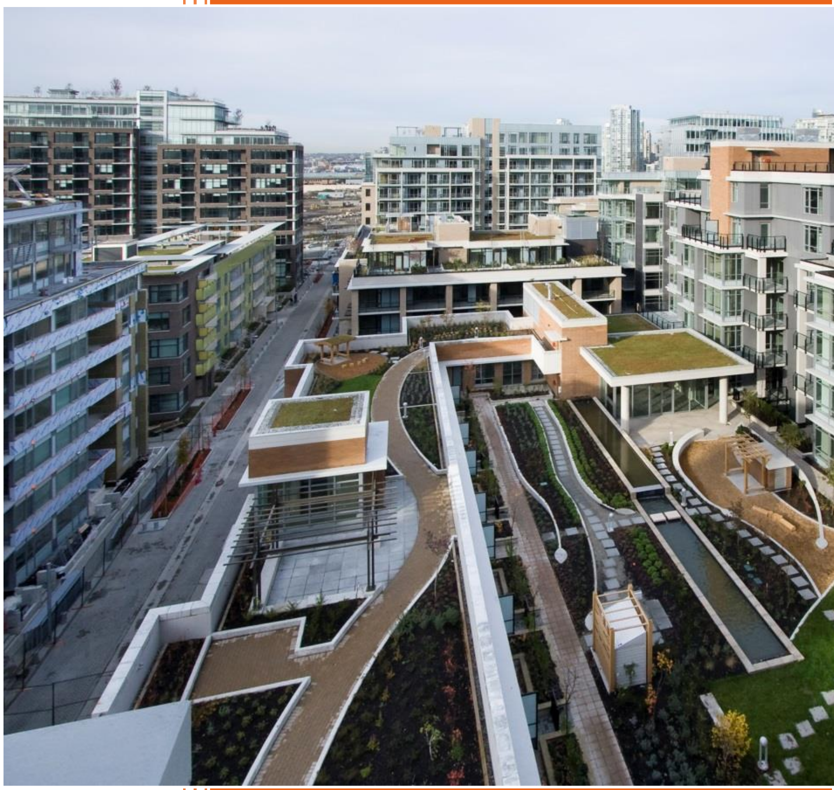
Extreme Heat, Cool Buildings

A Review of Alternatives to Traditional Air Conditioning



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1 Introduction

1.1 Project Context

Climate Change in Vancouver

Science has established that the climate is changing, and Vancouver is not immune to its impacts. The University of Victoria's Pacific Climate Impacts Consortium (PCIC) carried out a study of regional projections for Georgia Basin area participants in the ICLEI Adaptation Initiative, the results of which are summarized in the City of Vancouver's Climate Change Adaptation Strategy (City of Vancouver, 2012). The study found that, in general, the projected changes by the 2050s were modest, while the projected changes out to the 2080s describe a future climate that, compared to historical climate, is nearly unrecognizable.

In addition to projected changes of an increase in average annual precipitation with a decrease in precipitation during the summer, rising seas, and an increase in extreme events including windstorms and heavy rainfall, Vancouver is also expected to experience an increase in average annual temperature - +1.7°C by the 2050s and +2.7°C by the 2080s. In the 2050s, the frequency of summer days reaching a high of 24°C or greater is projected to more than double (compared to the baseline period of 1971-2000), and the frequency of extreme heat events that historically happened once every 25 years is projected to more than triple. By the 2050s, the expected summer daytime high temperatures suggest a summer climate between that of present-day Seattle and San Diego.

These rising temperatures are often exacerbated due to the Urban Heat Island (UHI) effect, which describes the phenomenon of elevated temperatures in urban and suburban areas compared to their outlying rural surroundings (EPA, 2008). Surface UHIs describe the effect of the sun heating dry, exposed urban surfaces like roofs and pavement to temperatures greater than the air temperature; on a hot, sunny summer day, the temperature differences can reach 27-50°C. Shaded or moist surfaces, on the other hand, that are more common in more rural areas, remain closer to the air temperature. Surface UHIs usually happen during the day and at night, but are often strongest during the day with the sun is shining. Atmospheric UHIs describe the warmer air temperatures in urban areas compared to cooler nearby rural surroundings. They are usually weakest in the morning and during the day, and become more pronounced after sunset because of the slow release of heat from urban infrastructure. Both the surface and atmospheric UHI effect are illustrated in Figure 1.

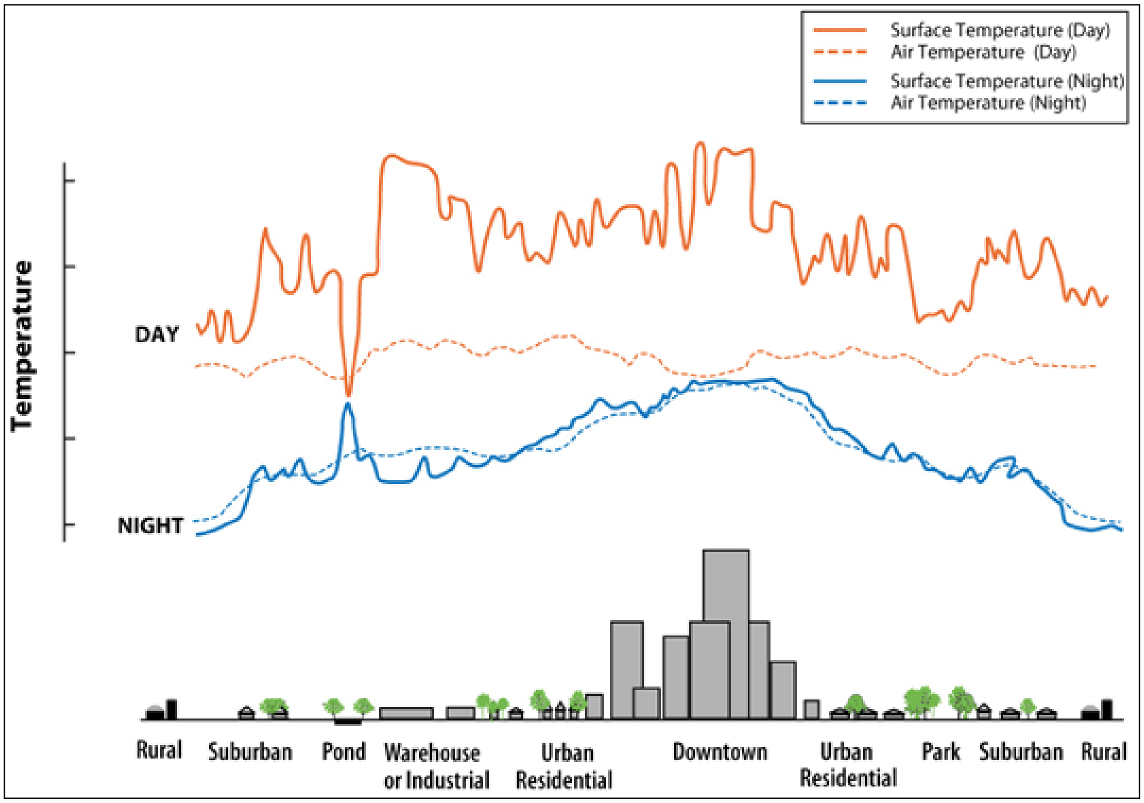

FIGURE 1 - VARIATIONS OF SURFACE AND ATMOSPHERIC TEMPERATURES (EPA, 2008)

While the thought of longer, warmer summers may be appealing to some, there are serious implications for infrastructure that has been designed for our historical climate. Heating, ventilation, and air conditioning (HVAC) systems, general building design, and the energy systems and infrastructure that support them are established around the number of heating and cooling degree days, which are a way to relate the energy needed to heat or cool a building relative to the outside temperature. Heating degree days in Vancouver are projected to drop by 25% and 35% by the 2050s and 2080s, respectively, while cooling degree days are expected to at least double by the 2050s and could increase by as much as a factor of 10 by the 2080s (City of Vancouver, 2012). These changes will reduce demand for heating in the winter, but also present major challenges for keeping our buildings cool in the summer.

EXTREME HEAT PROJECTS

The expected increase in temperatures and more frequent extreme heat events have serious implications not only for the thermal comfort of the citizens of Vancouver, but, more importantly, their health and well-being. It is of particular concern in vulnerable populations such as the elderly, children, and the homeless. In 2009, during the heat wave from July 26 to August 2, an estimated 122 "excess deaths" were recorded in Vancouver (City of Vancouver, 2012). To explore options for reducing the health impacts of extreme heat events in Vancouver, the City of Vancouver is pursuing a number of Extreme Heat projects, of which this review is a part of.

The Extreme Heat: Cool Buildings project is investigating alternatives to air conditioning for cooling multi-unit residential buildings and is composed of a number of phases. This report makes up the first phase of the project, and looks at alternative cooling strategies, as compared to the widespread use of traditional air conditioners, to adapt to the rising temperatures. While traditional air conditioners are a commonly used remedy, by removing heat from the home and dumping it outside the building, they are actually exacerbating the UHI and making things worse for those without air conditioners. Additionally, as part of its Greenest City 2020 Action Plan, the City of Vancouver has established a Green Buildings goal of leading the world in green building design and construction. It has set a target of reducing energy use and greenhouse gas emissions in existing buildings by 20% from 2007 levels (City of Vancouver, 2012); clearly, widespread adoption of energy intensive air conditioners is not compatible with this goal. Subsequent phases of this work will explore expanding on this research into potential on-the-ground solutions. Besides supporting Vancouver's Greenest City 2020 Action Plan, this project more specifically addresses goals from Vancouver's Climate Change Adaptation Strategy.

1.2 Project Methodology and Report Structure

As mentioned above, the focus of this research is alternative strategies to traditional air conditioning in buildings to address the issue of overheating, with an emphasis towards multi-unit residential buildings, and, in particular, retro-fitting existing buildings. It is concentrated on the building infrastructure side of the issue, but it is important to note that there are a number of other issues to consider when trying to address the problem of overheating, briefly explored in Section 5.2. The research considered both retro-fitting buildings with new technology or systems, as well as using existing building technology in new ways. In order to make the review as comprehensive as possible, a number of sources were considered:

1. Online search – The online search was conducted to identify a wide range of resources related to overheating, multi-unit residential buildings, new designs and retrofits, passive and low energy cooling, alternatives to air conditioning, and climate change adaptation. It also included a review of plans, policies and reports in other municipalities to see if these other jurisdictions have recognized overheating as a growing concern due to climate change, and how it is being addressed.

