

A conceptual image showing two hands, one from the left and one from the right, cupping a globe of the Earth. The hands are rendered with a texture that looks like weathered stone or aged parchment, with colors ranging from dark brown to light tan. The globe is a realistic representation of Earth, showing continents and oceans. The background is a solid, dark brown color.

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

Cheney Chen | Tyrone Marshall | Mohamed Imam

Perkins&Will

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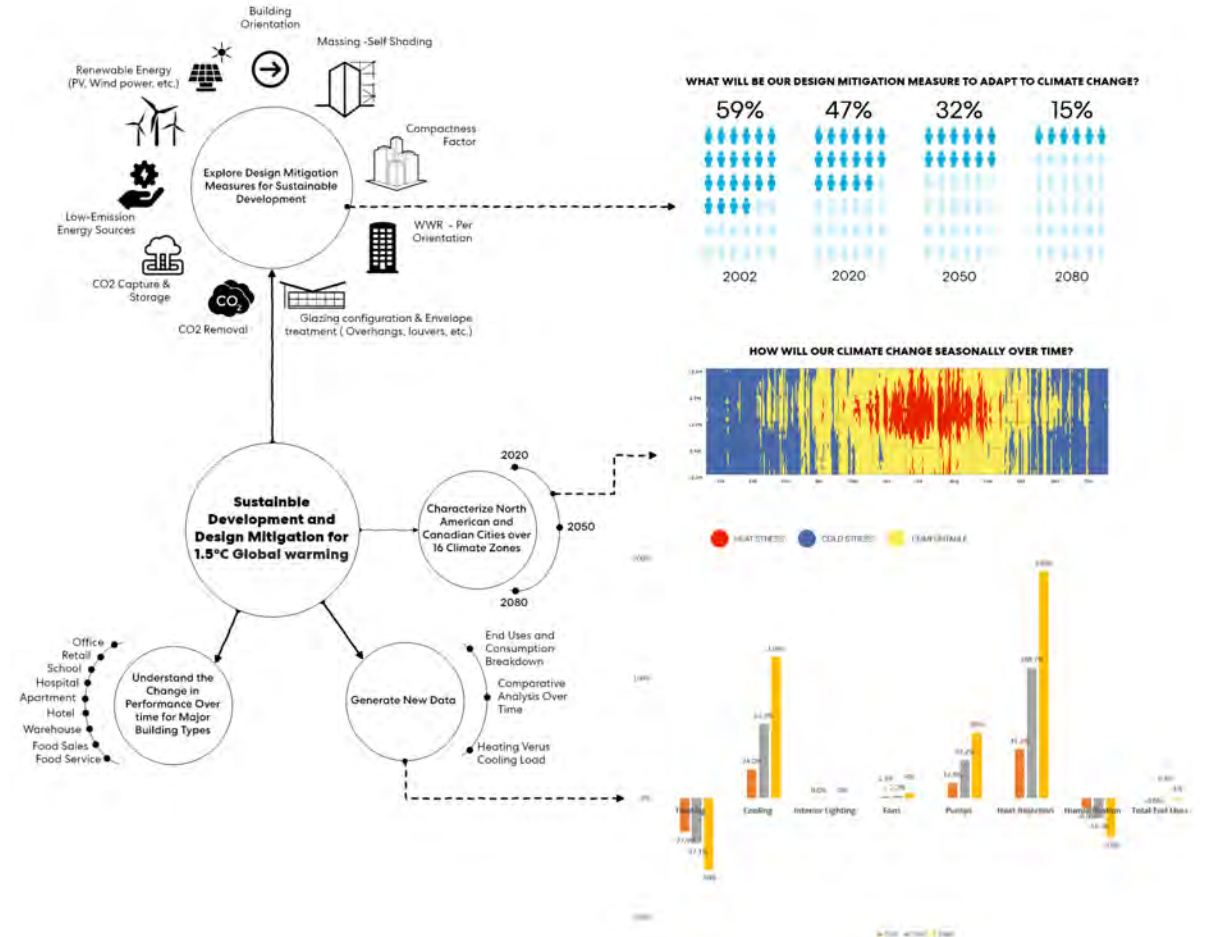
08 Limitations and Future Work

