Innovation Incubator Report

RESILIENT FUTURE

A design charge for performance design in an era of extreme weather conditions based on an energy simulation of the future

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Perkins&Will

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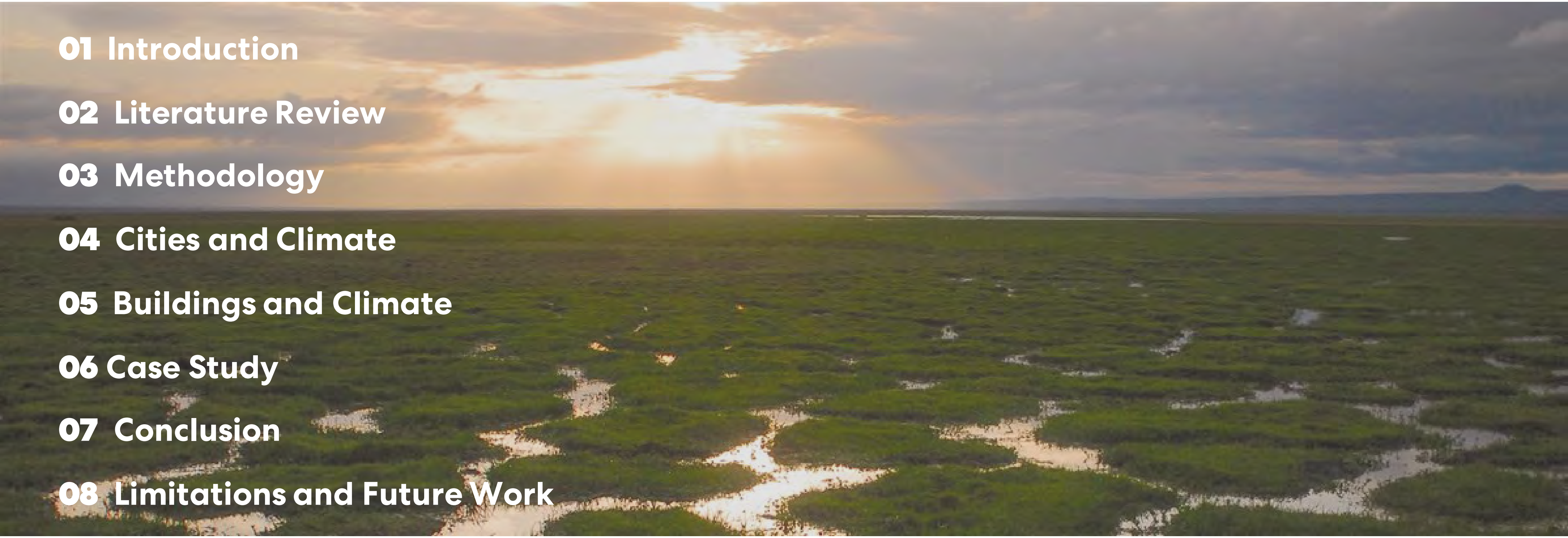
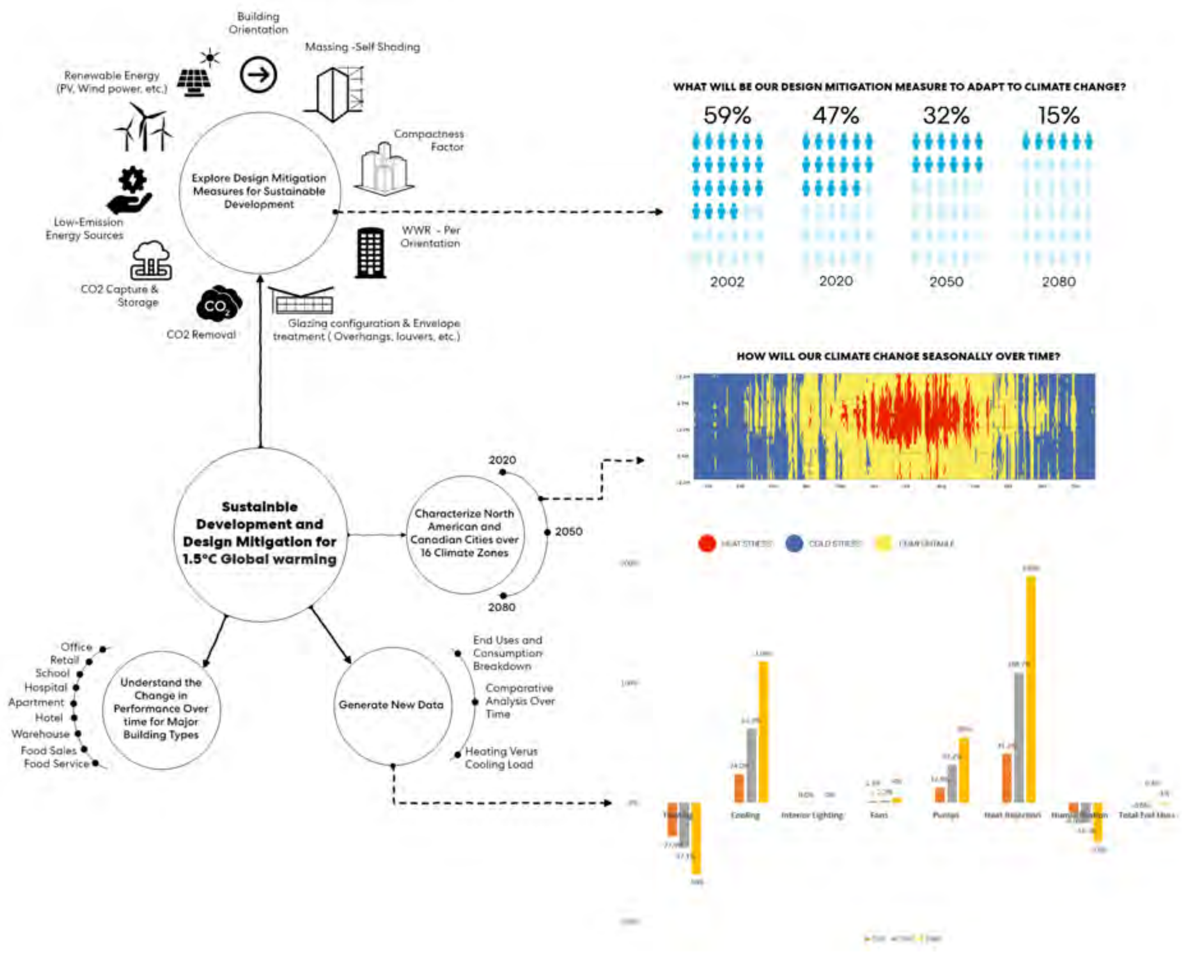


01 Introduction

A Future of Building-Based Design Climate Simulation

- Current energy modeling weather files are unlikely to include any indication of risk from potential climate change or increasing intensity and frequency of extreme weather events.

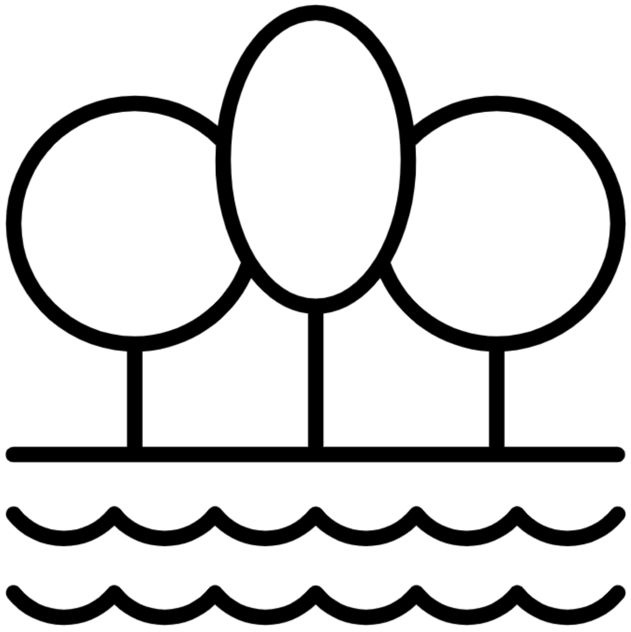
- There is a need to incorporate climate change projections in energy simulations and prepare architects for a better understanding of the change of design strategies echoing such climate change in the different climate zones.



Infographic by Tyrone, Cheney, and Mohammed

A Future of Building-Based Design Climate Simulation

- The research proposes:
  - Generate representative morphed weather file for many locations and climate zones using Energy
  - Develop an energy simulation database in the context of commercial reference building models and echo projected climate change impacts within the selected North American locations.
  - Connect the energy simulation database with proposed innovations in design protocols that promote resilience design strategies.



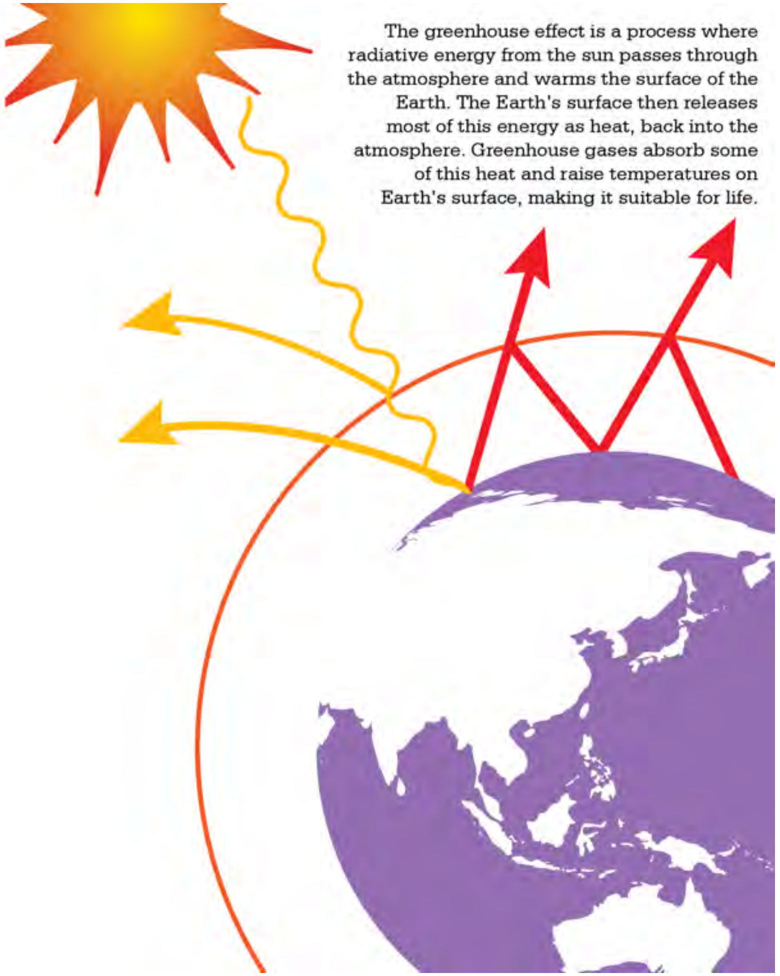
Why We Should Care?

Changes in the climate can have an impact on how we consider designing the character of exterior spaces and interior spaces.

Climate Indicator	Related Performance Design Indicator	Design Impact
More Frequent Record Warm Temperatures	Pedestrian Exterior Thermal Comfort	Exterior Space Programming
	Higher Outside Air Temperatures	Less Interior Thermal Comfort Cooling

The Problem

The earth has an organic process that works through the atmosphere that allows some shortwave solar radiation in and then re-radiates long wave radiation back into space. Our contribution to weakening the ability of our world to re-radiate long wave radiation back into space is the primary cause of rising sea levels, extreme weather events, degradation of natural resources. We understand the importance of designing and constructing buildings that diminish greenhouse gases because these supports the greater good in providing health, safety, and welfare.



Infographic by Climate Council (Australia)

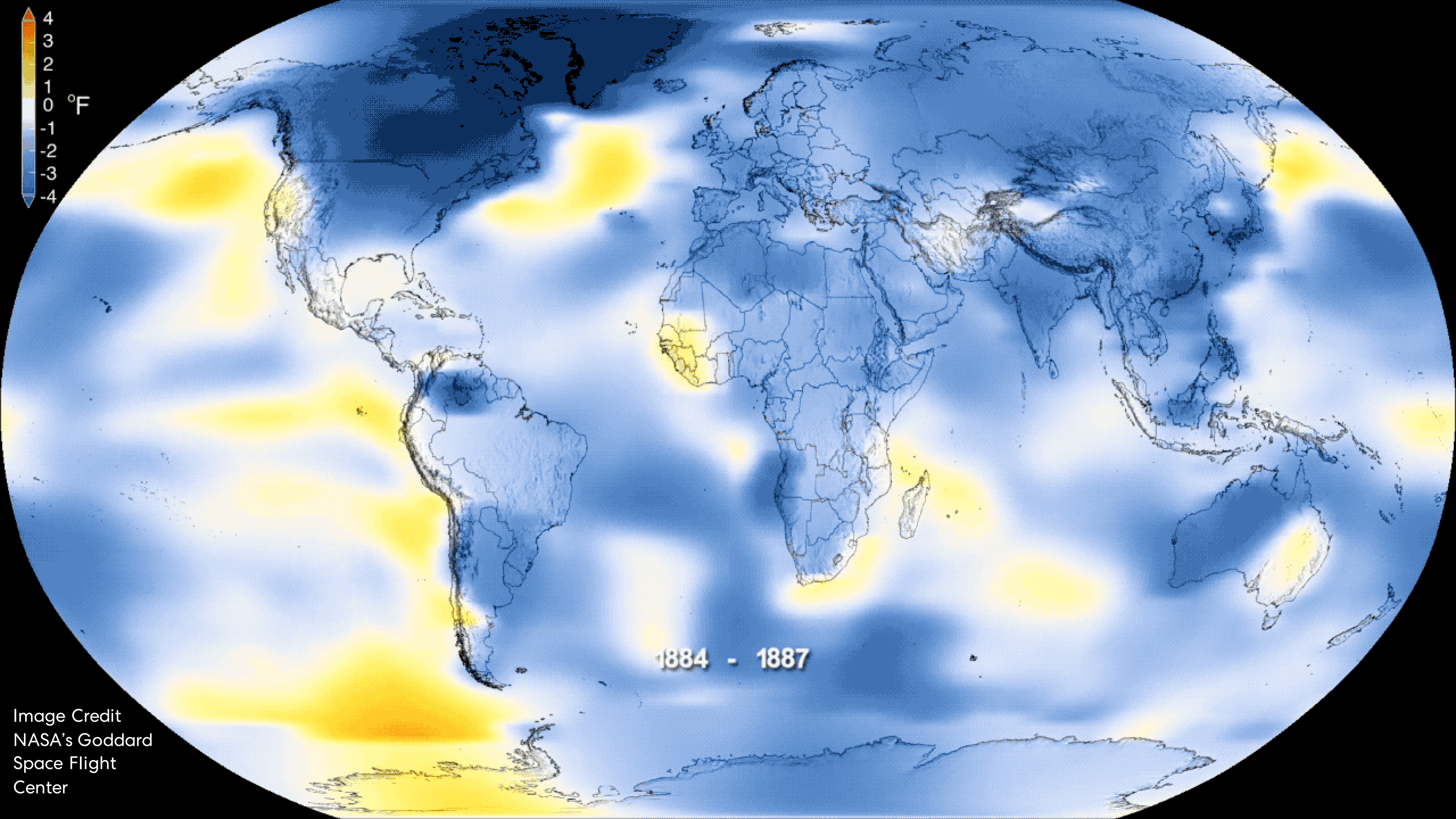


Image Credit
NASA's Goddard
Space Flight
Center

02 Literature Review

AIA

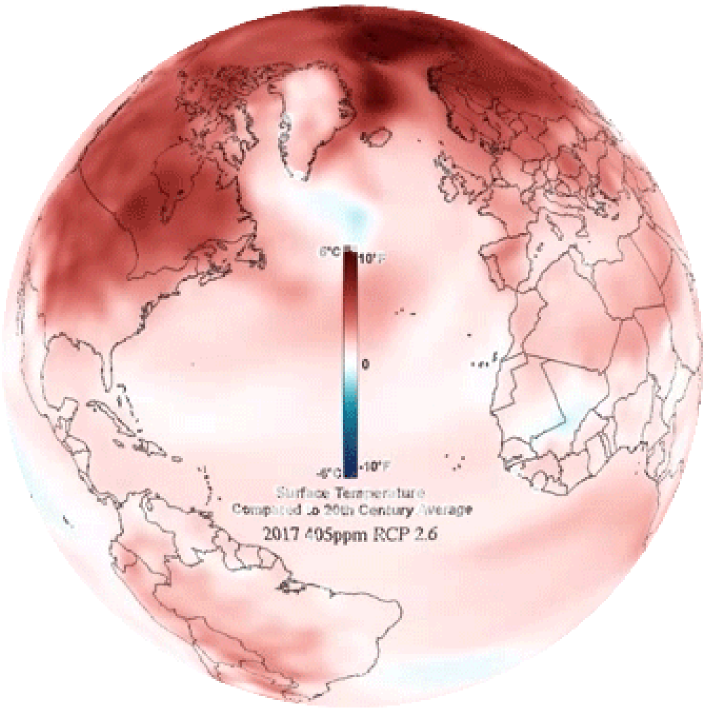
The American Institute of Architects (AIA) calls for an unrelenting commitment to sustainable and resilient design from there “Where We Stand Climate Change” website (Weblink). Our design work at least in the United States contributes just slightly below 40 percent of greenhouse gases in the carbon dioxide emissions from the construction process and in the production of electricity that we require for occupant comfort to heat, cool, and light our spaces (Weblink).

- Activate its Members to Advocate Resilient Design and Actions that Curtail Buildings’ Harmful Impact to the Climate

What is Representative Concentration Pathways (RCPs)?

Radiative forcing represents the difference in solar radiation from the sun and absorbed by the Earth from the amount of solar energy radiated back into space.

- Representative Concentration Pathways project how the Earth will absorb solar energy from the sun or reflect that energy back into space using projections from climate models to estimate conditions from changes in winds, temperature, and moisture from radiative forcing.
- If there is positive radiative forcing, then the Earth receives more solar energy then it radiates back into space and the additional energy can lead to warming conditions.