2. Academic literature – Academic literature was consulted to see what technologies and strategies are currently being reviewed or researched in the academic community.

3. Interviews with industry professionals – Interviews were conducted with a number of professionals from the building industry, to learn what is currently being used or explored in industry and to ensure that these strategies had been covered in the research. These interviews also provided an industry perspective on the challenges associated with addressing overheating in multi-unit residential buildings. Information gained in these interviews has been integrated into the body of the report.

The results of the research have been organized into the following sections of the report:

> *Section 2: Current State of Research and Practice* – This section outlines the main overall findings in relation to addressing overheating in buildings, as supported by the later sections, including a summary of the status in other jurisdictions.
>
> *Section 0:*
>
> *Alternative Strategies and* Evaluation – The strategies to address overheating and the specific measures for implementing each strategy that were identified during research have been

summarized in a table, along with the main associated considerations and limitations. Where available, information has been provided about cost and relative energy use, as well as any particularly relevant additional resources relating to that measure.

Section 4: Case Studies – Only one case study of retro-fitting of multi-unit residential buildings to address address overheating was identified; thus, the criteria for case studies was expanded to include alternative alternative strategies and measures in other building types, including new construction. These case case studies demonstrate how these alternative strategies and measures can be used to improve thermal thermal comfort and health while reducing reliance on mechanical air conditioning. Three of the most most relevant case studies are presented in detail, while additional case studies are identified with the with the measures that were employed and the case study resource if the reader would like to follow up. follow up. A reference to each case study is listed in the

Alternative Strategies and Evaluation table with each of the measures that are highlighted by the case study.

Sections 5-6: Recommendations and Conclusions – Based on the findings of the research, recommendations about the approach and choice of alternative strategies are made. The report then briefly explores some additional considerations for the potential implementation of the Cool Buildings Pilot Project, and wraps up with conclusions about the topic.

2 CURRENT STATE OF RESEARCH AND PRACTICE

Overheating in buildings is a concern facing many regions, particularly large cities where high temperatures are exacerbated by the UHI effect. In researching how other jurisdictions are addressing the issue of overheating, and particularly in response to climate change impacts, it was found that the approach favored by those who have done the most work in this area was a proactive one, focused on preventing overheating in buildings, rather than a reactionary approach in looking at methods of cooling.

Canada and the United States are seemingly just beginning to address the issue of overheating due to climate change. Sehizadeh and Ge at Concordia University are using future weather data in a building simulation to look at the impact of climate change on overheating in a typical Canadian single-family house that has been retrofitted to the PassiveHaus Standard and recently presented their research at the biennial conference of the International Building Performance Simulation Association (IBPSA) – Canada (Sehizadeh & Ge, 2014). No other such research was found. In 2007 the Clean Air Partnership looked at the impacts of rising temperatures on human health and electricity usage and suggested a number of strategies to address these impacts, including reducing the impact of heat waves and the UHI effect, reducing heat-related illness and death, reducing thermal discomfort in building, and reducing demand for cooling (Wieditz & Penney, 2007). Among these strategies, a number of general green building practices and passive measures were mentioned. In 2011 the City of Toronto published a report, Protecting Vulnerable People from Health Impacts of Extreme Heat (Toronto Public Health, 2011), that looked at a number of issues related to overheating, including Toronto's Heat Alert and Response System, in-home air conditioning statistics in Toronto, and mapping to identify vulnerable populations in the City; however, measures to adapt buildings to reduce overheating were beyond the scope.

Much work is being done across North America on mitigating the UHI effect, however, as is reflected in a recent report by the American Council for an Energy-Efficient Economy (ACEEE) entitled Cool Policies for Cool Cities: Best Practices for Mitigating Urban Heat Islands in North American Cities (Hewitt, Mackres, & Shickman, 2014). 26 cities in the United States and Canada, representing all of the major climate zones, geographies, and city sizes, were surveyed, and all but two had at least one voluntary policy or program for private construction to reduce excess heat; three quarters of the cities surveyed have established at least one mandatory private construction policy. 14 cities had strategies in place (either mandatory or voluntary) involving the urban canopy, while eight cities used vegetative roofs and 14 used reflective roofs. While UHI mitigation is an important strategy, it alone is not enough to address the problem of overheating.

The most extensive work on this issue was found to be done in the United Kingdom, with future weather data being established based on climate change projects, and much research being done into simulations and modeling of typical building types to evaluate risk of overheating as well as possible adaptation measures, based on this future weather data. AECOM's report, Investigation into Overheating in Homes – Literature Review (2012), prepared for the UK Department for Communities and Local Government, provides an extensive summary. The Chartered Institution of Building Services Engineers (CIBSE) is the professional body in the UK that is the authority on building services engineering, and publishes Guidance and Codes that are internationally recognized as authoritative (CIBSE, 2014). It has also recognized the implications of rising temperatures due to climate change on buildings and is working to address it by providing information and guidance to building designers and engineers. Publications by CIBSE on the issue include:

- TM36 Climate Change and the Indoor Environment: Impacts and Adaptation (CIBSE, 2005)
- TM48 The Use of Climate Change Scenarios for Building Simulation: the CIBSE Future Weather Years (CIBSE, 2009)
- TM55 Design for Future Climate: Case Studies (CIBSE, 2014)

The UK Department of Trade and Industry (DTI) commissioned research into the likely effect of climate change on thermal comfort and HVAC system performance, in which overheating risk, energy consumption and carbon emissions of several types of buildings were modelled; it was found that, "In response to rising summer temperatures simple passive design measures should be considered for all buildings to reduce overheating. Overall it is concluded that with appropriate design it is possible to produce low-energy solutions that will provide acceptable space conditions into the 2080s." (CIBSE, 2010). This is reflected in the report, Your Home in a Changing Climate: Retrofitting Existing Homes for Climate Change Impacts (Arup, 2008), which, due to concerns about the energy and emissions associated with widespread uptake of traditional air conditioning, focuses on passive measures.

The City of London has also adopted passive measures to prevent overheating as its primary approach. In its 2011 strategic plan, The London Plan, the City of London sets out its framework for the development of London to 2031. In the chapter, London's Response to Climate Change, Policy 5.9 on Overheating and Cooling outlines a cooling hierarchy that development proposals are to follow, to reduce potential overheating and reliance on air conditioning systems (City of London, 2011):

1. Minimize internal heat generation through energy efficient design
2. Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls
3. Manage the heat within the building through exposed internal thermal mass and high ceilings
4. Passive ventilation
5. Mechanical ventilation
6. Active cooling systems (ensuring they are the lowest carbon options)

Though less relevant because of the greater differences in climate compared to Vancouver, it is worth mentioning that relatively extensive research into the issue has also been completed in Australia. The National Climate Change Adaptation Research Facility prepared A Framework for Adaptation of Australian Households to Heat Waves (Saman, et al., 2013) that summarizes research into developing a framework to evaluate the potential impacts of heat waves, along with a technical, social, and economic approach to adapt its residential buildings. Drivers of this research, in addition to protecting vulnerable populations from the mortality and illness associated with overheating, include rising energy costs and increasing peak electricity demand due to increasing reliance on air conditioning. It was found that Australian households can be adapted to the impact of heat waves through a combination of behaviour change, dwelling modification, and improved air conditioner selection (National Climate Change Adaptation Research Facility, 2013).

Based on the extensive work that has been done in the UK and their success with passive adaptation measures, the original focus on active cooling strategies to deal with overheating evolved to include the passive preventative strategies as well. The Recommendations section elaborates on the justification for their inclusion.

3 Alternative Strategies and Evaluation

All measures to address the issue of overheating in buildings that were identified during the review have been compiled into the table on the following pages. It should be noted that passive strategies to prevent overheating played a central role in the approaches of other jurisdictions, and thus have been included in detail here. Considerations and concerns/limitations for each measure are noted, as well as the case study numbers in Section 4 in which each measure is included. Additional case studies in which only one or two measures were featured are cited in the table for reference as well. More detailed information than what has been presented in this table is available for some of the measures, as indicated under Additional Resources; these resources should be consulted when considering particular measures for adaptation. Where possible, information has been included on the approximate cost of the measure; however, as these costs are coming from different sources and jurisdictions, they should be taken as relative indicators only. Some measures are more or less suitable for low-, mid-, or high-rise buildings, as indicated in the table, and some are more complex to install than others. For the active strategies, where possible, the table provides a relative comparison of operating energy use.

The measures in this table are primarily considered from a building retro-fit project point of view. In the context of addressing overheating in new builds, many of the same strategies apply; however, there are many additional design considerations that should be attended to. There are a number of good resources that address these design concerns for new construction in the context of overheating, including:

- Adapting to climate change: a checklist for development (Three Regions Climate Change Group, 2005), which also addresses design concerns resulting from the climate change impacts of flooding and water shortages
- Adapting to climate change: a case study companion to the checklist for development (Three Regions Climate Change Group, 2007)
- Reducing overheating – a designer's guide (Energy Saving Trust, 2005)

