# Future Climate Design for Multi-Family Buildings | Project R-21007.001

**To Ralph Wells**
**UBC Sustainability and Engineering**
**Room 3331 - 2260 West Mall**
**Vancouver BC V6T 1Z4**

**Submitted Sept 27, 2021 by**
**RDH Building Science Inc.**
**4333 Still Creek Drive #400**
**Burnaby BC V5C 6S6**

# Executive Summary

Multi-family buildings in the Lower Mainland are overheating due to climate change. The health and wellbeing of occupants is linked to thermal comfort and is therefore a key focus for building design. New design strategies, modelling protocols and building policies are required to ensure that buildings are designed to maintain thermal comfort while also providing resilience to increasingly frequent climate-related events such as heat waves, wildfire smoke, and power outages. Designs that simply add mechanical cooling without due consideration to passive opportunities often miss the resiliency and durability impacts of well-designed passive measures, as well as the cost benefit of reducing demand first. They also risk adding peak electrical loads that cannot be easily managed at the grid level.

Overheating can be addressed in both new and existing multi-family buildings with design strategies that promote climate resilience, i.e. the ability to withstand and adapt to the effects of climate change using both adaptation and mitigation.

This report includes multiple recommendations related to defining thermal comfort and overheating risk; modeling of thermal comfort and overheating risk; design strategies to mitigate overheating, and potential changes to BC Codes and related requirements to address overheating risk in multi-family buildings.

The recommendations were vetted at a workshop with key stakeholders. Key high-level recommendations resulting from this work are as follows:

- The BC Building Code should address overheating risk as a health safety issue and incorporate requirements to mitigate health risks of overheating as a minimum.
- These requirements should include both frequency and magnitude of overheating and could either reference the NRC Overheating Framework or incorporate elements from CIBSE TM59.
- Building designs should be modeled at a minimum to current (2020s) weather files to reflect climate change that has already occurred, but also consider designing to a 2050s or 2080s climate (at a minimum as a sensitivity analysis).
- Require a sensitivity test that considers more extreme heat events. NRC has proposed the Reference Summer Weather Years (RSWY) methodology, which is recommended to be used for assessing overheating when available. Future shifted RSWY files may enable a sensitivity analysis for more extreme temperatures in future conditions.
- Passive design is encouraged, and the industry should be educated on the co-benefits and cost-savings potential of incorporating passive strategies in building designs.
- While passive measures and occupant controls are generally desirable in a multi-family building and can have a considerable impact on perceived comfort, models should not overly rely on user operation to maintain thermal comfort.
    - Consider requiring broader sensitivity analysis for resilience during extreme climate events (wildfires, heat waves, and power outages) in modelling requirements. During these events, measures such as natural ventilation and mechanical cooling are limited or turned off in the model. The test could require compliance with adjusted criteria. The University of Toronto has published a

guideline on modelling thermal resilience and passive survivability that could be referenced.[1]

  - If natural ventilation is permitted as an overheating mitigation strategy in building models, a consistent modeling method should be established, and a sensitivity analysis required to demonstrate adequate performance to the adjusted criteria in scenarios in which windows can not viably be opened.
- Providing mechanical cooling in concert with passive design strategies should be considered a requirement for all new multi-family buildings. Alternatively, any new multi-family buildings that do not incorporate mechanical cooling should bear the burden of proof that either the buildings will protect the health and safety of its occupants from overheating (through the 2050s) and/or provide a plan that allows for the easy incorporation of cooling in the future.
- To further the previous two points (in concert with achieving emissions mitigation targets), establish a standard definition of CEDI.
  - Require modeling and reporting of CEDI results on all new design permit submissions. This will provide valuable input for setting achievable limits in climate zones throughout the province.
- Project teams should model these metrics in a standardized method, and report the results as part of the permitting process.

Additional work is expected to further this work:

- To generate consensus on overheating criteria and limits.
- To set CEDI limits appropriate to each climate region (and potentially building types) in BC, including further consultation with both regulators and the design and modelling community.
- To understand the implications of requiring all new designs to meet the peak cooling demand of a 2050s (or 2080s) climate (e.g. how much additional capacity is required; what are implications on duct and equipment sizing, if any etc.).
- To establish a common methodology for representing natural ventilation in building models
- To establish common methodologies for completing sensitivity analyses and associated performance criteria.

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[1] https://pbs.daniels.utoronto.ca/faculty/kesik_t/PBS/Kesik-Resources/Thermal-Resilience-Guide-v1.0-May2019.pdf

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# 1 Overview

## 1.1 Background

Multi-family buildings in the Lower Mainland are overheating due to climate change. The health and wellbeing of occupants is linked to thermal comfort and is therefore a key focus for building design. New design strategies, modelling protocols and building policies are required to ensure that buildings are designed to maintain thermal comfort while also providing resilience to increasingly frequent climate-related events such as heat waves, wildfire smoke, and power outages. Designs that simply add mechanical cooling without due consideration to passive opportunities often miss the resiliency and durability impacts of well-designed passive measures, as well as the cost benefit of reducing demand first. They also risk adding peak electrical loads that cannot be easily managed at the grid level.

Overheating can be addressed in both new and existing multi-family buildings with design strategies that promote climate resilience, i.e. the ability to withstand and adapt to the effects of climate change using both adaptation and mitigation. RDH was previously retained by UBC to improve our understanding of current and future overheating risks in multi-family buildings and to evaluate potential passive and active strategies to mitigate these risks.[2]

This current project was initiated to support the BC Hydro Sustainable Communities “It’s Getting Hot In Here” Ideation project and was fully funded by BC Hydro, with participation from the Province of BC, local governments and UBC. The project intent is to further the development of modelling practices, design strategies, and potential code requirements that respond to our warming climate. RDH Building Science Inc. (RDH), in partnership with Zenon Management and ZGF, were engaged to complete this work as four key tasks:

- Task 1: Defining Thermal Comfort and Overheating – Review of key thermal comfort/overheating standards and recommendations for additions, revisions, or areas for future work related to building codes and standards in BC.
- Task 2: Modelling Thermal Comfort and Overheating - Recommendations for whole building energy modelling guidelines.
- Task 3: Design Implications - Recommendations on design implications and best practice solutions for optimizing thermal comfort and lifecycle costing of select design measures.
- Task 4: Recommending Changes to BC Codes and Requirements - Recommendations for potential changes to building codes and requirements in BC based on finding from Tasks 1-3.

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[2] 2020. Final Report: UBC – Designing Climate Resilient Multi-Family Buildings: https://planning.ubc.ca/sites/default/files/2020-05/REPORT_UBC_Climate%20Resilient%20Multifamily%20Buildings.pdf

# 2 Defining Thermal Comfort and Overheating

This section summarizes existing thermal comfort and health safety standards and other relevant research as they relate to overheating in multi-family buildings, as background for the development of additions or revisions to building codes and standards in BC.

The goal of this task was to review key thermal comfort standards and make recommendations for additions, revisions, or areas for future work related to building codes and standards in BC. This literature scan summarizes a brief overview of key documents, though is not intended as a comprehensive guide to thermal comfort nor a comprehensive summary of research, guidelines, and standards related to thermal comfort or occupant safety.

While the standards cover a range of building types and scenarios, comments focus primarily on overheating (as a subset of thermal comfort) and non-mechanically cooled buildings. A brief summary of the NRC paper *Climate Resilience of Buildings: Overheating in Buildings — Development of Framework for Overheating Risk Analysis* (Laouadi, A. et al, 2019) is also provided.

A glossary of terms and definitions is provided in Appendix A.

## 2.1 Summary of Thermal Comfort Models

Thermal comfort is typically described using an enviro-physiological model that is based on a heat balance between the subject and its environment. There are many models available, but the two primary ones are the steady-state PMV/PDD model (Fanger et al, 1967 to 1986) and the transient Pierce 2-Node model (Gagge et al, 1971, 1976). Adaptive models are not based on heat balance calculations of a subject, but instead inherently assume that the subject is able to alter their environment (for example by opening a window, or turning on a fan) to make it more comfortable (Humphrey and Nicol, 1998). ASHRAE Standard 55 and the European CEN Standard EN-15251 are both variations of adaptive models.

A list of salient variables used within these models are provided in Table 2.1. Models that omit these variables may risk losing precision and accuracy in their predictions.

TABLE 2.1 – THERMAL COMFORT VARIABLES

| Independent Environmental Variables | Independent Personal Variables |
|---|---|
| → Air temperature<br>→ Mean radiant temperature<br>→ Relative air velocity<br>→ Ambient water vapour pressure (i.e. humidity) | → Activity level<br>→ Clothing |
| **Physiological Variables** | **Secondary Variables** |
| → Skin temperature<br>→ Core temperature<br>→ Sweat rate<br>→ Skin wettedness<br>→ Skin-Core thermal conductance | → Age<br>→ Visual stimuli<br>→ Outdoor climate<br>→ Environmental thermal asymmetry<br>→ Sex |

### *Predicted Mean Vote/ Predicted Percentage Dissatisfied*

The Predicted Mean Vote (PMV), and its derivative Predicted Percentage Dissatisfied (PPD), based on Fanger (1967), calculates the associated skin energy loss of a thermally comfortable person in a given environment (and is covered in ISO 7730). The associated energy loss is then correlated to a thermal sensation vote, leading to the predicted mean vote. The PMV method is a steady-state model that assumes the core body temperature is constant, and the output is a thermal comfort sensation on a 7-point scale. The Predicted Percentage Dissatisfied elaborates on the PMV vote by converting it into a distribution of persons who would find a given environment uncomfortable. It has been updated to include features such as thermal radiant asymmetry and drafts to modify the thermal comfort experience.

### *Pierce 2-Node Model*

The Pierce 2-Node model (Gagge, 1986) describes the physiological experience of temperature sensation through describing the mechanism of heat transfer between the body core, skin, and the ambient environment. The derivation of the core and skin temperature, and the skin wetness, is based on physiological mechanisms (e.g. shivering, vasomotion, sweating). The acceptability criteria convert these outputs to predict thermal sensation (TSENS) and discomfort (DISC), with the former based on a 11-point comfort scale, similar to the PMV scale.

The 2-Node model also permits the calculation of the Effective Temperature (ET), and the associated Standard Effective Temperature (SET). The ET is the temperature of an equivalent environment at 50% RH resulting in the same total heat loss from the skin as in the actual environment. SET is normalized to clothing level that would be worn for a defined activity level. The SET is the environmental index preferred by Laouadi et al (2019) as part of their *Climate Resilience of Buildings: Overheating Buildings* framework.

### *Adaptive Models*

Adaptive models provide guidelines on acceptable thermal comfort criteria based on a running average of outdoor temperature and assuming the occupants have capacity to alter their environment to make it more comfortable. ASHRAE Standard 55 and EN-15251[3] both provide adaptive comfort models, with slight variations in the assumptions regarding activity levels, clothing, and temperature corrections.

ASHRAE 55's adaptive comfort model defines a threshold where 80% of occupants in a sedentary or slightly active level find the thermal environmental acceptable in naturally conditioned buildings. It is based on a study of thermal comfort by de Dear and Brager (1998). This approach is currently used within the BC Energy Step Code via the City of Vancouver Energy Modelling Guidelines for Passively Cooled Buildings.

The CIBSE TM52:2013 model (*The limits of thermal comfort: avoiding overheating in European buildings)* is based on the EN-15251 standard, but with supplemental guidance and provision of different means of describing acceptability limits. CIBSE TM59: 2017 (*Design methodology for the assessment of overheating risks in homes*) provides a strict

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[3] The CEN Standard BS EN-15251 is a European standard that presents methods for evaluating thermal comfort in mechanically and naturally conditioned buildings. The standard is not reviewed in this study.

threshold definition for thermal comfort (in terms of hours of exceedance), but refers to CIBSE T52 for more complicated buildings.

### *Acceptability Limits*

The PMV/PPD and 2-Node models both provide a method to determine thermal comfort limits based on a physiological basis. The PMV/PPD and 2-Node models do not provide acceptability limits on overheating exposure, but do provide descriptions on the point at which environmental conditions become uncomfortable. The ASHRAE and CIBSE standards provide guidance on maximum overheating thresholds, usually measured in terms of percentage of hours exceeding the upper acceptability limits.

## 2.2 Summary of Standards and Research

### 2.2.1 Standards

TABLE 2.2 STANDARDS AT A GLANCE

| | **Applicability** | **Acceptability criteria** | **Focus/use** |
|---|---|---|---|
| ANSHI/ASHRAE Standard 55-2013 | Overall thermal comfort (over-/underheating)<br>Spaces with mechanical heating and cooling | Operative temperature and humidity thresholds given certain clothing levels, metabolic rates, and average air speeds; or PMV index | How to measure and evaluate the risk of overheating |
| | Overall thermal comfort (over-/underheating)<br>Occupant-controlled naturally conditioned spaces | Operative temperature threshold (using an adaptive model) | |
| CIBSE TM59 | Overheating<br>Non-mechanically cooled residential buildings;<br>Residential buildings with vulnerable populations (with additional considerations for heat waves) | Operative temperature threshold (or difference between the operative temperature and maximum acceptable temperature) | Providing guidance on how to model the risk of overheating during design stage using hourly modelling tools |
| CIBSE TM52 | Overheating<br>Commercial buildings | N/A – summarizes other standards;<br>Recommends: (1) number of hours above an operative temperature threshold, (2) daily limit for temperature rise and its duration, (3) absolute maximum daily temperature. | Providing guidance to designers, developers, and other building industry professionals on how to mitigate overheating in buildings |

| TABLE 2.2 STANDARDS AT A GLANCE | | | |
|---|---|---|---|
| ISO 7730 | Spaces with mechanical heating and cooling | PMV index and PPD index | Methods for predicting the general degree of discomfort of people exposed to indoor environments where thermal comfort is desirable |

### *ANSHI/ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy*

ASHRAE 55 presents methods for evaluating thermal comfort for naturally and mechanically conditioned buildings. The standard considers six factors for thermal comfort: metabolic rate, clothing insulation, air temperature, air speed, radiant temperature, and humidity.

Section 5.3 of the standard provides two methods for determining acceptable thermal conditions in occupied spaces: Graphic Comfort Zone Method, and Analytical Comfort Zone Method. The Graphic Comfort Zone Method plots acceptable operative temperature and humidity conditions on a psychrometric chart given certain clothing levels, metabolic rates, and average air speeds. The Analytical Comfort Zone Method uses a computer model based on the PMV index. Additional criteria are provided for spaces with elevated air speeds, and local thermal discomfort. These methods are typically applied to spaces with mechanical heating and cooling.