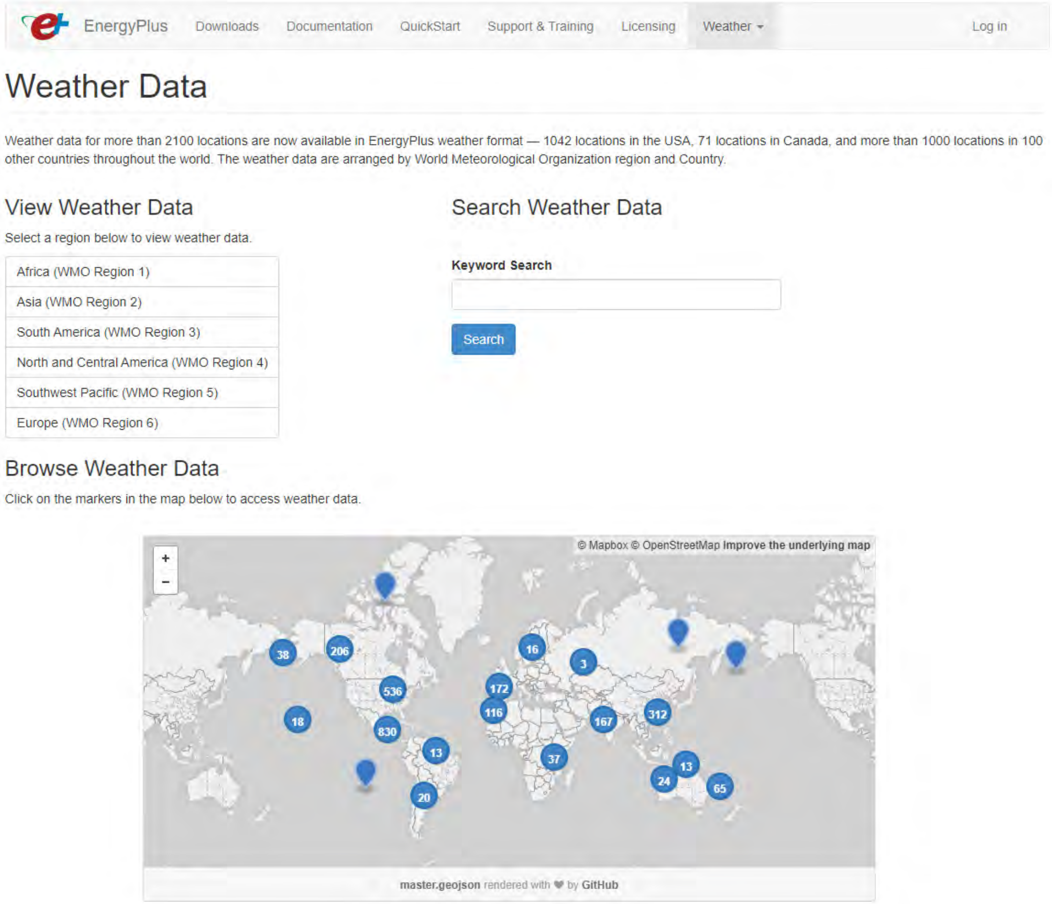


Animation by NOAA

Publicly Available Weather files

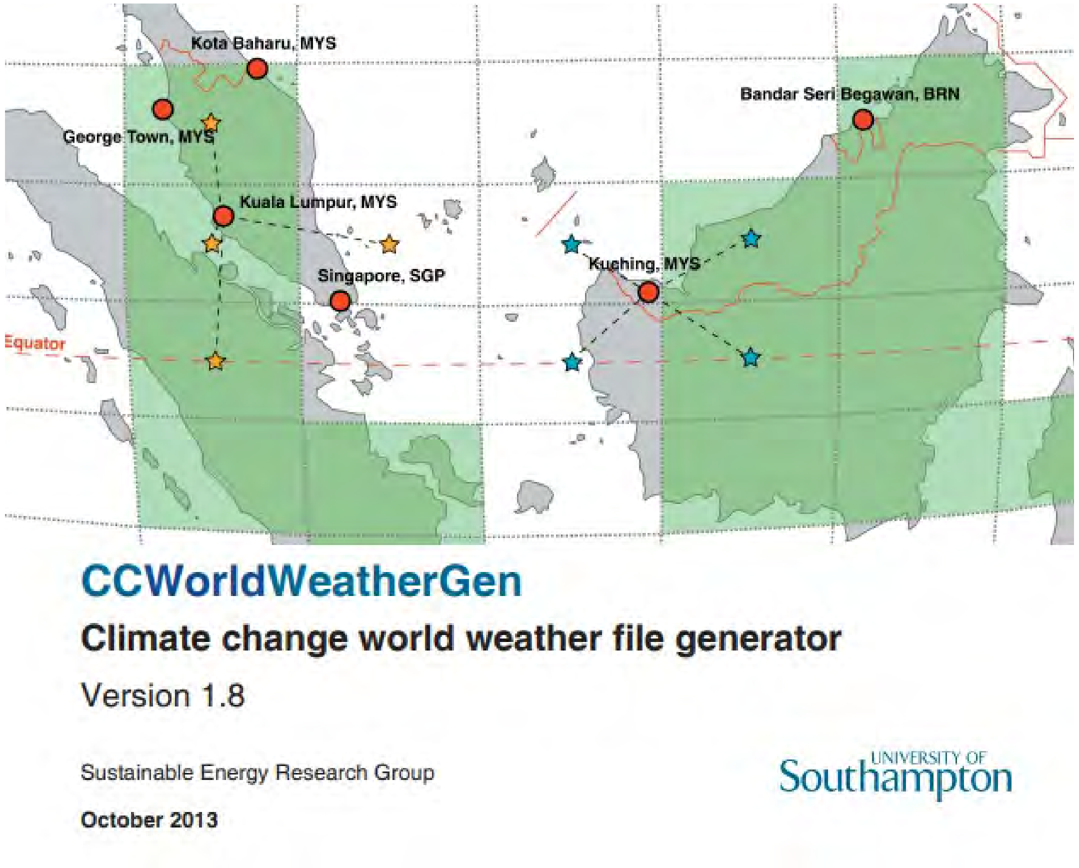
The currently available, widely used Energy Plus (EPW) Weather files are outdated.

Furthermore, these EPW files usually represent typical weather years and are unlikely to include enough information regarding severe weather events, which – in the context of climate change – are projected to increase in intensity and frequency.



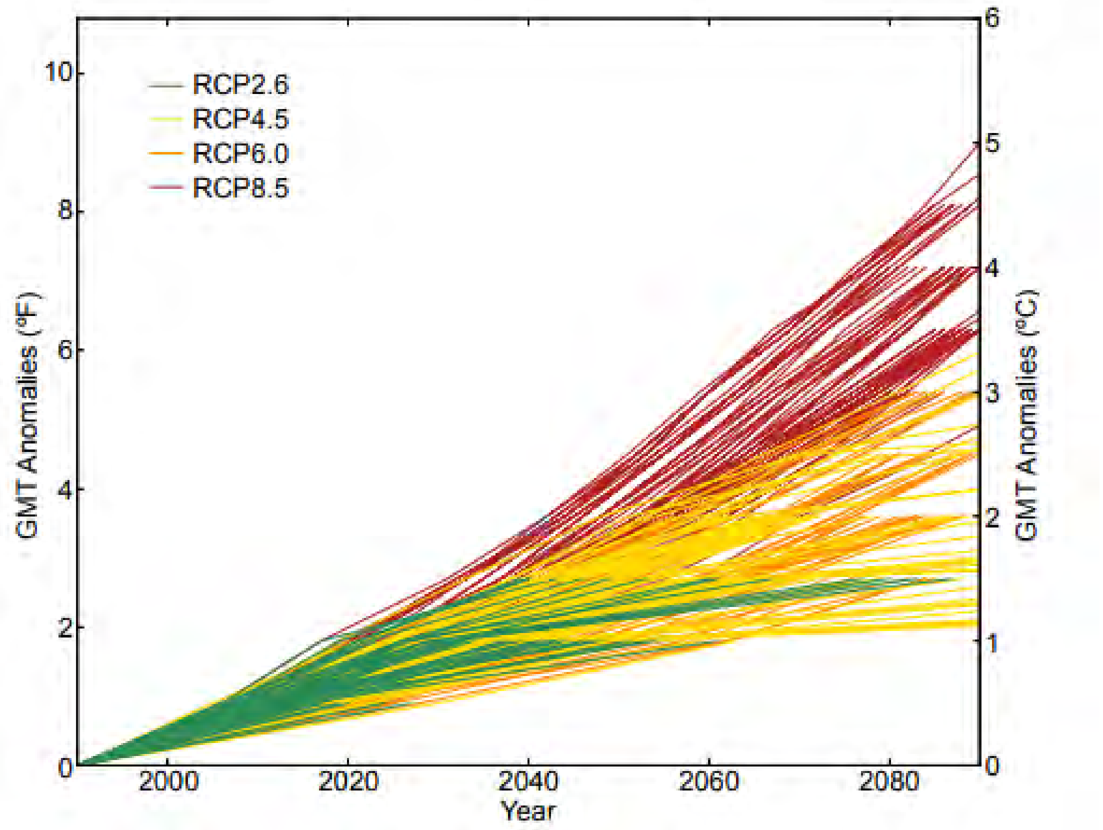
Climate Change World Weather Generator

- How can we apply RCP 2.6 to building performance scenarios?
  - The University of Southampton Sustainable Energy Research Group provides the workflow that generates climate change weather files based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report model summary data of HadCM3 A2 experiment ensemble.
  - It transforms "present-day" EPW weather files such as Atlanta Hartsfield TMY3 Model Year 1996 (1977-1996) into building performance compatible scenarios for 2020, 2050, and 2080 based on Representative Concentration Pathway 2.6 (2.6 w/m2 Radiative Forcing adjusts to 1.5C global average temperature rise by 2100). The generator uses a "morphing" methodology for climate change transformation of weather data developed by Belcher, Hacker, and Powell.
  - Weblink



Climate Science Special Report (CSSR)

U.S. Global Change Research Program CCSR on Global Mean Temperature (GMT) anomalies (°F & °C) relative to 1976–2005 for four RCP scenarios, 2.6 (green), 4.5 (yellow), 6.0 (orange), and 8.5 (red). Each line represents an individual simulation from the CMIP5 global climate models. Every RCP based simulation with annual or monthly temperature outputs available was used here. The values shown here were calculated in 0.5°C increments; since not every simulation reaches the next 0.5°C increment before end of century, many lines terminate before 2100. (Figure source: adapted from Swain and Hayhoe 201540).



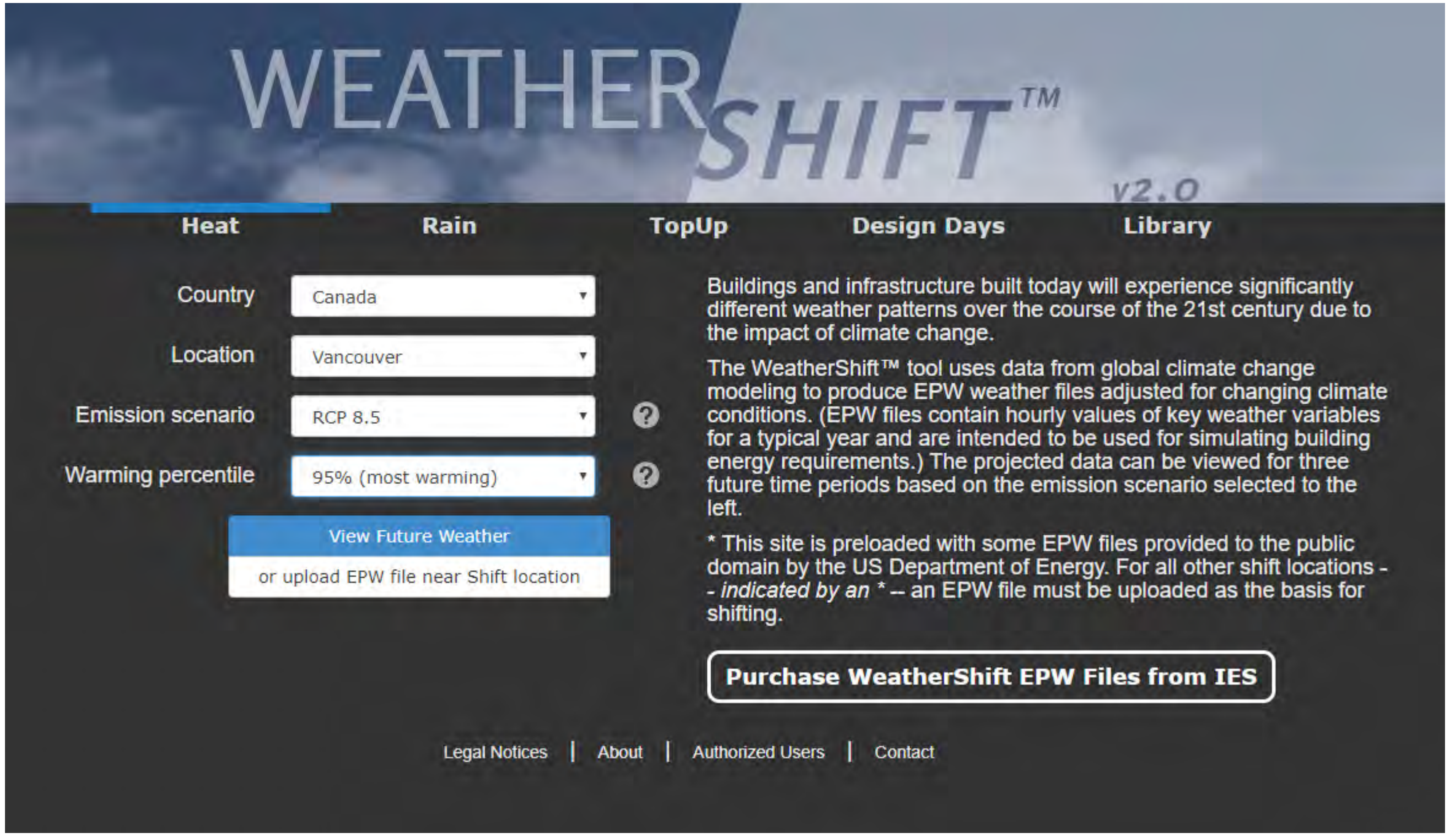
https://science2017.globalchange.gov/downloads/CSSR_Ch4_Climate_Models_Scenarios_Projections.pdf

Weathershift

The WeatherShift™ tool uses data from global climate change modeling to produce EPW weather files adjusted for a changing climate conditions.

The two RCPs that were mandatory were RCP 4.5 and 8.5.

Each set of WeatherShift future weather files contains three files for the specified location, time period and emission scenario (RCP), one each at the 10th, 50th and 90th percentiles of warming for that period.



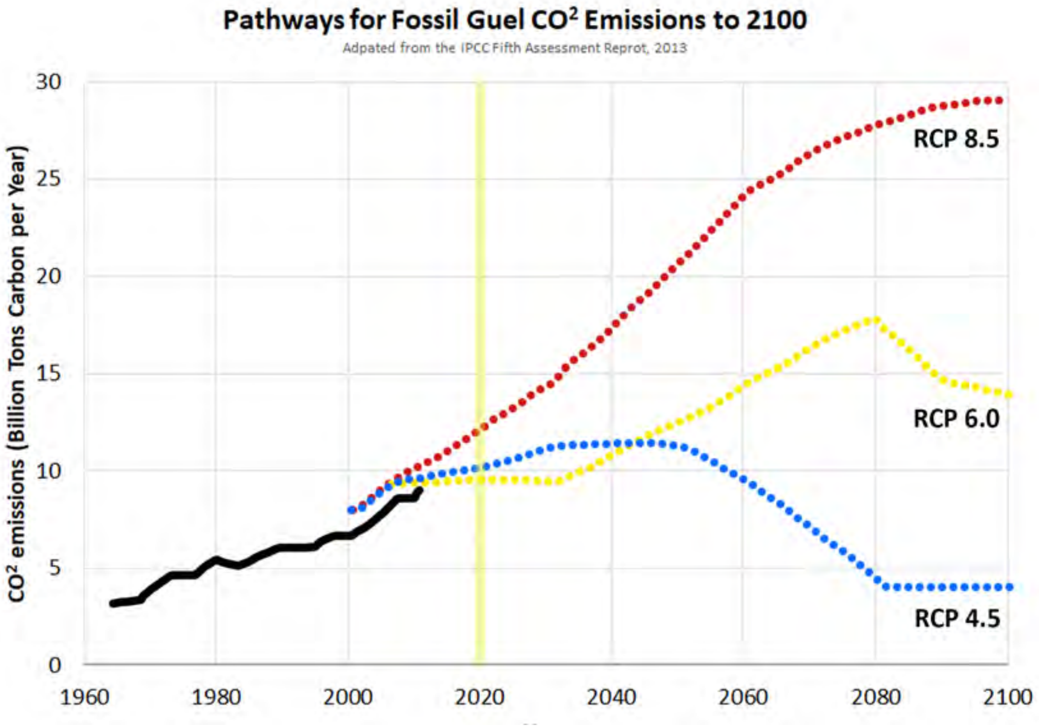
Source from http://www.weather-shift.com/

05 Methodology

Predictive Simulation

The climate generator generates climate change weather files based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report model summary data of HadCM3 A2 experiment ensemble. It transforms "present-day" EPW weather files such as Atlanta Hartsfield TMY3 Model Year 2002 (1973-2005) into building performance compatible scenarios for 2020, 2050, and 2080 based on Representative Concentration Pathway 2.6 (2.6 w/m2 Radiative Forcing adjusts to 1.5C global average temperature rise by 2100).

– Belcher SE, Hacker JN, Powell DS. Constructing design weather data for future climates. Building Services Engineering Research and Technology 2005; 26 (1): 49-61.



Graphic with 2020 Marker Adaptation by Tyrone, Cheney, and Mohammed, Original Source: Architecture 2030 Adapted from the IPCC Fifth Assessment Report, 2013.

Process

With **5** building types, ***17*** weather files, and ***51*** transformed climate change weather files the case study work provides ***340*** energy model simulations for the research study.

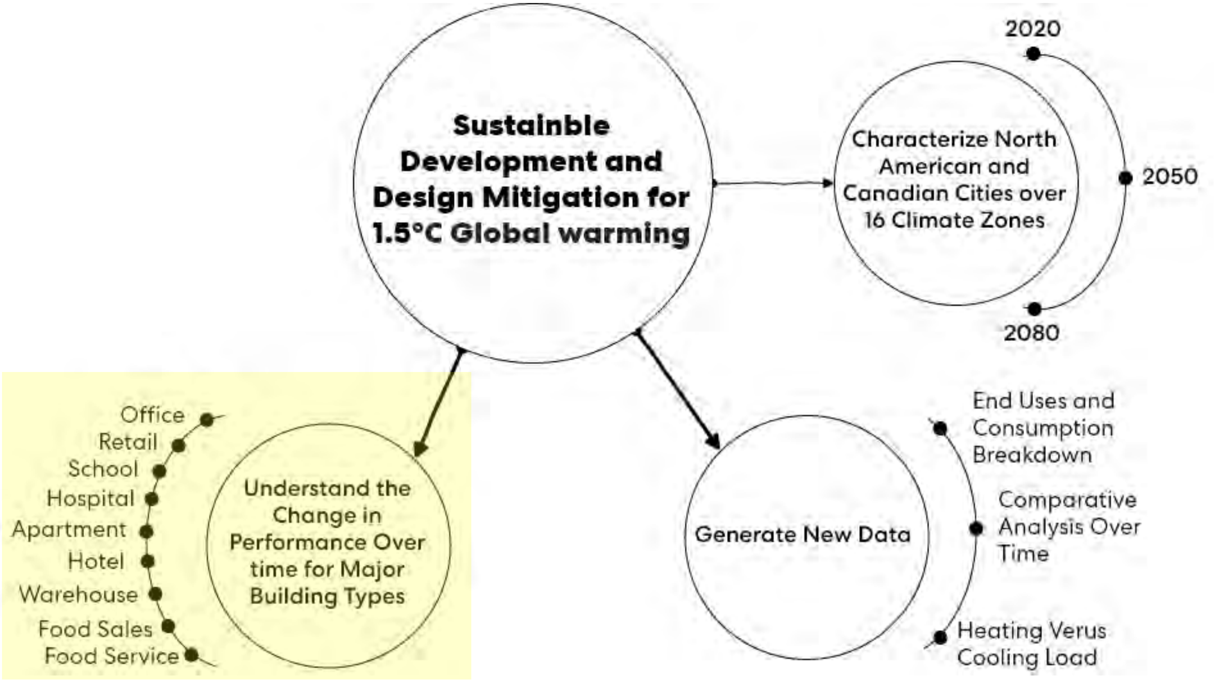
Define Scope

The team purchased two professionally climate change weather files from WeatherShift for Atlanta and Vancouver that represent the worse-case scenario regarding global temperature rise of 5-6ºC* for additional analysis.

The WeatherShift files represent the years 2040-2060 for a single period that represents the prediction for 2050.

However, out study did not include data on precipitation changes.

