4 Switchable Glazing

Has: Switchable glazing

Excludes: Natural ventilation

Needs: Some exterior shading and HRV bypass

Other Suites: Under this scenario, the 1-bedroom and SRO have between approximately $2,500 and $8,500 cost premium and <200 overheated hours.

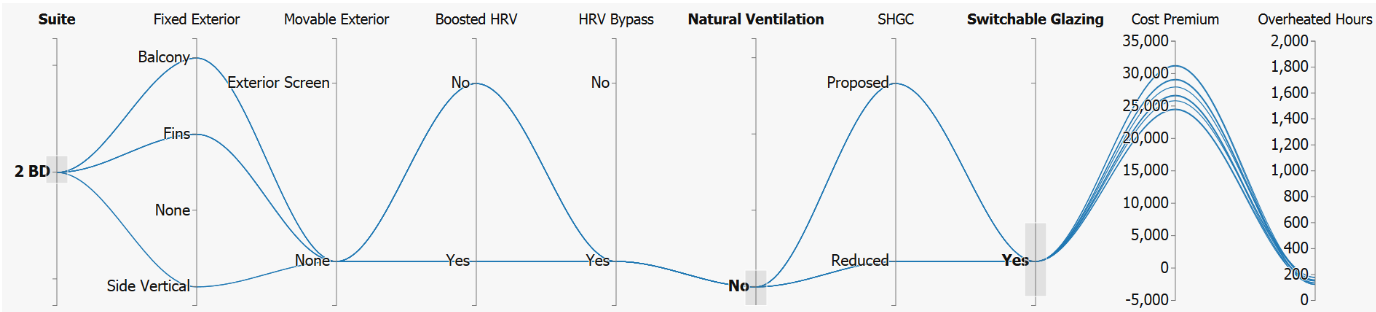


Figure 9. Switchable Glazing <200 Overheated Hours

4.2 Less than 20 Overheated Hours (2-bedroom)

There exist solutions to bring the overheated hours down significantly from the 200 hour threshold described above. Looking at solutions to bring the hours down to below 20 overheated hours, several scenarios are outlined below. For the 2-bedroom corner unit (most stringent suite type investigated), natural ventilation is required for all scenarios that achieve fewer than 20 overheated hours, and there is a significant cost premium to all scenarios (with a minimum cost premium of approximately $6,500 per unit).

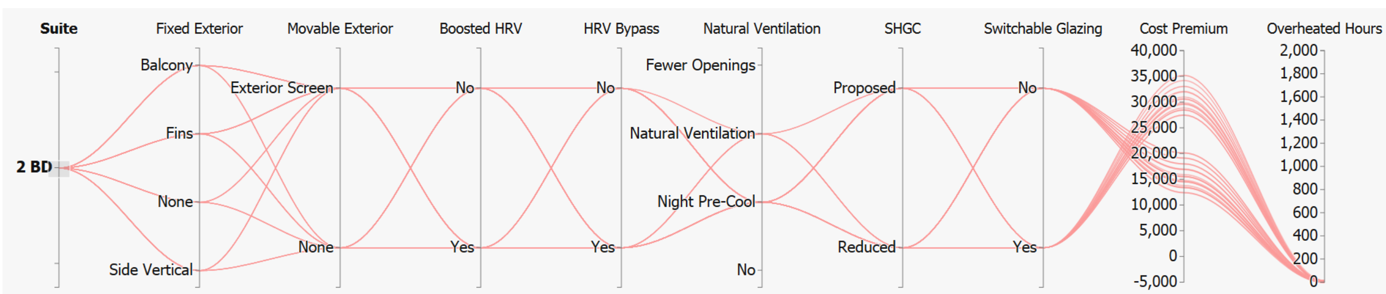


Figure 10. 2-Bedroom Solutions with <20 Overheated Hours

4.2.1 Likely Project Solution - Minimizes Cost Premium

Has: Minimizes overall cost premium.

Excludes: N/A

Needs: Night pre-cool, exterior screen, no HRV bypass, and either no shading or balconies (as balconies are considered to have $0 cost premium)
Other Suites: Under this scenario, the 1-bedroom and SRO have approximately a $500 cost premium and <20 overheated hours.