Section 5.4 of the standard defines acceptable thermal environments in occupant-controlled naturally conditioned spaces. This section is applicable only under certain conditions, namely (for upper limits, i.e. overheating) that there is no mechanical cooling system, that occupants are free to adapt their clothing to thermal conditions, and that the prevailing mean outdoor air temperature is below 33.5˚C (similar criteria apply to lower limits, i.e. under-heating).[4] For mean outdoor air temperatures above 33.5˚C the acceptability limits defined in Section 5.4 of the standard are no longer applicable and no alternate guidance is provided. It is referred to as an adaptive model, which is a model that relates acceptable indoor temperature ranges to outdoor climate parameters, as described above.

According to the standard, the allowable indoor operative temperatures for naturally conditioned buildings are determined using the 80% acceptability limits, meaning that 80% of the occupants find the space thermally acceptable. For the purpose of evaluating the risk of overheating, the *upper* 80% acceptability limit is calculated as described below:

$$Upper\ 80\%\ acceptability\ limit\ (°C) = 0.31 \cdot T_{PMA(OUT)} + 21.3 \qquad (1)$$

The upper 80% acceptability temperature limit is based on the prevailing mean outdoor air temperature ($T_{PMA(OUT)}$) calculated from a Typical Meteorological Year (TMY) or similar weather file.

Section 6 describes design and documentation requirements to demonstrate compliance with the standard, such as the method of design compliance, design conditions,

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[4] For mean outdoor air temperatures above 33.5˚C the acceptability limits defined in Section 5.4 of the standard are no longer applicable and no alternate guidance is provided.

calculation assumptions, explanation of local thermal discomfort, equipment capacities, etc. Section 7 describes evaluation of comfort in existing buildings, including comfort models for mechanically and naturally conditioned spaces, measurement methods, and evaluation methods.

### *CIBSE TM59: Design Methodology for the Assessment of Overheating Risk in Homes (2017)*

The Chartered Institution of Building Services Engineers (CIBSE) Technical Memorandum (TM) 59 was developed in the UK and describes a standardized approach to predict the risk of overheating for non-mechanically cooled residential buildings in design stage (new-build or major refurbishment) by using hourly (dynamic) simulation. The thermal comfort and acceptability criteria of CIBSE TM59 are based on TM52 which references the EN-15251 standard. (Note that the criteria for defining overheating in non-residential buildings are different from these criteria - see CIBSE TM52 below.)

Section 3 of the memorandum includes general modelling guidance on weather files, window and door openings, infiltration, mechanical ventilation, air speed assumptions, blinds and shading devices, mechanical heat loss, and common corridors. For weather files, it is suggested that a ‘design summer year’ (DSY) weather file is used in the simulation. CIBSE developed three different Design Summer Year (DSY) files for overheating analysis of naturally ventilated buildings; the DSYs represent a warmer than average, but not extreme, summer.

Section 4 defines criteria for naturally ventilated and mechanically ventilated homes. Naturally ventilated, in this standard, is defined by the homes having good opportunity for natural ventilation via operable windows, regardless of whether or not they also have mechanical ventilation.

For residential buildings that are predominantly naturally ventilated, compliance is based on passing both of the following two criteria:

a) *For living rooms, kitchens, and bedrooms*: the number of hours during which ΔT is greater than or equal to one degree (K) during the period May to September shall not be more than 3% of occupied hours.

   ΔT is the difference between the operative temperature in the room and the limiting maximum acceptable temperature. The maximum acceptable temperature is 3°C above the comfort temperature for naturally ventilated buildings and can be calculated from the running mean of the outdoor air temperature ($T_{rm}$) using the equation below.

   $$T_{max}\,(°C) = 0.33 \cdot T_{rm} + 21.8 \qquad (2)$$

b) *For bedrooms only*: to guarantee comfort during the sleeping hours the operative temperature in the bedroom from 10pm to 7am shall not exceed 26°C for more than 1% of annual hours.

For residential buildings that are predominantly mechanically ventilated, compliance is based on passing the following criteria:

a) For homes with restricted window openings, the fixed temperature test must be followed, i.e. all occupied rooms should not exceed an operative temperature of 26°C for more than 3% of the annual occupied hours.

The criteria described above are applicable for residential buildings with vulnerable populations. However, where there are particular concerns of high risk of overheating in buildings with vulnerable population, CIBSE TM59 recommends that a heatwave strategy should also be developed using additional weather files (such as future weather files) to explore performance and to demonstrate mitigation options under extreme events.

For common corridors, overheating should be assessed based on the number of annual hours for which an operative temperature of 28˚C is exceeded. While there is no mandatory target to meet, if an operative temperature of 28˚C is exceeded for more than 3% of the total annual hours, then this should be identified as a significant risk.

Sections 5 and 6 provides occupancy and internal gain details to be used in the analysis. The standard recommends a 24-hour occupancy profile for all bedrooms. Kitchen and living rooms are unoccupied during the sleeping hours (10 pm to 7am) and occupied during the rest of the day as a worst-case scenario since the rooms will be modelled as occupied during the hottest hours of the day.

### *CIBSE TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings (2013)*

This memorandum is intended to provide guidance to designers, developers, and other building industry professionals on overheating in buildings.

Section 2 discusses comfort and discomfort fundamentals. Section 3 provides background on predicting discomfort including key factors (temperature, air movement, and humidity) and thermal comfort models (e.g. PMV).

Section 4 summarizes existing thermal comfort standards including ISO 7730, ASHRAE 55, EN-15251. The section further discusses challenges with thermal comfort standards, including mechanically versus naturally ventilated buildings, and the general challenges of attempting to standardize phenomenon that are inherently imprecise.

Section 5 presents options for defining risk of overheating, including a single temperature overheating limit coupled with an "hours over" criteria, versus a deviation from comfort temperature such as the PMV.

Section 6 provides guidance to prevent overheating in buildings, specifically referencing the methodology and recommendations of EN-15251. For overheating in "free-running buildings", three criteria are recommended:

1. *The first criterion sets a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature (upper limit of the range of comfort temperature) by 1 ˚K or more during the occupied hours of a typical non-heating season (1 May to 30 September).*
2. *The second criterion deals with the severity of overheating within any one day, which can be as important as its frequency, the level of which is a function of both temperature rise and its duration. This criterion sets a daily limit for acceptability.*
3. *The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable.*

Each of the above three criteria are further defined in the standard.

### *ISO 7730: 2005 Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*

The International Organization for Standardization (ISO) 7730:2005 standard presents methods for predicting the general degree of discomfort of people exposed to indoor environments where thermal comfort is desirable. The ISO 7730 standard is applicable to new builds or assessment of existing buildings. Although the ISO 7730 standard is developed specifically for the work environment, it may be applicable to other kinds of environments as well.

The ISO 7730 standard uses the PMV and PPD model. The PMV index is used to predict the mean value of the votes of a large group of people on a 7-point thermal sensation scale. The PMV index is calculated under constant conditions based on the heat balance of the human body, variables such as metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity and air humidity are taken into account. The PMV predicts the mean value of the thermal comfort of a large group of people exposed to the same environment, but individual votes are scattered around this mean value. The PPD index predicts the number of people likely to feel uncomfortably warm or cool.

The ISO 7730 standard does not include thresholds for naturally conditioned residential buildings and cannot therefore be compared to ASHRAE 55 or CIBSE TM59. The standard briefly discusses thermal comfort adaptation and the application of the standard for naturally conditioned spaces during warm periods, where the thermal conditions of the space are regulated primarily by the occupants through the opening and closing of windows. Studies have shown that higher temperatures than the PMV values presented in earlier sections may be acceptable in such cases.

## 2.2.2 Research

### *Summary of NRC Climate Resilience of Buildings: Overheating in Buildings – Development of Framework for Overheating Risk Analysis*

Overheating thresholds that are based on a number or percentage of hours exceeding an upper acceptability limit (such as those provided in ASHRAE and CIBSE) are not directly applicable to evaluations of human heat stress. This research attempts to combine the results of the 2-Node model, using SET, and develops a severity index of heat event (SETH). The proposed method for the assessment of overheating risk uses the SETH index, whereby the acceptability limit is based on body water loss criteria to limit the dehydration of building occupants exposed to overheating events. Dehydration was the leading cause of mortality followed by heatstroke during the 2003 European heat wave. The proposed maximum allowable dehydration rate is 3% and 2% of body weight for healthy and vulnerable subjects, respectively. The proposed rehydration rates were fixed to 60% and 40% for the healthy and vulnerable subjects, respectively.

SETH values are the amount of temperatures exceeding active and dormant values of SET with the duration of exceedance. The severity index is expressed as the product of the intensity of a heat event (SET) and exposure time,

$$SETH = \sum_t (SET - SET_r) \cdot \Delta t \qquad (3)$$

where ΔT is the calculation time step (h) and $SET_r$ is the reference value of SET beyond which overheating events are identified. The $SET_r$ thresholds were developed for healthy and vulnerable occupants and correspond to a situation that is tolerable by most people (80%), and safe for both healthy and vulnerable occupants.

The corresponding reference value of SET is calculated for an un-acclimatized and acclimatized person. People are assumed not acclimatized during the first month of expected heat events in the summer season, which is set to May for Canadian locations. People are then assumed acclimatized to heat events from June to September. The $SET_r$ thresholds are summarized in Table 2.3.

TABLE 2.3 SUMMARY OF SET THRESHOLDS

| | SETsleep (˚C) | | SETawake (˚C) | |
|---|---|---|---|---|
| | Un-acclimatized | Acclimatized | Un-acclimatized | Acclimatized |
| Healthy Occupants | 26 | 27.2 | 30 | 31.2 |
| Vulnerable Occupants | 26 | 27.2 | 26 | 27.2 |

The threshold values of SETH in Canadian residential buildings is proposed to be 153+/-18 (˚C*h) and 56 +/-27 (˚C*h) for healthy and vulnerable occupants, respectively.

## 2.3 Applicability to BC Codes, Standards, and Certification Programs

Beyond the discussion of thermal comfort, overheating is also a potential life-safety issue that may fall within the mandate of codes- namely to ensure safely built environments. This section provides a brief summary of existing thermal comfort and overheating criteria in codes, standards, and certification programs that are currently in use in British Columbia.

### *Building Codes (BCBC, VBBL)*

The 2018 BC Building Code (BCBC) and the 2019 Vancouver Building By-Law (VBBL) do not include a direct reference to ASHRAE Standard 55 for thermal comfort, nor to any health safety-related overheating standards. The codes do include several related references via ASHRAE Standard 90.1-2016, NECB 2015, and the BC Energy Step Code (and City of Vancouver Energy Modelling Guidelines).

Both ASHRAE 90.1-2016 and NECB 2015 are focused on energy performance of buildings and do not directly address thermal comfort or overheating risk. Each includes an energy modelling path for compliance, which includes guidance on temperature setpoints to be used where more accurate design information is not available. Both standards include requirements for the number of hours simulated that do not meet the temperature setpoint in each thermal zone, typically referred to as “unmet load hours”. NECB 2015 limits unmet heating hours to 100 per year, and unmet cooling hours to within 10% between reference and proposed models. ASHRAE 90.1-2016 limits unmet heating and cooling hours to 300 hours each. In each of these standards, the primary purpose of the unmet hours limits is to ensure that the baseline and proposed models appropriately represent the building’s energy performance; in other words, there is not significant missing heating or cooling energy in the models. These guidelines are not intended as a thermal comfort or health safety metric, and only apply to mechanically heated and cooled spaces.

## *BC Energy Step Code and City of Vancouver Energy Modelling Guidelines*

The BC Energy Step Code and City of Vancouver energy performance targets (included in both the VBBL and Green Buildings Policy for Rezonings) introduce overheating criteria for non-mechanically cooled buildings via the City of Vancouver Energy Modelling Guidelines (EMGs). The guidelines require designed buildings to meet following overheating criteria:

*For buildings that do not incorporate mechanical cooling, it must be demonstrated that interior dry bulb temperatures of occupied spaces do not exceed the 80% acceptability limits for naturally conditioned spaces, as outlined in ASHRAE 55-2010 Section 5.3, for more than 200 hours per year for any zone.*[5]

For buildings with vulnerable groups, the above criteria is amended to a recommended target of 20 hours per year.

This criteria results in monthly acceptability limits that are location dependant as well as dependant on the climate file used. For the City of Vancouver, using the CWEC 2016 climate file, these range from 25.2 ˚C for May and September, to 26.9 ˚C for July and August.

Compliance with the criteria is demonstrated using hourly energy modelling following the EMGs, and may be shown for all zones in the building, or for a selection of zones chosen to create a representative picture including worst-case zones.

## *Certification Programs*

### **Passive House Institute**

Passive House certification is a voluntary design and construction certification that may also be used to demonstrate compliance with Step 4 of the BC ESC, or as a rezoning path within the VBBL. The Passive House Institute (PHI) defines overheating as when the average operative temperature exceeds 25˚C for more than 10% of the annual occupied hours, as modelled using their excel software tool Passive House Planning Package (PHPP). However, PHI recommends targeting a lower percentage. A significant limitation of this standard is that the PHPP tool is a simple, non-hourly, single-zone model, effectively providing an average temperature for all spaces within the building, which does not represent the varying zonal temperature profiles typical of a multi-family building.

PHI does have additional thermal comfort criteria, including surface temperature requirements and limits on the maximum temperature difference between enclosure elements (radiant asymmetry).

### **Leadership in Energy and Environmental Design (LEED)**

The LEED New Construction certification program includes an Indoor Environmental Quality (IEQ) credit for Thermal Comfort that requires HVAC designs to meet ASHRAE Standard 55, plus individual thermal comfort controls for at least 50% of individual occupant spaces. There are also LEED credits for Assessment and Planning for Resilience,

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[5] City of Vancouver Energy Modelling Guidelines v2.0; available online: https://vancouver.ca/files/cov/guidelines-energy-modelling.pdf

Designing for Enhanced Resilience, and Passive Survivability and Back-Up Power During Disruptions; the latter of which explicitly integrates considerations for thermal comfort.