* National Oceanic and Atmospheric Administration



Infographic by Tyrone, Cheney, and Mohammed

Process

Climate weather file collection

- **17** weather files are downloaded from EnergyPlus with updates for Vancouver & Atlanta from Climate One Building.

Climate Change Weather Files

- The International Panel on Climate Change World Weather Generator is used to transform the initial files into three simulated scenarios representing **2020**, **2050**, and **2080** corresponding to a 1.5°C global temperature rise.

- Collected Department of Energy (US) prototype models for **5** building types for the energy model simulations. These building typologies correspond with P&W design focus, ensuring the results directly support our sustainable design mandate.

Analysis, Design, and Conclusion

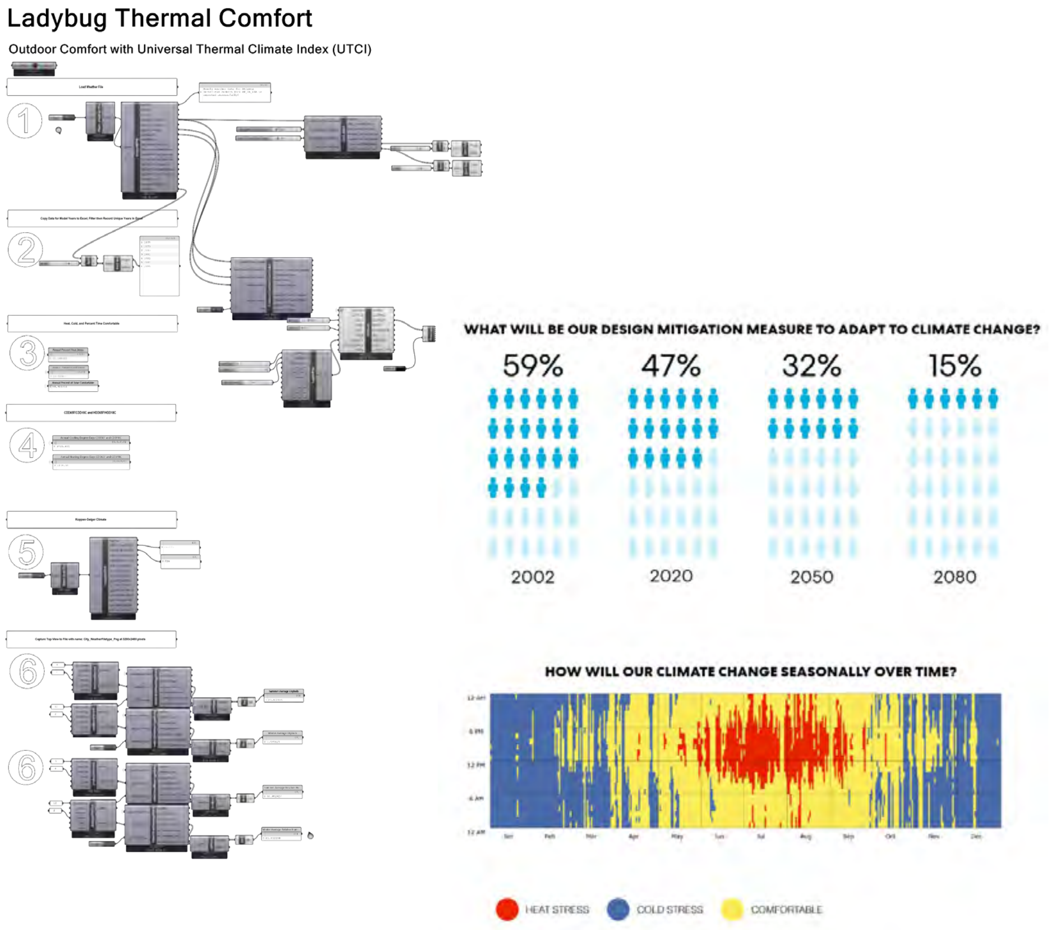
Heating and Cooling Trends

Resilience Considerations

Thermal Comfort and Stress for Cities Comparison

We use Rhinoceros and Grasshopper plugin Ladybug for each of the climate weather files to calculate the thermal climate project map, heating degree and cooling degrees, thermal stress, exterior environmental temperature conditions, and percent of time comfortable.

- The thermal comfort maps only report the data from weather file for temperatures, windspeed, and relative humidity.



Infographic by Tyrone, Cheney, and Mohammed

Climate Weather Files

We use the data for the closest airport to the site. We used the data for dry bulb temperatures, wind speed, relative humidity, longwave radiation from the sky, sun elevation, sun zenith, and sun azimuth.

We compare the exterior thermal comfort with adjustment for solar radiation, temperature, wind speed, and relative humidity with climate model year files from freely available or current TMY3 data and then with adjusted models that project 1.5 Celsius for the year 2100 from greenhouse gas emissions and Representative Concentration Pathway (RCP) 2.6 model years of 2020, 2050, and 2080 for 16 climate zones. RCP represents scenarios for predicting the trajectory of greenhouse gas emissions from the Intergovernmental Panel on Climate Change.

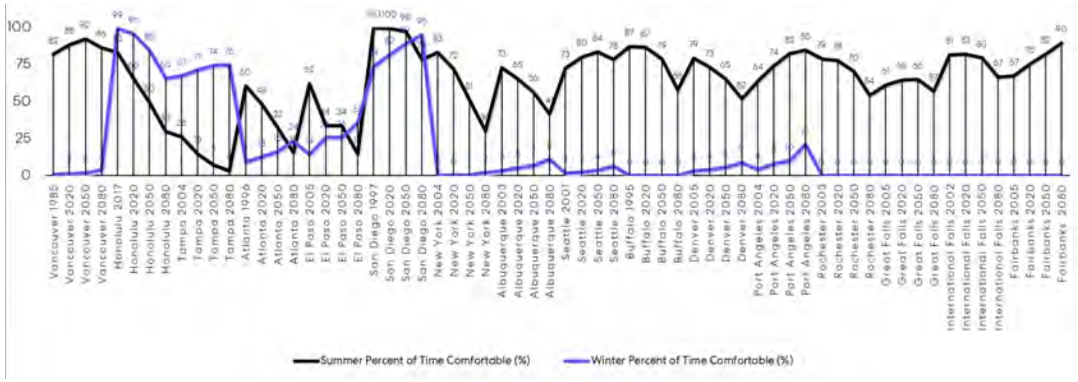
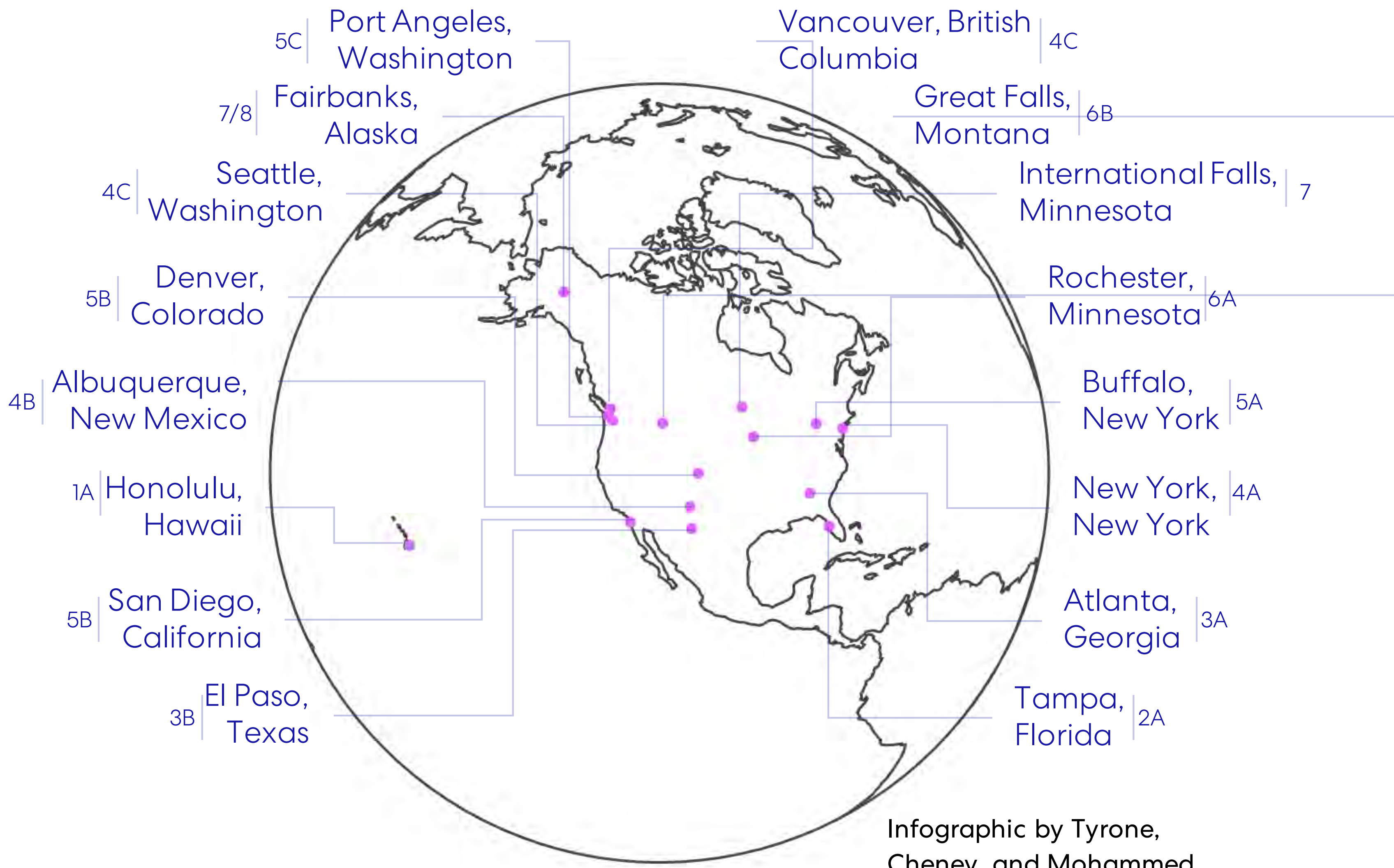


Chart by Tyrone, Cheney, and Mohammed

04 Cities and Climates

The Cities and Their Baseline Climate Zones

A study of exterior thermal comfort from the Department of Energy (US) freely available weather files and the transformed conditions for 2020, 2050 and 2080 reference the following cities with their climate zone designation:

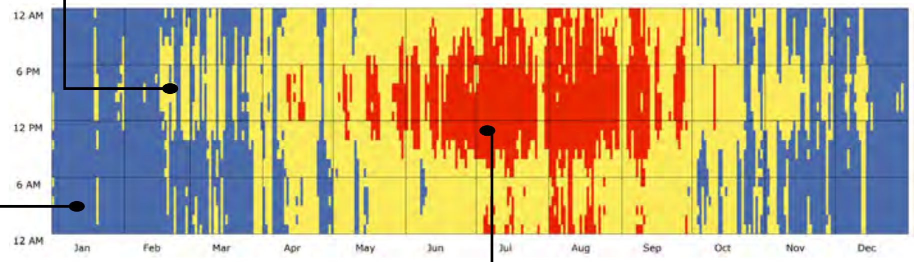


Infographic by Tyrone, Cheney, and Mohammed

Comfortable, Cold, and Heat Stress

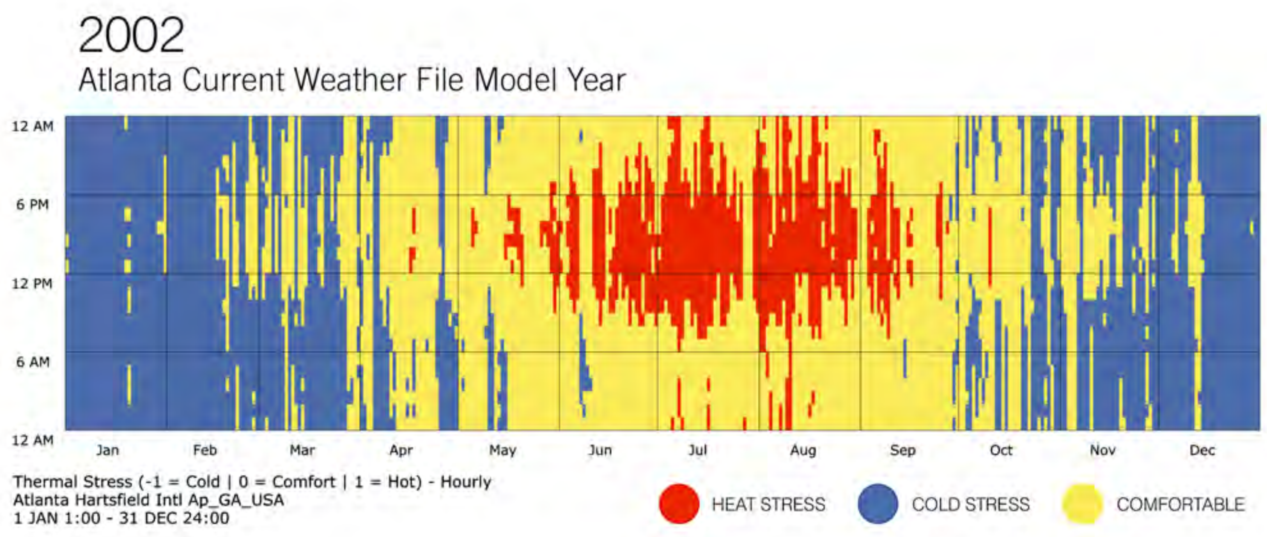
- The following assumptions were applied to each of the weather files for the Universal Thermal Climate Index (UTCI):
  - No Thermal Stress or "YELLOW" color or Comfortable!
    - The occupant in an exterior area would feel comfortable as the UTCI index is more than 9ºC or 48ºF and less than 26ºC or 79ºF.
  - Cold Thermal Stress or "BLUE" color or COLD!
    - The occupant in an exterior area would feel cold stress as the UTCI index is less than 9ºC or 48ºF.
  - Heat Thermal Stress or "RED" color or HOT!
    - The occupant in an exterior area would feel cold stress as the UTCI index is more than 26ºC or 79ºF.

Atlanta 2020 Weather File Transformation



Infographic by Tyrone, Cheney, and Mohammed

FUTURE CLIMATE WEATHER PROJECTIONS

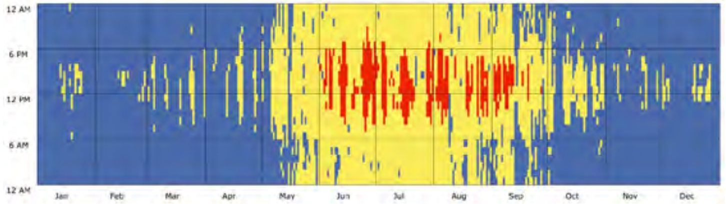


After comparing the changes annually in many different categories for each climate zone we map the freely available or current weather file climate zone per ASHRAE 169-2013 and then we plot the future weather projection climate for each of the locations from the change in heating and cooling degree days.

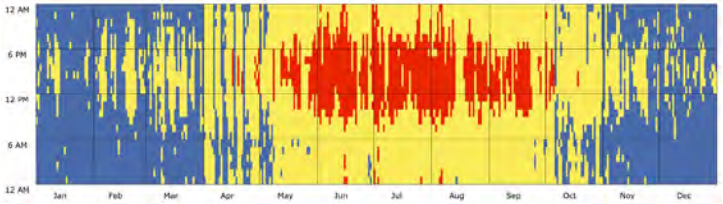
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

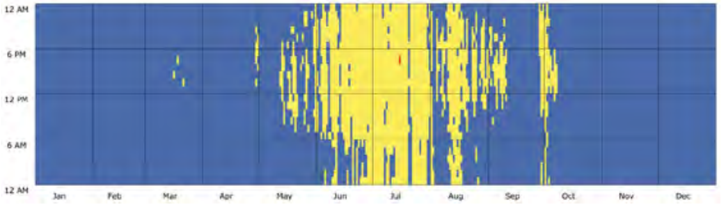
Denver 2005



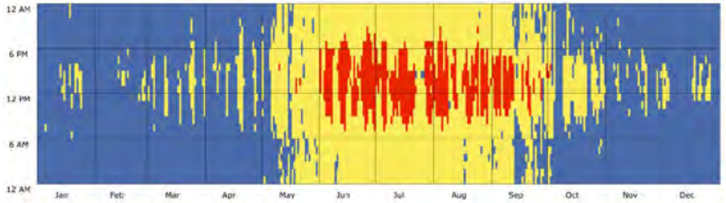
El Paso 2005



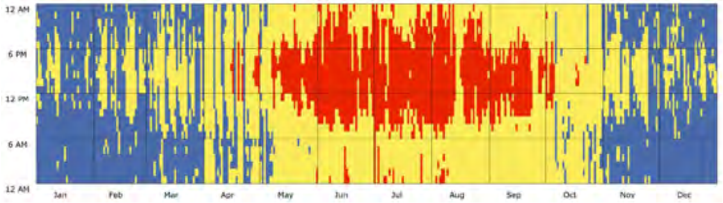
Fairbanks 2005



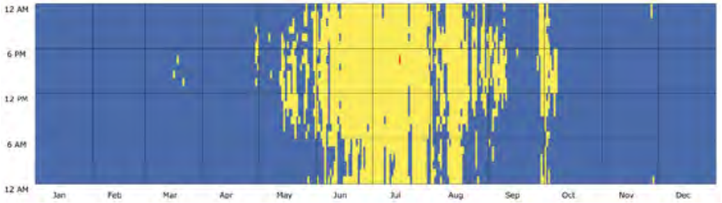
Denver 2020



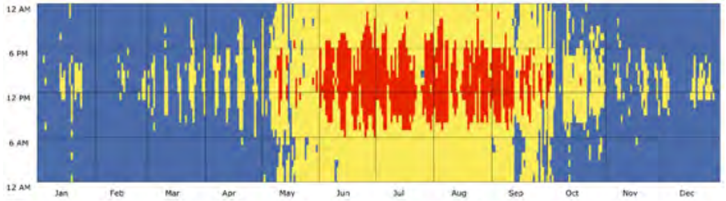
El Paso 2020



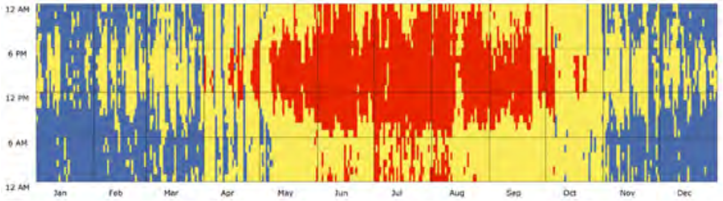
Fairbanks 2020



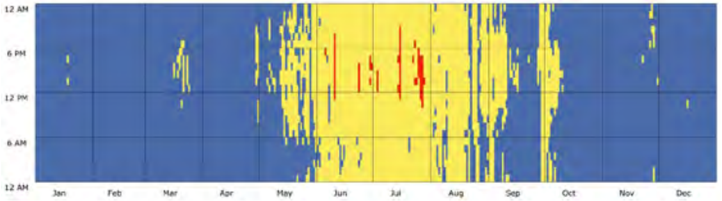
Denver 2050



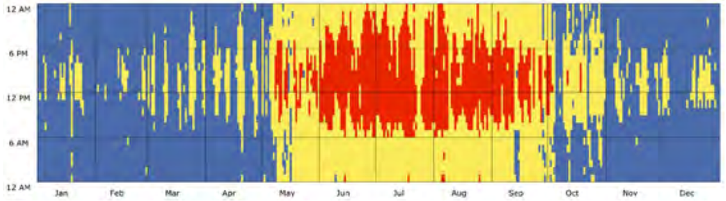
El Paso 2050



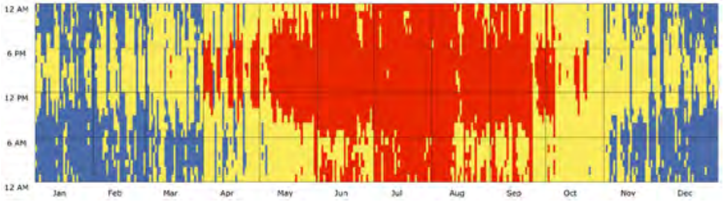
Fairbanks 2050



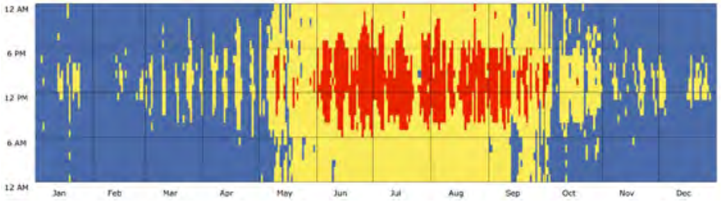
Denver 2080



El Paso 2080



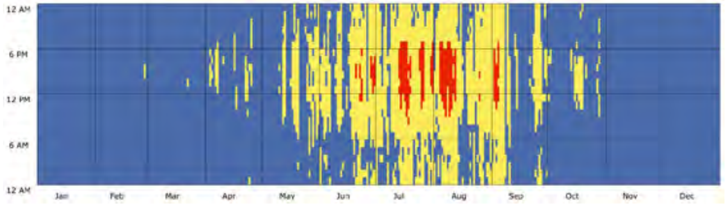
Fairbanks 2080



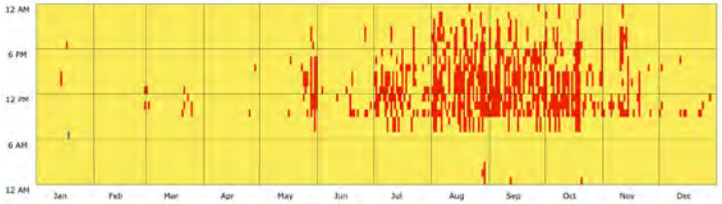
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