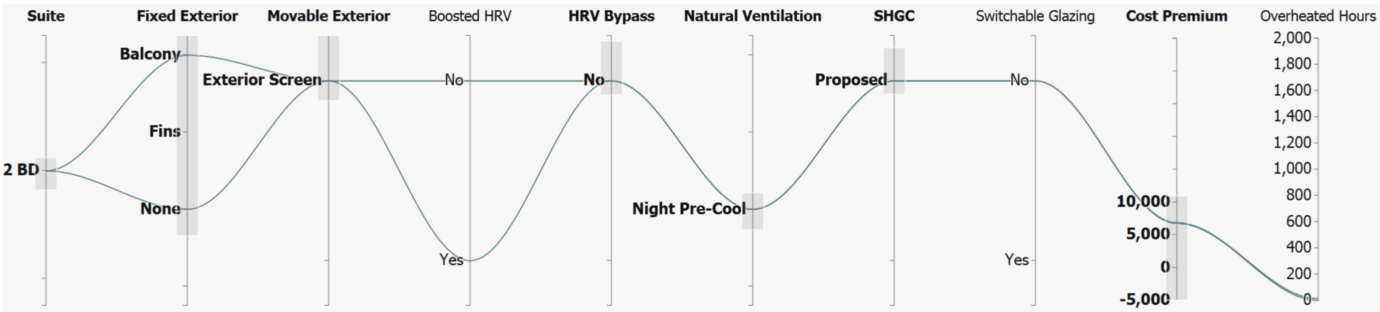


Figure 11. Likely Project Solution <20 Overheated Hours

4.2.2 Boosted HRV with Bypass

Has: Natural ventilation, HRV boost and bypass

Excludes: Switchable glazing, night pre-cooling

Needs: Exterior movable shading and either balcony or fins fixed exterior shading combined with proposed SHGC, or a reduced SHGC combined with either those shading or a smaller amount of shading provided by side vertical fins.

Other Suites: Under this scenario, the 1-bedroom and SRO have between approximately $0 and $4,000 cost premium and <20 overheated hours.

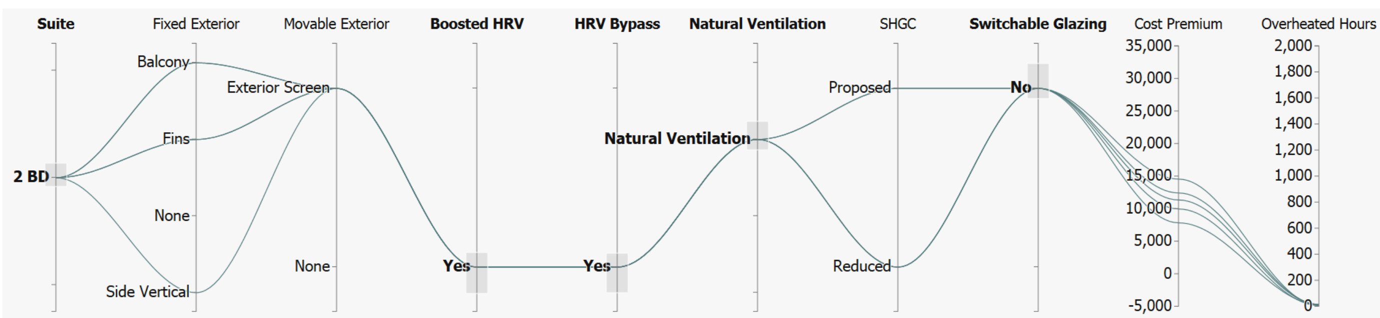


Figure 12. Boosted HRV with Bypass <20 Overheated Hours

4.2.3 Exclude Boosted HRV with Bypass

Has: Natural Ventilation

Excludes: HRV boost and bypass, switchable glazing, night pre-cooling

Needs: Exterior screen, as well as balcony or fins, and reduced SHGC

Other Suites: Under this scenario, the SRO has between approximately $500 and $1,600 cost premium and <20 overheated hours. The 1-bedroom suite would require some additional measure, for example a boosted HRV or night pre-cool would be needed to meet the target. Cost premiums are between $1,000 and $4,000.