TABLE 1 – ALTERNATIVE STRATEGIES AND EVALUATION

Cooling Strategy	Specific Measure	Considerations	Concerns/Limitations; Complexity of Installation	Associated Case Studies	Additional Resources	Cost Information (Various Sources)	Applicability to Building Height (Storeys): Low-rise ≤ 3 Mid-rise = 4-11 High-rise ≥ 12	Relative Operating Energy Use (N/A = not applicable)
Weatherization /insulation	Building insulation	▪ minimizes heat gain during the day	▪ can also minimize heat loss through the building envelope at night, which can contribute to overheating ▪ similarly, increasing air tightness when insulating makes ventilation even more important	4.4.3; 4.4.6; 4.4.11				N/A
	Roof, attic insulation	▪ reduces amount of heat transferred from outside/attic through ceiling into living space ▪ will also reduce winter heat loss, saving energy and money	▪ impact limited to upper floors, though these are often the ones at the greatest risk of overheating ▪ important to ensure proper attic ventilation so that heat can escape	4.1; 4.4.6		£1 - £1000 for a house (Arup, 2008)		N/A
Minimize solar heat gain through windows (Must balance desire to minimize solar heat gain in summer with need to maximize solar heat gain in winter)	Shade trees	▪ best on east and west sides where sun angles are low (overhangs, awnings, retractable sun shades that still allow winter sun access are best on south sides of building) ▪ deciduous trees will lose leaves in winter, allowing sunlight through	▪ challenges: time to grow; cost, if mature trees are brought in ▪ need to be planted far enough away to not cause problems with building foundations ▪ only works for low buildings		▪ Reducing Urban Heat Islands: Compendium of Strategies, Chapter 2: Trees and Vegetation (U.S. EPA, 2008)		▪ Only suitable for low-rise buildings	N/A
	Window shutters	▪ most effective on south and west facing windows ▪ may also provide security	▪ may limit ventilation through windows while closed	4.4.2		£1 - £1000 for a house (Arup, 2008)		N/A
	Awnings, brise soleil; other shading	▪ most effective on south and west facing windows ▪ provides shade while allowing light and maintaining window ventilation and view ▪ if properly designed, they can block high summer sun while allowing low winter sun to enter the building	▪ some designs will require maintenance, which can be challenging and expensive for mid- and high-rise buildings	4.1; 4.4.2; 4.4.3; 4.4.4; 4.4.11; 4.4.12; 4.4.15; 4.4.16; 4.4.17; 4.4.19; 4.4.20		£1001+ for a house (Arup, 2008)		N/A
	Reflective window blinds	▪ exterior shading is more effective than interior shading	▪ depending on window and blind design, blinds may inhibit ability to open window for ventilation	4.4.4		£1 - £1001+ for a house (Arup, 2008)		N/A
	Replace windows	▪ double or triple glazing will help reduce heat gain ▪ low-e (low emissivity) glazing	▪ will increase overheating if ventilation is inadequate (reduced heat gain from outside also means reduced heat loss from inside when trying to cool the room); thus, operable windows particularly important for ventilation	4.1; 4.4.1; 4.4.2; 4.4.6; 4.4.16		£101 - £1001+ for a house (Arup, 2008)		N/A
	Install secondary double glazing behind existing glazing	▪ can greatly reduce solar heat gain with external ventilation of outer cavity (between original window and secondary glazing) so long as the inner pane remains closed ▪ may be lower cost and more reversible than a replacement window	▪ original window must have space for secondary glazing			£1001+ for a house (Arup, 2008)		N/A
Minimize internal heat	Energy efficient lighting,	▪ also saves energy and money ▪ may be able to take advantage of existing grants		4.4.2		Energy efficiency		Will reduce energy use by

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gains	appliances	and rebates to lower cost				programs and rebates should be investigated		lighting, appliances; could lead to higher energy use for heating in winter
	Turn off equipment when not in use	▪ also saves energy and money	▪ behavioural – up to occupant to control			Free		N/A
	Insulate possible internal heat gain sources, such as hot water tanks, pipes, space heating equipment, etc.	▪ also saves energy and money, particularly in winter						Could save energy overall by making other systems operate more efficiently
Minimize solar heat gain via warming of external surfaces	Reflective paint in light colours for external surfaces of buildings	▪ increases reflectance of buildings	▪ alters appearance of building, which may impact acceptability by residents, particularly for historical buildings			£1 - £1000 for a house (Arup, 2008)		N/A
	Green (vegetated) walls	▪ provides shade for building walls and lowers temperature through evapotranspiration	▪ usually require maintenance and upkeep, which increase the cost, particularly for taller buildings ▪ alters appearance of building, which may impact acceptability by residents, particularly for historical buildings		▪ The Potential for Perennial Vines to Mitigate Summer Warming of an Urban Microclimate (Blake, 2013)		▪ Maintenance may be cost-prohibitive for mid- and high-rise buildings	N/A
	Cool roofs	▪ keeps roof temperatures lower and reduces heat gain to the building by increasing reflectance of the roof (more solar radiation is reflected when it strikes the roof) and increasing emissivity (a measure of how much of the radiation that wasn't reflected is still released from the roof)	▪ usually requires maintenance and cleaning to maintain initial performance ▪ in colder climates there is a winter heating penalty, in which more energy is used to heat the building because of the reduced heat gains from the sun through the roof; there are a number of factors that lessen the severity of the heating penalty, such that the energy savings from reduced cooling, or the increase in thermal comfort if there is no additional cooling, may be worth accepting the heating penalty (Zimmerman, 2004) ▪ calculators can be used to estimate overall energy savings, such as the DOE Cool Roof Calculator (Oak Ridge National Laboratory, Unknown)	4.4.9	▪ A Practical Guide to Cool Roofs and Cool Pavements (Global Cool Cities Alliance, R20 Regions of Climate Action, 2012) ▪ Cool Roofs and Cool Pavements Toolkit (Global Cool Cities Alliance, n.d.) ▪ Reducing Urban Heat Islands: Compendium of Strategies, Chapter 4: Cool Roofs (U.S. EPA, 2008) ▪ Adapting to Urban Heat: A Tool Kit for Local Governments, Cool Roofs Chapter (Hoverter, 2012)	US $0.00-1.50/ft^2 price premium over traditional technology (Hewitt, Mackres, & Shickman, 2014)		N/A
	Green roofs	▪ reduce heat penetration through roof by absorbing heat into their thermal mass, and through evaporation of moisture	▪ requires professional review to ensure roof structure is adequate to bear extra weight, and to determine which type is most suitable	4.4.9; 4.4.10; 4.4.18	▪ Reducing Urban Heat Islands: Compendium of Strategies, Chapter 3: Green Roofs (U.S. EPA, 2008)			N/A

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					▪ Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto (Banting, et al., 2005) ▪ Green Roofs (City of Toronto, 2014) ▪ Adapting to Urban Heat: A Tool Kit for Local Governments, Green Roofs Chapter (Hoverter, 2012)			
Thermal mass	Use of concrete, tile, stone inside the building	▪ exposed, internal high thermal mass absorbs heat gains during the day, preventing a temperature rise ▪ hollow floor slabs allow cooling of the thermal mass through ventilation within the slab	▪ important to be able to purge air when temperatures are lower outside, as the thermal mass will release the heat at night ▪ Building with concrete usually results in higher embodied CO_2 emissions than alternative materials; however, these are usually offset early in the life of building by the saved operational emissions. Research in the UK found the carbon payback period of a medium-weight typical two bedroom home to be 11 years, compared to the same home built using lightweight construction	4.4.2; 4.4.3; 4.4.12; 4.4.13; 4.4.14; 4.4.18; 4.4.19; 4.4.20	▪ Thermal Mass Explained (The Concrete Centre, 2012) ▪ Thermal Mass for Housing (The Concrete Centre, 2008) ▪ Night Flushing and Thermal Mass: Maximizing Natural Ventilation for Energy Conservation Through Architectural Features (Griffin, 2010)		▪ Concrete construction more typical for mid- and high-rise buildings	N/A
	Replace carpets with wooden floors or tiles	▪ this strategy takes advantage of the thermal mass of the ground	▪ only relevant in ground floor rooms with solid floor construction ▪ adoption may be limited by personal preferences ▪ could be uncomfortable in winter; rugs can be used during colder periods	4.1		£1001+ for a house (Arup, 2008)	▪ Limited to first floor of any building	
	Phase change thermal storage wallcoverings	▪ stores sensible heat as the temperature increase, but also stores/releases large quantities of latent heat during the phase change	▪ still in development ▪ may be feasible down the road		Development of Phase Change Thermal Storage Wallcoverings in Buildings (Ip, Miller, Corner, & Dyball, 2008)			N/A
Natural Ventilation (including cooling through night purging)	Open windows when outside temperature is lower than inside temperature	▪ automatic system can be installed to open and close windows at certain times or certain temperatures ▪ when used in combination with thermal mass, natural ventilation provides "free cooling" throughout the next day	▪ usually behavioural – up to occupant to control; knowledge barriers regarding indoor/outdoor temperatures can limit the effectiveness of this measure ▪ noise, security concerns may limit willingness to open windows, especially at night ▪ as temperatures rise and the UHI effect worsens, opportunities for adequate night purging are reduced ▪ possibility of air quality issues	4.1; 4.4.2; 4.4.3; 4.4.5; 4.4.11; 4.4.12; 4.4.19		Free		N/A
	Solar chimneys; wind cowls; turbines mounted on roof (mechanically	▪ uses stack effect and pressure differentials to encourage air movement ▪ may be possible to use elevator shaft to take advantage of stack effect to provide cooling at	▪ essentially limited to new buildings, because it is very dependent on building design	4.4.7; 4.4.16; 4.4.17; 4.4.18; 4.4.20	▪ Solar Chimney and Building Ventilation (Harris & Helwig, 2007) ▪ Ventilation Shaft to Increase Effectiveness of Natural Ventilation			N/A

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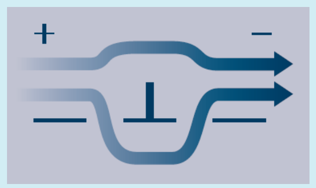
	assisted natural ventilation)	night; no documentation could be found on this, but may be worth exploring further			(Nagory, 2012)			
	Side fins on the outside of the building	▪ side fins can create a positive pressure on one side and a negative pressure on the other side, enhancing cross flow ventilation in situations where windows are along the same side of a building:  **FIGURE 2 - CROSS VENTILATION USING SIDE FIN; SOURCE: (BOROUGH OF ISLINGTON, 2012)**	▪ requires air flow along the side of the building, which can limit its applicability ▪ may also be ineffective in dense urban areas where building may be blocked from wind by other buildings ▪ may limit visibility out window					
Reduce urban heat island effect	Various measures	▪ by addressing the UHI effect, the external temperatures can be reduced, not only lowering the amount of heat that must be kept outside of buildings, but also making night time purging and natural ventilation a more viable option	▪ research in the United Kingdom considered the relative importance of the UHI effect compared to building thermal quality, and found that while location plays a part in potential to overheat, the effects of built form and other dwelling characteristics appeared to be more important determinants than the building's location within London's UHI (Oikonomou, et al., 2012); this may also be true in Vancouver		▪ Cool Policies for Cool Cities: Best Practices for Mitigating Urban Heat Islands in North American Cities (Hewitt, Mackres, & Shickman, 2014) ▪ Reducing Urban Heat Islands: Compendium of Strategies (U.S. EPA, 2008) ▪ Adapting to Urban Heat: A Tool Kit for Local Governments (Hoverter, 2012)			N/A
Air circulation	Fans; ceiling fans	▪ Ceiling fans can allow a person to tolerate temperatures approximately 2°C warmer without an impact on thermal comfort (U.S. Department of Energy, Unknown)	▪ could lead to dehydration issues (ARCC CN, 2013) ▪ noise can be an issue, though newer fans can be very quiet, and fans are usually quieter than air conditioning (Arup, 2008) ▪ it is important to turn off when not being used because fans cool people, not rooms	4.1		£1 - £1000 for a house (Arup, 2008)		
Ground source cooling	Passive or active air cooling (also known as "Provencal well")	▪ uses pipes or "earth tubes" buried in the ground to passively cool fresh air that is then supplied to the building interior ▪ also provides free pre-warming of air in winter ▪ in summer, air can be cooled from 28°C to about 17°C; in winter, air can be warmed from below zero to about 5°C (Borough of Islington, 2012) ▪ heat pumps can increase the system efficiency compared to simple heat exchangers	▪ must be designed to balance heat deposit (for cooling) and heat withdrawal (for warming) to ensure continuous operation over lifetime ▪ land in Vancouver is at a premium, which would likely make it difficult to find the space to install the piping system ▪ better suited for new builds, when excavation costs can be absorbed more readily into building costs ▪ pipes need to be designed prevent bacterial growth	4.4.7	Earth Tube Ventilation Systems – Applicability in the Canadian Climate (Canada Mortgage and Housing Corporation, 2011)		▪ In general, the more cooling that must be provided (ie. for larger or taller buildings), the more piping will be necessary,	