## 2.4 Discussion and Recommendations for Defining Thermal Comfort

While the BC Building Code does not specifically include thermal comfort or overheating safety requirements for all buildings, the City of Vancouver and BC ESC have introduced limited thermal comfort requirements for non-mechanically cooled buildings. The current CoV EMG approach of using hourly modelling to demonstrate a number of hours within ASHRAE Standard 55's 80% acceptability limits has established a starting point for assessing overheating potential in non-mechanically cooled buildings, and has become familiar to the BC modelling community. However, several limitations with this approach have been identified via the literature scan:

→ The EMG limits of 200 and 20 hours per year are arbitrary and do not guarantee thermal comfort, nor health and safety.

→ Limiting values of indoor temperature do not provide a measure of severity (e.g. exceeding a threshold by 1 °C vs 5 °C). A degree-hours measure better accounts for both severity and occurrence, particularly if correlated to a known human physiological acceptability limit (CIBSE, 2017).

→ Thermal discomfort over a whole cooling season or year may not be a good measure compared to periods of thermal discomfort (and overheating risk) concentrated over a shorter period of time (CIBSE, 2017).

→ Prediction of thermal comfort and health safety in future climates requires a standardized definition of a heat wave for the industry, as well as a method to select and modify climate in a justifiable manner. This also extends into the need to define acceptable timelines and future climate scenarios.

→ The EMG limits do not include a requirement to assess the thermal comfort implications of future climate changes, heat waves, or warmer than average summers.

→ The EMGs do not provide guidance on handling thermal comfort or health safety during extreme events, such as power outages or poor outdoor air quality days (e.g. wildfire smoke), both of which are expected to occur more frequently in the future.

→ The EMGs limits focus on passively cooled buildings. Partially cooling buildings with only minimal space conditioning lack definitive thermal comfort requirements.

Based on the literature scan performed for this task, there are several possible approaches that merit further consideration to strengthen the overheating requirements for non-mechanically cooled buildings in BC codes and standards:

→ Establish a common definition of overheating, possibly differentiating overheating as a health safety risk (that, for instance, might be codified) versus overheating as a thermal comfort issue. At a minimum, a health safety limit/definition could be established, similar to the NRC recommended approach.

→ A simple frequency-based metric, such as the 200-hr (or 20-hr vulnerable population) limit in the EMGs and the 10% of hours above 25°C limit in Passive House, is not sufficient to address the magnitude of overheating (i.e. consecutive hours above a threshold), nor zone specific variations. Give further consideration to additional criteria and potential limits to the magnitude of overheating, the frequency or length of overheating events, and a recognition of acclimatization of occupants. Existing standards or guides that will be particularly useful to furthering this work include:

  - The newly published NRC guideline, which proposes options for how to characterize overheating using the severity index of heat events (SETH) and provides guidance on how to evaluate it using simulation.
    - This method will require adaptation of energy modelling practices and may limit the modelling software used for analysis since SET values are not available from all modelling software. Further exploration into this approach should seek input from the energy modelling community.
    - Since the SET for a given space is dependant on climate, consideration of which climate to use for the evaluation of SETH is required.
  - The CIBSE method, which uses three criteria when evaluating overheating: absolute maximum temperature, number of hours of exceedance, and degree-hour of exceedance.
- Recognize that any significant changes to the definition and/or method of evaluating overheating will require industry engagement and education. An initial step could be to require reporting of peak temperature or other supplemental overheating metrics prior to requiring associated limits to be met.

# 3 Modelling Thermal Comfort

This section provides recommendations to standardize the modelling of overheating and to incorporate future climate weather files.

## 3.1 Context

Hourly energy modelling software tools use algorithms to simulate energy consumption in buildings for various end-uses, and can also be used to assess thermal comfort. For example, EnergyPlus has multiple thermal comfort models built into it (Fanger, Pierce, ASHRAE 55, CEN-15251). eQuest can output operative temperature and humidity metrics, permitting the calculation of a SET. These values can then be converted to associated comfort metrics. All hourly energy modelling tools include calculation of “unmet load hours”, which is the number of hours simulated that fall outside of the setpoint temperature; this metric can be compared to criteria for adaptive thermal comfort models.

While many hourly energy modelling tools can and are used to assess thermal comfort, it is important to recognize that there are limitations inherent in the tools when modelling thermal comfort and overheating. One of the primary limitations is that energy modelling tools do not accurately represent all of the variables that impact thermal comfort, such as mean radiant temperature, relative air velocity (and airflow into, out of, and within buildings), humidity, and personal variables like clothing level. Various programs use different algorithms that will naturally lead to slightly different results. And, significantly, the quality of any energy model is dependent on the quality of the inputs and assumptions used to develop the model.

In the BC Energy Step Code and the Vancouver Building Bylaw, hourly energy models are used to assess thermal comfort for non-mechanically cooled buildings via the City of Vancouver Energy Modelling Guidelines (EMGs). The guidelines use the modelled interior dry bulb temperature to confirm a number of hours below a setpoint temperature determined based on the monthly ASHRAE 55 80% upper acceptability limit for naturally conditioned spaces.

Energy modelling guidelines are important to ensure consistency. The current EMGs focus on guidelines to ensure consistent modelled energy performance, and do not focus specifically on consistency of modelled thermal comfort or overheating. The following sections summarize key modelling requirements to standardize how overheating is assessed in models. These recommendations are relevant to the current approach of using interior dry bulb temperature to compare to an upper acceptability limit. Other thermal comfort models discussed in Task 1 may warrant a different modelling methodology and guidelines.

## 3.2 Energy Model Inputs

The following energy model inputs should be considered as part of the development of a more robust and consistent approach to evaluating overheating within the BC ESC framework.

→ **Natural Ventilation**

Effectively designing a building to facilitate natural ventilation can have a considerable impact on occupants' real or perceived experience of thermal comfort and overheating. The ability to optimize for natural ventilation for a particular building is also highly dependent on the site, surrounding buildings, building height, window placement, window opening, wind speed, etc.

As the climate warms, the cooling effect of natural ventilation may have less impact on reducing the risk of overheating; further, smoke events due to increased forest fires may lead to occupants to keep operable windows closed. Even with the current climate, many occupants in urban areas do not open windows due to noise, air quality and/or security concerns.

Currently, natural ventilation can be used as a modelling strategy to reduce modelled overheating hours and comply with the current EMG thermal comfort criteria. However, the modelling approach is left to the modeller and can vary significantly between models and from reality. While it is beneficial to encourage building design that maximizes the potential for natural ventilation, overestimating natural ventilation in the model can lead to severe risk of overheating in both current and future climate conditions.

For the purpose of standardizing how the risk of overheating is determined in models, a conservative approach is to disallow the use of natural ventilation when modelling overheating. An alternate approach would be to prescribe a maximum allowable ACH rate to be modelled, such as 0.5 ACH for suites without cross ventilation and 1.0 ACH for suites with cross ventilation. A third approach would be to require a sensitivity analysis that turns off natural ventilation.

→ **Control of Operable Exterior Shades**

Operable exterior shading should consider how the system is controlled. Operable shading devices that are controlled automatically based on incident solar radiation should be permitted to be modelled as such, effectively optimizing solar control for cooling energy and thermal comfort.

However, operable shading devices that are manually controlled are sometimes modelled based on optimal solar control, when in reality the user's operation may not be optimal and the modelled solar heat gain reduction may be overestimated. For reference, LEED does not allow manually controlled exterior shades to be included in the model.

A conservative approach is to disallow the use of manually controlled operable exterior shading. An alternate approach would be to require the use of a schedule based on both the interior temperature and occupancy schedule; for example, shades are closed when the indoor operative temperature exceeds 22 °C and the occupancy fraction is higher than 50% (based on the NECB occupancy schedule).

If the operable shades are slatted blinds, they could be modelled positioned at a 45° angle (or the designed angle) and covering the whole window.

→ **Interior Shades and Blinds**

Interior blinds are mainly used for occupant privacy and do not significantly reduce solar heat gains. Therefore, interior blinds should not be modelled as contributing to solar heat gain reduction.

→ **Horizon Shading**

Horizon shading such as existing surrounding buildings and established landscaping that may impact the heat balance of the building can be modelled, but are not required to be modelled. Future planned developments and new landscaping could be considered, although the timing and likelihood of this future shading and landscape growth needs to be recognized and not overly relied upon if it will not be in effect in the very near term.

→ **Dynamic Glazing**

Dynamic glazing, also referred to as electrochromic glass, allows the glass to tint on demand or automatically to decrease unwanted solar heat gains during warm periods and allow solar heat gains during cold periods. If dynamic glazing is modelled the manufacturer's modelling protocol should be followed.

→ **Air Speed**

Operative temperature calculations take air speed in the room into account. If the software provides the option to enter the air speed it is recommended to be set at 0.1 m/s unless there is a ceiling fan or other means of generating air movement.

→ **Mechanical Boost**

Boost mode may be part of the mechanical ventilation design to allow for increased supply air. The increased supply air can improve thermal comfort and can increase cooling if there is a cooling coil included in the ventilation system. Heat recovery ventilation units tend to operate more efficiently at part loads, so sizing of equipment so that it spends the majority of its operating hours at its most efficient is a good design practice. Mechanical boost that is automatically controlled should be modelled per the design. Boost that is occupant controlled (e.g. via a boost switch) should not be modelled.

→ **Exterior Surfaces**

The modelled solar absorptance of exterior surfaces should represent the proposed material and/or paint colour. This includes roof and cladding surfaces. Current practice does not require energy modellers to modify solar absorptance and therefore default values pre-set by the software are typically used.

→ **Thermal Mass**

Building enclosure and primary structure assemblies should be modelled with material layers per the design in order to capture correct thermal mass properties.

→ **Zoning**

Current practice is to model units and corridors as individual thermal zones. This approach may overestimate the mix of air in the unit and underestimate the risk of overheating in rooms with high solar or internal heat gains.

CIBSE TM52 recommends zoning the worst-case unit into separate rooms, including bedrooms, kitchens, living rooms, bathrooms, and halls. The CIBSE TM52 standard requires all occupied spaces to meet the overheating criteria. A room-by-room zoning approach is not practical for large building energy models and is therefore not recommended for all of the suites in a building. However, consideration should be made to modelling individual rooms for the suite with the highest overheating potential.

## 3.3 Weather Files

Current practice is to use a weather file representative of historical average climate (Typical Meteorological Year) for building energy simulations. These weather files represent the average climate for a certain location and are therefore not suitable to assess the risk of overheating under severe conditions, nor under the present climate which is already warmer than the historical record. It is increasingly acknowledged that new weather files that consider heat events and climate change need to be incorporated into standard modelling practice.

→ **Heat Events**

NRC[6] has proposed a methodology for developing Reference Summer Weather Years (RSWY) for Canadian locations. The methodology is based on using historical climate data for years with extreme heat events. The distribution of heat events was then used to select RWSYs as the years that included events of a high enough severity that they would occur with an approximate frequency of every 15.5 years.

→ **Climate Change**

It is recommended that future climate weather files be used in new building modelling to understand how the design will perform in response to climate change. The Pacific Climate Impacts Consortium (PCIC) has developed future climate weather files based on the emission scenario RCP-8.5, as established by the International Panel on Climate Change for every location with a 2016 CWEC file in BC. The RCP-8.5 future climate weather files are available for three different time scenarios: 2020s, 2050s and 2080s.[7]

At a minimum, we recommend the RCP-8.5 weather climate file for the 2020s timeframe be used to assess overheating. This would ensure the analysis considers climate change impacts that have already occurred at the time the building will be first occupied.

A more resilient approach would be to use the RCP-8.5 weather climate file for the 2050s timeframe. This approach is recommended to assess the future performance of the building under a reasonable lifecycle.

The future climate weather files are based on the "average" weather year that a CWEC file represents and do not take extreme weather events into account. Further work is recommended to develop future climate weather files that are based on the RSWY files or similar for assessing overheating in extreme conditions. This is particularly important for reducing potential health and life safety risks from extreme heat events

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[6] A. Laouadi et al. *Climate Resilience of Buildings: Overheating in Buildings — Development of Framework for Overheating Risk Analysis.* NRC-CNRC Construction. 10-June-2019.

[7] https://services.pacificclimate.org/demo/wx-files/app/

that are likely to become more frequent, such as the heat dome that occurred in BC in June 2021.

- **Urban Heat Island Effects**

  The weather files used today are often based on data from weather stations that are located outside of the city, for example the CWEC 2016 weather file used for Vancouver is based on data from the YVR International Airport in Richmond. These files may not capture local urban heat island effects, which can have a significant impact on the overheating risk of a building. Further work is recommended to study how urban heat island effect and microclimate can be incorporated into overheating analysis, but at a minimum, modelling should use local weather files as available.

## 3.4 Model Outputs and Reporting

The current EMGs do not include requirements for interpretation, reporting, and/or documentation of model outputs and results. However, such requirements may be captured in jurisdiction-specific documentation/submission forms. Examples include the City of Vancouver Energy Checklist for Zero Emissions Building Plan (ZEBP), and the BC Energy Step Code Part 3 Energy Design Report.

We recommend that standard documentation requirements include details on achievement of overheating criteria for non-mechanically cooled buildings, or buildings that provide mechanical cooling but do not meet the full design load. The following items may be considered for documentation:

- Provide the number of hours per year exceeding the 80% acceptability limits.
- Provide the monthly peak operative temperature to understand the magnitude of overheating.
- Provide the Cooling Energy Demand Intensity (CEDI) – applicable to mechanically cooled buildings. CEDI would be calculated as the annual cooling energy demand (kWh/m2/yr) for space conditioning and conditioning of ventilation air per unit area. Note that CEDI does not account for system efficiency.
- Consider providing TEDI and CEDI values for both current and future weather files – applicable for all buildings, including mechanically cooled buildings.
- Provide any required resilience or sensitivity tests – applicable for all buildings, including mechanically cooled buildings.

In addition to minimum reporting requirements for Authorities Having Jurisdiction (AHJs), the energy modelling report should include details related to the thermal comfort and/or overheating modelling. In British Columbia, the Joint AIBC and EGBC *Professional Practice Guidelines – Whole Building Energy Modelling Services* include Energy Modelling Report requirements, which should be reviewed and updated to ensure that conditions related to the thermal comfort modelling are reported as part of minimum professional practice standards.

## 3.5 Recommendations for Modelling

In addition to energy modelling guidelines, the current BC ESC criteria could be expanded to consider a wider range of scenarios. The following additional criteria are presented for consideration.