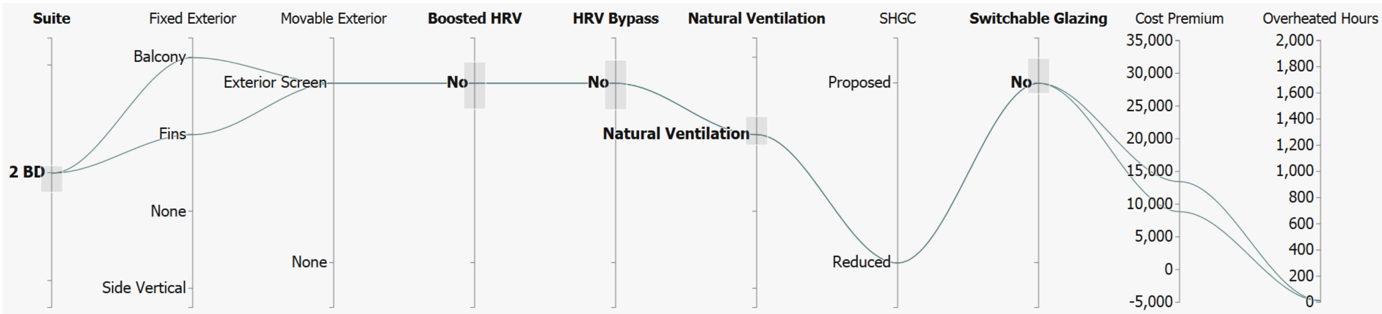


Figure 13. Exclude Boosted HRV with Bypass <20 Overheated Hours

4.2.4 Switchable Glazing

Has: Natural ventilation, switchable glazing

Excludes: Exterior screen, night pre-cooling

Needs: Fins and HRV bypass

Other Suites: Under this scenario, the 1-bedroom and SRO have between approximately $2,500 and $8,700 cost premium and <20 overheated hours.

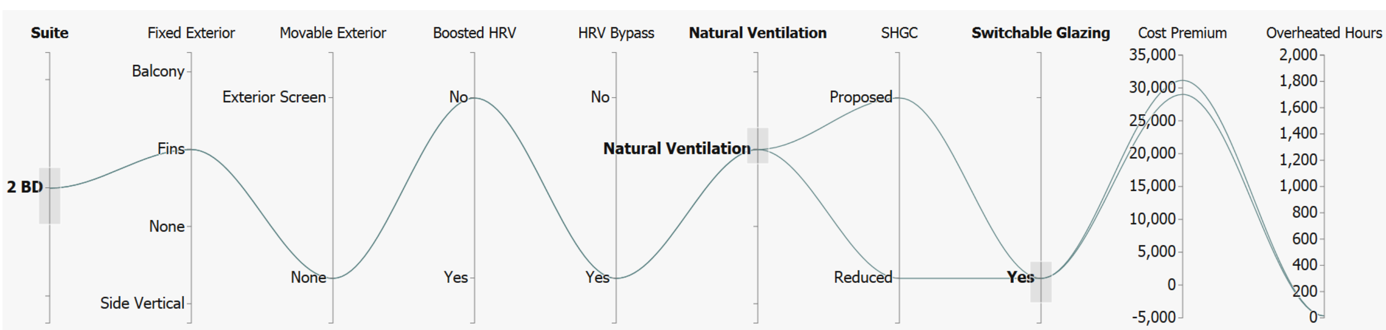


Figure 14. Switchable Glazing <20 Overheated Hours

4.3 1-Bedroom and SRO Cases

The results above look at the 2-bedroom corner suite unit as this is generally the worst case scenario and the design strategies used for the 2-bedroom unit will generally meet the requirements of the SRO and 1-bedroom unit as well. However, the cost implications of some of the strategies differ, and a minimal cost scenario is shown below for both the 1-bedroom and SRO.

4.3.1 Likely Project Solution - SRO Minimizes Cost Premium

The SRO has a number of passive cooling options that are a cost savings compared to adding a mechanical cooling system, as shown below. Night pre-cooling, natural ventilation, and reduced SHGC are the key strategies to minimizing cost in the SRO passive cooling model. All of the options below have fewer than 200 overheated hours, with 30 options having fewer than 20 overheated hours.