Cooling Strategy	Specific Measure	Considerations	Concerns/Limitations; Complexity of Installation	Associated Case Studies	Additional Resources	Cost Information (Various Sources)	Applicability to Building Height (Storeys): Low-rise ≤ 3 Mid-rise = 4-11 High-rise ≥ 12	Relative Operating Energy Use (N/A = not applicable)
			▪ air filters may be required depending on quality of intake air ▪ building must be designed to use the stack effect or wind to draw the cooled air through the building, which limits applicability for retrofits; alternative is to use fans to move the air through the building, but this uses energy				forcing a larger footprint for horizontal piping or deeper, more expensive boreholes for vertical piping	
	Liquid cooling (mechanical)	▪ liquid (such as water) is circulated through a heat exchanger to draw heat from the warm air of a building, and travels through the pipes to transfer the heat to the ground ▪ can also provide free pre-warming in winter ▪ closed loop systems recirculate the water (or other liquid), while open loop systems make use of cooling from nearby rivers, etc. ▪ heat pumps can increase the system efficiency compared to simple heat exchangers	▪ must be designed to balance heat deposit (for cooling) and heat withdrawal (for warming) to ensure continuous operation over lifetime ▪ land in Vancouver is at a premium, which would likely make it difficult to find the space to install the piping system ▪ better suited for new builds, when excavation costs can be absorbed more readily into building costs	4.4.13				▪ System consumes energy to circulate liquid through pipes and heat exchanger
Active cooling	Mixed mode ventilation/ cooling	▪ by using a passive ventilation and cooling system when possible, and mechanical cooling when necessary, a building can maintain desired temperatures in the hottest months but use less energy than a strictly mechanical system ▪ zoning designs can allow for the two systems to work in different parts of a building	▪ because of complex interactions between the two systems, it could be very difficult to retrofit into a building; better suited for design of new buildings ▪ control system is critical for this system to be successful; it must be able to monitor internal and external environments, predict how much natural and mechanical ventilation is needed, and adjust the equipment accordingly		▪ Principles of Hybrid Ventilation (Hybrid Ventilation Centre, 2002) ▪ Introduction to EC RESHYVENT-EU cluster project on demand controlled hybrid ventilation for residential buildings (Op't Veld, 2008)			
	Traditional air conditioning (A/C)	▪ uses the vapour compression refrigeration cycle to produce cooling effect, by transferring heat from the warm air to the refrigerant in the evaporator, and releasing the heat from the refrigerant in the condenser	▪ heat is dumped to outside, worsening the UHI and making it harder for neighbours without A/C to cool off ▪ installation is relatively simple for room air conditioners; central A/C installation is more complex if ductwork is not already in place		▪ Energy Saver 101: Everything You Need to Know About Home Cooling (U.S. Department of Energy, Unknown)			
	Evaporative cooling	▪ spray water into air to cool the air ▪ uses only water, not refrigerants	▪ requires more frequent maintenance ▪ only suitable in regions with low humidity					▪ Uses about ¼ of the energy of a central A/C (U.S. Department of Energy, Unknown)
	Absorption cooling	▪ uses heat to drive refrigeration cycle	▪ best suited for situations where excess heat is already present, such as in combined heat and power situations	4.4.8				

Cooling Strategy	Specific Measure	Considerations	Concerns/Limitations; Complexity of Installation	Associated Case Studies	Additional Resources	Cost Information (Various Sources)	Applicability to Building Height (Storeys): Low-rise ≤ 3 Mid-rise = 4-11 High-rise ≥ 12	Relative Operating Energy Use (N/A = not applicable)
	Desiccant cooling	▪ desiccants are either natural or synthetic substances, liquid or solid, that are capable of absorbing or adsorbing water vapour ▪ by providing dehumidification, allows for evaporative cooling in more humid climates	▪ not yet widely common		▪ Desiccant-Assisted Cooling: Fundamentals and Applications (Nobrega & Brum, 2014) ▪ Desiccant Cooling Air Conditioning: A Review (Daou, Wang, & Xia, 2006)			
	Chilled beams or ceilings	▪ require a relatively modest cooling water temperature (14-17°C) that can be attained via natural cold water storage or free cooling from outside air, as well as through mechanical cooling ▪ various designs available, including radiant and convective ceiling systems, and passive and active beam systems ▪ some systems can provide heating as well as cooling	▪ very challenging to retrofit into an existing buildings so essentially limited to new construction		▪ An Introduction to Chilled Beams and Ceilings (Chilled Beam and Ceiling Association, 2012)	Lower running costs than traditional HVAC systems (Chilled Beam and Ceiling Association, 2012)		
Thermal energy storage	Phase change materials (PCM)	▪ provides the same benefits of thermal mass, discussed above ▪ can provide free cooling throughout the day; can store "coolth" overnight by passing cool night supply air over the PCM, to be released throughout the day by passing warm supply air over the PCM	▪ important to be able to purge air when temperatures are lower outside, as phase change materials will need to release the heat in order to be effective the next day	4.4.8	▪ Review on Free Cooling of Buildings Using Phase Change Materials (Raj & Velraj, 2010)			
District cooling	Various	▪ centralized production and distribution of cooling energy via chilled water ▪ could also use lake or ocean water to provide cooling	▪ very challenging and expensive to retrofit, both in terms of connecting an existing building to the district cooling network, and to establish the distribution system for the cooling throughout the building					Climespace in Paris claims savings of 30-50% compared to a stand-alone air conditioning installation (Climespace GDF Suez, n.d.)
Mechanical ventilation	Compartmentaliz-ation with individual unit ventilation systems	▪ stack effect driven interior airflows are controlled by isolating units from each other and from corridors, shafts, elevators, and stairwells ▪ ventilation is provided to each individual unit across exterior walls instead of interior pressure boundaries ▪ allows individual unit control, as well as individual metering, which can encourage energy conservation ▪ can provide individual cooling through heat pump	▪ also addresses the issue of simultaneously over-ventilating some areas of the building and under-ventilating other areas ▪ retrofit situation involves extensive exterior wall penetrations		▪ HVAC in Multifamily Buildings (Lstiburek, 2006) ▪ Multifamily Ventilation Retrofit Strategies (Ueno, Lstiburek, & Bergey, 2012)		▪ applicable to mid- and high-rise buildings, where the stack effect is greatest	▪ reduces wasted energy that resulted from over-ventilating portions of the building, but unknown if overall energy use is reduced

4 Case Studies

As the issue of overheating in residential buildings is only recently beginning to be addressed, particularly in North America, a limited number of case studies of multi-unit residential buildings could be found. The case studies have thus been supplemented with additional case studies that illustrate alternative cooling strategies in other building types and jurisdictions as well.

4.1 Adaptation of Social Housing Apartment Buildings in London

Source: Your Social Housing in a Changing Climate (Sustainable Homes, 2013)

The renovations to the Colne and Mersea apartment buildings in the London Borough of Barking and Dagenham (LBBD) were the first large-scale test of implementing climate change adaptation measures for social housing. The project came about through an opportunity to add the adaptation measures to renovations that were already scheduled, including some through the Decent Homes program, which was established to ensure that all social housing in the UK meets a minimum standard of decency. These towers, built in the late 1960s to early 1970s for social housing, are both 17 storeys and each contain 100 apartments, most of which are social housing properties. The project used the guidelines and recommendations in the report Your Home in a Changing Climate (YHCC) (Arup, 2008) to determine the adaptation measures that were appropriate for these buildings.

It should be noted that overheating calculations and modelling for the two buildings were done using Cymap during the selection of the overheating adaptation measures. Cymap, an industry standard software package in the UK for building services design, uses steady state modelling and equations from CIBSE to analyze the effects of a building's envelope/fabric and ventilation rates to calculate an internal temperature, given an external temperature.

The project team reviewed the recommendations in the YHCC report when considering overheating adaptation measures, as well as a number of others that weren't covered in the report. These measures are listed below along with major considerations relating to the project and impacting measure selection; for a full list of considerations, the Your Social Housing in a Changing Climate (Sustainable Homes, 2013) report should be consulted.

Measures considered for the project include (☑ = implemented; ☒ = not implemented):

- ☑ **Install external shading** – The project team decided to use triple-glazed windows (that is, three panes of glass) with blinds incorporated into the third section of glazing on the south- and west-facing sides of the building, and the same windows without the internal blinds on the north- and east-facing sides of the building. This option allows operation from inside, while blocking sun's rays before they enter the unit. Awnings were considered but were not plausible because they could only be maintained from the outside, which would make maintenance costly, and extra detailing of how they were to be fixed to the existing structure would have been necessary. The triple glazing also improves the energy efficiency of the apartment building, which will save energy during the winter. The additional cost of replacing the double glazed windows with triple paned was justified by the avoided costs of ensuring the external walls were structurally sound for attaching awnings or external shutters, the saved maintenance costs of external solutions, and the energy savings from the improved efficiency.