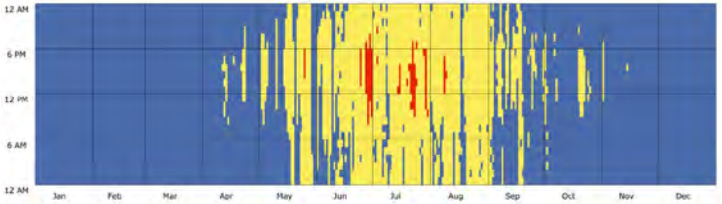
Great Falls 2005



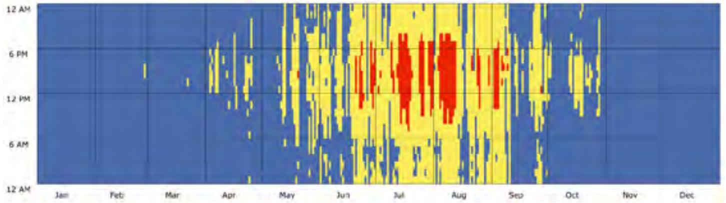
Honolulu 2017



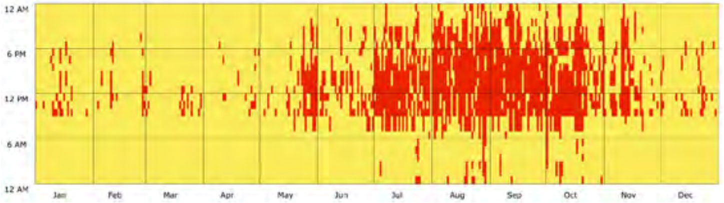
International Falls 2002



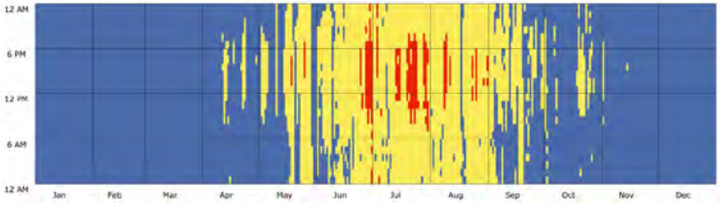
Great Falls 2020



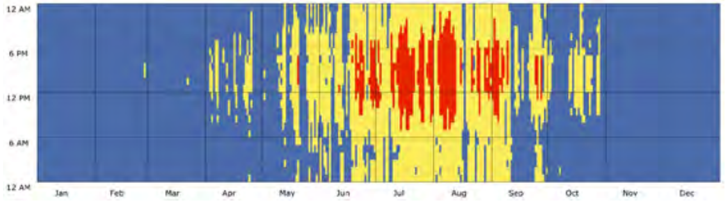
Honolulu 2020



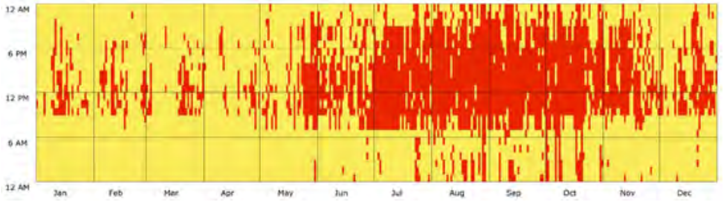
International Falls 2020



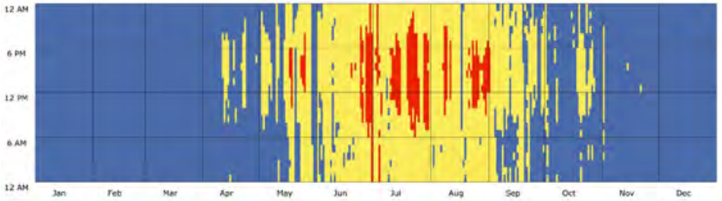
Great Falls 2050



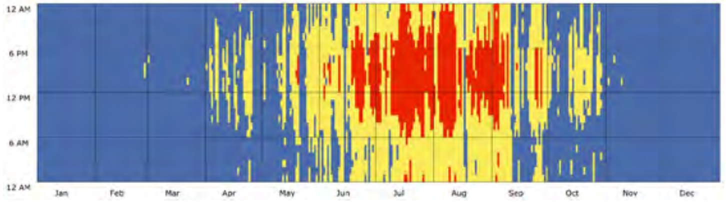
Honolulu 2050



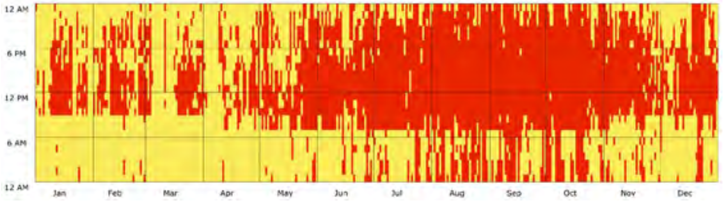
International Falls 2050



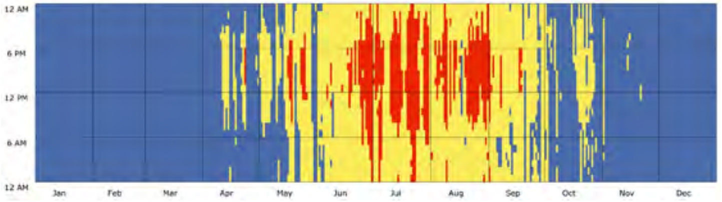
Great Falls 2080



Honolulu 2080



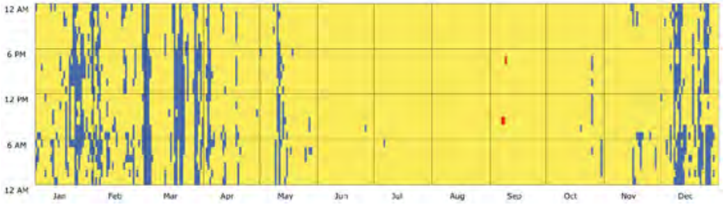
International Falls 2080



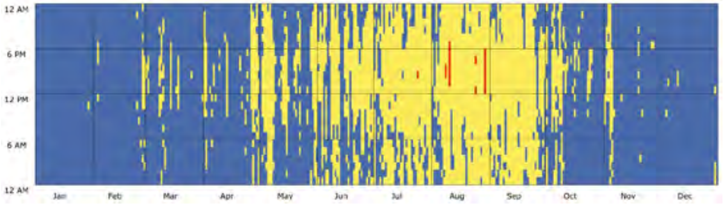
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

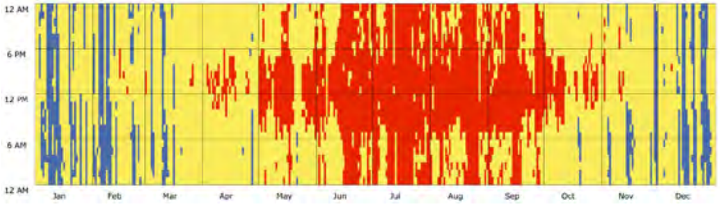
San Diego 1997



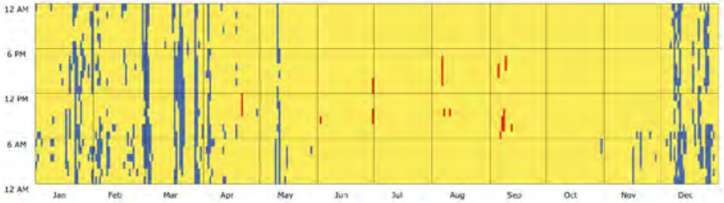
Seattle 2001



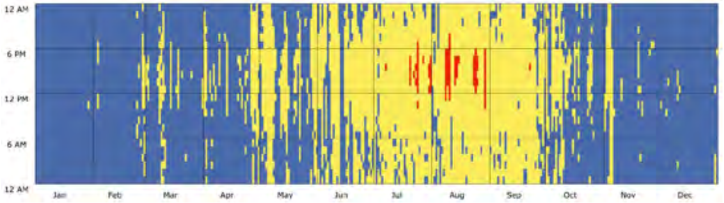
Tampa 2004



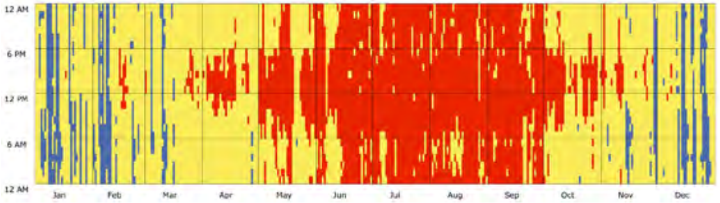
San Diego 2020



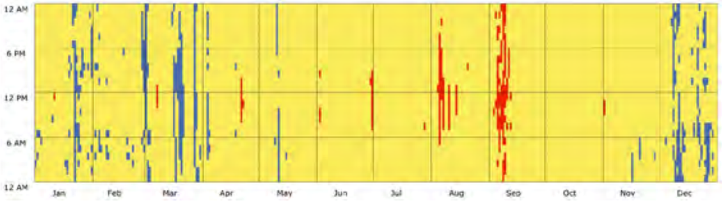
Seattle 2020



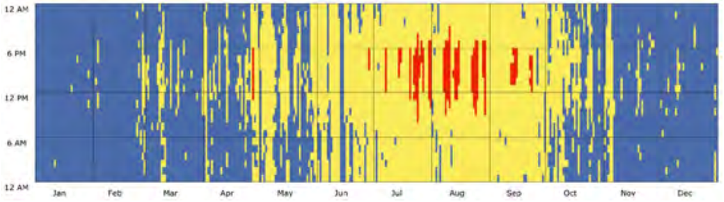
Tampa 2020



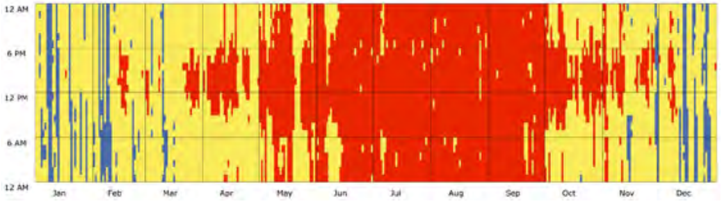
San Diego 2050



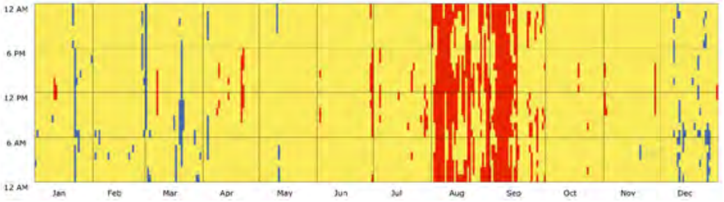
Seattle 2050



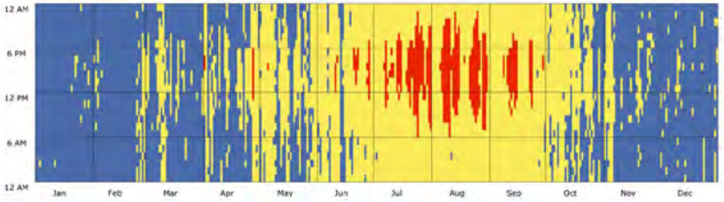
Tampa 2050



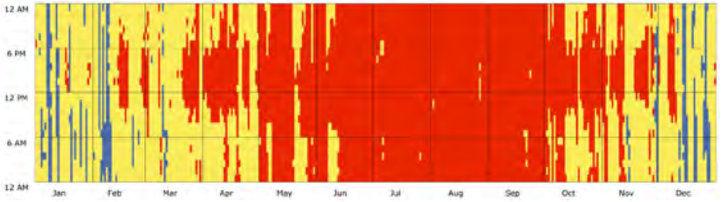
San Diego 2080



Seattle 2080

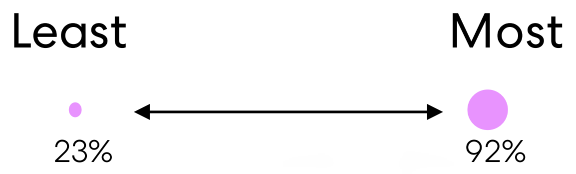


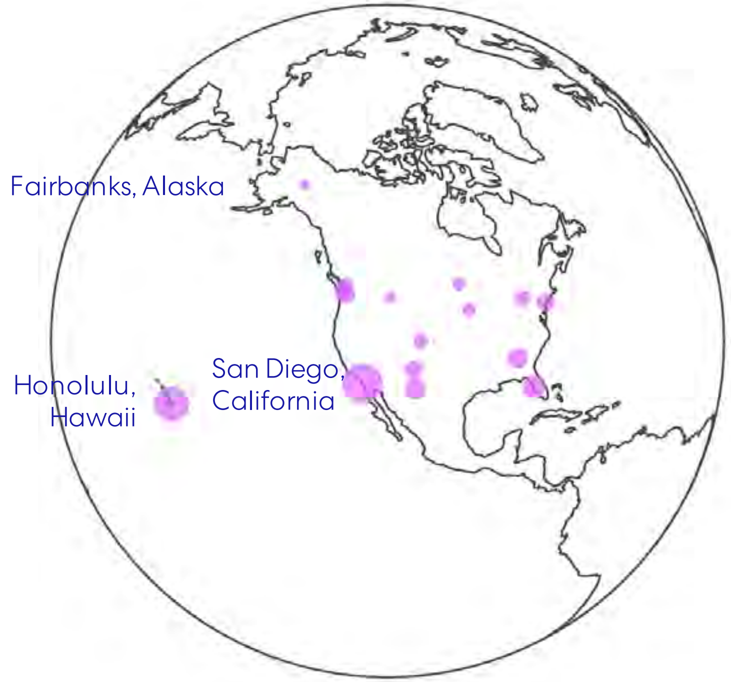
Tampa 2080



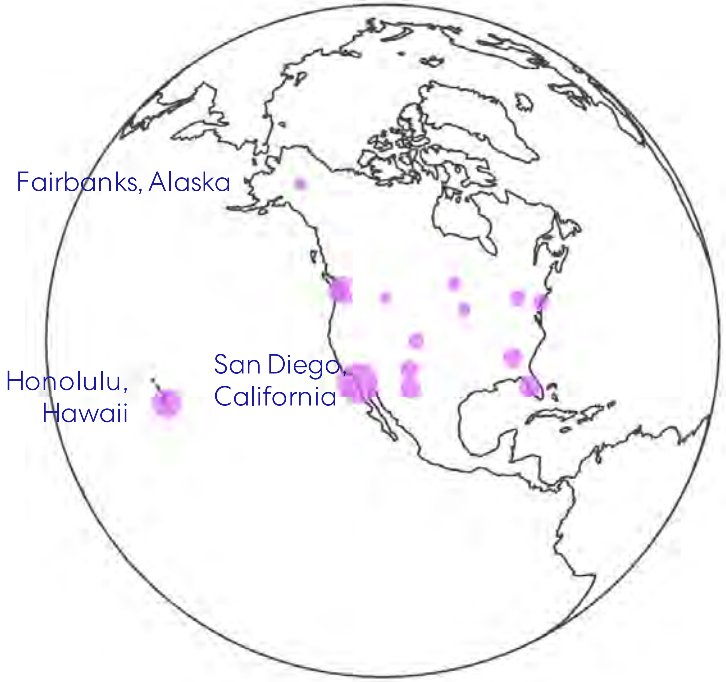
Infographic by Tyrone, Cheney, and Mohammed