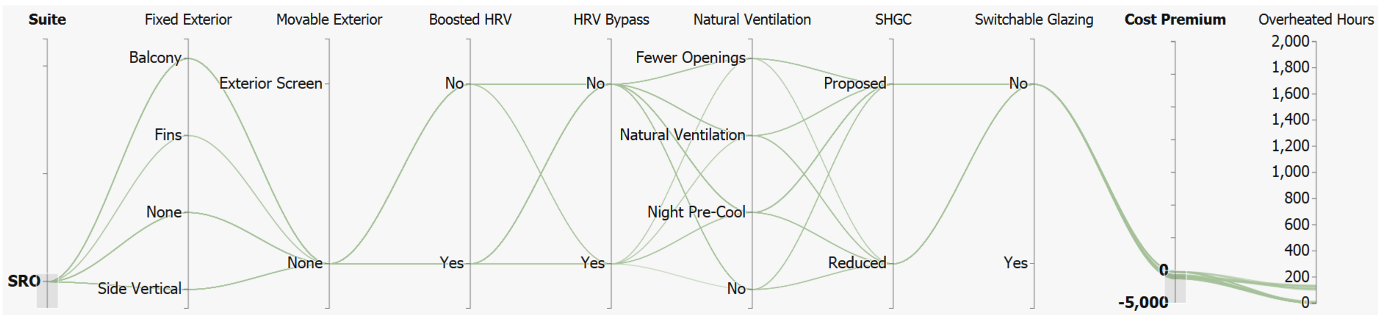


Figure 15. SRO Likely Project Solution <200 Overheated Hours

4.3.2 Likely Project Solution - 1-Bedroom Minimizes Cost Premium

The 1-bedroom unit likewise has a number of design paths to achieve below 200 overheated hours at a cost savings compared to a mechanical cooling system. These paths include natural ventilation, along with either night pre-cooling or reduced SHGC. 5 of the options below are capable of achieving <20 overheated hours at a cost savings compared to installing mechanical cooling.

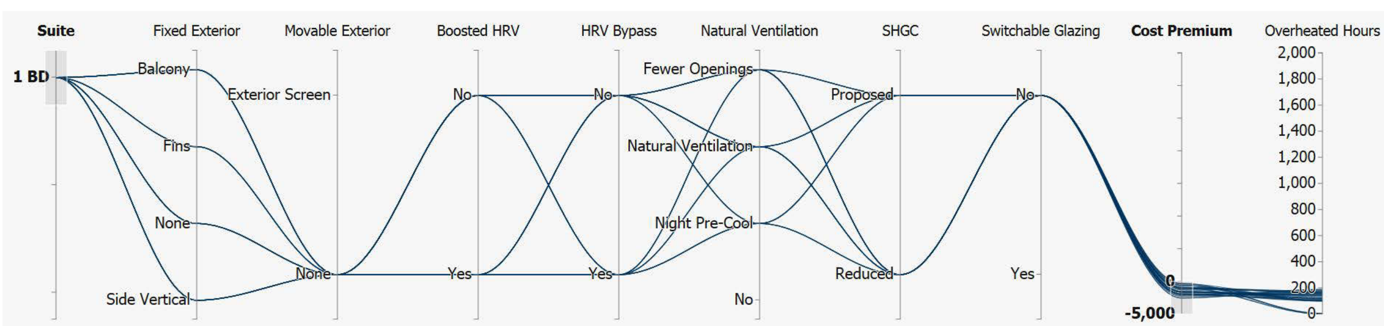


Figure 16. 1-Bedroom Likely Project Solution <200 Overheated Hours

5. FUTURE CLIMATE IMPACTS

The impact of a 2050's weather file is also modeled, using a Vancouver weather file adjusted to reflect a typical 2050's year. The weather file was modified using the Climate Change World Weather File Generator (http://www.energy.soton.ac.uk/ccworldweathergen/).

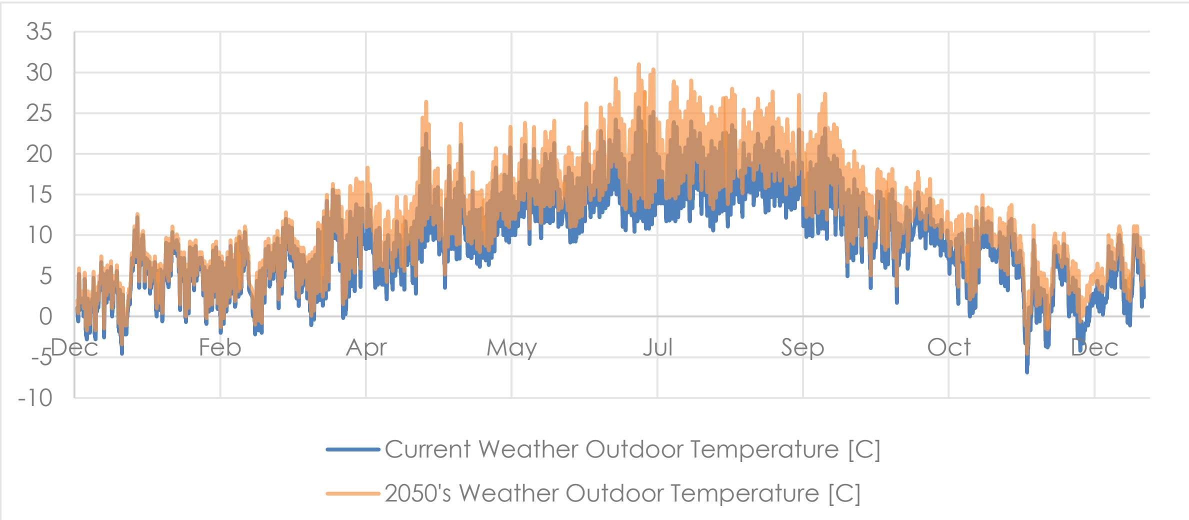


Figure 17. Current and 2050's Typical Year Outdoor Air Drybulb Temperature (°C)

The acceptability limits for naturally conditioned spaces outlined in Section 5.4 of ASHRAE 55-2010 is dependent on the mean monthly outdoor air temperature, and can be applied when the mean monthly outdoor air temperature is between 10C and 33.5C. Currently (using the CWEC weather file), this occurs in Vancouver from May through September. In the 2050's weather file, the cooling season for naturally conditioned spaces is extended to April through October.