- ☑ **Increase reflectivity on walls and roofs** – A light colour was selected for the external wall cladding system that covered the existing dark-coloured brick.
- ☑ **Improve roof insulation** – The addition of solar PV panels and a communal satellite dish were considerations in choosing a system to insulate the roof. The chosen option was an integrated warm roof from Kemper System, an international manufacturer of waterproofing and roofing membranes, consisting of insulated panels secured to the existing roof with dedicated resins and covering the panels with a layer of resin membrane. This system could still be walked on, was inert to UV degradation, and had a 30-year guarantee.
- ☑ **Install cavity insulation** – The project team chose an insulated rendering system (external cladding) because it was lightweight and easier to install compared to a rainscreen system, consisting of panels fixed to a heavy steel frame that may have necessitated reinforcement of the existing structure. The chosen system was the Wetherby Building System, consisting of rigid insulation panels fixed to panel beads that have been fixed to the outside wall. This system is then covered by a spray-on insulating, weatherproof render (a substance similar to stucco). External cladding usually reduces air permeability into buildings so ventilation was of particular concern (and was addressed as described below).
- ☑ **Install double glazing with low e-coating** – The chosen triple pane windows had double low emissivity glass.
- ☒ **Switch off unused appliances** – This measure can only be offered as advice to residents.
- ☒ **Open windows at night** – This measure can only be offered as advice to residents.
- ☒ **Use ceiling or desk fans** – Ceiling fans were not chosen because it was believed that the other overheating prevention measures would be adequate in maintaining comfortable temperatures, and residents can purchase stand-alone fans if they are needed.
- ☒ **Install secondary glazing** – This measure is unnecessary as the existing double glazed windows were replaced with triple glazed windows.

Additional measures considered for the project include:

- ☑ **Install ventilation units** – A fan driven extraction unit was installed in the bathroom of each apartment, to extract steam from the bathroom as well as heat, which helps prevent overheating.
- ☑ **Install mechanical extract fans** – The passive stack system originally considered by the project team was unsuitable because with the new door entry system to the elevators and mostly closed doors, not enough new air would reach the units. Mechanical extract fans with a background mode were selected which draw air through the trickle vents in the windows.
- ☒ **Plant trees** – This measure was considered but eliminated because the asbestos levels in the soil at the site, which used to be an asbestos factory, would be troublesome with the soil disturbance required for planting. Climbing plants were considered but eliminated because of the necessary ongoing maintenance. A raised bed was installed and vegetation planted, but overheating reduction is expected to be minimal.

In addition to the overheating adaptation measures detailed above, water scarcity was addressed with low flow kitchen and basin taps, small volume baths, new low flow showers and water meters; flood risk was addressed through flood barriers to ground floor apartments, flood resilient external wall finishes, non-return valves for soil pipes, and existing drainage refurbishment; and non-adaptive measures included new kitchens, new bathrooms, a new centralised gas heating system to replace the existing storage heaters, a new door entry system, a new elevator system, and a solar photovoltaic system. The costs of these measures, as well as the overheating measures, are summarized in Table 2.

TABLE 2 – PROJECT COSTS FOR RENOVATION OF 1960S-70S SOCIAL HOUSING APARTMENT BUILDINGS CASE STUDY (SUSTAINABLE HOMES, 2013)

	Reported Cost (2013 £)
General items (including scaffolding, design work, and survey work)	£2.71 million
Water stress measures	£0.14 million
Overheating measures	£1.90 million
Flood risk reduction	£0.03 million
All other works	£5.92 million
Total	**£10.7 million**

Splitting the cost of the renovations over the 200 units (assuming each to be the same) gives a per unit total cost of £53,500 and a per unit overheating adaptation cost of £9,500. Of note, the external cladding system was considered an overheating adaptation measure with energy efficiency as an added benefit by LBBD, even though the design engineers maintained that the energy efficiency benefits far outweighed the overheating reduction benefits. (The YHCC report maintains the same.) As such, the costs of the external cladding system are captured under Overheating Measures. Additional information on the financial costs and benefits of the project, including a net present value analysis, can be found in The Business Case: Incorporating Adaptation Measures in Retrofits (Sustainable Homes, 2014).

Lessons learned and recommendations relating to the overheating measures include (quoted directly):

- Triple glazed windows with incorporated blinds are common in other European countries and can be viably installed in the UK for retrofit projects. They should be considered for future projects.
- Value engineering is possible when using triple glazed windows with integral blinds and should be encouraged.
- Mast climber access is better than traditional scaffolding and should be considered for future projects.
- Jealousy issues can arise between residents who have extra equipment and those who do not. These must be managed carefully.
- Installing external cladding has the extra benefit of improving energy efficiency whilst at the same time helping prevent overheating. However a conscious effort must be made to ensure that ventilation devices are also installed.
- Existing walls on tower blocks are often not straight and some kind of framework is necessary when installing external cladding. It is recommended that experienced contractors are used for external cladding works.
- Many of the recommendations in YHCC are more applicable for social housing providers to provide to residents as advice, rather than as installed measures.
- Some residents complained about lack of advice; others clearly stated that advice was given. Perhaps the advice given and to whom could be more formally recorded, so that all parties are sure that advice has been effectively communicated.

- Consider installation of remote sensors when monitoring internal temperatures.

The Your Social Housing in a Changing Climate (Sustainable Homes, 2013) report also details the resident feedback and social benefits of the overall project, as well as identifying keys to success, other lessons learned, and recommendations for further renovation projects on social housing buildings. This would be valuable information at the design stage of future Cool Buildings implementation.

4.2 Simulated Adaptation of 1930s House in UK

Source: Your Home in a Changing Climate: Retrofitting Existing Homes for Climate Change Impacts (YHCC) (Arup, 2008)

London, the East and the South East of England are expected to experience the most dramatic impacts of climate change of all the areas of the UK. Research by Arup for the Three Regions Climate Change Group looked at the effects of flooding, water stress, and overheating in these areas, and possible adaptation measures for each. (Only the overheating adaptation measures are examined here.) It looked at the building stock in these areas and chose three households that represent a large portion of the building stock: a 1930s house, a 1960s flat, and a block of flats. The latter two case studies are detailed in a separate Case Study Technical Report that is no longer available online. Expected climate change impacts for the UK (related to overheating) for the time period 2071-2100 (2080s), from research into future climate scenarios coordinated by the UK Climate Impacts Programme (UKCIP), include:

- hotter summers, with the mean temperature rising by 1 to 5°C
- “extremely” warm days in summer occurring more frequently, with the maximum temperature exceeding 30°C on one in ten days during the summer under the high emissions scenario

Although the UK and Vancouver have somewhat different climates and will see different impacts due to climate change, there is still much to be learned from their experience.

The modelled 1930s house is a three-bedroom semi-detached home (more commonly known in Canada as a duplex), with a paved front yard and regular back yard, and no basement. The house was assumed to be occupied by a family of two adults and three children, with little renovation done. It was modelled with partial daytime occupation and full weekend and evening occupation. Construction consists of cavity walls (consisting of a cavity between an outer layer of usually brick and an inner layer of brick or concrete block), single glazing, and minimal insulation. The adaptation measures chosen to address flooding, water stress, and overheating are ones that could be applied to a range of homes but the report stressed that without specific knowledge of the individual property, adaptation measures are impossible to specify. This case study report focuses only on the adaptation measures to address overheating, which can be seen in Table 3 below.

Table 3 – Overheating adaptation measures for case study 1930s home (Arup, 2008)

Measure	Reported Cost (2008 £)
Measures which aid overheating only	
• External solar control: awnings on all south/west windows	£1,700
• Natural ventilation through windows	No cost for existing windows
• Enhance air movement: ceiling fans (DIY installation)	£545

• Floor coverings: replace carpets with wooden floor or tiles on ground floor	£2,100
• Façade upgrade: paint walls to increase reflectivity	£3,750
Total cost of measures for overheating only	**£8,095**
Additional cost of winter insulation measures	
• Roof: improve roof insulation standard	£2,200
• Façade upgrade: cavity insulation where cavities are present	£1,100
• Fenestration upgrade: replace single glazing with double glazing, with low-e coatings	£5,000
Grand Total	**£16,395**

The study noted that although the total costs appear high, the first three items on the list had a substantial effect and are relatively low cost. The remaining measures, at a higher cost, are well suited to incorporate into planned renovations, upgrades, and maintenance of the home. The single most effective measure was found to be increasing ventilation rates, particularly when it is cooler at night.

The Chartered Institute of Building Services Engineers (CIBSE) Guide A (2006) classifies overheating in dwellings as an exceedance of 28°C for one percent of occupied hours in living areas, and an exceedance of 26°C for one per cent of occupied hours in bedrooms. It also defines an upper limit on comfort temperatures of 25°C in living areas and 23°C in sleeping areas. Figure 3 and Figure 4 illustrate the significant drop in overheating (the red bars in each of the figures) from the unadapted to the unadapted house, for July of both 1989 and projected 2050. With the adaptation measures outlined above, in the 2050s, the overheating temperature was exceeded for just over 2% of occupied hours in the living room, and for just over 1% of occupied hours in the bedroom. There is also a significant drop in the number of hours that the comfort temperature is exceeded (the orange bars in each of the figures).

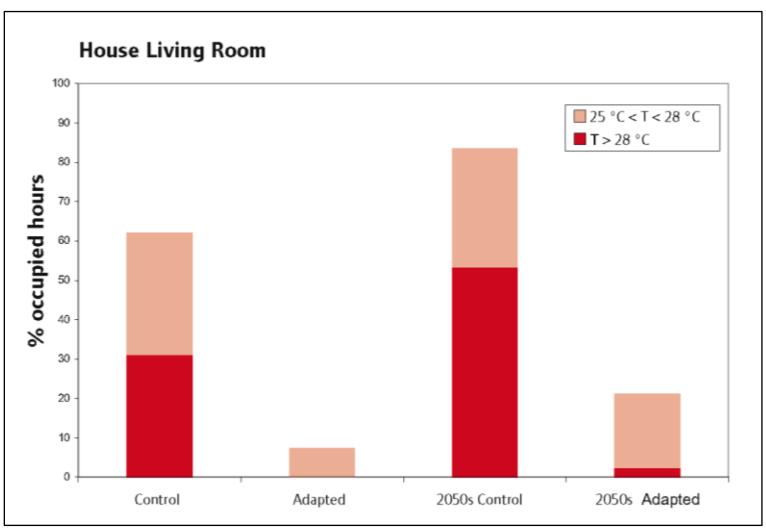


FIGURE 3 – TEMPERATURES IN THE LIVING ROOM OF THE UNADAPTED AND ADAPTED HOUSE FOR JULY 1989 AND 2050. FROM (ARUP, 2008).