Annual Exterior Thermal Comfort Design Summary

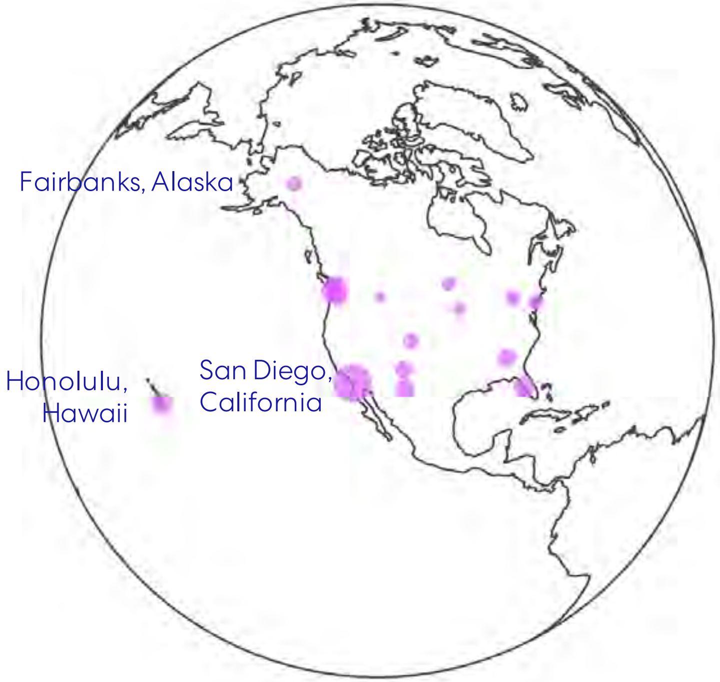




2020 Percent Comfortable



2050 Percent Comfortable



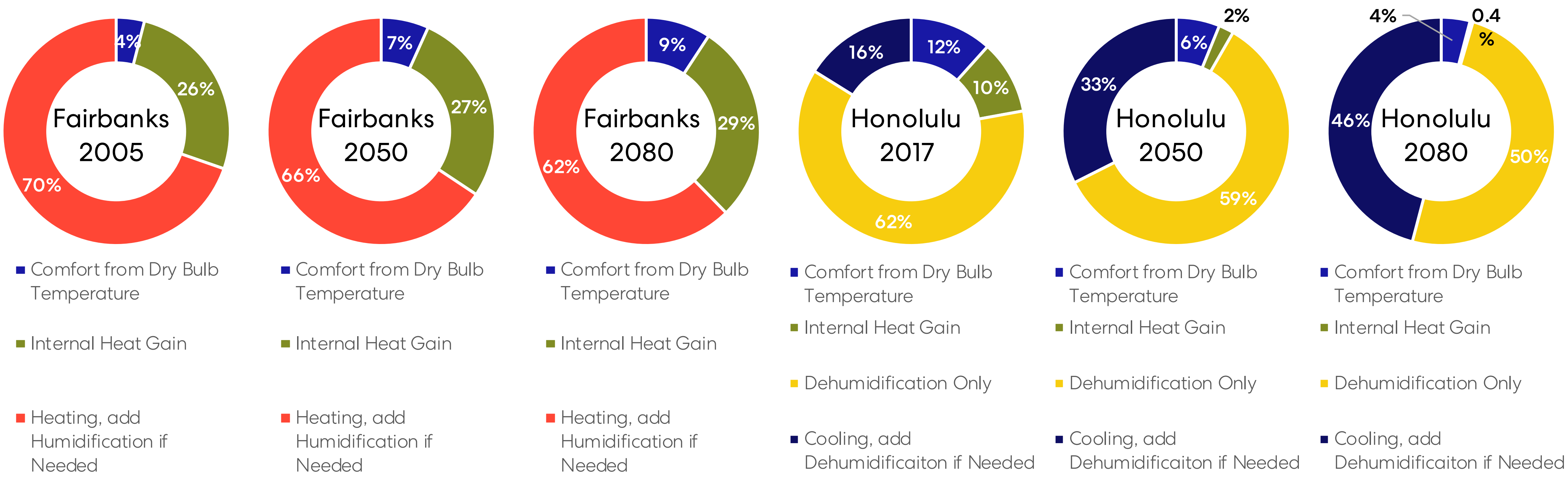
2080 Percent Comfortable

Infographic by Tyrone, Cheney, and Mohammed

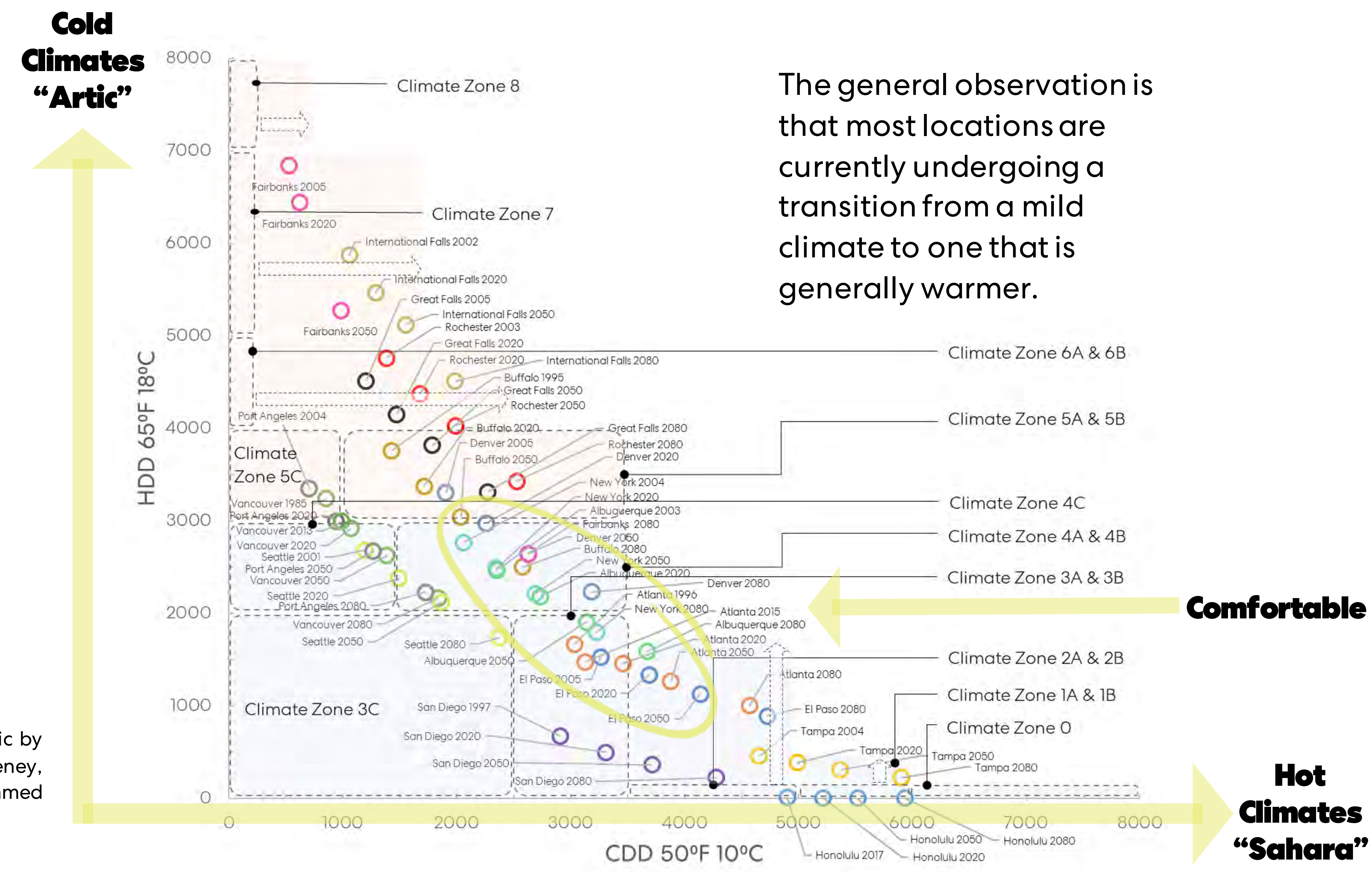
Climate Design Strategies for Indoor Thermal Comfort

Fairbanks climate will over-time require slightly less emphasis on well-insulated walls and insulated glazing units with low U-value and high SHGC to retain internal heat gain from occupants and equipment.

Honolulu climate will over-time require 3x more artificial cooling and somewhat less dehumidification.

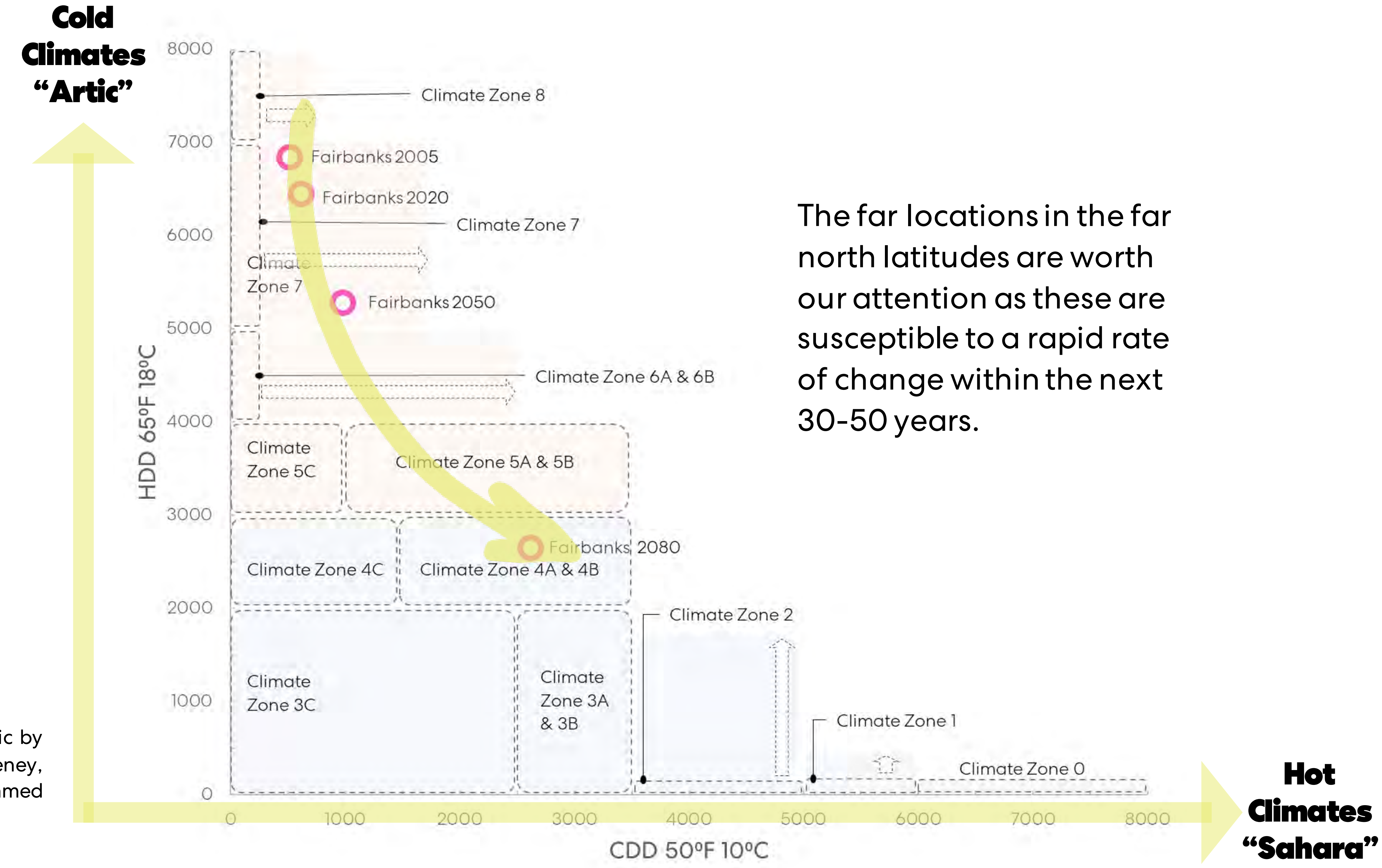


Infographic by Tyrone, Cheney, and Mohammed



The general observation is that most locations are currently undergoing a transition from a mild climate to one that is generally warmer.

Infographic by Tyrone, Cheney, and Mohammed



Infographic by Tyrone, Cheney, and Mohammed

The far locations in the far north latitudes are worth our attention as these are susceptible to a rapid rate of change within the next 30-50 years.