- → While passive measures and occupant controls are generally desirable in a multi-family building and can have a considerable impact on perceived comfort, models should not overly rely on user operation to maintain thermal comfort.
  - → Consider requiring broader sensitivity analysis for resilience during extreme climate events (wildfires, heat waves, and power outages) in modelling requirements. During these events, measures such as natural ventilation and mechanical cooling are limited or turned off in the model. The test could require compliance with adjusted criteria. The University of Toronto has published a guideline on modelling thermal resilience and passive survivability that could be referenced.[8]
  - → If natural ventilation is permitted as an overheating mitigation strategy in building models, a consistent modeling method should be established, and a sensitivity analysis required to demonstrate adequate performance to the adjusted criteria in scenarios in which windows can not viably be opened.
- → Require modelling of the Cooling Energy Demand Intensity (CEDI) to promote a cooling approach that incorporates comfort, energy efficiency and climate resilience, regardless of whether mechanical cooling is provided. CEDI should be modelled to a standardized setpoint temperature and be calculated with a standardized set of modelling inputs for shading control and natural ventilation where these are user controlled.
  - → As an example, within the *UBC - Designing Climate Resilient Multifamily Buildings* report it was demonstrated that through the implementation of passive shading strategies, a CEDI value of 15 kWh/m$^2$/yr is feasible for a Step 3 and 4 high-rise MURB under a 2050 Vancouver climate (15 kWh/m2/yr is the Passive House cooling demand maximum).
  - → Setting achievable CEDI targets for all building types and locations will require additional exploration, modelling, and consultation with industry representatives.
- → At a minimum, model all new buildings using the RCP-8.5 weather climate files for the 2020s timeframe to reflect climate change that has already occurred.
  - → Require a sensitivity test using future climate weather files. The RCP-8.5 climate file for the 2050s timeframe is recommended as a minimum, although 2080s may also be suitable (especially given that these temperatures were well exceeded during the June 2021 heat dome event). This sensitivity test could also be used when calculating CEDI.
- → Require a sensitivity test that considers more extreme heat events. NRC has proposed the Reference Summer Weather Years (RSWY) methodology, which is recommended to be used for assessing overheating when available. Future shifted RSWY files may enable a sensitivity analysis for more extreme temperatures in future conditions.

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[8] https://pbs.daniels.utoronto.ca/faculty/kesik_t/PBS/Kesik-Resources/Thermal-Resilience-Guide-v1.0-May2019.pdf

# 4 Design Implications

The previous UBC resilience study[9] was leveraged along with other project experience to establish the most promising solutions to mitigate overheating. This section summarizes the best practice approaches, their strengths and limitations, other resiliency aspects, and design implications including lifecycle costs.

Design strategies are focused on Part 3 multi-family typologies in Climate Zone 4.

An accompanying spreadsheet matrix tool (see Appendix B) summarizes design implications for a comprehensive list of potential overheating mitigation strategies, including considerations for mechanical design, architectural design implications, and the pros and cons to the design strategies including energy efficiency, constructability, durability, operability, and climate resilience.

Design strategies are organized into the following broad categories:

1) Passive design – passive design features that mitigate the risk of overheating without consuming additional energy.
2) Mixed mode design – a combined mechanical and passive strategies to significantly increase thermal comfort and minimize negative impacts on GHG emissions, total energy use, or operating energy cost of the building.
3) Active (mechanical) design – mechanical solutions that function independently of passive solutions, with typically increased energy and GHG impacts.

## 4.1 Design Implications of Overheating Mitigation Measures

This section summarizes the design implications of key overheating mitigation measures.

### 4.1.1 Passive Design Measures

Passive design measures are those that mitigate the risk of overheating without consuming additional energy. They include:

- Exterior Shading – (fixed overhangs/fins, manually operated, or automated)
- Reduced WWR
- Low SHGC Glazing
- Natural Ventilation
- Form Factor
- Orientation
- Thermal Mass
- Green Roof or Reflective Roof
- Thermal Performance of the Enclosure (high R-value roof or wall; low U-value window)

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[9] https://planning.ubc.ca/sites/default/files/2020-05/REPORT_UBC_Climate%20Resilient%20Multifamily%20Buildings.pdf

→ Reduced Infiltration Rate

→ Strategic Landscaping

### *Applicability of Measures*

Passive design measures are generally applicable to both high-rise and low-rise multifamily buildings. An exception includes strategic landscaping, which may only provide shading to the lower levels of a high-rise building.

### *Climate Change Mitigation*

Passive measures reduce cooling energy demand (and associated electricity consumption) in buildings with mechanical cooling, or potentially remove the need for mechanical cooling. In grids with high GHG emissions, this can contribute to reducing carbon emissions, though electricity has low emissions in BC.

In some cases, solar control measures may increase energy consumption and emissions slightly by blocking passive solar heat gains that are desired during times of heating. Careful design to optimize solar control should be considered.

Embodied carbon from additional shading devices or massing should also be considered.

### *Capital and Operational Impacts*

Most passive measures come with a degree of capital cost, though some exceptions such as lower SHGC windows, high albedo materials, natural ventilation, and lower WWR have either no additional cost or a cost savings. Passive measures inherently do no have a cost to operate (e.g. from the use of electricity) though some maintenance costs do need to be considered such as maintaining operable blinds and landscaping.

Other building maintenance practices may be impacted by exterior blinds or fixed shading; for example, window washing may become more challenging.

### *Design Implications*

From a design perspective, exterior shading impacts the appearance of the building and should be considered early in the design process to tie it into the overall visual goals of the project.

### *Impacts on Resilience*

Green roofs and well-designed vegetation and landscaping can help with storm water management and managing heat island effect.

## 4.1.2 Mixed Mode Design

Mixed mode designs include a combined mechanical and passive approach to significantly increase thermal comfort and minimize GHG emissions, total energy use, and/or operating energy cost of the building. These measures may include a reliance on power, though still implement passive principles, for example:

→ Internal Load Management

→ Dynamic Glazing

- → Bypass and Boost Mode within HRVs
- → Coupling Passive Measures with Active Measures (e.g. solar control with mechanical cooling)

### *Applicability of Measures*

Mixed-mode design measures are generally applicable to both high-rise and low-rise multifamily buildings. Some internal load management measures in multifamily buildings, such as appliance operation optimization and lighting controls, may only be feasible in common areas.

### *Climate Change Mitigation*

As with passive measures, mixed-mode measures reduce cooling energy demand (typically provided by electricity). In grids with high GHG emissions this can contribute to reducing carbon emissions, though electricity has low emissions in BC.

### *Capital and Operational Impacts*

Internal load management measures are generally low cost (for controls and pipe insulation, etc.). Dynamic glazing providers often require annual service fees as part of ongoing operation. HRVs with boost and bypass modes tend to be higher performance units with better heat recovery effectiveness.

If not already part of the design, full mechanical cooling does have significant capital and operational costs, though by mixing modes and coupling with passive demand reduction measures, these costs can be reduced.

### *Design Implications*

Consider occupant acceptance of mixed-mode measures such as automated lighting controls, smart appliances, and dynamic glazing. Residents may prefer to maintain control of these features (or be able to easily override them).

### *Impacts on Resilience*

Power outages will render controls inoperable unless they are on a backup system.

Resilience during power outages is improved by coupling passive measures with active measures to help buffer large temperature swings/extremes.

### 4.1.3 Active (mechanical) design

Active measures are mechanical solutions that can prevent or mitigate overheating, but also increase energy consumption and emissions, for example:

- → Cooling coil in corridor pressurization system (Make-Up Air unit) and/or in centralized HRV
- → Full mechanical cooling via hydronic distribution
- → Full mechanical cooling via air distribution
- → Cooling in amenity room (localized)

- → Occupant supplied fan

### Applicability of Measures

Active design measures are generally applicable to both high-rise and low-rise multifamily buildings. In some cases, the measures may be more applicable to larger buildings or buildings with centralized mechanical systems.

### Climate Change Mitigation

Active design measures will increase energy consumption and peak electricity demand over a case with no mechanical cooling. In grids with high emissions this can also contribute to increased carbon emissions.

### Capital and Operational Impacts

Centralized systems typically have more complex controls that operational staff will need to understand to control optimally. Both central and decentralized equipment will require ongoing maintenance. Centralized air systems will need to consider fire protection (i.e. fire dampers crossing each fire rated wall, which add capital cost and require periodic testing and maintenance). For distributed systems, periodic access to suites for maintenance of terminal units or distributed heat pumps (e.g. to change filters) may be required.

### Design Implications

The design of mechanical cooling systems requires consideration of several potential impacts:

- → The architectural impacts on floor to floor height or vertical shaft requirements.
- → The location of centralized cooling equipment (e.g. rooftop, at grade, parking garage) must be considered early (view impacts, setback impacts/zoning requirements, space requirements, access for maintenance, etc.)
- → A centralized air handling unit will require larger ductwork than a central system that is only providing ventilation.
- → Radiant terminal units (e.g. ceilings, panels) can be built into the interior design and may be less obtrusive than other terminal units. Radiant cooling requires careful consideration of surface condensation; it is most effective if implemented in conjunction with a ventilation system that can remove humidity from the space.
- → Location of terminal units within the space needs to be coordinated with other trades/disciplines. For example, if a radiant system is in the ceiling, it will need to be coordinated with the lighting layout.
- → Terminal units require physical space within a dropped ceiling, in a mechanical closet, or on a wall. Exposed units can look 'bulky' if not considered from the outset and integrated into the design.
- → Mini-split heat pump units or other ‘split’ decentralized units require space outside each suite for the condensing unit, which can impact building aesthetics. Heat pumps

also require a condensate drain at the cooling coil location (i.e. at fan coil unit, distributed heat pump, or air handling unit).

→ If taking a "refuge room"/localized cooling approach, refuge room design must be coordinated with other municipal and code requirements (e.g. accessibility, occupancy limits), keeping in mind that amenity room cooling may not need to meet general overheating criteria in other occupied spaces, such as dwelling units, though should be sized appropriately for high occupancy during extreme heat events.

### *Impacts on Resilience*

Active measures inherently rely on power and are thus not effective during power outages. For an amenity room refuge area to be functional during a power outage, it can be connected to a back up generator or PV array with battery storage. Coupling active measures with passive measures improves the resilience of buildings during power outages (see mixed-mode example).

## 4.2 Lifecycle Costing

Life-cycle cost estimates for design measures were calculated based on the costing completed for the previous UBC study[10] and in consultation with ZGF and Zenon. Select design measures for lifecycle costing were selected to show a range of passive and active measures, to be representative of what is most feasibly implemented by industry, and to be effective at mitigating the risk of overheating.

Capital costing and operational energy impacts were refined from the previous study to evaluate incremental capital costs (ICC) and the net present value (NPV). NPV was calculated based on estimated energy impacts (where applicable) from the previous modelling project and project experience, an analysis period of 40 years, and a discount rate of 7%. The baseline reference scenarios for costs and energy savings are assumed to be an archetypal Step 3 low-rise multifamily building and a Step 2 high-rise multifamily building. Assumptions sometimes differ for the low-rise versus the high-rise buildings. For example, it is assumed that both building archetypes have HRVs to meet their Step code targets, though only the high-rise has full mechanical cooling in its baseline design. Table 4.1 summarizes the baseline scenarios for each archetype. The low-rise archetype is assumed to have a floor area of 4,700 m$^2$ (50,590 ft$^2$) and 48 suites. The high-rise archetype is assumed to have a floor area of 26,530 m$^2$ (285,450 ft$^2$) and 230 suites.

TABLE 4.1 BASELINE ASSUMPTIONS FOR BOTH ARCHETYPES

| | **Low-Rise MURB Baseline** | **High-Rise MURB Baseline** |
|---|---|---|
| Enclosure | → Wood frame with batt insulation (R$_{eff}$–15.6).<br>→ Double glazed windows in non-metal frames (USI-1.8 [U-0.31], SHGC-0.36), 40% window to wall ratio. | → Concrete construction (R$_{eff}$-3).<br>→ Double glazed windows in aluminum frames (USI-2.6 [U-0.46], SHGC-0.36). Tower: 55% window to wall ratio, townhouse: 30% window to wall ratio. |

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[10] https://planning.ubc.ca/sites/default/files/2020-05/REPORT_UBC_Climate%20Resilient%20Multifamily%20Buildings.pdf

TABLE 4.1 BASELINE ASSUMPTIONS FOR BOTH ARCHETYPES

| | | |
|---|---|---|
| HVAC | *Case 1:*<br>→ In-floor hydronic radiant heating with district energy connection provides heat to the suites.<br>*Case 2:*<br>→ Electric baseboard heating provides heat to the suites.<br>*Both Cases:*<br>→ Tempered outdoor air pressurizes the corridors.<br>→ Outdoor air is provided via minimum efficiency (60%) in-suite HRV units with no by-pass.<br>→ No mechanical cooling. | → Hydronic fan coil units provide heating (district energy connection) and cooling (chiller) to suites and corridors.<br>→ Outdoor air is provided via minimum efficiency (60%) in-suite HRV units with no by-pass, with tempered corridor make-up air. |
| DHW | → District energy connection | → District energy connection |

### 4.2.1 Description of Measures for Analysis

Five individual design measures and one bundle were evaluated for each of the archetypes. The measures include a selection of passive measures, mixed-mode measures, and active (mechanical) measures.

**Exterior Shading** - This is a passive measure that falls within the sub-category of solar control of glazing components. Exterior shading could be fixed overhangs, vertical fins, and/or operable shades. The lifecycle costing and considerations of fixed exterior shading, such as overhangs or fins, are fairly well known; however those of the operable options are not as well understood. Lifecycle costs are only evaluated for fixed exterior shading, for both the low-rise and high-rise archetypes.

**Reduced Window-to-Wall Ratio** - This is a passive measure that falls within the sub-category of solar control. Lowering the window-to-wall ratio reduces the cooling and heating load on the building by reducing the direct solar gain through glazed components. This measure is only evaluated for the high-rise archetype, as these are typically designed with a higher window-to-wall ratio than low-rise buildings. For this assessment the ratio is reduced from 50% to 30%.

**Low Solar Heat Gain Coefficient Glazing** – This is a passive measure that falls within the sub-category of solar control of glazing components. Depending on the window design and specification, low SHGC glazing can be a zero cost item and as such, it is not included in this financial analysis but should nevertheless be considered a viable measure to mitigate solar gains.