01 Introduction



A Future of Building-Based Design Climate Simulation

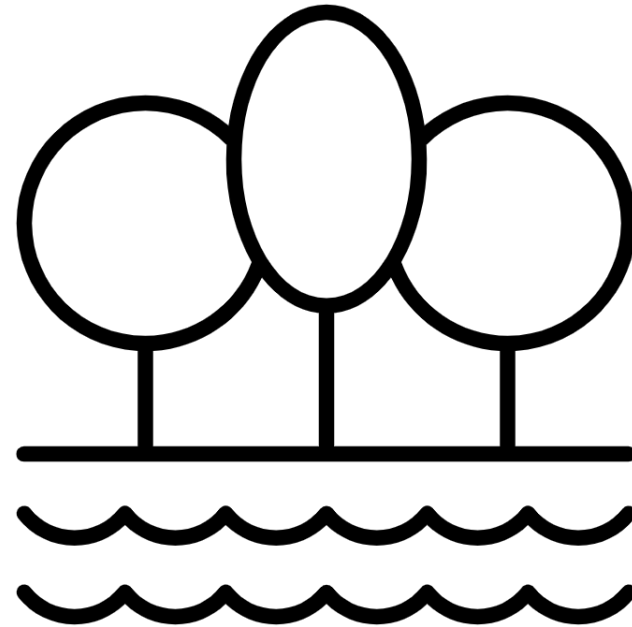
- Current energy modeling weather files are unlikely to include any indication of risk from potential climate change or increasing intensity and frequency of extreme weather events.
- There is a need to incorporate climate change projections in energy simulations and prepare architects for a better understanding 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.



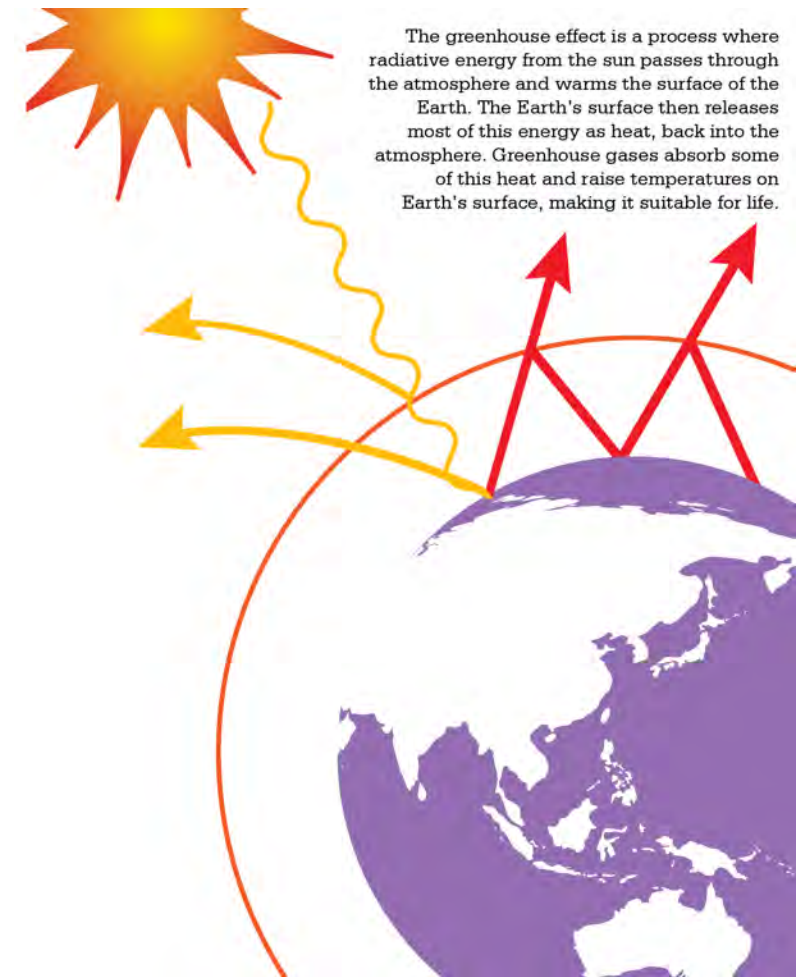
Why We Should Care?

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
<i>More Frequent Record Warm Temperatures</i>	Pedestrian Exterior Thermal Comfort Higher Outside Air Temperatures	Exterior Space Programming 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)