05 Buildings and Climate

Heating/Cooling Ratio - Hospital

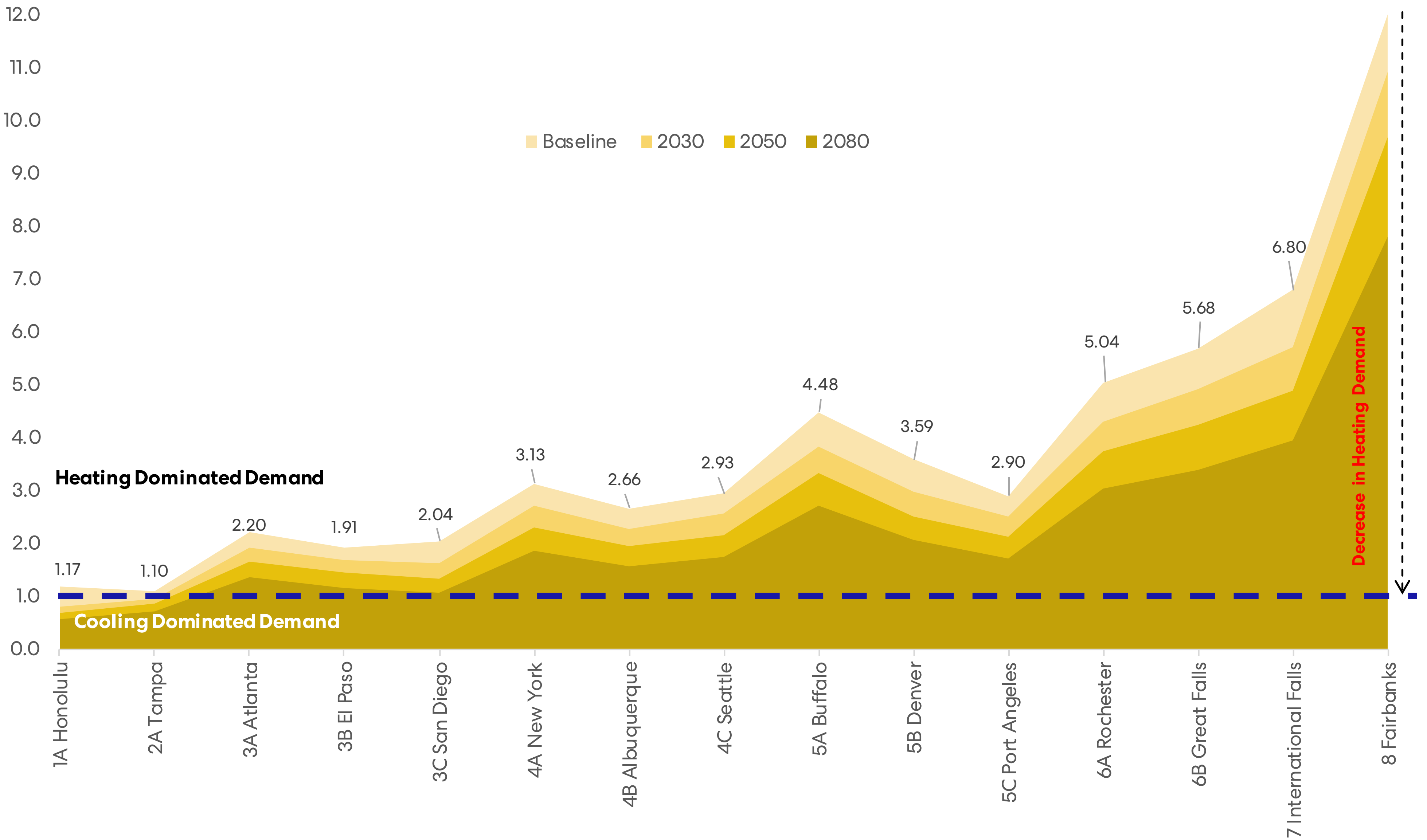


Chart by Tyrone, Cheney, and Mohammed

Heating/Cooling Ratio – Highrise Apartment

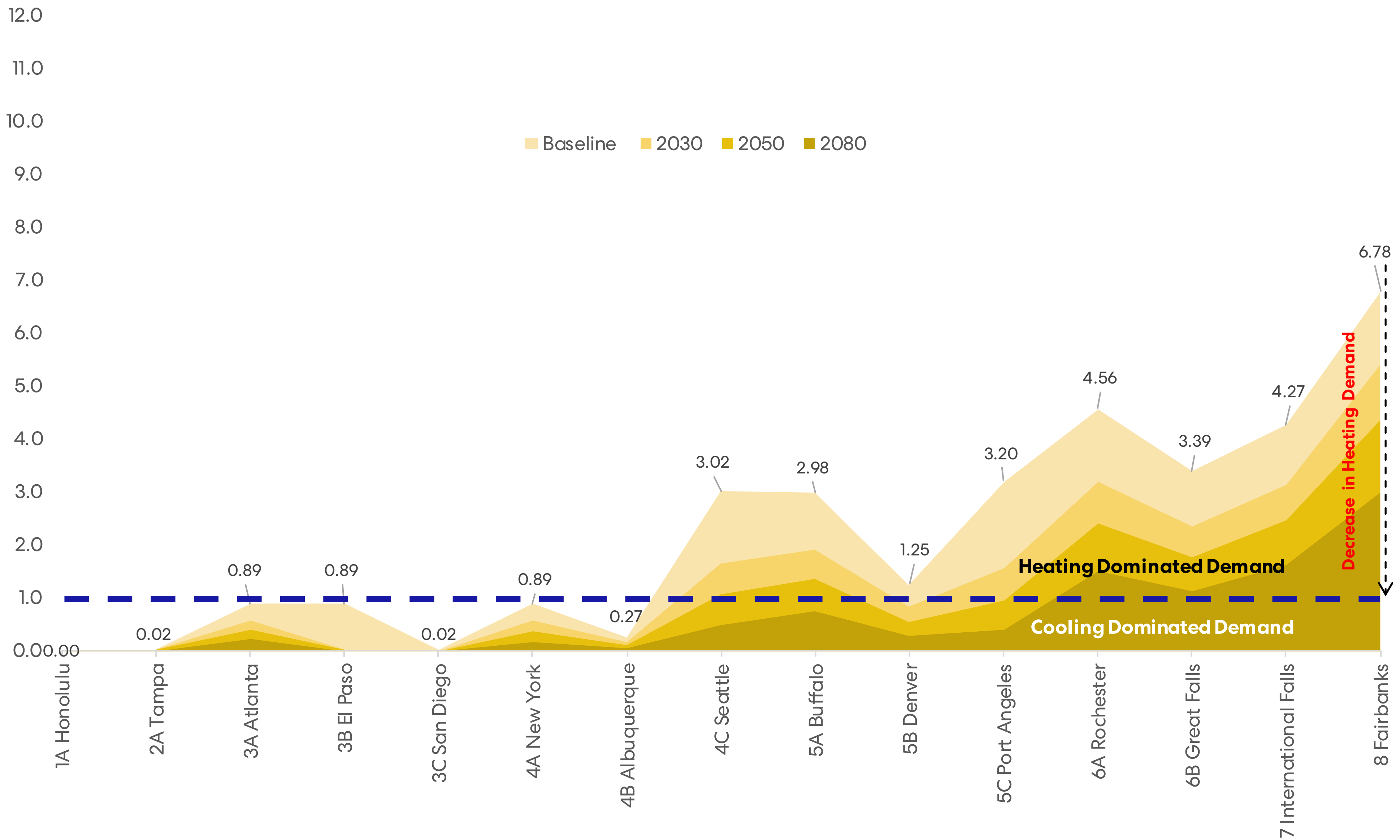


Chart by Tyrone, Cheney, and Mohammed

Heating/Cooling Ratio – Hotel

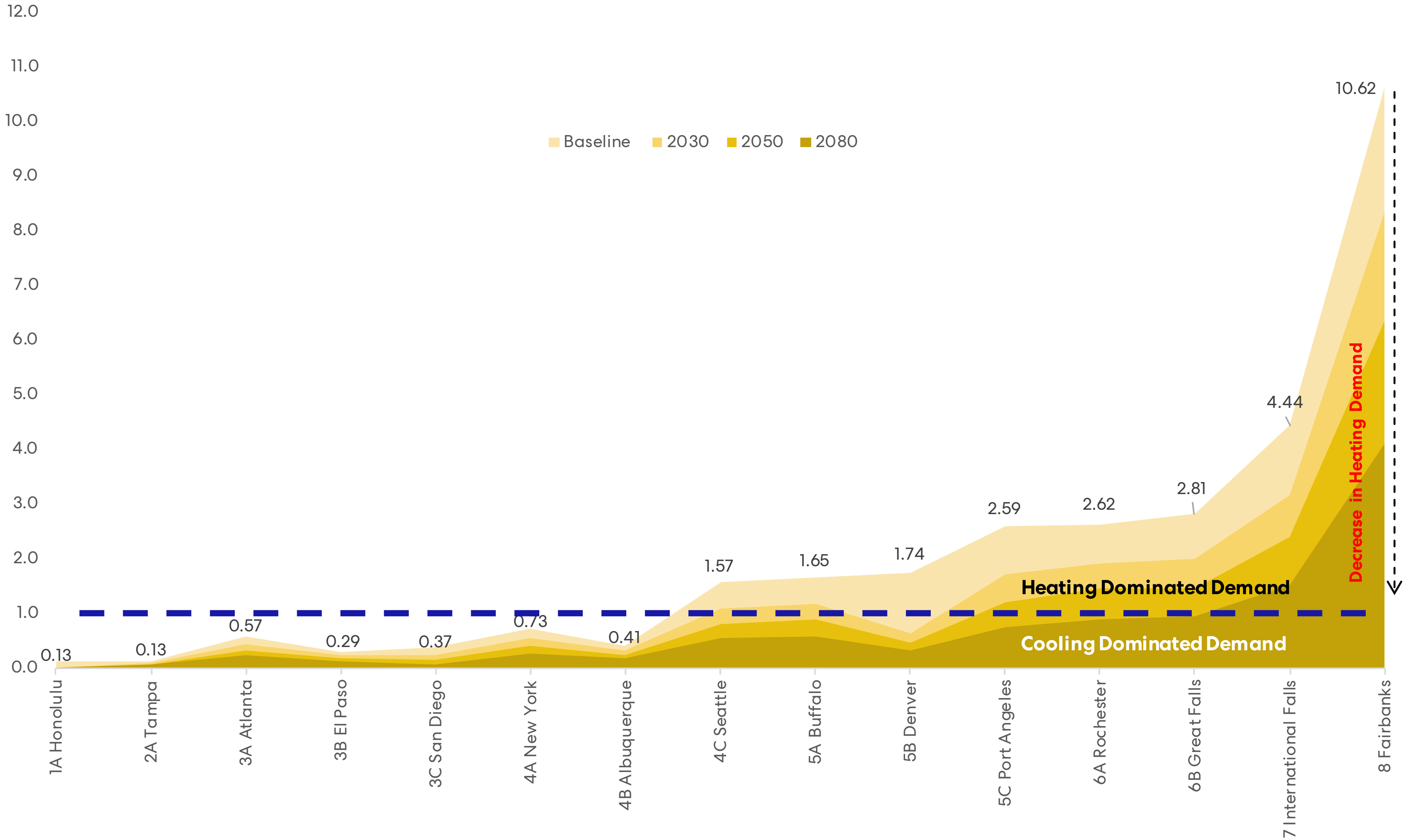


Chart by Tyrone, Cheney, and Mohammed

Heating/Cooling Ratio – Office

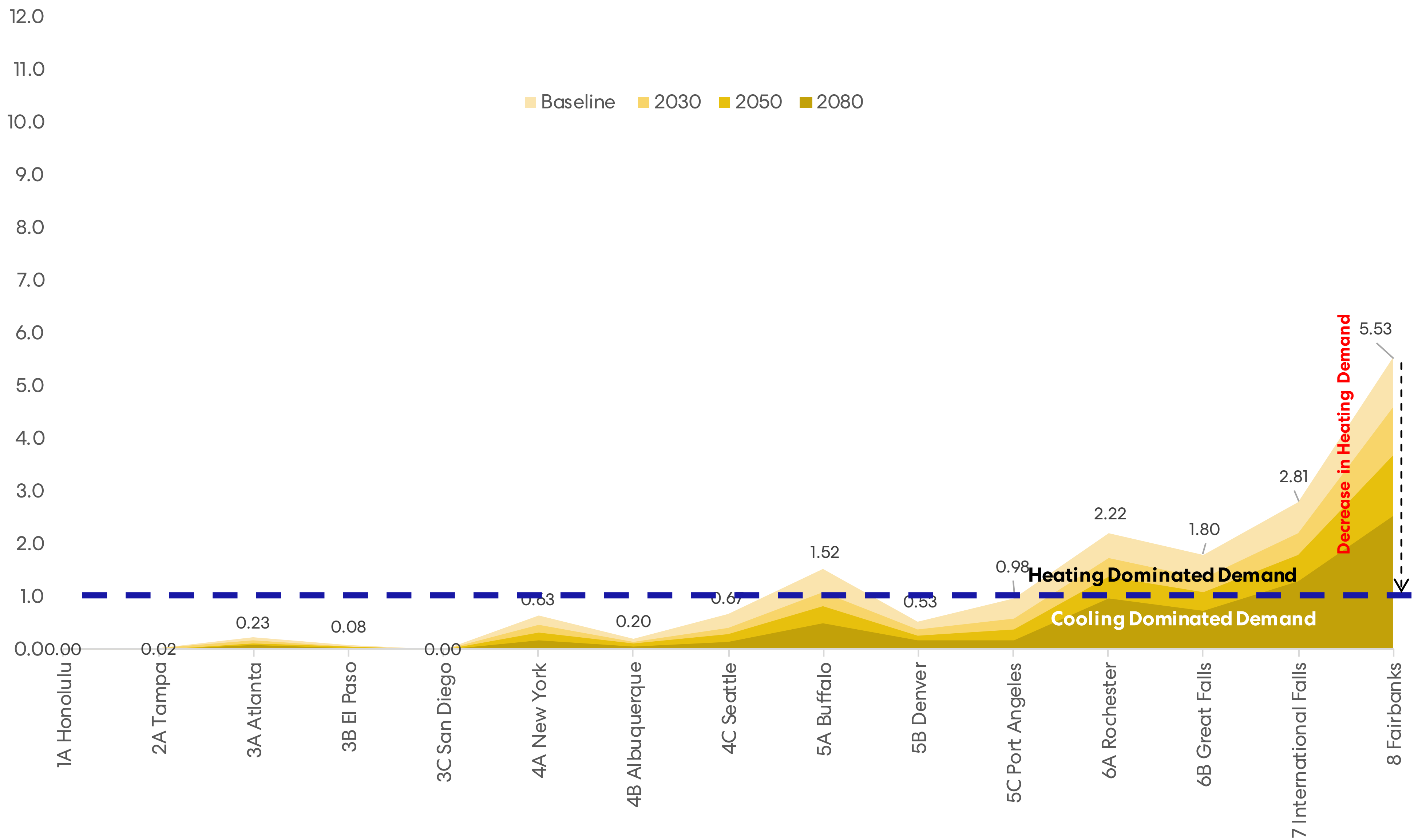


Chart by Tyrone, Cheney, and Mohammed

Heating/Cooling Ratio – Primary School

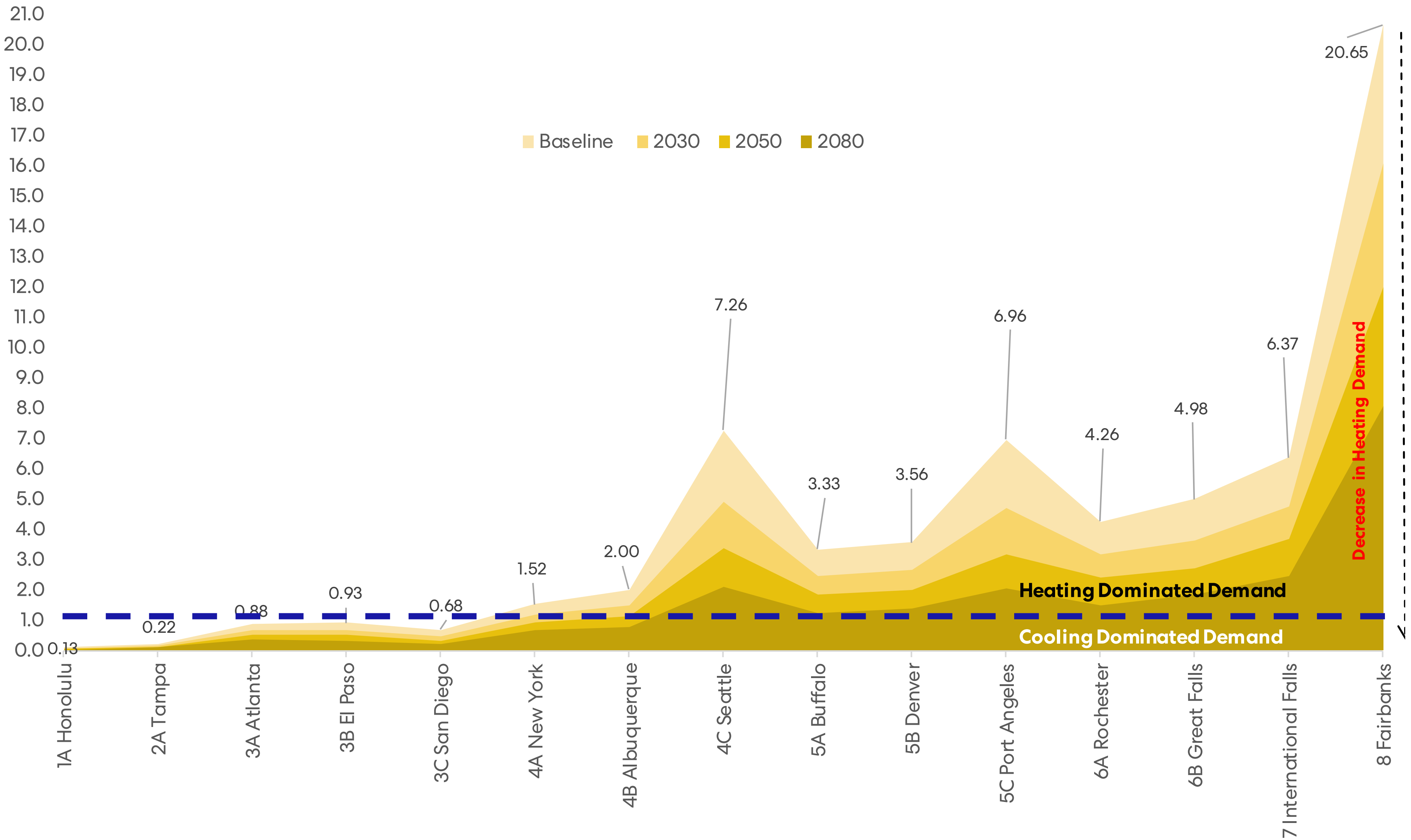


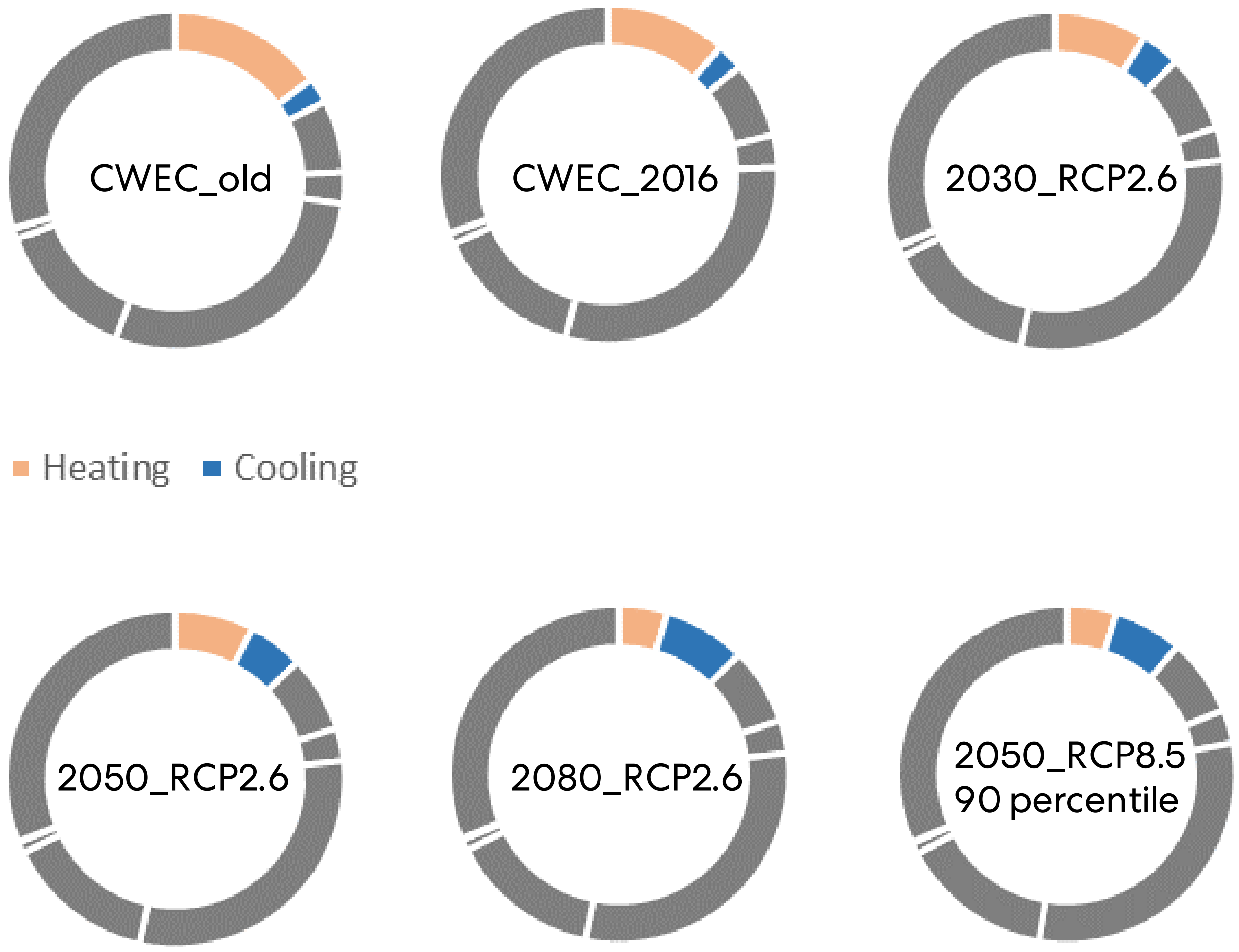
Chart by Tyrone, Cheney, and Mohammed

06 Case Study

Vancouver, British Columbia

Vancouver Case Study

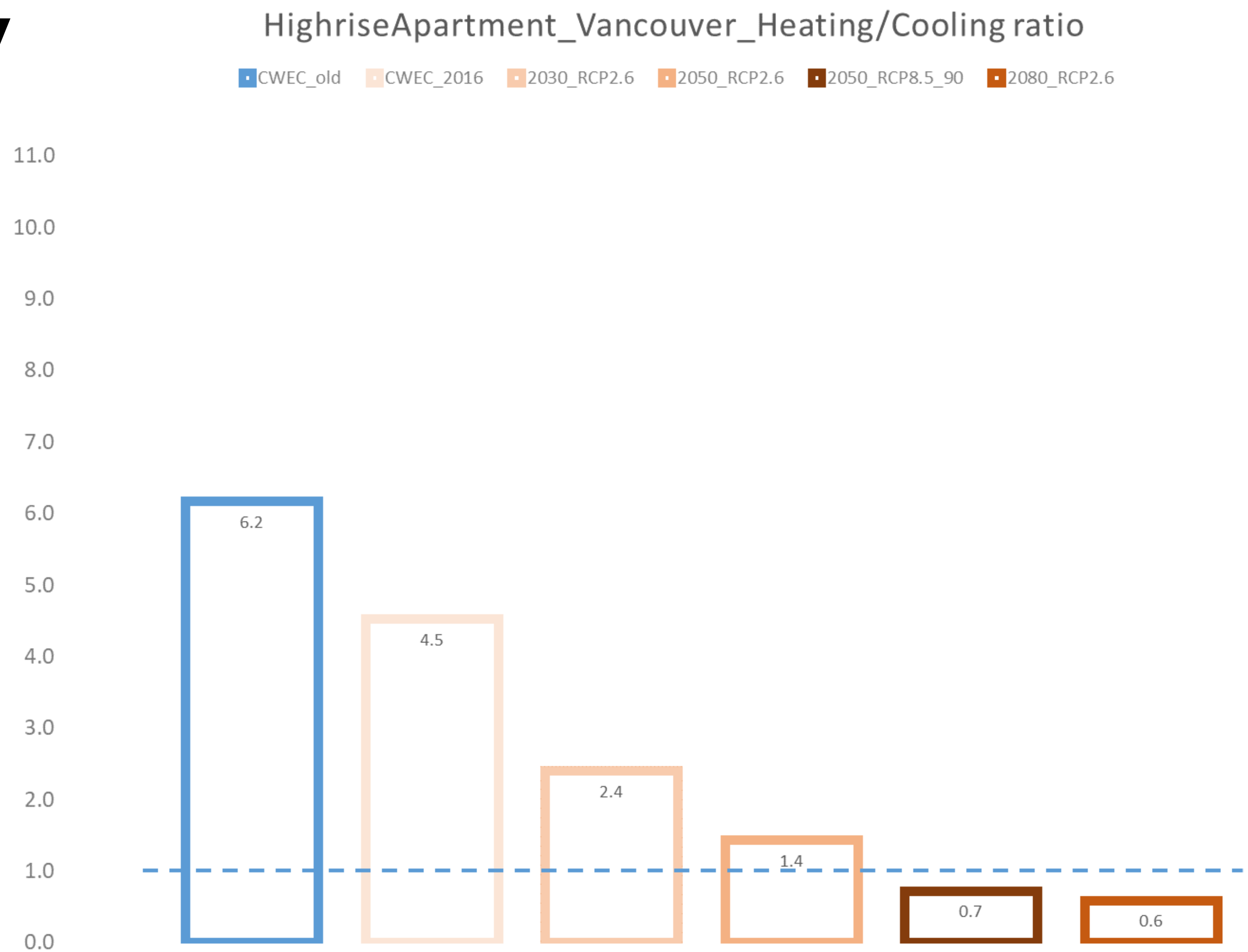
- **Highrise Apartment** in Vancouver will definitely switch from heating energy dominated to cooling energy dominated;
- If RCP increases too quick, in 2050 at RCP8.5, the heating/cooling ratio will be close to 2080 at RCP2.6.