**Heat Recovery Ventilator (HRV) with Bypass and Boost Modes** - This is a mixed-mode measure that falls into the sub-category of ventilation. The HRV would be equipped to operate in bypass and boost mode which allows it to increase airflow and bypass the heat exchanger when the outside air is cooler than the inside air. These HRVs can be in-suite, semi-centralized (e.g. floor by floor) or centralized. This measure is evaluated for both the low-rise and high-rise archetypes.

**Cooling Coil in the Corridor Pressurization System (Make-Up Air unit)** - This is an active partial cooling measure. Adding a mechanical cooling coil to the MAU system will cool the volume of air typically delivered by the system, but may not meet the full peak cooling demand nor reach the targeted occupied spaces. This measure is evaluated for both the low-rise and high-rise archetypes.

**Cooling Localized to One Room** - This is an active partial cooling measure. It provides full mechanical cooling only in a refuge zone within a building, such as an amenity or common meeting space, but does not provide mechanical cooling to any other parts of the building. This measure is only evaluated for the low-rise archetype.

**Full Mechanical Cooling** - Full mechanical cooling (meaning that the full design cooling load of the building is met) could be achieved through a radiant system (e.g. ceiling, wall panels) or an air-based system (e.g. mini-split heat pumps, centralized air handler, or central heat pump with fan driven terminal units). This measure is evaluated for both the low-rise and high-rise archetypes, though for costing it is assumed that the high rise baseline would already have cooling so is shown as a zero cost measure and is included for comparison to the mixed-mode bundle.

**Bundled Measure** - The bundled measure evaluated in this financial analysis combines passive and mechanical cooling options. In this option, fixed exterior shading is bundled with full mechanical cooling, such as through a radiant system or an air delivery system. This reflects the preferred scenario of several measures being implemented together. The added exterior shading can offset the peak cooling load of the mechanical equipment and reduce the cooling energy impact throughout the year. This bundle is evaluated for both the low-rise and high-rise archetypes.

### 4.2.2 Lifecycle Costing Results

The overheating mitigation measures that are assessed in this lifecycle costing analysis are applicable to both high-rise and low-rise MURBs. However, the results are presented separately for each of these building types due to differences in the baseline (Step 2) common designs. For example, for high-rise MURBs it is common to have full mechanical cooling, whereas this is less common currently for low-rise MURBs. As such, the incremental life-cycle costs assessed for mechanical cooling are treated differently. Additionally, the differences in window-to-wall ratios for high-rise versus low-rise MURBs result in variations for the costs of window measures on a floor-area-normalized basis.

#### *Measures for Low-Rise MURBs*

The ICC and NPV for each design measure and the bundle are shown in Table 4.2 for the low-rise archetype. For all measures evaluated as part of this analysis, some ICCs are incurred. In the case of the cooling coil in the corridor pressurization system and the cooling localized to one room, ICCs are shown as minimal. In this analysis, the cost of a cooling coil in the corridor pressurization system is compared to a MAU without a cooling coil, and thus has a small incremental capital cost that rounds to zero. Because the ICCs are represented as $/m², the gross building floor area dilutes the costs of the MAU cooling coil and the refuge area cooling system.

For all measures, a negative NPV is found over the 40-year period considered because they are designed specifically to mitigate overheating rather than for energy savings. In addition to the initial capital investment, the costs to maintain and replace the equipment contribute to the lifecycle costs.

The mixed-mode bundle that includes exterior shading coupled with full mechanical cooling has a lower cost than the two individual measures added together. This is due to the cooling demand reduction from the passive shading measure, which enables equipment downsizing and reduced energy costs.

The number of overheating hours (i.e. number of hours exceeding ASHRAE 55 Acceptability Limits) are also provided in the table. These are taken from the previous study where the same measure or bundle was modeled.

TABLE 4.2 FINANCIAL ANALYSIS FOR LOW-RISE DESIGN MEASURES

| **Design Measures** | **Incremental Capital Cost ($/m²)** | | **Net Present Value ($/m²)** | | **Number of Overheating Hours (from previous study)** |
|---|---|---|---|---|---|
| | **Low** | **High** | **Low** | **High** | |
| Exterior shading (Passive) | $70 | $140 | ($75) | ($145) | 318 |
| HRV with bypass and boost (Mixed-Mode) | $20 | $30 | ($30) | ($45) | 516 |
| Cooling coil in the corridor pressurization system (MAU) (Active) | $0 | $0 | ($5) | ($5) | Not available |
| Cooling localized to one room (Active) | $5 | $5 | ($10) | ($10) | Not available |
| Full Mechanical Cooling (Active) – 4-pipe fan coil system compared to in-floor hydronic heating baseline | $30 | $30 | ($55) | ($55) | Not available |
| Full Mechanical Cooling (Active) – mini-splits compared to electric baseboard heating | $50 | $75 | ($75) | ($95) | Not available |
| Bundle: Full Mechanical Cooling (4-pipe fan coil system compared to in-floor hydronic heating baseline) and Exterior Shading | $85 | $160 | ($105) | ($175) | Not available |
| Bundle: Full Mechanical Cooling (mini-splits compared to electric baseboard heating) and Exterior Shading | $95 | $180 | ($110) | ($195) | Not available |

### *Measures for High-Rise MURBs*

The ICC and NPV for individual design measures and the mixed-mode bundle are shown in Table 4.3 for the high-rise archetype. Similar to the low-rise archetype, most measures result in a negative NPV over the 40-year period considered. Again, the initial capital investments and the costs to maintain and replace the equipment contribute to the negative NPVs. The negative ICC of the reduced window-to-wall ratio results from the high costs of windows compared to the costs of exterior wall material. This cost savings results in a positive NPV for this measure. Reducing the window-to-wall ratio may also improve energy efficiency and operational costs, though for this analysis it was assumed that the building continues to meet the same Step 2 targets as the baseline.

Similar to the low-rise building, the mixed-mode bundle that includes exterior shading coupled with full mechanical cooling for the high-rise building has a lower cost than the two individual measures added together. This is due to the cooling demand reduction from the passive shading measure, which enables equipment downsizing and reduced energy costs.

TABLE 4.3 FINANCIAL ANALYSIS FOR HIGH-RISE DESIGN MEASURES

| **Design Measures** | **Incremental Capital Cost ($/m²)** | | **Net Present Value ($/m²)** | |
|---|---|---|---|---|
| | **Low** | **High** | **Low** | **High** |
| Exterior shading (Passive) | $110 | $220 | ($110) | ($220) |
| Reduced window to wall ratio (Passive)* | ($30)* | ($15)* | $30 | $15 |
| HRV with bypass and boost (Mixed-Mode) | $15 | $25 | ($25) | ($40) |
| Bundle: Full Mechanical Cooling and Exterior Shading | $120 | $230 | ($110) | ($220) |

*Indicates a capital cost savings.

## 4.3 Future-Ready Considerations

Because multi-family buildings are highly occupied at all times, design teams must apply rigour in demonstrating that overheating is adequately addressed in a range of conditions, including during heat waves, other extreme weather events, and future climate conditions.

The concept of “future ready” means that the design of the building includes adaptive capacity to address future overheating risks (i.e. potentially vulnerable systems are designed to be readily upgraded to improve occupant comfort without adding significant capital costs or disruptive work).

Buildings with mechanical cooling are typically designed for cooling loads per the design day temperatures in CWEC 2016 weather files, which reflect 30-year past averages. As cooling loads in BC are already increasing as the climate changes, new construction and retrofit design should include considerations for adapting to this need for additional cooling – if not in their first design, then with an allowance to increase cooling in future retrofits. The use of more current and future weather files in the modelling of all new multi-family was addressed earlier in this report.

If buildings are already designed for mechanical cooling, it is recommended that the major infrastructure be designed and built to meet future loads (for example, using a 2050s climate file), as the incremental cost to do so at the time of construction will be minimal.

If buildings are not initially designed to have mechanical cooling, or if the costs of incorporating future capacity can be demonstrated as cost prohibitive, consider requiring a 20-year plan to assess the need for mechanical cooling in the future and to demonstrate how the current design can easily adapt to this future need. This could include designing each suite with the electrical capacity to add a heat pump, for instance, and designing the electrical capacity of the building for the future load. The potential implications of transferring this capacity burden onto future owners who may not be aware that performance to future climate was not already built in must be carefully considered. UBC has chosen to design and build for 2050s now, and this is likely to be the most cost-effective approach when considered over the building’s lifecycle. Any measures that would be costly and disruptive to occupants to do in the future are likely best incorporated in the original design.

## 4.4 Recommendations Considering Design Implications

- → Encourage the incorporation of passive strategies in all designs. This can be achieved through inclusion of a CEDI requirement to complement the current TEDI performance requirement.
- → Encourage the incorporation of cost-effective measures that provide multiple co-benefits (for example, landscape design that reduces cooling demand within the building, but also reduces urban heat island effect, improves access to nature, and improves passive survivability). The best choices for each project will depend on the project constraints, and design teams should have flexibility in developing those solutions. The Design Matrix in Appendix B provides detail on the design implications that should be considered for each project.
- → Consider codifying easily adoptable (e.g. low cost and low design barrier) passive measures such as lower SHGC windows (noting that lower SHGC could make achieving TEDI targets more challenging for certain building types).
- → Promote industry education to help developers and owners understand how to realize the cost savings from coupling passive measures with full mechanical cooling (from both operational cost and capital cost/equipment sizing).
- → Reduced window-to-wall ratios are the only measure evaluated whose capital cost is less than the baseline case (with a Step 2 or Step 3 enclosure). Incorporating a reduced window-to-wall ratio with other measures that are beneficial but have a higher capital cost can be an effective way to improve a building’s resilience to overheating without added cost, although this measure must be designed carefully to avoid undesirable effects such as lack of access to natural daylight and views.
- → Test overheating performance via sensitivity analysis and/or passive survivability criteria.
- → Require mechanically cooled buildings to meet future peak loads (e.g. 2050s), either through the base design or demonstrable adaptive capacity.
- → Demonstrate that designs can meet CEDI limits in a future climate, unless doing so is cost prohibitive, in which case a future ready plan should be developed and provided such that this additional capacity can be easily added in the future.

# 5 Summary Recommendations and Future Work

This report includes multiple recommendations related to defining thermal comfort and overheating risk; modeling of thermal comfort and overheating risk; design strategies to mitigate overheating, and potential changes to BC Codes and related requirements to address overheating risk in multi-family buildings. Based on the previous tasks, the project team hosted a workshop with stakeholders to discuss recommendations to move forward. Results of the previous three tasks were presented as a basis for discussion. Key takeaways from the workshop are included in Appendix D.

Below are high level summary recommendations resulting from the tasks summarized herein as well as the discussion at the workshop.

- The BC Building Code should address overheating risk as a health safety issue and incorporate requirements to mitigate health risks of overheating as a minimum.
- These requirements should include both frequency and magnitude of overheating and could either reference the NRC Overheating Framework or incorporate elements from CIBSE TM59.
- Building designs should be modeled at a minimum to current (2020s) weather files to reflect climate change that has already occurred, but also consider designing to a 2050s or 2080s climate (at a minimum as a sensitivity analysis).
- Require a sensitivity test that considers more extreme heat events. NRC has proposed the Reference Summer Weather Years (RSWY) methodology, which is recommended to be used for assessing overheating when available. Future shifted RSWY files may enable a sensitivity analysis for more extreme temperatures in future conditions.

- Passive design is encouraged, and the industry should be educated on the co-benefits and cost-savings potential of incorporating passive strategies in building designs.
- While passive measures and occupant controls are generally desirable in a multi-family building and can have a considerable impact on perceived comfort, models should not overly rely on user operation to maintain thermal comfort.
  - Consider requiring broader sensitivity analysis for resilience during extreme climate events (wildfires, heat waves, and power outages) in modelling requirements. During these events, measures such as natural ventilation and mechanical cooling are limited or turned off in the model. The test could require compliance with adjusted criteria. The University of Toronto has published a guideline on modelling thermal resilience and passive survivability that could be referenced.[11]
  - If natural ventilation is permitted as an overheating mitigation strategy in building models, a consistent modeling method should be established, and a sensitivity analysis required to demonstrate adequate performance to the adjusted criteria in scenarios in which windows can not viably be opened.
- Providing mechanical cooling in concert with passive design strategies should be considered a requirement for all new multi-family buildings. Alternatively, any new multi-family buildings that do not incorporate mechanical cooling should bear the burden of proof that either the buildings will protect the health and safety of its occupants from overheating (through the 2050s) and/or provide a plan that allows for the easy incorporation of cooling in the future.
- To further the previous two points (in concert with achieving emissions mitigation targets), establish a standard definition of CEDI.
  - Require modeling and reporting of CEDI results on all new design permit submissions. This will provide valuable input for setting achievable limits in climate zones throughout the province.
- Project teams should model these metrics in a standardized method, and report the results as part of the permitting process.

Additional work is expected to address the following:

- To generate consensus on overheating criteria and limits.
- To set CEDI limits appropriate to each climate region (and potentially building types) in BC, including further consultation with both regulators and the design and modelling community.
- To understand the implications of requiring all new designs to meet the peak cooling demand of a 2050s (or 2080s) climate (e.g. how much additional capacity is required; what are implications on duct and equipment sizing, if any etc.).
- To establish a common methodology for representing natural ventilation in building models

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[11] https://pbs.daniels.utoronto.ca/faculty/kesik_t/PBS/Kesik-Resources/Thermal-Resilience-Guide-v1.0-May2019.pdf

- → To establish common methodologies for completing sensitivity analyses and associated performance criteria.

# 6 Closure

The issue of overheating in multi-family buildings has grown in relevance and urgency as the climate warms. This report has provided a foundation to move forward on several of recommendations to better address overheating in new building designs, while some topics will require further analysis and discussion amongst relevant stakeholders. We look forward to participating as the conversation continues.

PROFESSIONAL
PROVINCE
C. M. S. LOVE
# 43581
BRITISH
COLUMBIA
ENGINEER

True copy of original

**Christy Love** | P.Eng., CPHC
Principal, Senior Project Manager
clove@rdh.com
T 250-479-1110 x104
**RDH Building Science Inc.**

*Reviewed by*
**Eric Catania** | M.Eng., P.Eng., BEMP, CPHD, LEED AP BD+C
Associate, Senior Energy and Sustainability Analyst

**Brittany Coughlin** | MASc, P.Eng., BEMP, CPHC, LEED AP
Principal, Energy and Sustainability Specialist
bcoughlin@rdh.com
T 604-873-1181 x129
**RDH Building Science Inc.**

**Elyse Henderson** | MSc, CMVP, LEED Green Associate
Associate, Energy and Sustainability Consultant
ehenderson@rdh.com
T 604-873-1181 x144
**RDH Building Science Inc.**

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# Appendix A

## Terms and Definitions

**Air temperature:** the air temperature ($T_a$) decides the heat loss from the body by convection.

**Clothing insulation:** the resistance to sensible heat transfer provided by a clothing ensemble (expressed in units of clo). The definition of clothing insulation relates to heat transfer from the whole body and includes the uncovered parts of the body, such as head and hands.