For occupants who have control over window operation in naturally ventilated spaces, the temperatures in which they feel comfortable are dependent on the mean monthly outdoor air temperature during the previous month, according to ASHRAE 55-2010 Section 5.4. Therefore, during a warmer month, occupants with control and connection to the outdoors are more willing to accept a higher temperature indoors. Since the mean monthly outdoor air temperatures are higher in the 2050's weather scenario than they are today, occupants would be expected to be comfortable at higher indoor temperatures, based on ASHRAE's acceptability model. The maximum 80% acceptability limit for both the current weather conditions and the 2050's weather conditions are shown below.

Table 14. 80% Acceptability Limits Delineated Monthly

	Current Weather	2050's Weather
April	N/A (Mean temperature too low)	24.9 ˚C
May	25.0 ˚C	25.7 ˚C
June	26.0 ˚C	26.7 ˚C
July	26.6 ˚C	27.7 ˚C
August	26.6 ˚C	27.7 ˚C
September	25.6 ˚C	26.5 ˚C
October	N/A (Mean temperature too low)	25.1 ˚C

The likely project solutions, minimizing the overall cost premiums in the 2050's weather scenario, are summarized in the table below.

Table 15. Summary of Likely Project Solutions

		Description	Cost Premium	Overheated Hours	Peak Temperature
<200 Hours	SRO	Night pre-cool, exterior screen, balcony, HRV bypass	$1,250	15	25.0 ˚C
	1-bedroom		$1,500	175	26.2 ˚C
	2-bedroom		$8,000	170	26.8 ˚C

5.1 Future Climate Impacts Performance Map

The same parametric analysis as done in Section 4 was conducted using the 2050's weather file. For the 2-bedroom corner suite, there are no design scenarios investigated that lead to fewer than 100 overheated hours. In order to reduce overheated hours below 200 hours, natural ventilation and fixed exterior shading is required.

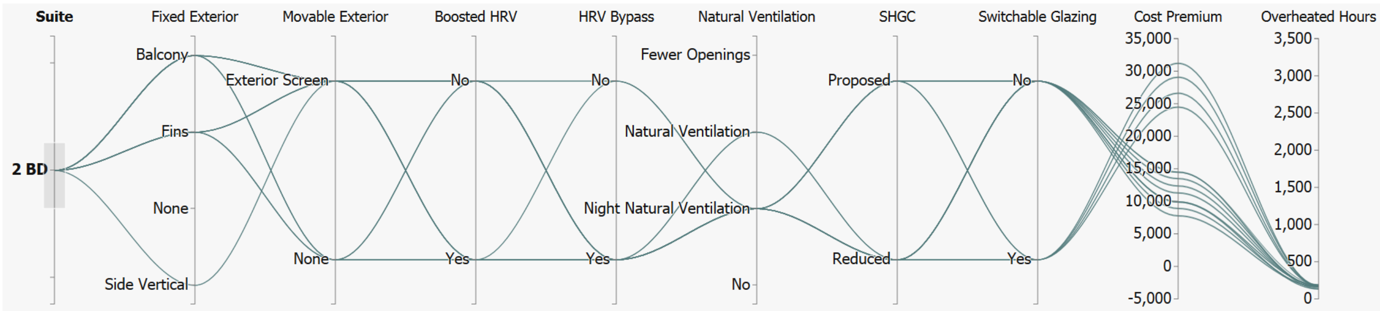


Figure 18. Future Climate Impacts <200 Overheated Hours

A few potential design scenarios are outlined below.