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

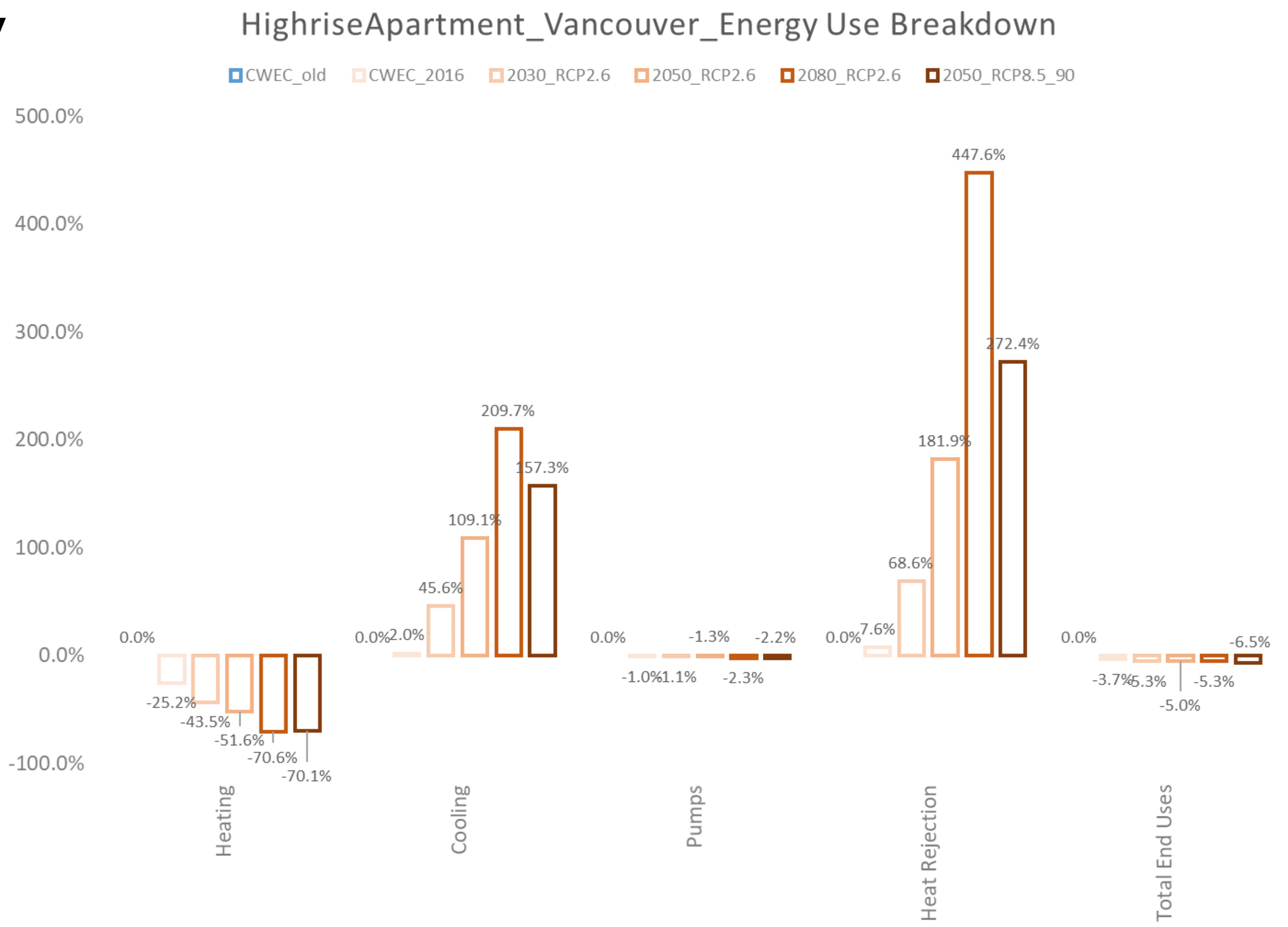
- **Highrise Apartment** in Vancouver Heating/cooling ratio maximum difference is 5.6 (CWEC_old vs. 2080_RCP2.6);



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

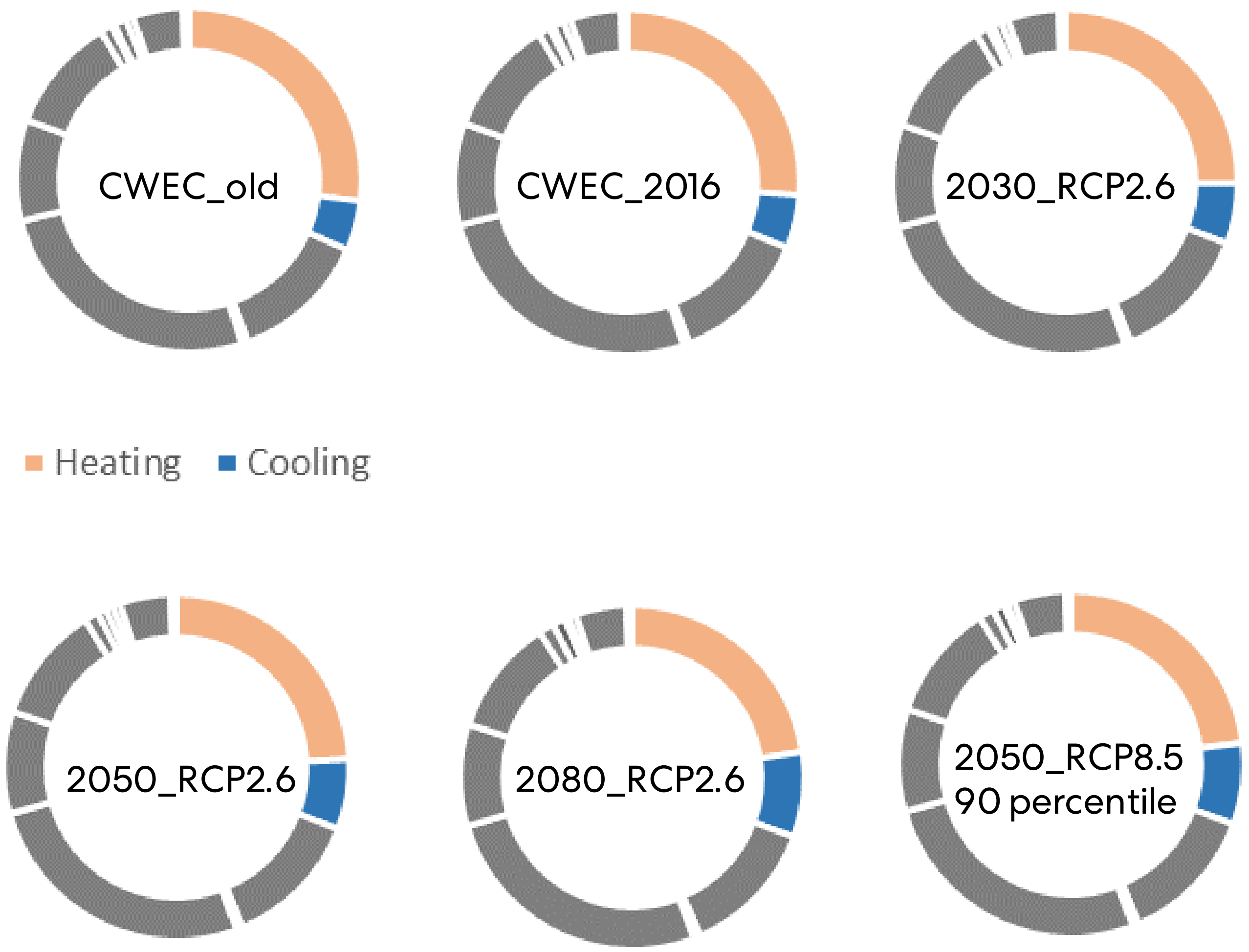
- **Highrise Apartment** in Vancouver overall building energy use will decrease up to 6.5%. The climate change concerns will mainly be associated with thermal comfort, cooling equipment size, etc.;



Infographic by Tyrone, Cheney, and Mohammed

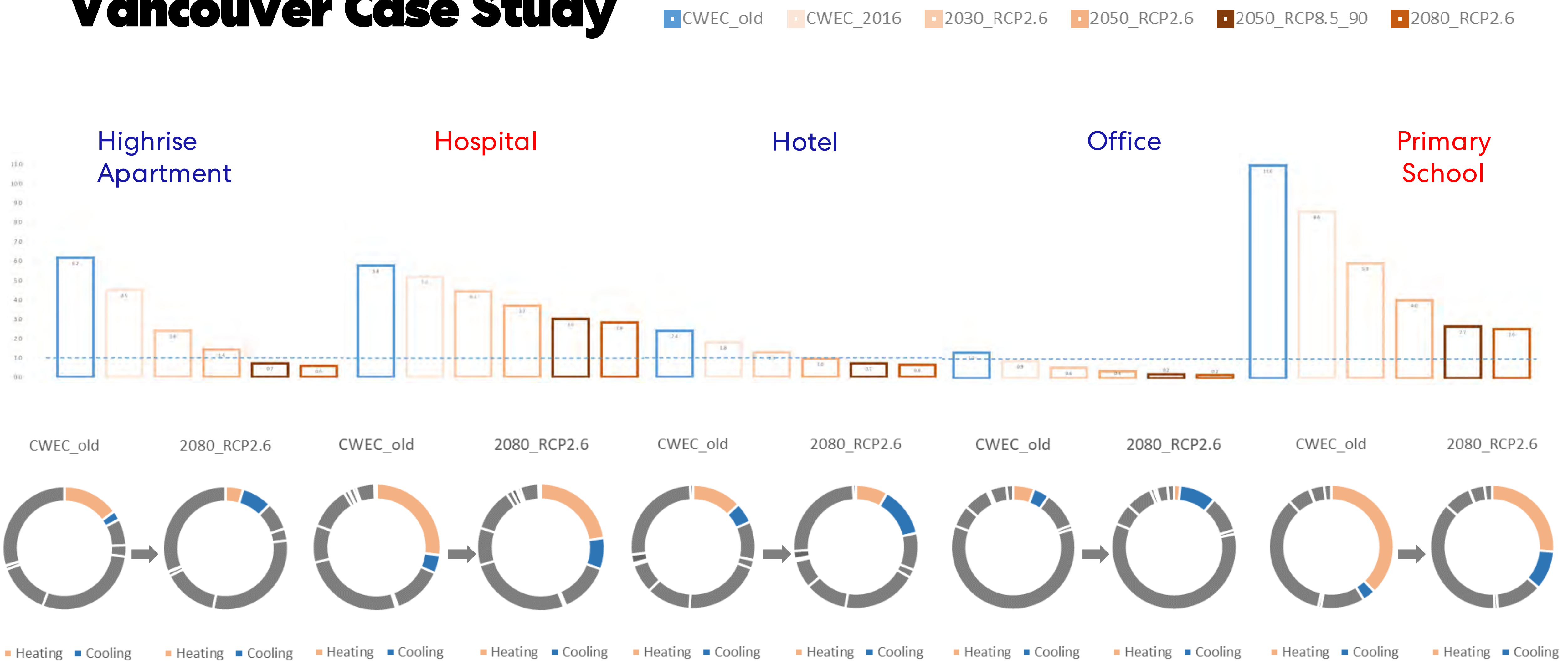
Vancouver Case Study

- **Hospital** in Vancouver will NOT switch from heating energy dominated to cooling energy dominated



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study



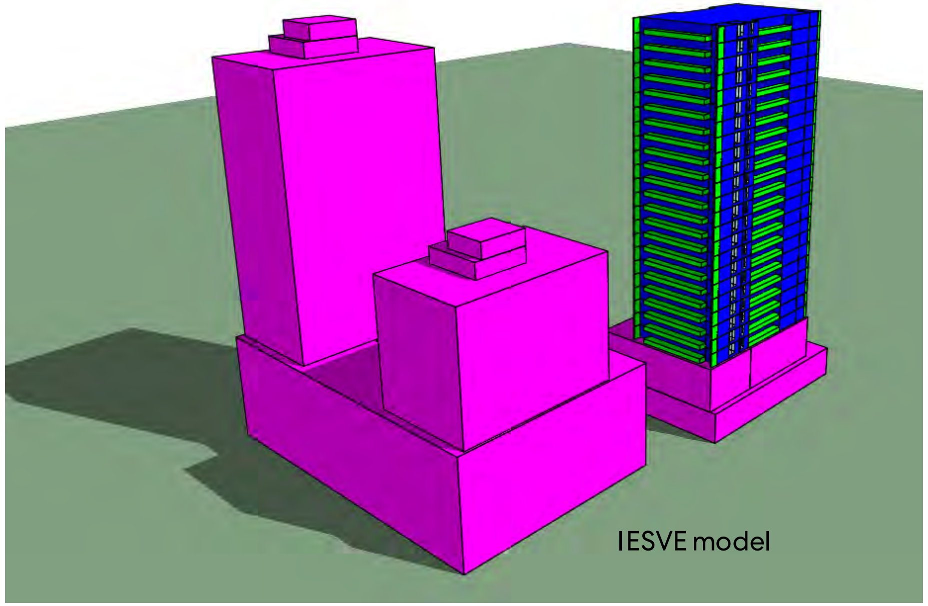
Infographic by Tyrone, Cheney, and Mohammed

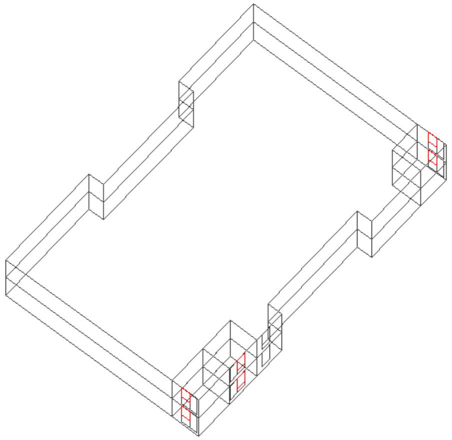
Vancouver Case Study

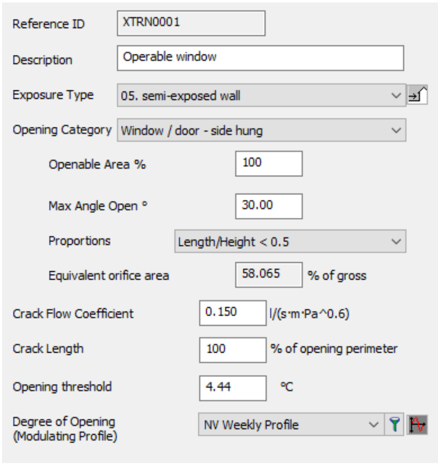
Vancouver Case Study

In order to evaluate the impact of climate change on thermal comfort (naturally ventilated condition), the following two weather files are employed in the simulations:

- CAN_BC_Vancouver.Intl.AP.718920_CWEC2016.epw (new CWEC 2016 weather file currently using for BC step code compliance);
- CAN_BC_Vancouver Intl AP_HadCM3-A2-2050.epw (CWEC 2050 weather file generated by CCWorldWeatherGen based on RCP2.6)







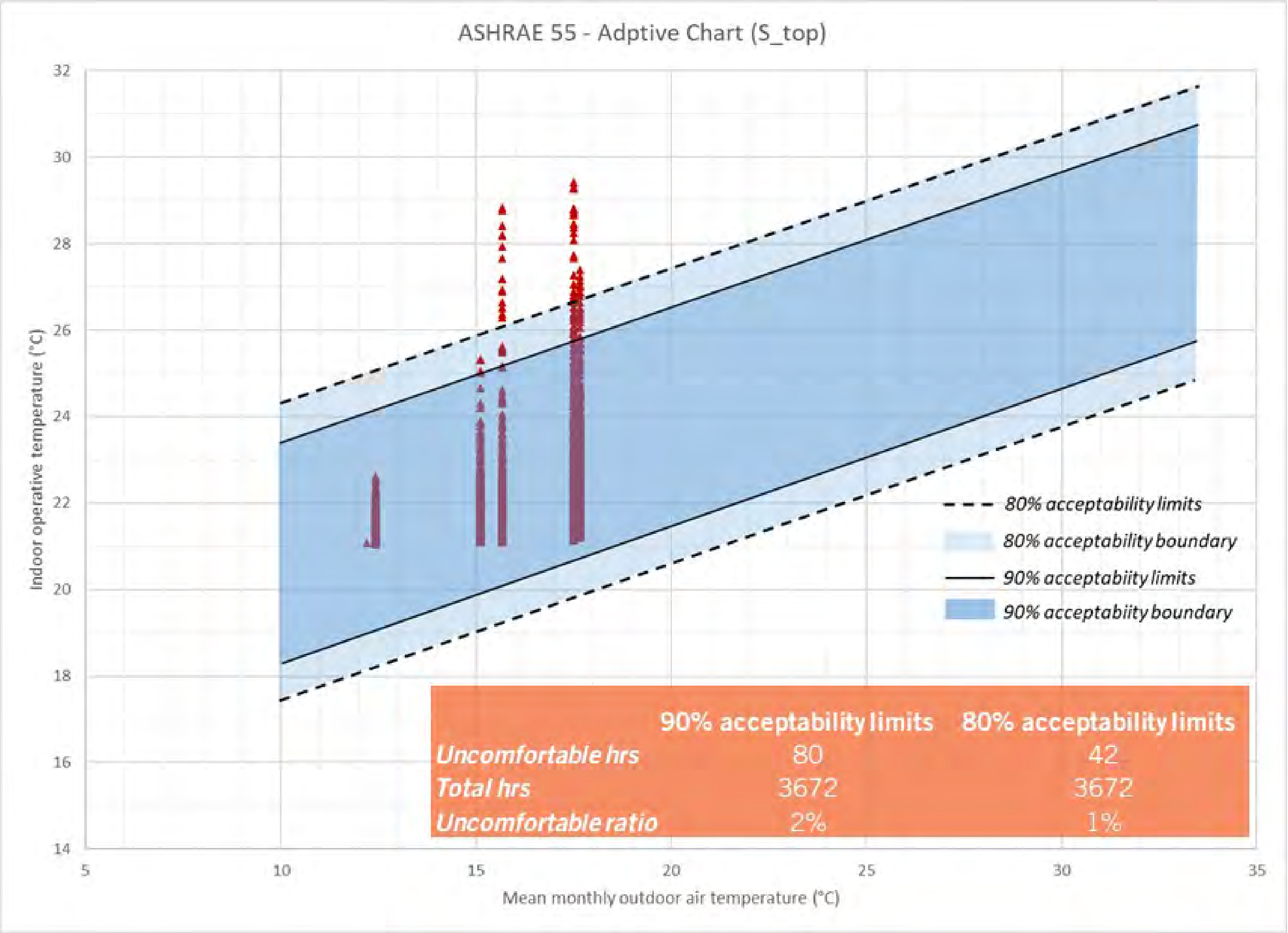
Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

2016 South orientation

As per ASHRAE 55 adaptive method, thermal comfort condition is defined by the relationship between indoor operative temperature and mean monthly outdoor air temperature. In Vancouver, the mean monthly outdoor temperatures for the hotter months are:

	Mean temp. (ºC)
May	12
June	15
July	17
August	18
September	16



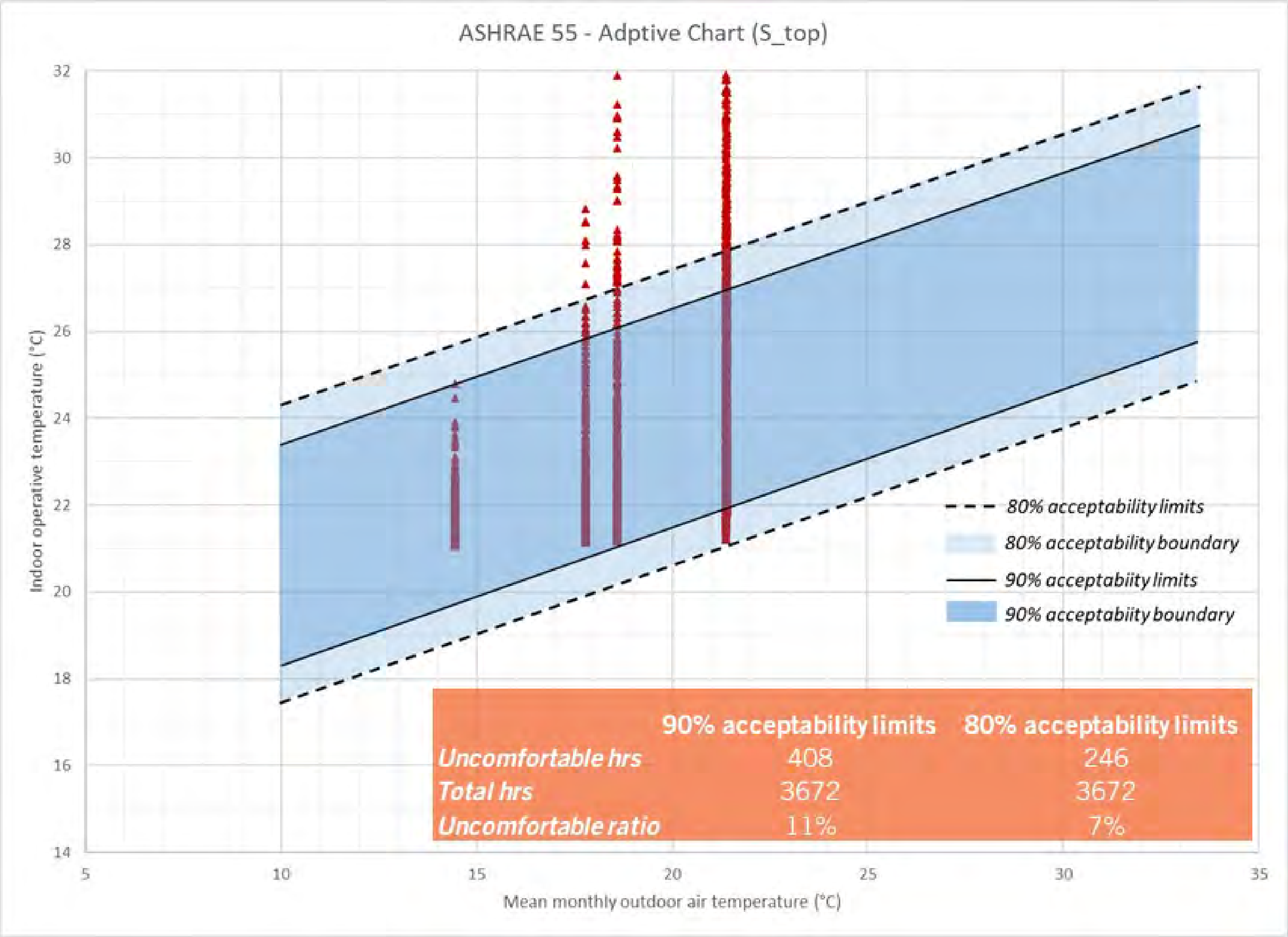
Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