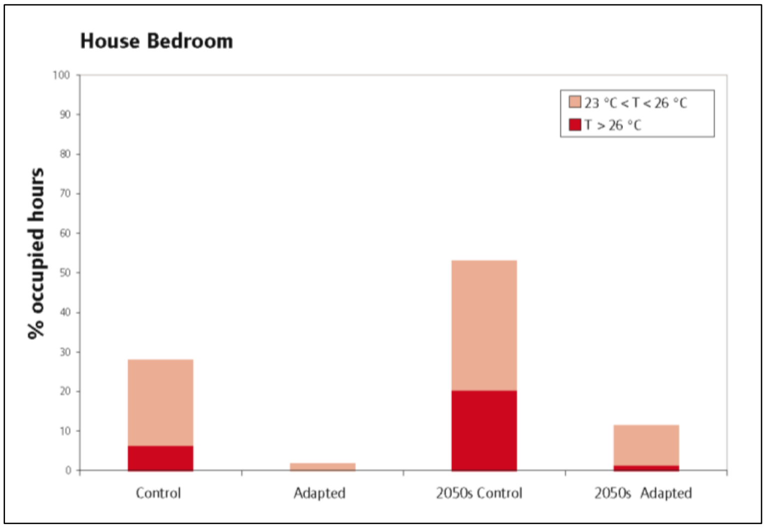


FIGURE 4 - TEMPERATURES IN THE BEDROOM OF THE UNADAPTED AND ADAPTED HOUSE FOR JULY 1989 AND 2050. FROM (ARUP, 2008).

The cooling degree hours for the month of July were also determined for the unadapted and the adapted homes, as shown in Figure 5 and Figure 6, as the number of degrees by which the comfort temperature is exceeded for each hour the house is occupied. These figures also show the amount of energy needed to run an air conditioner to achieve cooling to the thermal comfort temperature in the unadapted homes. It is clear that a significant savings in energy can be had through the installation of these non-energy intensive adaptation measures.

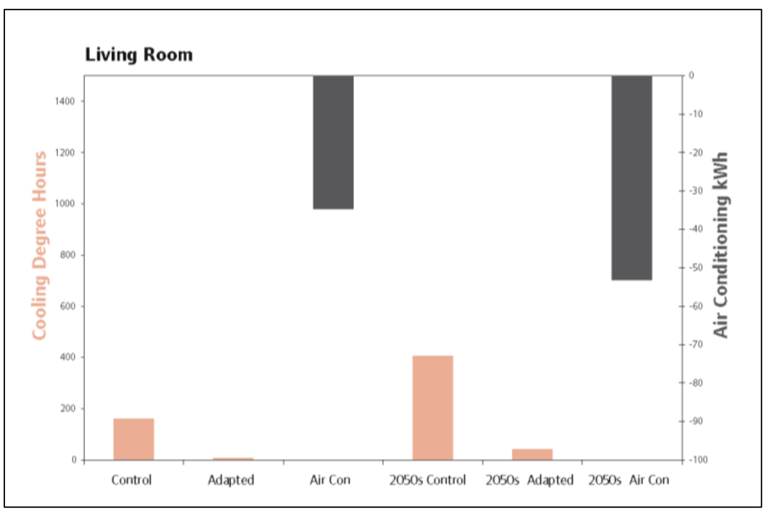


FIGURE 5 – COOLING DEGREE HOURS IN THE LIVING ROOM FOR THE MONTH OF JULY. THE RIGHT HAND AXES SHOW THE TOTAL POWER CONSUMPTION OF AN AIR CONDITIONING SYSTEM (IN KWH) USED TO CONTROL OVERHEATING IN THE UNADAPTED HOME. FROM (ARUP, 2008).

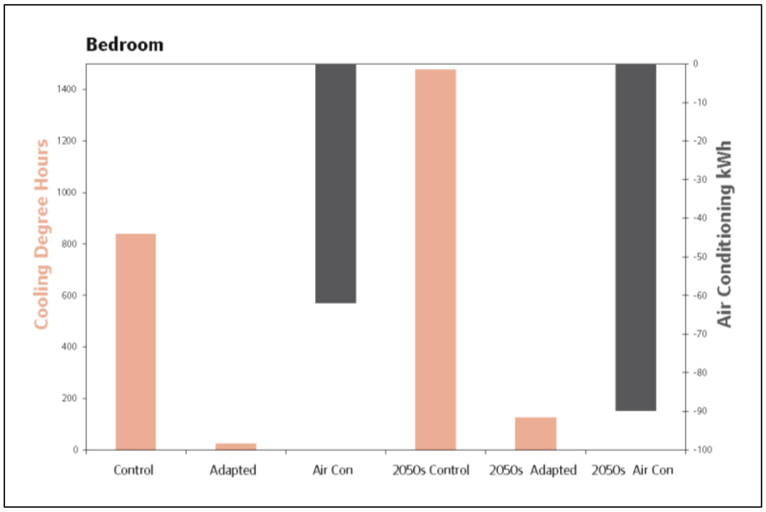


Figure 6 - Cooling degree hours in the bedroom for the month of July. The right hand axes show the total power consumption of an air conditioning system (in kWh) used to control overheating in the unadapted home. From (Arup, 2008).

4.3 Room Acclimatisation with Plants: Biohof Achleitner, Eferding, Austria

Sources: Adaptation Inspiration Book, 22 Implemented Cases of Local Climate Change Adaptation to Inspire European Citizens (CIRCLE-2, 2013); Coolregion, WP 3 - D19 (ESV, Upper Austria) Best practice example No. 2 (Intelligent Energy Europe, unknown)

The Biohof Achleitner in Eferding, Austria is a 2 storey, ~3370 m^2 building containing office space, a restaurant area, a supermarket, and food storage and processing areas. Cooling is primarily accomplished passively through transpiration from the plants that are located throughout the building, as seen in Figure 7. The plants use heat from the surrounding environment to evaporate water through their leaves, providing cooling to the building. When this passive cooling is insufficient, it is supplemented by an in floor cooling system using a ground water heat pump. Monitoring and testing of conditions in the Biohof have shown that the plants contribute 2.3-16.2 W/m^2 of cooling, which translates to a 2°C reduction in temperature during the summer. The plants also help to control the humidity levels in the building; when 5-10% of the total indoor space is allocated to plants, they are capable of increasing the humidity inside 10-15%. At the Biohof, humidity during the winter usually does not fall below 35% and in the summer usually does not rise above 60%.

In order to allow adequate sun light for the plants, the roof and west side of the foyer have double glazed windows, while the rest of the windows in the building are triple glazed, passive building quality. Aluminum or textile sun protectors (depending on the orientation) shadow the rooms if the solar radiation is greater than 150 W/m^2. The plants that are located more than four metres from the building façade require additional sources of light, provided by supplemental UV lights installed in the building, two thirds of which can be switched off again after a short while.

The associated costs of installing the plants were estimated at €20-40/m^2. Employees at Biohof Achleitner are responsible for maintenance tasks like water and trimming, which take approximately four hours per week.

Additional information on the project, including concepts, methods, data, project planning and results, and monitoring by the Danube University Krems, is available in the report Neubau Biohof Achleitner, Gebäude aus Holz, Stroh & Lehm, Raumckimatisierung met Hilfe von Pflanzen (Preisack, Holzer, & Rodleitner, 2008); however, only the Abstract is presented in English within the report, so translation would be necessary.

Figure 7 – Plants, used for air conditioning, in the Biohof Achleitner; Photos: ©EBP GmbH

4.4 Additional Case Studies

The following case studies present good examples of some of the alternative strategies and measures outlined in

Alternative Strategies and Evaluation. Due to time constraints, a detailed summary of these case studies could not be completed; however, the main strategies or measures employed in each of the case studies is identified here, along with the case study source if the reader would like more information.

Table 4 - Additional Case Studies, Various Sources

Title	Building, Location	Highlighted Strategies or Measures	Source
4.4.1 – One Wall Centre	One Wall Centre, Vancouver	▪ replacement of failed insulated glazing units	One Wall Centre (RDH, 2013)
4.4.2 – Church View	Church View, Doncaster, UK	▪ essentially all passive measures considered and modelled	TM55 Design for Future Climate – Case Studies (CIBSE, 2014)
4.4.3 – ExtraCare4Exeter	Extra Care Facility, Exeter, UK	▪ thermal mass ▪ ventilation (single-sided compared to cross-ventilation) ▪ shading ▪ intelligent window control ▪ insulation	
4.4.4 – Passive features at Millennium Water	Southeast False Creek Olympic Village, Vancouver	▪ operable blinds on exterior of buildings ▪ fixed and movable shades ▪ balconies extended to improve shading below	Passive Features at Millennium Water (The Challenge Series, 2009)
4.4.5 – Night purge natural ventilation system for Birmingham University	Metallurgy and Materials Building, Birmingham University, Birmingham, UK	▪ fully automated natural ventilation system, based on room temperature and CO2 sensors and data from a nearby weather station ▪ manual override options ▪ system responds to wind direction, for effective ventilation, and wind speed, for safety	Case Study: Night Purge Natural Ventilation System for Birmingham University (SE Controls, Unknown)
4.4.6 – Benny Farm redevelopment	Benny Farm, Montreal, Quebec	▪ external building envelope upgrades and insulation, with removal and reinstallation of existing brick cladding ▪ rigid roof insulation ▪ heat recovery ventilation system ▪ replacement of windows and entry doors with more energy efficient options	Innovative Buildings: Benny Farm Redevelopment, Montreal (Canada Mortgage and Housing Corporation, 2006)
4.4.7 – Station Pointe Greens	Station Point Greens, Edmonton, Alberta	▪ earth ducts ▪ solar stack	Final Report Equilibrium Communities Initiative (The Communitas Group Ltd., 2012); Station Pointe Greens –