**Metabolic rate:** the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, which is the energy produced per unit skin surface area of an average person seated at rest.

**Operative temperature:** the operative temperature ($T_{op}$) combines the air temperature and the mean radiant temperature into a single value to express their joint effect. The operative temperature is a weighted mean temperature of the two, the weights depending on the heat transfer coefficient by convection, which depends on the air velocity, and by radiation at the clothed surface of the occupants.

**Predicted Mean Value (PMV):** the PMV index describes the predicted mean value of the thermal sensation of a large group in a given environment on a 7-point scale expressed from -3 to +3 corresponding to the categories “cold”, “cool”, “slightly cool”, “neutral”, “slightly warm”, “warm”, and “hot”. The PMV method is a steady-state model that assumes the core body temperature is constant. The PMV index is based on air velocity, air temperature, mean radiant temperature, relative humidity, clothing, and metabolic rate.

**Predicted Percentage Dissatisfied (PPD):** the PPD elaborates on the PMV vote by converting it into a distribution of persons who would be dissatisfied with the environment. It has been updated to include features such as thermal radiant asymmetry and drafts to modify the thermal comfort experience.

**Prevailing mean outdoor air temperature:** this temperature is used to calculate the 80% acceptability limits as described in ASHRAE 55. The prevailing mean outdoor air temperature is based on the arithmetic average of the mean daily outdoor temperature over a given period of days.

**Radiant mean temperature:** the temperature of a black sphere at the point in question that would exchange no net radiation with the surroundings.

# Appendix B

## Design Strategies Matrix

| General Information | | | | | Overheating Mitigation | Climate Change Mitigation | | Capital and Operational Impacts | | | Design Implications | | | | | Impacts on Resilience | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode | Sub-Category | Measure | Description | Applicable Building Types or Limitations | Overheating Mitigation | Energy Impacts | GHG Impacts | Capital Cost Considerations | Cost ($) | Maintenance & Replacement | Architectural | Mechanical | Structural | Envelope | Electrical | Indoor Environmental Quality | Passive Survivability | Storm Resistance | Longevity or Durability Notes | Flood Resistance |
| Passive | Solar Control | Exterior shading - operable (automated) | Exterior shades with motors that minimize solar gain based on automated control strategies. | Likely higher end multi-family given higher cost and complexity | 4 - Excellent | May reduce cooling load and potentially the required cooling equipment.<br>Can be modeled according to operating strategy, although manual overrides by users could impact actual impact. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon reduction. | Increased cost with motors and controls in automated system.<br>Similar to manually operated exterior shades, local manufacturer options are limited, which will impact cost. | $$+ | Periodic cleaning required to maintain the design intent.<br>Maintenance/repairs on moving parts, including motors.<br>Access to spaces to maintain / replace motors to be taken into consideration with management plans.<br>Potential impact on ability to access/clean windows. | Early design integration is recommended. Considerations with automated shading system options include:<br>- material durability<br>- maintenance requirements/ expectations<br>- full automation versus some level of user control | Same implications as fixed exterior shading, except that optimization is automated and as such requires implementation as part of whole building automation system. Adds complexity. Will require commissioning.<br>Must consider how the system responds to interior/exterior temperatures, heating or cooling system operation, and/or manual overrides. | Coordinate early with structural to design cost effective structural connection system and/or details.<br>Evaluate snow loads on horizontal fixed shading needs to be considered<br>Must be specified and designed for design wind loads + contingency for climate change (particularly roller-blinds) | Consider detailing around structural connections, and any additional penetrations required for conduit/controls.<br>Evaluate options with structural to minimize thermal bridging from connections. | Power for motors and controls.<br>System will need to be integrated within overall building management system. | Automatically optimized solar gains by season. | Power outage will render motor-driven blinds inoperable. May need to prioritize failure state (e.g. 'normally closed' in case of power disruption in summer). Means of egress must also be considered (especially if blinds fail closed) | Depends on the systems in place.<br>Fixed shade tied to top and bottom fairly resilient to storms/high winds.<br>Roller blind type of system - limited use through storm / high wind | System/materials used will determine longevity / durability. Roller blind less durable than a metal panel tethered to top and bottom with rollers.<br>Concern with long term durability of systems in West Coast climate. | N/A |
| Mixed-mode | Solar Control | Dynamic glazing | Electrochromatic coating on windows to adjust SHGC with electrical controls (either manually or automatically) | All building types | 4 - Excellent | Reduced cooling load and potentially the required cooling equipment.<br>Energy requirement to operate is minimal. | If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon reduction (for buildings that provide mechanical cooling). | Expensive product compared to conventional glazing. Costs may reduce as the market matures. | $$ | Uncertain life-time durability and maintenance requirements given relative newness of product. | Dynamic glazing can appear dark from exterior and blue tinted from interior. | Must consider how the system responds to interior/exterior temperatures, heating or cooling system operation, and/or manual overrides; and how it ties into overall building management system if there is one. | N/A | N/A | Dynamic glazing units require additional electrical panel within unit for controls and some require additional electrical components at the units. | N/A | Power outage will controls inoperable (or make part of emergency power system if there is one). May need to prioritize failure state (e.g. 'fully shaded' in case of power disruption in summer). | N/A | N/A | N/A |
| Active (mechanical) | Full Cooling | Full mechanical cooling via radiant distribution | Providing mechanical cooling via radiant system (e.g. ceiling, wall panels) to meet the full design cooling load. | All building types, although more likely to be an option for large buildings with other central systems. | 4 - Excellent | Will increase cooling energy consumption over a case with no mechanical cooling. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon increase. | Will add capital cost over a building with no cooling. If combined with passive measures, the sizing of the cooling system may be reduced. | $$$ | Central equipment and system maintenance (whether chiller or heat pump); adds complexity to building systems and controls. | The distribution of the system to be considered through the design; e.g. if the radiant system is in the ceiling, it will need to be coordinated with the lighting layout.<br>Radiant terminal units (ceilings, panels) can be built into the interior design and are less obtrusive than other terminal units. Considerations need to be made for condensation, e.g. use fan coil units to disperse cooling rather than integrated floor radiant systems that could pose condensation/durability issues. | Radiant cooling, with thermal mass based systems such as radiant floors/ceilings, is not as responsive as air cooling. Radiant cooling requires careful consideration of surface condensation; most effective if implemented in conjunction with an air based system (such as ventilation) which can remove humidity from the space. | Design structural support for centralized mechanical equipment. | Consider cross effects of envelope performance with cooling system sizing. | Electrical requirements for central equipment and controls. | N/A | Non-functional during power outage unless on emergency power/generator | N/A | Typical replacement lifecycles for mechanical equipment will need to be considered. | N/A |
| Active (mechanical) | Full Cooling | Full mechanical cooling via air distribution | Providing mechanical cooling via air delivery systems (e.g. mini-split heat pumps, or centralized air handling or heat pump units with fan driven terminal units) to meet the full design cooling load. | All building types | 4 - Excellent | Will increase cooling energy consumption over a case with no mechanical cooling. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon increase. | Will add capital cost over a building with no cooling. If combined with passive measures, the sizing of the cooling system may be reduced. | $$$ | Central equipment and system maintenance in the case of centralized system; adds complexity to building systems and controls.<br>Access for maintenance of terminal units or distributed heat | Location of terminal units within the space to be coordinated with disciplines.<br>Terminal units require physical space within a dropped ceiling or mechanical closet, and must be located within the space or general location they serve. They can look 'bulky' if not considered from outset | Air cooling is typically how space cooling is provided, as the cooling coil can control both space air temperature and humidity by removing water (condensate) at the cooling coil<br>Requires condensate drain at cooling coil location (i.e. at fan coil unit, distributed heat pump, or air handling | Design structural support for centralized mechanical equipment (and potentially pads for decentralized outdoor units). | Additional enclosure penetrations for mini-split systems. | Electrical requirements for equipment and controls. | N/A | Non-functional during power outage unless on emergency power/generator | N/A | Typical replacement lifecycles for mechanical equipment will need to be considered. | N/A |
| Mixed-Mode | Full Cooling & Solar Control | Passive fixed exterior shading is bundled with full mechanical cooling. | Fixed exterior shading is bundled with full mechanical cooling, such as through a radiant system or a air delivery system. This reflects the realistic scenario of several measures being implemented together. The added exterior shading helps to offset the cooling load of the mechanical equipment and reduce the cooling energy impact throughout the year. | All building types | 4 - Excellent | Less energy consumption than full mechanical cooling without passive measures. | Lower GHGI impacts than full mechanical cooling without passive measures. | Reducing cooling demand via passive measures can enable downsizing of mechanical cooling equipment, resulting in potential cost savings compared to full mechanical cooling without load reduction. | $$$ | (see full mechanical cooling & passive solar shading row items) | (see fixed shading row) | exterior shading helps to offset the cooling load of the mechanical equipment and reduce the cooling energy impact throughout the year. This allows for the equipment to be downsized, reducing the capital and operating costs for the equipment. | (see fixed shading row) | (see fixed shading row) | (see full mechanical cooling row) | (see full mechanical cooling & passive solar shading row items) | The addition of passive demand reduction (solar shading) to mechanical cooling helps the passive survivability of having full mechanical cooling to mitigate overheating. | (see full mechanical cooling & passive solar shading row items) | | N/A |
| Passive | Solar Control | Exterior shading - operable (manual) | Multiple options, including shutters, awnings, variable fins, exterior blinds such as rollers or venetian, inner-glass blinds. | Expected occupants are a consideration - e.g. rental vs. condo; seniors housing etc. | 3 - Good (depends on users) | May reduce cooling load and potentially the required cooling equipment.<br>However, as they are user operated, can be difficult to predict energy impact. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon reduction. | As the local market is not mature, there are limited, if any, local manufacturers, which can affect pricing and available options. Capital costs can be high depending on the product. | $$ | Periodic cleaning required to maintain the design intent. Maintenance on moving parts. Repairs to finish (paint or fabric replacement, depending on system).<br>Repair to damaged components (inner blind repairs are expensive). | Early design integration is recommended. Considerations with operable shading system options include:<br>- material durability<br>- maintenance requirements/ expectations<br>- user control as well as user needs (sophistication vs simplicity of controls depending on the | Same implications as fixed exterior shading, except that with proper training of building users such that the exterior shades are open when solar gains are desirable (heating season) and closed when they are not desired (cooling season). | Coordinate early with structural to design cost effective structural connection system and/or details.<br>Evaluate snow loads on horizontal fixed shading needs to be considered<br>Must be specified and designed for design wind loads + contingency for climate change (particularly roller-blinds) | Consider detailing around structural connections.<br>Evaluate options with structural to minimize thermal bridging from connections. | Some "manual" shades may be operated mechanically by the user (e.g. via a remote control that powers the blinds), in which case power must be considered. | Reduced direct solar gain and resulting mean radiant temperature (= increased thermal comfort during cooling season).<br>Individualized occupant control allows for variability in comfort preferences. | Improves: by mitigating overheating during cooling season power outage or brown out | Depends on the systems in place.<br>Fixed shade tied to top and bottom fairly resilient to storms/high winds.<br>Roller blind type of system - limited use through storm / high wind | System/materials used will determine longevity / durability. Roller blind less durable than a metal panel tethered to top and bottom with rollers<br>Concern with long term durability of systems in West Coast climate. Moving parts are potentially subject to more environmental damage in this climate. | N/A |
| Passive | Solar Control | Reduced WWR | Between 20% and 30% for highly efficient buildings (prescriptive code max is 40% WWR; typical high rise in excess of 50%). | All building types | 3 - Good | A lower WWR will reduce both the cooling and heating load. | Reduction in operating GHGs from reduced heating and cooling demand if grid/energy source is not clean, or not clean during peak demand.<br>If considering lifecycle carbon, evaluate tradeoff in glazed to opaque | Lower WWR generally reduces capital cost. | -$ (savings) | Less maintenance is typically required for opaque wall assemblies vs fenestration | Visualizing a lower WWR (using renderings, daylight analysis) can help design team and client understand that the design impact for daylight in the space can be minimal. Use daylighting tools to optimize the interaction of the space with daylight and views.<br>Consider reducing WWR in | Potentially reduced passive solar gains are offset by significantly reduced space heating demand through increased opaque enclosure area (with much higher thermal resistivity).<br>May reduce space cooling demand and lower peak loads for mechanical system design. | N/A | N/A | N/A | More even temperature distribution within space with less fenestration (in both winter and summer).<br>Reduced window performance issues (e.g. maintenance, condensation concerns). | Improves: by mitigating overheating via solar gains during cooling season power outage, and reducing heat loss during winter season power outage. | Resilient to storms | Opaque assemblies are generally more durable than glazed assemblies. | N/A |