2050 South orientation

As per ASHRAE 55 adaptive method, thermal comfort condition is defined by the relationship between indoor operative temperature and mean monthly outdoor air temperature. In Vancouver, the mean monthly outdoor temperatures for the hotter months are:

	Mean temp. (ºC)
May	14
June	18
July	21
August	21
September	19

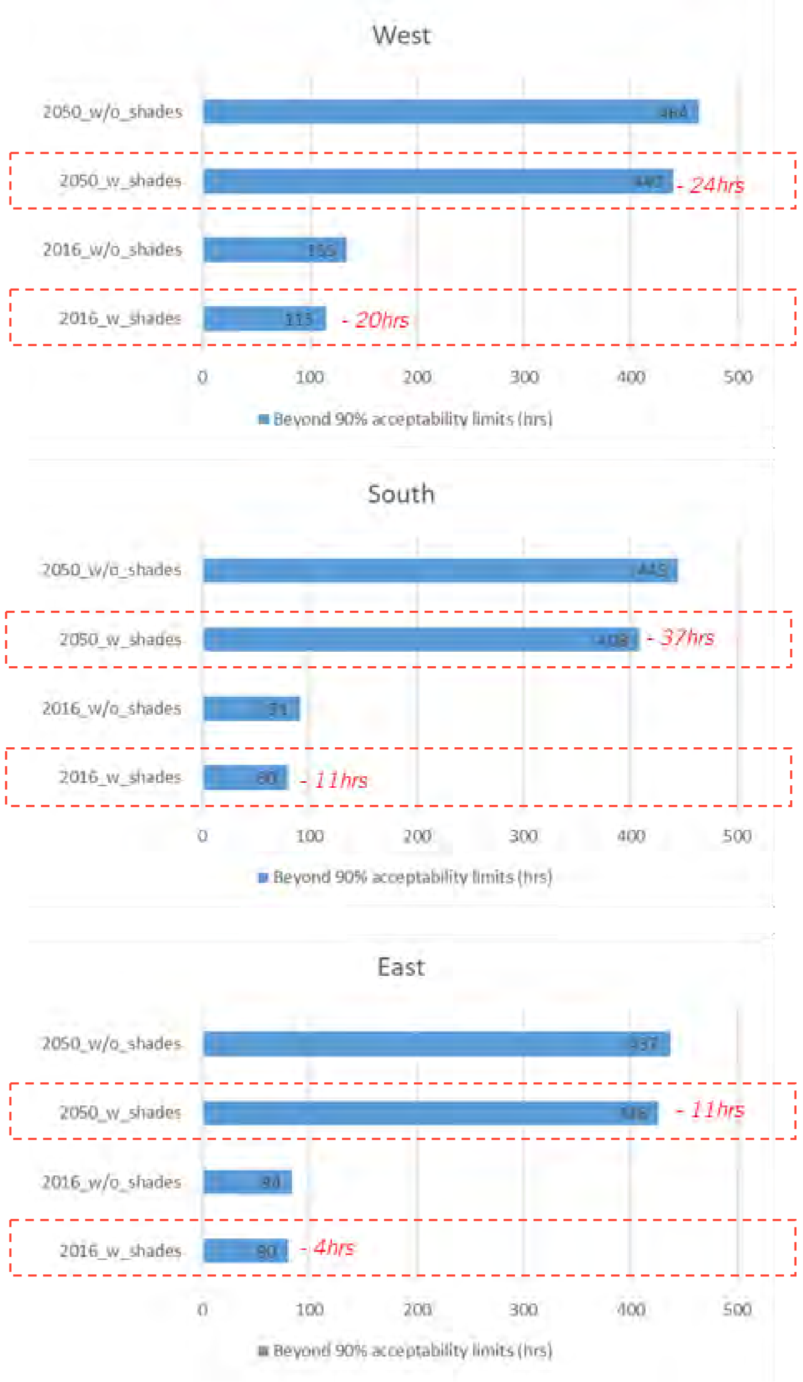


Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

The operative temperatures (what humans experience thermally in a space, it is the combined effects of the mean radiant temperature and air temperature) profiles indicate the impact of climate change (2016 vs. 2050).

Passive solar gain reduction strategies could work **but**...



Infographic by Tyrone, Cheney, and Mohammed

07 Conclusion

Cities and Climate Key Findings

We assessed various locations, building types, and climate characterization for the typical Department of Energy weather files, and in some cases more current one with a transformation to 2020, 2050, and 2080 prediction for 1.5ºC and found the following takeaways:

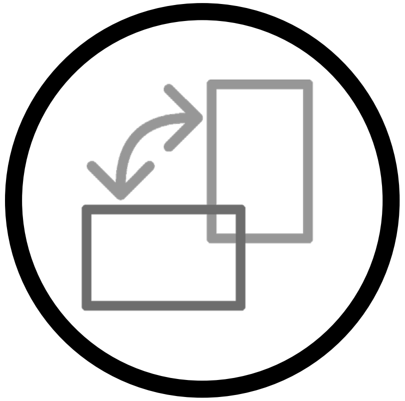
- Very Cold Climates like Fairbanks, Alaska
  - There were more hours where the mechanical system does not adequately manage heating or cooling setpoints
- Cool Humid Climates like Buffalo, New York
  - The mechanical systems were less effective at removing heat gain through the glazing system. There were more hours where the mechanical system does not adequately manage heating or cooling setpoints.
- Very Hot Climates that are most like Honolulu, Hawaii
  - There were more hours where the mechanical system does not adequately manage cooling setpoints, and much more dramatic requirements to reduce the moisture content of the indoor air, and issues with excessive solar heat gain from the fenestration.

Building and Climate Key Findings

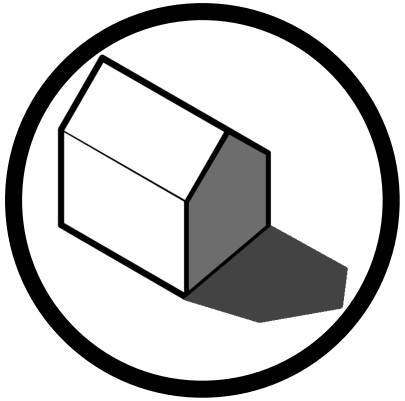
- Temperate Climates like Cool and Dry
  - Buildings in temperate climate zones are more sensitive to climate change and more vulnerable to the switch of heating/cooling plants;
- Vancouver Case Study
  - In Vancouver, high-rise apartments, hotels, and offices are more likely to switch the heating/cooling plants (challenge to the current system design);
- Expected Energy Use
  - Even with heating/cooling plants switch potential, no significant energy use increases are observed in the future climate simulations (a further investigation is necessary);
- Passive cooling strategies
  - They are important, but mechanical system would be more reliable in extreme climate conditions.

Adaptable and Resilient Passive Design Strategies

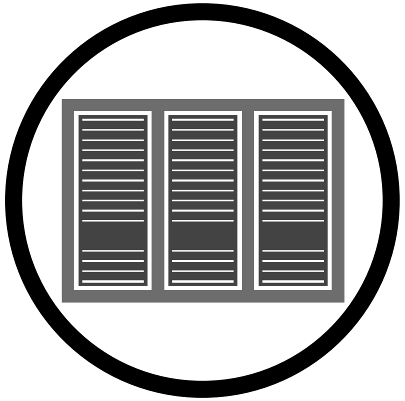
Infographic by Tyrone, Cheney, and Mohammed



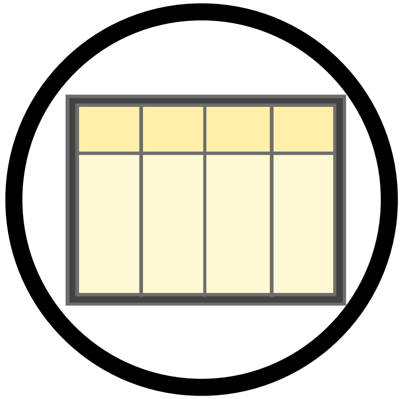
Orientation



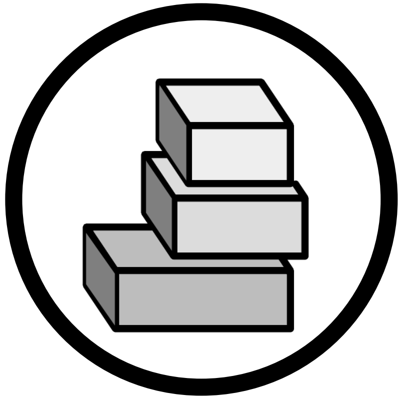
Self-shading



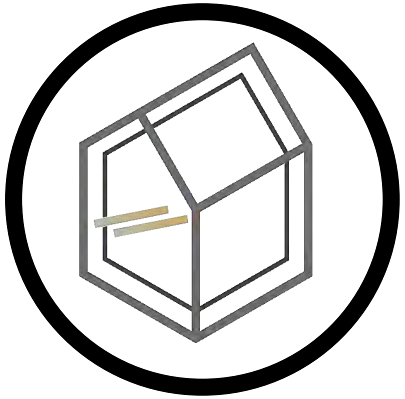
Shading Devices



Low-emissive glazing



Massing



High Thermal Mass

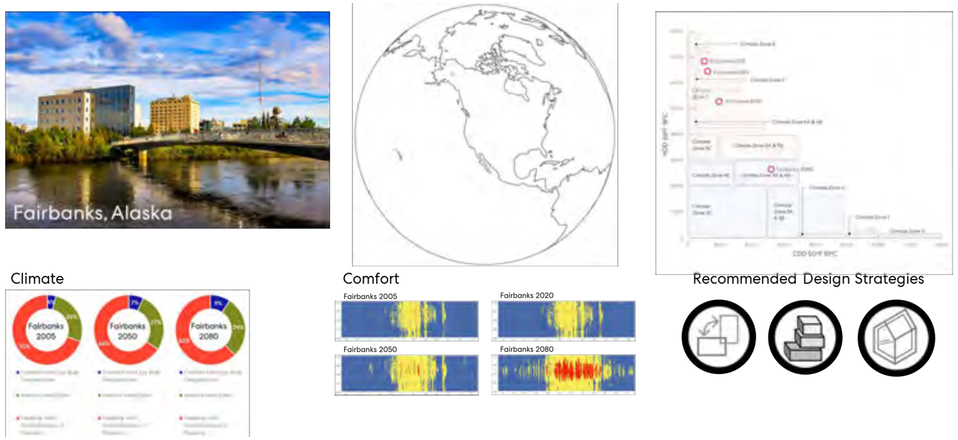
Evaporative Cooling

Active Cooling

Deliverables

We studied the impacts of available and current weather files with transformed ones to approximate a 1.5ºC global temperature rise by 2100 and assessed them for:

- Determination of passive strategies, thermal envelope load, and changes in temperature and relative humidity
- Breakdown of energy consumption by end-use, and by building type, and by location.
- Develop an online location-based weather transformation database coupled with energy simulation, exterior thermal comfort, and passive design strategies with indicators that address resilience design strategies to be online in early spring of 2020.



Infographic by Tyrone, Cheney, and Mohammed

Chena River, Fairbanks Alaska Photograph by Karen Mallonee via Flickr

08 **Limitations** | **Future Work**

More Locations

More Building Types

The research assessed a small number of building types such as a ***Large Office Building, Primary School, Hospital, Large Hotel, and High-Rise Apartment***.

It is important to consider other building types like:

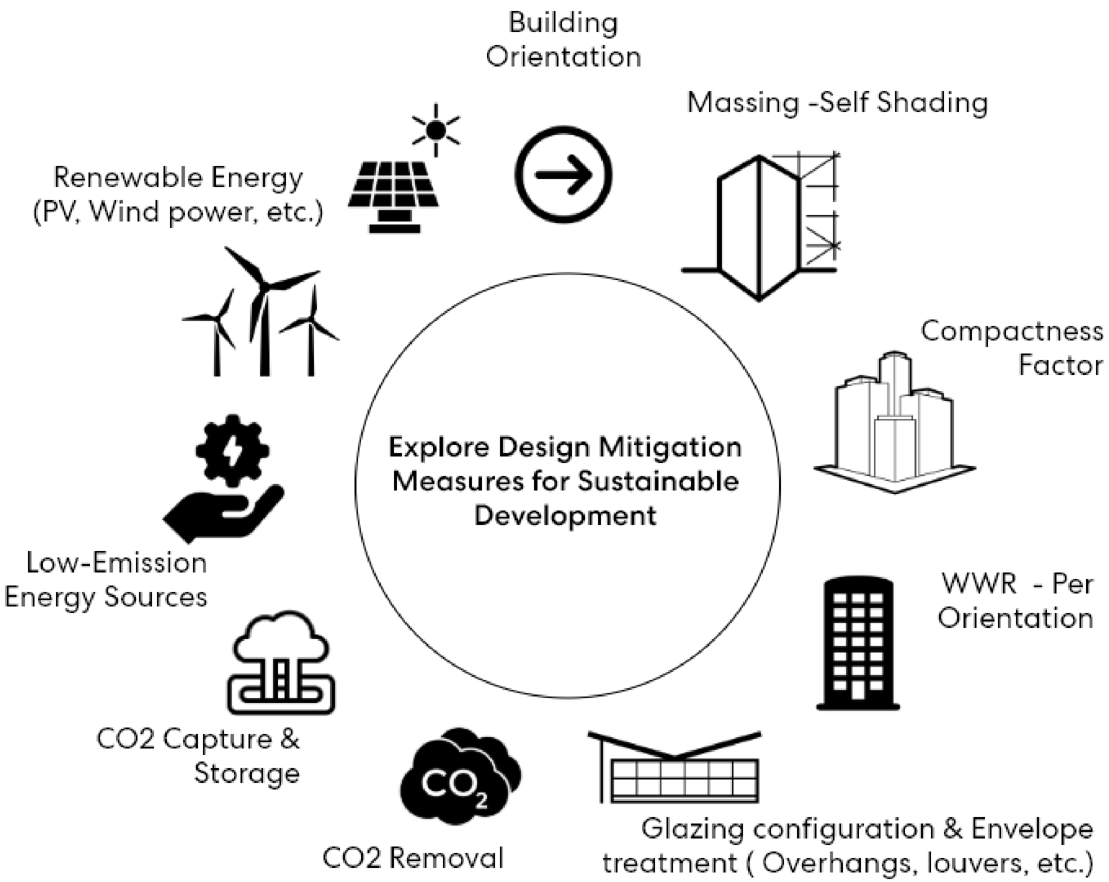
- Secondary School
- Quick Service Restaurant
- Full-Service Restaurant
- Outpatient Health Care

An extension of the work may seek interest in developing new models for additional building types such as:

- Indoor Arena and Stadiums
- Library
- Transportation Terminal

Future Work

The next steps will consider extending the case studies to understand the relative **trade-offs** between enhanced energy efficiency, building massing and orientation, glazing configuration and window to wall ratio, envelope insulation, low-emission energy sources, renewable energy, carbon dioxide capture and storage, carbon dioxide removal, and lower energy intensity for sensitivity that most impact design mitigation strategies.

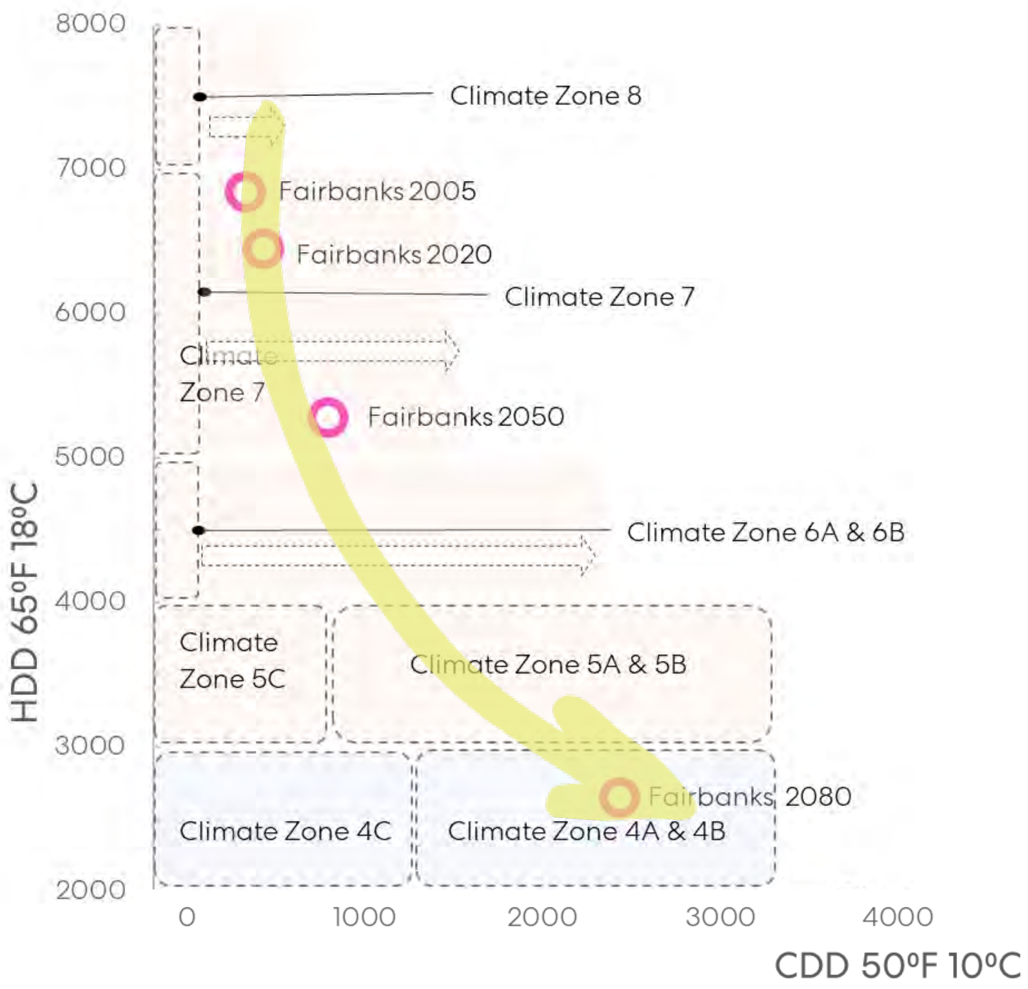


Design Space Exploration of Cities and Climate Zones

The limited scope of locations and climate zones reveal that most of these areas are either in transition or will soon change in their heating degree and cooling degrees consistent with a warming trend in the next 30 to 50 years:

- Most of the locations experience a remarkable climate zone. An example would be for El Paso, which is 3B or Warm and Dry, which may become 2B or Hot and Dry.
- A few were more aggressive such as Fairbanks, which may transition from climate zone 7 or 8 or Very Cold to 4B or Mixed and Dry.

- More work is necessary to understand the impact of these changes to the common use of a 10-15% safety factor in assumptions for future equipment density, occupancy, and weather pattern changes.



THANK YOU!

Perkins&Will