5.1.1 Likely Project Solution - Minimizes Cost Premium

Has: Minimizes cost premium

Excludes: N/A

Needs: Night pre-cooling and natural ventilation, movable exterior screen, HRV bypass, reduced SHGC, and fixed exterior shading

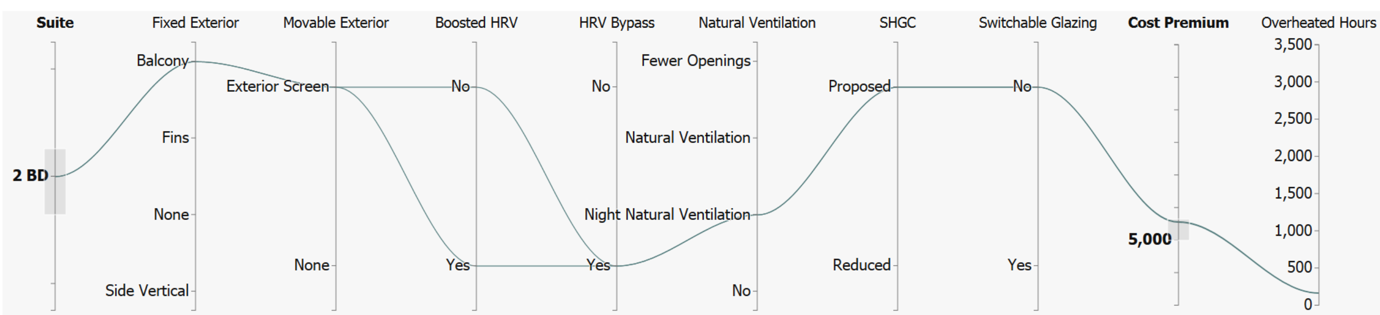


Figure 19. Likely Project Solution <200 Overheated Hours

5.1.2 No Night Pre-Cooling

Has: N/A

Excludes: Night pre-cooling

Needs: exterior screen, natural ventilation, fins or balcony, reduced SHGC, and HRV bypass

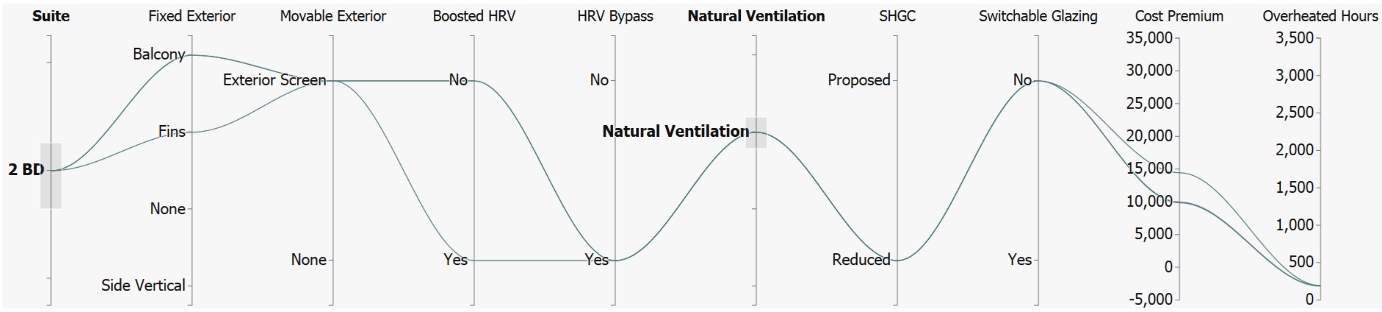


Figure 20. No Night Pre-Cooling <200 Overheated Hours

5.2 1-Bedroom and SRO Cases

The results above look at the 2-bedroom corner suite unit as this is generally the worst case scenario and the design strategies used for the 2-bedroom unit will generally meet the requirements of the SRO and 1-bedroom unit as well. However, the cost implications of some of the strategies differ, and a minimal cost scenario is shown below for both the 1-bedroom and SRO.

5.2.1 Likely Project Solution - SRO Minimizes Cost Premium

The SRO has a number of passive cooling options that reduce overheated hours to fewer than 200 hours. A number of options achieve fewer than 200 hours overheated at a cost savings compared to adding a mechanical cooling system. All of the options below have fewer than 200 overheated hours, with 32 options having fewer than 20 overheated hours. The solutions achieving the greatest cost savings compared to adding mechanical cooling include fixed exterior shading, HRV bypass, and natural ventilation, and exclude switchable glazing and exterior screens.