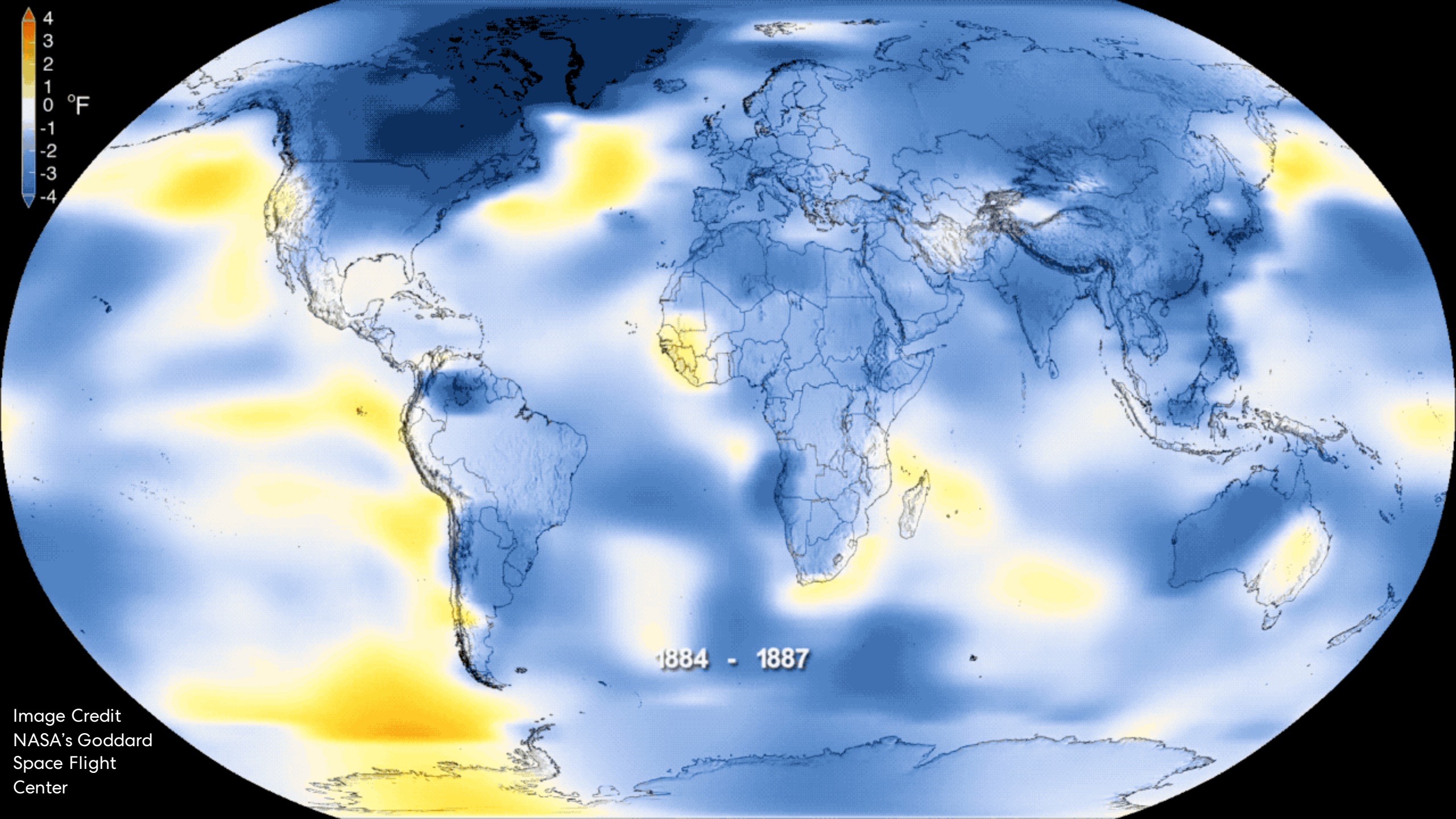


Image Credit
NASA's Goddard
Space Flight
Center



02 Literature Review



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



AIA commentary on climate change mitigation

The architect's critical role in climate change mitigation

The following commentary relates to AIA's Public Policies and Position Statements on Sustainability, Category II, The Practice: Public Policy II.C, Architects Are Environmentally Responsible, Position Statement 57.

Climate change caused by human activity remains one of the most urgent challenges of the 21st century. Levels of carbon dioxide and other greenhouse gases already are causing rising sea levels, extreme weather, and degradation of natural resources. These trends are projected to continue and possibly accelerate, posing significant risks to national security, human health, food supply, global economies, and natural ecosystems. These result in refugee crises. The threat of climate change is understood by climate scientists, the U.S. Department of Defense, the general public, and the financial and insurance industries.

The built environment accounts for the majority of human-caused carbon emissions globally, and as an ethical and practical obligation of every architect to work to combat climate change. To do this, each architect must educate ourselves on the consequences of climate change on the built environment so we can educate and make decisions that protect people and the planet.

This includes extreme temperatures and precipitation, drought and wildfires, and sea level rise. Architects must plan and design to adapt to these future conditions and mitigate the impacts of a changing climate by ways to reduce carbon dioxide and other greenhouse gas emissions. We must also learn how to work with our collaborators to deliver projects with robust energy savings and carbon reductions.

Climate change urgency

Since AIA's sustainability position statements were approved in December 2007, we have experienced unprecedented rise in global temperatures. Every month from May 2015 through July 2016 presented high for that month's global temperature, with July and August 2016 tying for the hottest months on record. Over a year ago the world came together in Paris for the 21st Conference of the Parties (COP21) of the Framework Convention on Climate Change (UNFCCC), and signed an historic agreement to keep the global temperature increase to "well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C."