| General Information | | | | | Overheating Mitigation | Climate Change Mitigation | | Capital and Operational Impacts | | | Design Implications | | | | | Impacts on Resilience | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode | Sub-Category | Measure | Description | Applicable Building Types or Limitations | Overheating Mitigation | Energy Impacts | GHG Impacts | Capital Cost Considerations | Cost ($) | Maintenance & Replacement | Architectural | Mechanical | Structural | Envelope | Electrical | Indoor Environmental Quality | Passive Survivability | Storm Resistance | Longevity or Durability Notes | Flood Resistance |
| Passive | Form Factor | Form Factor | The Heat Loss Form Factor is the relationship between the exterior thermal surface area and the internal floor area (total surface area / floor area).<br>This is generally between 0.5 and 5; the lower the number, the more compact the building. For a high performing building it should be below 3, with larger buildings (multi-storey) less than 1.5 to limit losses through the building enclosure. | All building types | 3 - Good | A lower form factor will reduce both the cooling and heating load, although other details such as the window frame detailing, remain important for optimizing energy consumption. | Reduction in operating GHGs from reduced heating and cooling demand if grid/energy source is not clean, or not clean during peak demand.<br>If considering lifecycle carbon, a more compact enclosure is typically | A lower form factor generally reduces complexity in the building envelope and reduces capital cost compared to a more complex form. | N/A | Less articulations can lead to simpler enclosure maintenance and renewal over the building's lifecycle. | Evaluate form factor early in the project, including cost implications.<br>Municipally dictated building setbacks (for example, setting back higher floors to reduce visual street impact) can negatively impact form factor. | A lower form factor may lend itself to more efficient layout of distribution systems<br>A lower form factor can reduce space heating and cooling demand and associated system and sizing options. | A lower form factor simplifies structure | A lower form factor reduces heat loss, and simplifies detailing of air and water control layers. | N/A | Reduced enclosure complexity reduces heat loss through the enclosure, which can improve comfort and temperature distribution within a unit. | Negligible. | Resilient to storms | A lower form factor leads to a simpler building shape with less failure points (corners, articulations etc.), which leads to a more durable building enclosure. | N/A |
| Passive | Solar Control | Orientation | Orientation of major axes of the building to optimize solar heat gains/losses via optimal placement of vision glass and shading. | All building types, although in practice few lots offer much flexibility in building orientation | 3 - Good | Optimized orientation can reduce cooling demand in summer. | Reduction in operating GHGs from reduced cooling demand if grid/energy source is not clean, or not clean during peak demand. | Capital cost neutral | N/A | N/A | Since many urban sites do not provide flexibility for overall building orientation, consider program areas / location of glazing / balconies / shading in response to the site constraints. | Orientation can impact passive solar gains, which can impact cooling equipment sizing and system choices. | N/A | N/A | N/A | N/A | Reduced solar gains from orientation can reduce overheating risks in summer; but trade-off with reduced heat gains in winter. Pairing strategy with shading can mitigate this tradeoff. | Resilient to storms | N/A | N/A |
| Passive | Solar Control | Low SHGC glazing | A lower Solar Heat Gain Coefficient allows less direct solar gains into a space. The previous maximum prescriptive value in ASHRAE 90.1 - 2010 was 0.4. In the 2016 version, the maximum is 0.36. | All building types | 3 - Good | Reduces cooling demand, although can increase heating demand by limiting winter solar gains. Impacts would need to be modeled for a specific building. | Reduction in operating GHGs from reduced cooling demand if grid/energy source is not clean, or not clean during peak demand.<br>Could increase GHGs from heating if solar gains reduced sufficiently and | Capital cost neutral | N/A | N/A | Consider the impact on the look of the glazing system - lower SHGC glazing can have a more 'tinted' appearance.<br>Balance SHGC with visual transmittance (there are now numerous glazing options that maintain very high visual transmittance with a low SHGC) | As with exterior shading, low SHGC glazing can decrease space cooling demand and potentially increase space heating demand, although impact may be minimal and should be modeled. | N/A | Review low SHGC strategy (placement of films etc.) | N/A | N/A | Reduced solar gains can reduce overheating risks in summer; but trade-off with reduced heat gains in winter. | Resilient to storms | Durable although placement (i.e. glazing surface) and durability of films should be considered. | N/A |
| Active (mechanical) | Partial Cooling | Cooling coil in corridor pressurization system (Make-Up Air unit) or in centralized HRV | Adding a mechanical cooling coil to the MUA system or HRV will cool the volume of air typically delivered by those systems, but may not meet the full peak cooling demand given the low air volumes being delivered into the occupied space. | All building types | 3 - Good | Will increase cooling energy consumption over a case with no mechanical cooling. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon increase. | Small added capital cost over same systems with no coil. | $ | Minor additional coil maintenance that could be rolled into regular HVAC maintenance. | Consider as part of overall strategy with other passive measures such as fixed and operable shading.<br>This will likely lead to a centralized HRV design, for which distribution impacts will need to be considered (impact on floor to floor height; vertical shaft | Consider sizing ductwork to allow for boosted airflows. | N/A | N/A | N/A | N/A | If adding cooling to MUA unit, could turn corridors into a refuge area; would need to be on emergency power to provide resiliency during a power outage | N/A | N/A | N/A |
| Passive | Ventilation | Natural ventilation | Designing to introduce outside air using natural forces of buoyancy and wind; i.e. without using mechanical assistance.<br>Because the BC Building Code now requires a balanced mechanical ventilation system, this option is considered as a supplemental means of reducing overheating when outdoor conditions allow. | All building types | 2- Moderate | Negligible, since natural ventilation is typically relied upon in buildings that do not have mechanical cooling. | N/A | Negligible | N/A | Operable windows require more maintenance than fixed windows.<br>Occupant education on how natural ventilation works within an overall cooling strategy may be required. | Window placement choices should optimizing cross ventilation potential (e.g. operable windows on opposite or adjacent walls to encourage airflow)<br>Because natural ventilation relies on natural forces (such as stack effect) to drive airflow, large openings may be necessary to be | Consider interaction between the natural and mechanical ventilation systems - potentially with controls to limit mechanical ventilation while natural ventilation is in use (e.g. while windows are open, reduce HRV airflow)<br>Consider occupant effects, e.g. windows | N/A | N/A | N/A | Consider acoustical impacts (street noise etc.)<br>Not a desirable means of ventilation during a wild fire smoke or other event causing poor outdoor air quality. | Allows for manually introducing ventilation air in the event of power failure. | N/A | N/A | N/A |
| Passive | Solar Control | Exterior shading - overhangs/fins | Fixed overhangs or vertical fins that shade adjacent glazing. | All building types | 2 - Moderate | Shading systems will reduce cooling load and potentially the required cooling equipment.<br>There may be an increase in heating load due to reduced solar heat gain. NOTE: heating from plug loads is likely to be higher than losses. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be an operational carbon reduction. | Additional capital cost to be compared with potentially reduced cooling load and size of peak cooling equipment.<br>A simple panel design with aluminum is most economical, although aesthetics are also a consideration.<br>Custom fabrication can be quite expensive. | $$ | Periodic cleaning required to maintain the design intent.<br>Maintenance of additional linear feet of sealant.<br>Potential impact on ability to access/clean windows. | Evaluate shading early in design process. Clarify the design intent (e.g. 100% shading at solstice, or optimized via energy model to minimize CEDI)<br>Consider depth and orientation by elevation, i.e. horizontal for south and vertical for east and west. Optimize design through modelling with solar paths.<br>Consider balcony design as part of the shading strategy. | Shading devices can impact both heating and cooling loads, and so building and location specific trade-offs must be considered. Evaluate:<br>- Potential to reduce the size of cooling equipment<br>- Potential to increase space heating demand by reducing passive solar heat gains during the heating season<br>- Potential to increase space heating demand by added thermal bridging of exterior shading structural supports.<br>- Potential impact on available locations of mechanical penetrations | Coordinate early with structural to design cost effective structural connection system and/or details.<br>Evaluate snow loads on horizontal fixed shading.<br>Evaluate wind loads. | Consider detailing around structural connections.<br>Evaluate options with structural to minimize thermal bridging from connections. | N/A | Reduced direct solar gain and resulting mean radiant temperature (= increased thermal comfort during cooling season).<br>Potential acoustic concerns (rain, vibrations) | Improves: by mitigating overheating during cooling season power outage or brown out | May reduce wind-driven rain on fenestration | Factor in considerations for future wind load / snow load | N/A |
| Passive | Solar Control | Green Roof | A vegetated roof system that provides cooling benefits. Could be extensive (shallow plantings, not typically occupiable, less loading on structural) or intensive (deeper plantings, more landscaping variety; often occupiable, greater structural load). | All building types, although those with larger roof areas relative to total building area will see more of a benefit | 2 - Moderate | A green roof can absorb solar energy through evapotranspiration, thereby reducing solar gains through the roof and reducing cooling demand | Reduction in operating GHGs from reduced cooling demand if grid/energy source is not clean, or not clean during peak demand.<br>If considering lifecycle carbon, consider material for potential structural upgrade to support green roof. | Will add capital cost compared to a conventional roof. | $ | Added maintenance compared to a conventional roof: Irrigation systems often needed, especially during establishment period. Leak detection system may also be needed. Extremely costly to repair in case of leak. Potential impact of soil erosion to drains. | Co-benefit as outdoor amenity for building occupants (if intensive). Trees can provide shading for occupants as well. | Possible reduction in cooling system requirements. Irrigation system may need to be integrated into the plumbing system design. | Increase in structural load for green roof will need to be evaluated and designed for. | Requires high quality roofing system, possibly including leak detection system. Generally advised not to store water on a roof as it increases the likelihood and severity of a leak. | If leak detection or automatic irrigation system is used, consider controls/electrical in design. | N/A | Possibly provides outdoor livable space for refuge, should conditions permit. | Rooftop plantings can be damaged by severe storms | Can improve durability of underlying roof system by limiting solar exposure, although green roofs bring other durability risks - green roofs must be maintained and monitored to ensure ongoing roof enclosure performance. | Green roof can reduce surge rain water run-off from building site, though from a building science perspective it is generally advised to shed water from building  as soon as possible to avoid water ingress. |

| General Information | | | | | Overheating Mitigation | Climate Change Mitigation | | Capital and Operational Impacts | | | Design Implications | | | | | Impacts on Resilience | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mode** | **Sub-Category** | **Measure** | **Description** | **Applicable Building Types or Limitations** | **Overheating Mitigation** | **Energy Impacts** | **GHG Impacts** | **Capital Cost Considerations** | **Cost ($)** | **Maintenance & Replacement** | **Architectural** | **Mechanical** | **Structural** | **Envelope** | **Electrical** | **Indoor Environmental Quality** | **Passive Survivability** | **Storm Resistance** | **Longevity or Durability Notes** | **Flood Resistance** |
| Passive | Solar Control | Reflective Roof | High albedo roof (e.g. white, greys) that minimize solar absorption or maximize emissivity | All building types, although those with larger roof areas relative to total building area will see more of a benefit | 2 - Moderate | High albedo (white roof) - reflects solar energy, thereby reducing cooling demand | Reduction in operating GHGs from reduced cooling demand if grid/energy source is not clean, or not clean during peak demand. | Cost neutral compared to a conventional dark roof. | N/A | White roofs typically have longer service lives due to reduced thermal wear and tear. Depending on material (TPO/PVC), the surface may be slippery (for access, maintenance) | High reflectivity may affect adjacent neighbours overlooking with light reflected from roof to their space. | A high albedo roof can reduce peak cooling loads. They also usually have a cooler roof surface, meaning roof-top mechanical systems are drawing in cooler air than in a low albedo roof. | N/A | White roofs have reduced drying potential from reduced solar drying. Careful attention to air and vapour control measures are required as with any roof assembly. | N/A | N/A | Depending on roof surface area, minor reduction in solar gains through roof. | N/A | White roofs typically have longer service lives due to reduced thermal wear and tear. | N/A |
| Passive | Thermal Performance | Enclosure thermal performance (window, wall, and roof) | Windows (and walls) with thermal resistivity beyond code.<br>Supplemental (beyond code) roof insulation | All building types | 2 - Moderate | Reduced conductive heat loss and heat gain.<br>Window frame design and material are the key components in improving the window performance (aluminum vs. vinyl vs. fiberglass and frame design for each). | Reduction in operating GHGs from reduced heating and cooling demand if grid/energy source is not clean, or not clean during peak demand.<br>If considering lifecycle carbon, evaluate frame and glazing material choices versus operating carbon savings. | Account for additional cost of insulation.<br>Wide variation in capital costs - high performing triple glazed vinyl versus fiberglass versus metal.<br>Passive House level of performance generally requires triple glazed system. | $$$ | Consider the weight (can be significant during construction) and ease of operation for operable windows. Senior residents / assisted living residents may require different operable mechanisms. The frame system will have different lifespans, with vinyl needing replacement sooner than aluminum and fiberglass systems.If exterior insulated above roof membrane, the membrane will be protected and require less maintenance/replacement. | Minimal difference in appearance between double and triple glazed windows, although framing material and systems will impact aesthetics (e.g. vinyl tends to have a thicker frame than metal or fiberglass).<br>Added insulation may create topology constraints (greater thickness affecting parapets/overhangs, etc.) | Higher thermal performance enclosure will improve the enclosure thermal performance, thereby decreasing the space heating and cooling demand (although there must be an effective means of removing internal gains from the space via ventilation or cooling). | Weight increased with triple glazed windows vs double. This will impact a curtain wall system more than punched window system. | Other high performance measures may be able to be reduced if triple glazed windows are used.<br>If exterior insulated above roof membrane, the membrane will be protected and require less maintenance/replacement. Roof design will require attention to placement and continuity of air and water control layers and associated detailing. | N/A | Better insulated windows reduce acoustical intrusion from outdoors. | Can mitigate heat loss or gain in the event of a power failure if the space is not dominated by high internal loads. | Potential uplift risk for inverted roof assemblies in strong winds, depending on roof configuration (conventional vs protected) and attachment mechanism. | If exterior insulated above roof membrane, the membrane will be protected and require less maintenance/replacement. | N/A |
| Passive | Demand Reduction | Reduced Infiltration Rate | Through attention to air barrier detailing, a reduced infiltration rate can be achieved. This minimizes the infiltration of hot air during heat events and allows better control of space conditioning. | All building types | 2 - Moderate | Reduces the potential loss of conditioned air, leading to space conditioning energy savings. | Reduction in operating GHGs from reduced heating and cooling demand if grid/energy source is not clean, or not clean during peak demand. | Nominal labour and material cost for air barrier detailing (a continuous air barrier is technically required by base BC Building Code). | $ | No additional maintenance compared to typical building enclosures | Detailed design to consider infiltration goals and associated detailing. Clearly indicate continuous air barrier on drawings.<br>Minimize the number of complex details. | Limited mechanical penetrations will reduce the number of air barrier penetrations to be sealed. | Limited structural penetrations (e.g. for attaching balconies) will reduce the number of air barrier transitions required. | Requires testing (already required for Step Code)<br>Provide input on air barrier detailing and transitions. | N/A | Quality of the air barrier has a significant impact on IAQ infiltration (e.g. wild-fires, or outdoor traffic pollution). Can also reduce drafts. | Will need another method to provide outside air in the event of a power failure (e.g. operable windows) | N/A | N/A | N/A |
| Mixed-mode | Ventilation | Bypass and boost mode with HRV | Selecting an HRV that is equipped to operate in bypass and boost mode can be controlled to increase airflow and bypass the heat exchanger when the outside air is cooler than the inside air. HRVs can be in-suite, semi-centralized (e.g. floor by floor) or centralized | All building types | 2 - Moderate | Negligible, as this method would typically be used in a building that does not have mechanical cooling. | N/A | Higher performing HRVs will have this functionality and will cost more than an lower performing unit with limited controls. | $ | No additional maintenance beyond filter replacement that is standard for all HRVs. | Nothing beyond normal considerations for space planning/layout for an HRV. | Generally sized on ventilation rate at "normal" flow rates; boost can allow for free cooling during an overheating event | N/A | N/A | N/A | N/A | Non-functional during power outage. | N/A | N/A | N/A |
| Active (mechanical) | Partial Cooling | Cooling in amenity room (localized) | Providing full mechanical cooling only in a refuge zone within a building, such as an amenity or common meeting space. | All building types large enough to have amenity/common spaces, although refuge zone could also be considered the corridor. | 2 - Moderate | Will increase cooling energy consumption over a case with no mechanical cooling, but only modestly. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be a small operational carbon increase. | Will add minimal capital cost over a building with no cooling. | $ | Typical maintenance for small HVAC system. | Coordinate refuge room design with other municipal and code requirements (e.g. accessibility, occupancy limits etc.) | Same comments as other cooling systems apply, except that amenity room cooling will not meet general overheating criteria in other occupied spaces, such as dwelling units. | N/A | N/A | Electrical requirements for localized equipment and controls. | N/A | Would need to be on emergency power to provide resilience in the event of a power outage | N/A | N/A | N/A |
| Active (mechanical) | Ventilation | Occupant supplied fan | Manually operated and mobile fan to assist convective heat transfer as needed. | All building types | 2 - Moderate | Will increase plug load energy consumption. | Negligible if only considering operating GHGs and the electricity grid is GHG-free.<br>If grid is not clean, or not clean during peak cooling demand, there will be a nominal operational carbon increase. | Minimal, and typically borne by suite occupant | $ | N/A | Post design consideration.<br>Could plan optimal location for fan during design. | Added plug-load | N/A | N/A | Added plug-load | Convective air movement can improve feeling of comfort in a space even when the temperature is quite warm. A fan can also speed the cooling of the space when used with operable windows during times when the outdoor air temperature has cooled faster than the indoor temperature. | N/A | N/A | N/A | N/A |
| Passive | Urban Heat Island | Strategic Landscaping | Adding plants/trees to provide shade, increase evapotranspiration to provide localized reduction in ambient heat. | Limited to building with useable landscape area (e.g. constraints for zero-lot line sites) | 2 - Moderate | Depending on placement and coverage, can mitigate cooling energy demand for mechanically cooled buildings. | Negligible if only considering operating GHGs and the electricity grid is GHG-free. | Landscaping cost, which can vary widely depending on site and extent of landscaping. | $ | Maintenance is required (mowing lawn, irrigation, arborists, etc. | Wider urban planning design consideration that can provide localized relief to heavily built-out urban areas.<br>Integrate into the design intent from the outset of the project; understand sun path and shading impact on the project and local surroundings. | Negligible | May need additional structural support if landscaped areas are on decks. | Attention to enclosure detailing required if landscaped areas are on decks (i.e. above occupied space). | N/A | N/A | Resilient to power outages and a potential area of refuge, e.g. during heat wave with power outage. | Potential risks of tree/plant damage during extreme storms. | Prioritize native and/or drought tolerant plants and trees. | If combined with bioswales and flood retention ponds, can form part of comprehensive flood management system. |