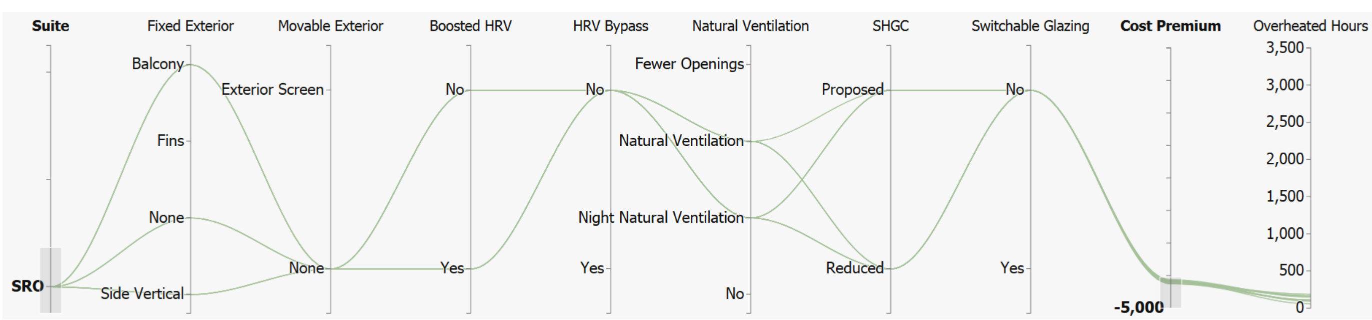


Figure 21. SRO Likely Project Solution <200 Overheated Hours

5.2.1 Likely Project Solution – 1-Bedroom Minimizes Cost Premium

Similar to the 2-bedroom future climate scenario, fixed exterior shading, night pre-cooling, and HRV bypass are key to achieving fewer than 200 overheated hours. No scenarios achieve fewer than 100 overheated hours. The lower cost premium solutions exclude switchable glazing and require exterior screens.

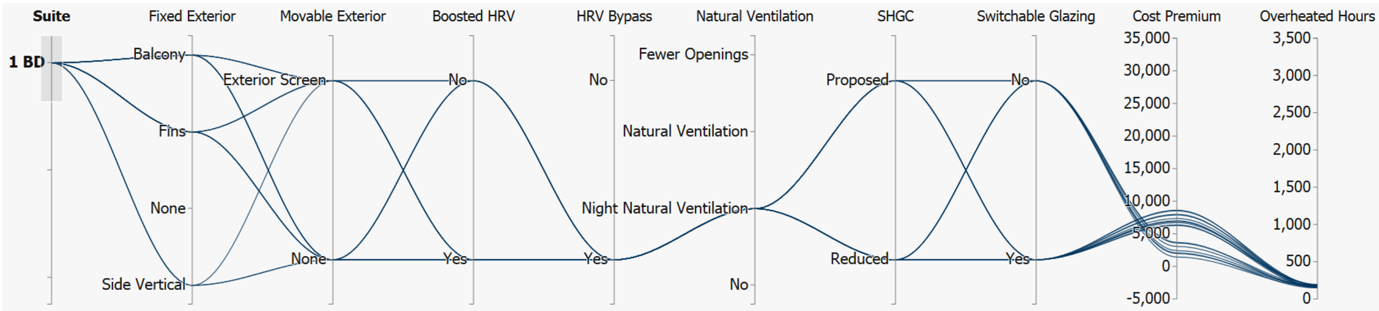


Figure 22. 1-Bedroom Likely Project Solution <200 Overheated Hours

6. CLOSING

This study investigated the impact of the City of Vancouver's Zero Emissions Building Plan on the anticipated overheated hours in suites using passive cooling measures, which shows an increase in the number of overheated hours for all three of the suite types investigated.

A number of passive cooling measures were simulated, and costs estimated, to look at ways to mitigate this increase in overheated hours. There are passive cooling solutions for all three suite types to bring the overheated hours below two thresholds investigated at 200 overheated hours and 20 overheated hours. Passive cooling measures that are less expensive than adding a mechanical cooling system can bring the suites below 200 overheated hours.

For the warmer 2050's climate, additional passive cooling measures are required to achieve the same performance, and none of the solutions investigated allow the southwest facing 1-bedroom or corner unit 2-bedroom suite below 100 overheated hours.

We trust that this meets the City of Vancouver's requirements for this study.

Yours truly,

MORRISON HERSHFIELD LIMITED

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Principal, Building Energy Practice Lead