Title	Building, Location	Highlighted Strategies or Measures	Source
			The Journey to Net Zero Affordable Housing (Hancock & Scott, 2013)
4.4.8 – Soccer Special	Qatar Showcase Soccer Stadium, Qatar	▪ solar powered absorption chiller ▪ phase change thermal storage	Soccer Special (Pearson, 2011)
4.4.9 – Eco-Roof Case Studies	Various, Toronto, Ontario	▪ green roofs ▪ cool roofs	Resources, Live Green Toronto (City of Toronto, 2013)
4.4.10 – Waterfall Building green roof	Waterfall Building, Vancouver	▪ green roof system	Innovative Buildings: Waterfall Building Green Roof Case Study (Canada Mortgage and Housing Corporation, 2002)
4.4.11 – City centre office building maximising potential for natural ventilation	Plantation Place, London, UK	▪ mixed mode ventilation (air conditioning and natural ventilation) in one part of building; full natural ventilation in another ▪ masonry "fins" to reduce solar heat gain ▪ double skin façade	Adapting to climate change: a case study companion to the checklist for development (Three Regions Climate Change Group, 2007)
4.4.12 – Site layout reduces solar gain and improves natural ventilation	Wessex Water Operations Centre, Bath, UK	▪ natural ventilation ▪ passive cooling ▪ exposed structure provides thermal mass ▪ solar shading ▪ room layout within building	
4.4.13 – Thermal mass used in office building to improve thermal comfort	Portcullis House, London, UK	▪ exposed concrete slab provides thermal mass ▪ ground water as cooling source ▪ room layout within building	
4.4.14 – Mechanically assisted passive cooling	Elizabeth Fry Building, Norwich, UK	▪ thermal mass ▪ hollow core slab provides ventilation ducting and, thus, pre-heating and pre-cooling ▪ no mechanical cooling	
4.4.15 – Shading a commercial building envelope	Chiswick Park, London, UK	▪ external aluminum louvres ▪ retractable external fabric blinds, activated by light sensors ▪ awning shading on certain facades	
4.4.16 – Office building with solar protection and rainwater	Red Kite House, Oxfordshire, UK	▪ natural ventilation ▪ main façade curved to improve ventilation ▪ solar control glass	

Title	Building, Location	Highlighted Strategies or Measures	Source
collection		▪ external shading ▪ roof mounted turbines draw air into top floor of building	
4.4.17 – Façade of office building assists in ventilation and solar shading	BRE Environmental Building, Watford, UK	▪ solar chimneys on south façade, connected to inside of building at each floor, increase natural ventilation ▪ motorised translucent louvers	
4.4.18 – Residential development with air-tight envelope and passive solar heating	Beddington Zero Energy Development, London, UK	▪ large areas of exposed thermal mass ▪ passive ventilation system, through wind cowls on roof that combine inlet and outlet ducts, and turn with wind direction ▪ green roofs	
4.4.19 – Passive cooling techniques for small office building	National Energy Centre Phase 1, Milton Keynes, UK	▪ thermal mass ▪ external shading ▪ natural ventilation	
4.4.20 – External shading and advanced passive cooling maintain comfortable conditions	Arup Campus Office Building, Solihull, UK	▪ naturally ventilated floor slabs ▪ exposed thermal mass in floor slabs ▪ specially designed vents above floor slabs open and close to ventilate and cool floor slabs ▪ wind driven stack ventilation pods on roofs of pavilions and operable windows to increase natural ventilation ▪ solar shading	

5 Recommendations

5.1 General Approach, and Specific Strategies and Measures

Based on the literature and case studies that have been found, the recommended overall approach for Vancouver is to follow the cooling hierarchy outlined by the City of London, and focus on the prevention of overheating as its primary approach. The cooling hierarchy (City of London, 2011) is:

1. Minimize internal heat generation through energy efficient design
2. Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls
3. Manage the heat within the building through exposed internal thermal mass and high ceilings
4. Passive ventilation
5. Mechanical ventilation
6. Active cooling systems (ensuring they are the lowest carbon options)

Though available measures are somewhat limited when considering the retro-fit of existing building stock (as compared to the design options available for a new development), it has been found that there are affordable measures that can address overheating without turning to active cooling systems. As stated earlier, research in the UK into ways to address overheating in existing dwellings has shown that passive measures exist that can prevent overheating: “Passive measures can greatly reduce mechanical cooling needs. For homes in London, they have been shown to work well into the 2080s. For London’s offices and schools, it is likely they will need to be supplemented by mechanical cooling from the 2050s onwards.” (Hacker, Belcher, & Connell, 2005).

While there are differences between the climate in the UK and in Vancouver, they are relatively similar, and passive measures are expected to be adequate in Vancouver as well. Although a precise comparison of future cooling degree days (CDD) cannot be made between the two cities from available data, a rough comparison can be made. Figure 8 shows a comparison of CDD over the last three years, determined from a base temperature of 22°C. While cooling degree days in Vancouver are expected to at least double by the 2050s and could increase by as much as a factor of 10 by the 2080s (City of Vancouver, 2012), this is still less than the projected CDD for London in the 2050s and 2080s, which are shown in Figure 9. (22°C is the base temperature used for Figure 9, and hence was chosen for the present day comparison.)

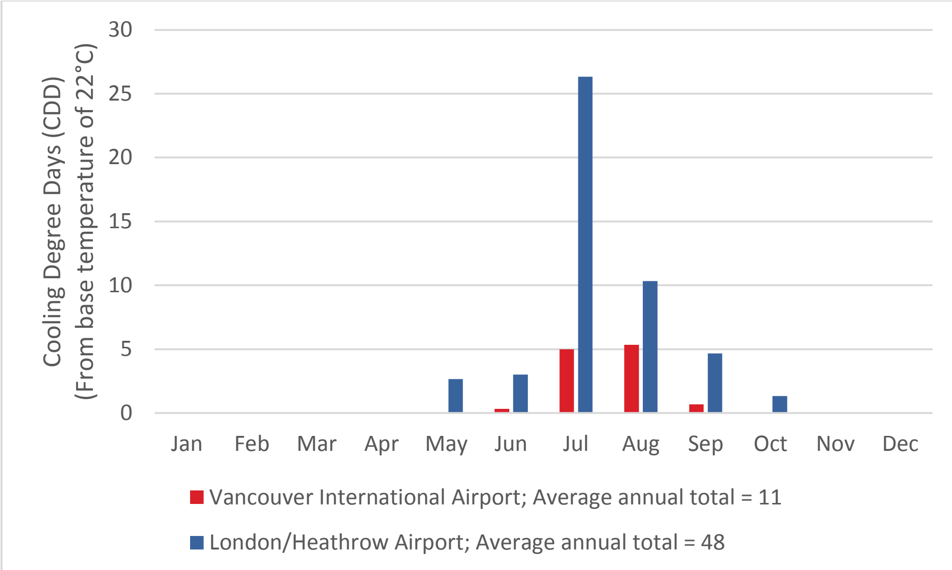


Figure 8 - Comparison of Cooling Degree Days in Vancouver and London From August 2011 to July 2014; Data From www.degreedays.net (BizEE Software Limited, 2014)

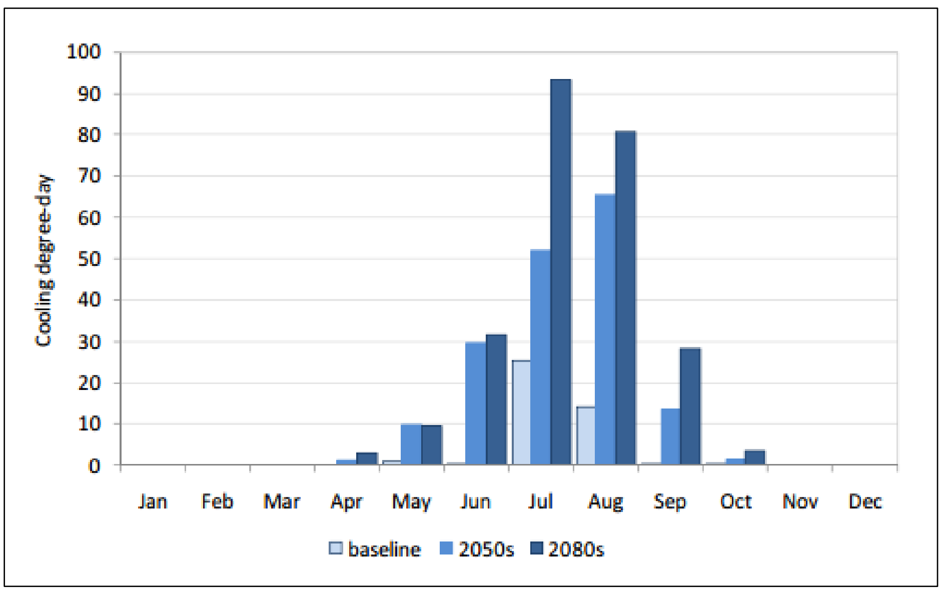


Figure 9 - Baseline and projected 2050s and 2080s cooling degree days (CDD) in London; From (Lim, Cripps, & Elder, 2011)

Another reason for passive adaptation measures to be the primary approach is the growing issue of passive survivability, which describes “a building’s ability to maintain critical life-support conditions if services such as power, heating fuel, or water are lost” (BuildingGreen, Inc., 2006). When considering measures to adapt a building to protect a population from overheating, particularly vulnerable populations as is the case with the Extreme Heat projects, passive survivability should be a serious design criterion. Heat waves often put a strain on an area’s electrical grid because of the increased demand by air conditioners, which can lead to power outages. Loss of electricity during a heat wave leading to failure of an active cooling system, in a building known to house populations particularly vulnerable to overheating, would likely be fatal. Additional emergency measures would need to be in place to deal with such a situation, putting additional strain on resources already stretched to deal with other impacts of the power outage. Passive measures to prevent overheating are inherently stronger in terms of passive survivability, which should be seriously considered when looking at building retro-fits to protect vulnerable populations.

In terms of recommendations about specific measures, unfortunately at this point generalizations cannot be made about any particular measures that will work best for certain buildings, even for a given building height or construction type. Given Vancouver's high use of glazing in buildings, measures associated with windows are likely to be effective. Properly designed awnings, deciduous shade trees, and external, operable blinds and shutters allow a building to maximize solar heat gain during the winter, which is desirable given the dominant heating load of the Vancouver climate, while minimizing solar heat gain through windows in summer. Of particular note are the triple glazed windows with internal blinds that were used in Case Study 4.1; these prevent solar heat gain from entering the unit, but do not have the maintenance concerns of shutters or awnings. Triple glazed windows not only keep the heat out in summer, but also keep the heat in during winter; however, an important co-strategy to remember when increasing the air tightness and energy efficiency of a building is ventilation. Operable windows should be used wherever possible, and should be designed to maximize natural ventilation, while vertical fins should be considered to improve ventilation in units with windows on only one side of the building. It should be noted that specific building and site characteristics, such as building orientation, age, construction, and condition, will influence what measures are appropriate. As such, it is recommended that the cooling hierarchy be followed for each building under consideration.