| General Information | | | | | Overheating Mitigation | Climate Change Mitigation | | Capital and Operational Impacts | | | Design Implications | | | | | Impacts on Resilience | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mode** | **Sub-Category** | **Measure** | **Description** | **Applicable Building Types or Limitations** | **Overheating Mitigation** | **Energy Impacts** | **GHG Impacts** | **Capital Cost Considerations** | **Cost ($)** | **Maintenance & Replacement** | **Architectural** | **Mechanical** | **Structural** | **Envelope** | **Electrical** | **Indoor Environmental Quality** | **Passive Survivability** | **Storm Resistance** | **Longevity or Durability Notes** | **Flood Resistance** |
| Passive | Thermal Performance | Thermal mass | High mass building - can temper overheating during the day and release heat at night to recharge the potential for heat absorption during the day. This only works if night temperatures are low enough. Alternatively, smart materials with heat transfer properties may be used. | All building types, typically concrete construction. | 1 - Small | Potential to reduce peak space heating and cooling loads by absorbing heat and releasing it back to the space over a prolonged period, though overall energy consumption may be minimally impacted. | Potentially significant embodied carbon considerations with thermal mass materials. | Potential increase in material quantity and associated cost. | $ | There should not be any additional maintenance/replacement. | Consider requirements for effectiveness of thermal mass:<br>- volume of mass<br>- exposed mass material (integration w/ interior design)<br>Viability for large projects to be considered. | Potentially reduce peak space heating and cooling loads by absorbing heat and releasing it back to the space over a prolonged period. But can have a long lag for heating and cooling whereas a 'light' building can be quick to heat and cool. This could influence the mechanical systems and the controls, i.e. how easy is it to have a building in 'balance'. | If mass is provided by structure (e.g. concrete) can have weight implications. | There may be a trade off between thermal conductivity and thermal massing. Consider operational energy impacts from thermal conductivity of the mass if implemented on exterior enclosure. | N/A | N/A | Thermal mass can pose life-safety hazards to occupants in summer overheating (retains internal/solar gains). Natural ventilation and night-time flushing may have reduced efficacy from stored thermal energy, particularly with increase in tropical nights (with long duration of elevated MRT). On return of power, it can take a long time for mechanical system to return interior space to habitable conditions. Thermal mass can be more beneficial in power outage in winter, but similar issue of long run-time to re-instate building thermal equilibrium. | Can make buildings more structurally resilience to heavy storms. | If there is a change of use on interiors (e.g. layout & moving interior walls), retrofits need to take into consideration original intent of thermal mass design. | N/A |
| Mixed-mode | Thermal Performance | Internal load management | Automated controls to optimize lighting and appliance operation; DHW pipe insulation & pipe design (e.g. minimizing number of risers) to mitigate internal heat losses. | All building types to some degree, though it may not be possible to implement measures such as appliance operation optimization in multifamily residential buildings. Lighting controls would only be applicable to common areas. | 1 - Small | Reduced electricity consumption from optimizing lighting & appliance loads; potentially an increase in winter heating energy if heat loses from DHW piping are controlled. | Minimal. | Controls have a small cost associated with them, as does extra piping insulation. There may be slight cost savings from shortening DHW pipe runs through optimal design. | $ | | Considerations to space use and users (demographic) with this type of strategy, lights turning off and on can cause confusion and irritation. | Reduced mechanical cooling need from reduced internal gains. Higher efficiency equipment (heat pump clothing dryers, motion sensor corridor lighting, etc.) can reduce internal gains, thereby increasing space heating demand and decreasing space cooling demand. | N/A | N/A | Code considerations regarding lighting requirements. | N/A | During power outage, plug loads inoperable. | N/A | Lighting and appliances may last longer if operated less frequently through internal load management controls. | N/A |

| | |
|---|---|
| 0 - No benefit | Unmitigated risk of overheating |
| 1 - Small | Risk of overheating with some mitigation |
| 2 - Moderate | Mitigated risk of overheating, dependent on implementation |
| 3 - Good | Minor risk of overheating |
| 4 - Excellent | No risk of overheating (except maybe during power outage) |

# Appendix C

## Lifecycle Costing: Capital and Operating Cost Details

# Lifecycle Costing: Capital and Operating Cost Details

| LOW-RISE DESIGN MEASURES - CAPITAL AND OPERATING COST SUMMARY | | | |
|---|---|---|---|
| **Design Measures** | **Avg. Capital Cost per Building** | **Operating & Maintenance Costs** | **Operating & Maintenance Notes** |
| Exterior shading (Passive) | $502,000 | $800/yr | Maintenance once a year (One 8 hour day for 1 maintenance person ($100/hr)) |
| HRV with bypass and boost (Mixed-Mode) | $120,000 | N/A (no change from baseline) | Replacement every 15 years |
| Cooling coil in the corridor pressurization system (MAU) (Active) | $5,000 | $10/suite/yr | Replacement every 20 years |
| Cooling localized to one room (Active) | $20,000 | $500/yr | Replacement every 15 years |
| Full Mechanical Cooling (Active) – 4-pipe fan coil system compared to in-floor hydronic heating baseline | $144,000 | $100/suite/yr | Replacement every 20 years |
| Full Mechanical Cooling (Active) – mini-splits compared to electric baseboard heating | $288,000 | $100/suite/yr | Replacement every 20 years |
| Bundle: Full Mechanical Cooling (4-pipe fan coil system compared to in-floor hydronic heating baseline) and Exterior Shading | $574,000 | $800/yr + $70/suite/yr | Maintenance once a year (One 8 hour day for 1 maintenance person ($100/hr)) + Replacement every 20 years |
| Bundle: Full Mechanical Cooling (mini-splits compared to electric baseboard heating) and Exterior Shading | $646,000 | $800/yr + $70/suite/yr | Maintenance once a year (One 8 hour day for 1 maintenance person ($100/hr)) + Replacement every 20 years |

| HIGH-RISE DESIGN MEASURES - CAPITAL AND OPERATING COST SUMMARY | | | |
|---|---|---|---|
| **Design Measures** | **Avg. Capital Cost per Building** | **Operating & Maintenance Costs** | **Operating & Maintenance Notes** |
| Exterior shading (Passive) | $4,373,000 | $1,600/yr | Maintenance once a year (Two 8 hour day for 1 maintenance person ($100/hr)) |
| Reduced window to wall ratio (Passive) | ($646,000) | N/A | N/A |
| HRV with bypass and boost (Mixed-Mode) | $575,000 | N/A (no change from baseline) | Replacement every 15 years |
| Bundle: Full Mechanical Cooling and Exterior Shading | $4,718,000 | $1,600/yr + $70/suite/yr | Maintenance once a year (Two 8 hour day for 1 maintenance person ($100/hr)) + Replacement every 20 years |

# Appendix D

## Summary of Workshop Outcomes

# Summary of Workshop Outcomes

Based on the previous tasks, the project team hosted a workshop with stakeholders to discuss recommendations to move forward. Results of the previous three tasks were presented as a basis for discussion. Below are key takeaways emerging from the workshop and comments submitted by stakeholders who were unable to attend the workshop.

## *Defining thermal comfort*

- It is important to distinguish between *overheating* and *thermal comfort*. Work here is focused on overheating, which is a subset of thermal comfort.
- A simple frequency-based metric, such as the 200-hr (or 20-hr vulnerable population) limit in the EMGs and the 10% of hours above 25°C limit in Passive House, is not sufficient to address the magnitude of overheating (i.e. consecutive hours above a threshold), nor zone specific variations typical of multi-family buildings.
- Some stakeholders prefer an absolute temperature limit that cannot be exceeded; others prefer the hours of exceedance model, with additional metrics to evaluate the degree of exceedance.
- There was some skepticism expressed that the BC market would accept a European-based method such as CIBSE TM59 or TM52, which use three criteria when evaluating overheating (absolute maximum temperature, number of hours of exceedance, and degree-hour of exceedance), although there may be merit in incorporating some aspects of the method into a BC-based approach.
- The newly published NRC guideline (as summarized in Section 2.2.2) should be considered, as it proposes options for characterizing overheating using the severity index of heat events (SETH) and a methodology to evaluate it using simulation.
- Unresolved: Is there a different definition of overheating for a naturally ventilated vs. a mechanically cooled/ventilated building, or a building with “partial” cooling?

## *Modelling thermal comfort*

- While passive measures and occupant controls are generally desirable in a multi-family building and can have a considerable impact on perceived comfort, models should not overly rely on user operation to maintain thermal comfort.
    - This reliance could be tested in the model through sensitivity analysis whereby user controls are disabled and limits are imposed on the acceptable frequency and magnitude of overheating under these conditions.
- Modelling natural ventilation continues to be a challenge, and it is unlikely that a consistent and straightforward modelling approach will be established, though there was consensus that natural ventilation is an important design measure in mitigating overheating and improving occupant comfort. Having said this, it is likely to only be a complementary strategy in future climate scenarios.
- Regarding future climate files, there was a preference among stakeholders to use a single future weather file, e.g. 2050s climate file in modelling (likely in addition to the current weather file).

- The use of Reference Summer Weather Years was discussed as a means of evaluating warmer than normal summer temperatures although there was not a clear consensus on how these should be used in modelling, or whether they would adequately address extreme conditions.

### *Design strategies and implications*

- Simply providing mechanical cooling is not an adequate solution when considering intersecting impacts such as total and peak electricity demand and climate resilience.
- Design teams prefer performance-based standards that allow them to devise creative solutions that best suit a given project/site. This also frees any requirements from a limited shelf life as new solutions become available, economies of scale are reached, etc.
- Stakeholders agreed that introducing a performance target to encourage passive cooling measures and to allow for innovation (similar to the TEDI target) is a supportable approach (i.e. cooling energy demand intensity (CEDI)).
- Stakeholders felt that, despite modelling challenges, natural ventilation is still a viable design strategy to deliver occupant comfort and reduce real or perceived overheating. Passive measures and natural ventilation are architectural approaches that must be considered in tandem with the architecture itself from the earliest phases of design.

### *Potential code changes/other requirements*

- There was general consensus that a performance-based cooling energy demand intensity (CEDI) metric would enable regulators to address thermal comfort without causing undue consequences.
- A prescriptive approach was generally not seen as the way forward. A performance based approach considers the building as a system and is more consistent with the current framework of the BC Energy Step Code.
- As an initial step, require only *reporting* to help establish future requirements and familiarize the industry with the concepts, approaches, and solutions.
    - Reporting should include peak temperatures along with other potential overheating indicators such as frequency of peaks.
    - Reporting should include results of the sensitivity analysis. Guidance would be required for code officials re: what is acceptable and what is not?
    - Reporting should include performance under future climate conditions.
- Unresolved: When modelling to a future climate scenario, what, then is required of the present day design? Refer to section 4.3 Future Ready Considerations for possible options.
- Unresolved: What might CEDI targets be, to achieve multiple benefits (cost, climate resiliency, overheating mitigation)? Passive House requires a maximum of 15 kWh/m2/hr. Projects in the Lower Mainland, such as the Evolve project at UBC, have reportedly modelled very low values (3.1 kWh/m2/hr), primarily through the use of exterior shading. The achievable values would likely vary by climate.