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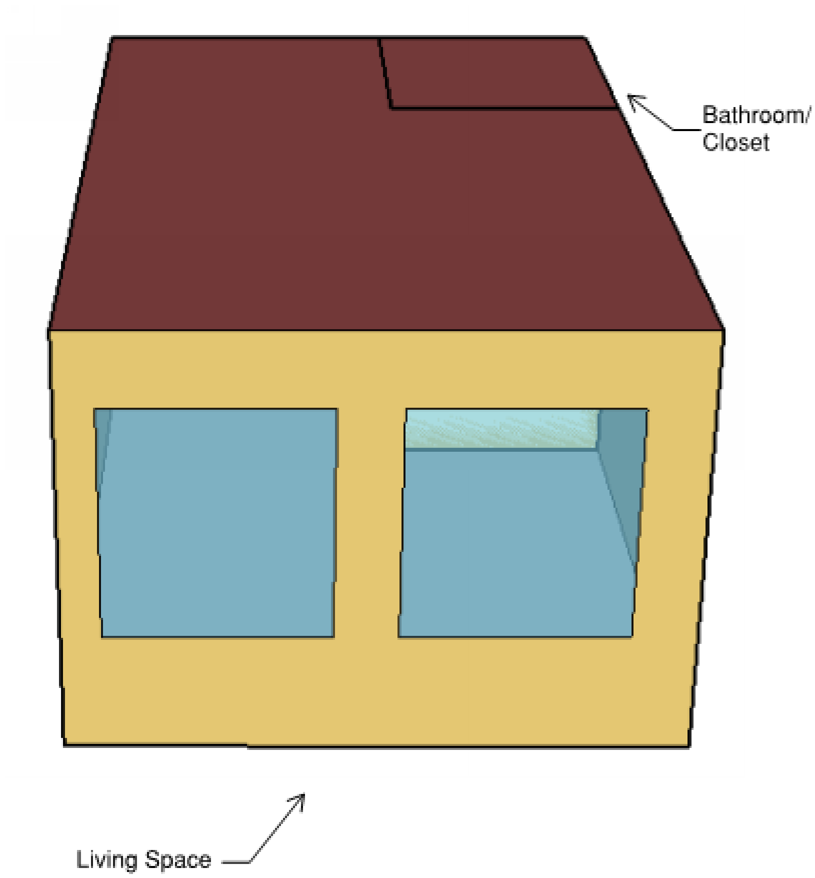
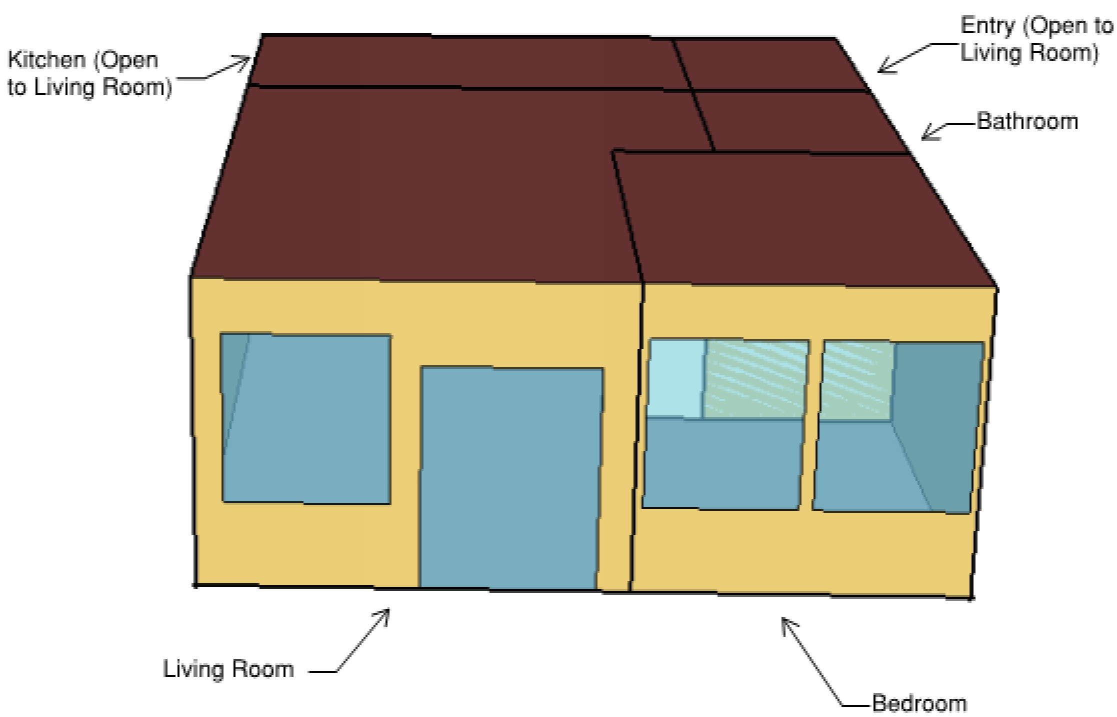
Principal, Building Energy Consultant

APPENDIX A: Suite Layouts

Southwest facing SRO



1-bedroom southwest rental unit



2-bedroom southwest corner condo