Additionally, it is recommended that building simulations and thermal modeling of the possible measures be completed to evaluate the effectiveness of each, so that the chosen suite of measures adequately addresses the issue of overheating without wasting money on excess measures; however, this will also require the establishment of future weather data for Vancouver based on climate change modelling. (Porritt et al. discuss a number of alternatives to using future weather data (2013).) This is consistent with the recommendation of the Your Social Housing in a Changing Climate report, that the risks of overheating be assessed, and solutions modelled, when major works are planned (Sustainable Homes, 2013).

In the case that passive measures are found to be inadequate to adapt to future rising temperatures, there are still options within the active cooling suite of measures that can help to minimize energy use and associated emissions. In some situations air conditioning may be considered necessary for individual suites, such as in apartments or care facilities where occupants may have limited mobility or other reasons for inability to seek refuge in cool areas, or air conditioning may be chosen to provide a "cool room" for all residents to use, as was done in Toronto Public Health's "Cool Room" Project (Toronto Public Health, 2011). In a study for The New York City Housing Authority (NYCHA), it was found that the NYCHA could recoup the costs of replacing existing air conditioner units with new energy efficiency units, well within the unit's lifetime, after which was a net savings (Fiedler, et al., 2009). In addition to the higher efficiencies, by choosing units with demand management features, such as thermostats and timers, the daily usage could be lowered. While the potential for savings by replacing existing units may be limited in Vancouver, given the current low adoption rates, this demonstrates the potential and importance of ensuring that efficient models with appropriate feature are chosen when air conditioning is the only option.

Besides individual unit air conditioners, most active cooling systems are very difficult to retrofit into a building if allowances have not been made for future implementation during the initial building design. This highlights the importance of following the cooling hierarchy and exploring all passive measures to prevent overheating before turning to active cooling. As with the passive measures, unfortunately there is no clear winner that is best suited for certain buildings; there are a large number of factors that must be considered. Whatever method is chosen, it will be important to try to prevent excessive cooling that happens simply because residents now have access to cooling, beyond what is needed. Individual control and metering will help to encourage conservation.

5.2 Additional Research Needs and Considerations for Implementation

In the course of the research, a number of additional considerations, beyond the technical alternatives to air conditioning that were reviewed, were identified for consideration in potential implementation of the alternatives in future phases of the Cool Buildings project.

Establish future weather data for Vancouver – By establishing future weather data for Vancouver based on climate change projections, the overheating risk of existing buildings and the effectiveness of various adaptation measures can be evaluated. Equally important, however, is the use of the future weather data in the design of new buildings. Concern has been expressed in the UK about newer lightweight, air-tight buildings with single sided apartment units being prone to overheating (Dengel & Swainson, 2012), and similar concern has been expressed that climate change mitigation policies are leading to an inability to adapt to the rising temperatures of climate change (Procter, 2011). By establishing future weather data to be used in future building design, Vancouver can ensure that its new buildings will be prepared to deal with the rising temperatures and increasing frequency of extreme heat events, without the hassle and expense of retrofitting the buildings down the road, as is now being done for existing buildings. In cases where passive measures to prevent overheating are adequate in the shorter term but active cooling is known to be necessary in the long term, design decisions can be made now to better enable implementation of active cooling down the road, minimizing future construction and costs. As mentioned earlier, Porritt et al. discuss a number of alternatives to using future weather data when that is not a viable option (2013).

Review Vancouver's building stock, establish representative buildings, and evaluate overheating risk – As part of future implementation, it is suggested that Vancouver's existing building stock be examined to establish a number of representative typical multi-unit residential buildings, as was done during studies in the UK. These buildings can then be subjected to future weather data for Vancouver to establish the risk of overheating, and to evaluate the possible measures. Knowing what building types are more subject to overheating will assist the City of Vancouver in targeting buildings for retrofits, as well as helping allow for more specific recommendations for these typical buildings that can be used down the road. A study in London found that building characteristics were more important than UHI in determining risk of overheating (Oikonomou, et al., 2012); while this cannot be generalized to the Vancouver context, it highlights the importance of considering building characteristics in an attempt to address overheating. Occupancy profiles should also be considered in the simulations, as the variation in internal heat gains from occupancy can affect risk of overheating. Lastly, as mentioned above, research in the UK has highlighted concerns about air-tight, lightweight construction that has become the norm being prone to overheating (AECOM, 2012); it may be worth investigating this concern in the Vancouver context through one of the chosen representative buildings.

Consider overheating adaptation at the same time as other adaptation strategies – In many of the reports from the UK on adaptation to climate change to prevent overheating, adaptation to address the climate change impacts of flooding and water stress (shortages) were also considered. Flooding and water supply shortages were identified as climate change impacts in Vancouver in the Climate Change Adaptation Strategy (City of Vancouver, 2012), and progress has already been made in adaptation to reduce the risk and impacts of flooding (City of Vancouver, 2014). Where possible, adaptation for a building should consider multiple climate change impacts.

Schedule Cool Buildings renovations to coincide with other planned renovations – This approach can greatly increase the cost-effectiveness of the adaptation options by sharing certain costs with the other work. It was used in Case Study 4.1, Adaptation of Social Housing Apartment Buildings in London, where the adaptation work was completed at the same time as renovations required to upgrade the buildings to meet minimum standards for social housing. Other possible triggers for work in the Vancouver context that adaptation works could be scheduled with include energy efficiency retrofits and seismic upgrades, or retrofits through the BC Sustainable Energy Association’s RetrofitBC program (BC Sustainable Energy Association, 2014). In choosing a building for the pilot program, it is worth investigating if any of the possible choices have major renovations scheduled in the near term. In addition to cost savings, this approach can also increase acceptance by residents who must endure the noise and interruptions associated with construction, as was the case in the Social Housing case study.

Partner with RDH or similar consultant to provide adaptation information with depreciation reports (Interviewee suggestion) – It was suggested by an interviewee that the City of Vancouver could team up with RDH to establish a system whereby the consultant includes adaptation measures for future consideration within the depreciation reports (reserve studies) that they prepare for stratas. As of December 2013, depreciation reports are mandatory for all strata corporations (with a few small exceptions) and must be updated every three years (Real Estate Board of Greater Vancouver, 2014). It was suggested that if the adaptation measures information system could be integrated into this requirement soon, it might be viewed as a natural evolution of the amendment instead of a new headache for stratas.

Plan for collection of empirical data, ideally pre- and post-retrofit – Much research has been done in terms of modelling and simulation, but these often make assumptions like perfect control, certain behavioural adaptations, etc. Empirical data will allow evaluation of pilot project and of the modelling/simulation used to select the adaptation measures. For guidance, Mirzaei et al. collected measurements to monitor indoor thermal conditions in 55 buildings from areas in Montreal most vulnerable to the UHI effect (2012). This data can also be used to develop tools to predict indoor thermal conditions under the UHI effect (Mirzaei, et al., 2012) (Ashtiani, Mirzaei, & Haghighat, 2014).

Review the Your Social Housing in a Changing Climate (Sustainable Homes, 2013) **report in detail –** In addition to lessons on the technical side of things, the case study also details feedback from residents on the project and the social benefits of the overall project, as well as identifying keys to success, other lessons learnt, and recommendations for further renovation projects on social housing buildings. Depending on the building chosen and the details of the chosen pilot project, this information could be very useful in helping the project run more smoothly and in gaining greater acceptance of the renovations by the residents.

Consider other, non-technical approaches – While this report has focused on adaptation in the built environment for preventing overheating, there are a number of other angles that can support Vancouver's efforts. Planning and response for extreme heat events, such as issuing advisories and warnings, information on and free transit to cool public locations, ways to keep healthy, and emergency contact information, can be critical in reducing heat related mortality and illness. A registry of self-identified vulnerable individuals that are contacted regularly via phone during extreme heat waves to ensure their health and safety, as is done in Paris (Mairie de Paris, 2007), can also reduce illness and mortality. Though it wasn't examined here, occupant behaviour can have a large impact on the success of the implemented strategy or technology. This behavioural component can sometimes be removed from the equation by automation or controls, but ultimately occupant knowledge must be there. There can also be a social aspect to the solution, as was the case in Toronto Public Health's "Cool Room" Project in 2010 (Toronto Public Health, 2011), in which one room in the building was chosen as a "cool room" and was air-conditioned and used by all tenants.

6 CONCLUSIONS

Increasing overheating of buildings due to the rising temperatures and increased frequency of extreme heat events due to climate change is a serious problem faced by many, particularly with regards to populations that are already vulnerable to the health dangers of overheating such as the elderly or those with chronic health problems. While traditional air conditioning is an effective solution for cooling, there are serious implications for the rise in energy demand and associated emissions that would result from widespread adoption of air conditioning. In addition to reviewing alternative strategies for addressing overheating, this research found that a common approach to this issue was to follow a cooling hierarchy, similar to that outlined in London's framework for the development of London to 2031, The London Plan (City of London, 2011):

1. Minimize internal heat generation through energy efficient design
2. Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls
3. Manage the heat within the building through exposed internal thermal mass and high ceilings
4. Passive ventilation
5. Mechanical ventilation
6. Active cooling systems (ensuring they are the lowest carbon options)

This cooling hierarchy reflects the recommended approach for the City of Vancouver in addressing its concerns about overheating in buildings. Research in the UK found that passive measures to prevent overheating are often adequate (Hacker, Belcher, & Connell, 2005) (CIBSE, 2010), and as Vancouver has lower cooling demands than the UK, it is expected that passive measures will also be able to prevent overheating in Vancouver. As has been done in most research, thermal modelling and building simulation is recommended for evaluating the effectiveness of possible adaptation measures. In addition to this, there are a number of additional points to consider going into future stages of implementation, including non-technical approaches to addressing overheating, such as a registry of self-identified vulnerable individuals, and improving occupant knowledge. Adaptation of the built environment, as was explored in detail in this report, coupled with these strategies, will allow Vancouver to achieve its simultaneous goals of protecting vulnerable populations from overheating, as well as minimizing energy use and emissions from buildings.

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