To meet this target, the world must reach zero fossil fuel CO2 emissions in the built environment by at least 2050 and zero total global greenhouse gas emissions by 2060 to 2080. Just days after the Paris Agreement, the UN hosted the second ever "Buildings Day" at COP22 in Morocco. "Buildings Day" highlighted the building and construction industry in addressing climate change, and laid out a framework for the industry to reach the goals of the Paris Agreement.

In recognition of these events, this commentary expands on the language in the existing AIA Public Policy Position Statements with increased urgency. AIA's public policy, "Architects are Environmentally Responsible," states: "The creation and operation of the built environment require an investment of the earth's resources. Architects must be environmentally responsible and advocate for the sustainable use of those resources."

The supporting position statements go beyond the investment of earth's resources and touch on resource consumption in both material selection and building operations, as well as energy efficiency and renewable energy generation as a form of resource conservation. In addition, the position statement on resilience addresses the need for adaptation to climate change. These position statements are tied together by their recognition of the profound impact that the built environment has on the natural environment.



AIA CLIMATE ACTION – URGENT & SUSTAINED

June 2019 • announcement



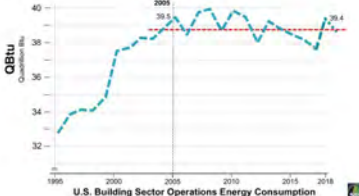
AIA Climate Action URGENT & SUSTAINED

Last week, at the American Institute of Architects (AIA) Conference on Architecture in Las Vegas, the architecture and building community made history when they overwhelmingly voted for the "AIA Resolution for Urgent and Sustained Climate Action." 4,860 yes to 312 no.

The AIA's resolution (see below) calls for its 94,000 members worldwide to "exponentially accelerate the decarbonization of buildings, the building sector, and the built environment."

Make no mistake, we know that when the building community decides to act, change happens.

In 2005, the 2006 Challenge set in motion the development of programs, code improvements and other actions by the AIA, firms, cities, states, and other organizations that leveled off rising CO2 emissions in the building sector, even though the U.S. continued to add about 3 to 4 billion square feet to its building stock every year.

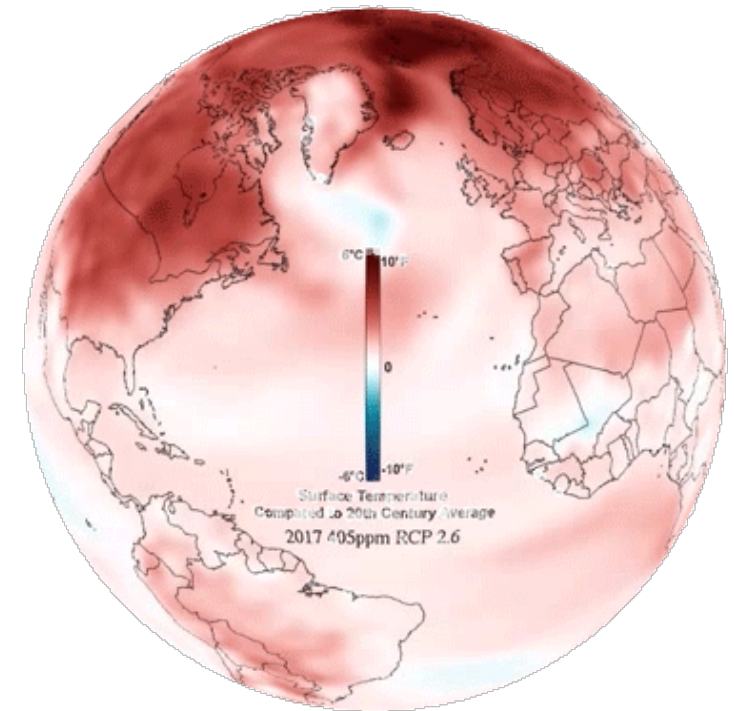


Year	Energy Consumption (Qbtu)
1985	32.5
1990	34.5
1995	36.5
2000	38.5
2005	38.5
2010	38.5
2015	38.5
2018	38.5

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 than 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.

 EnergyPlus

DownloadsDocumentationQuickStartSupport & TrainingLicensingWeather

Log in

Weather Data

Weather data for more than 2100 locations are now available in EnergyPlus weather format — 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. The weather data are arranged by World Meteorological Organization region and Country.

View Weather Data

Select a region below to view weather data.

Africa (WMO Region 1)
Asia (WMO Region 2)
South America (WMO Region 3)
North and Central America (WMO Region 4)
Southwest Pacific (WMO Region 5)
Europe (WMO Region 6)


Search Weather Data

Keyword Search

Search

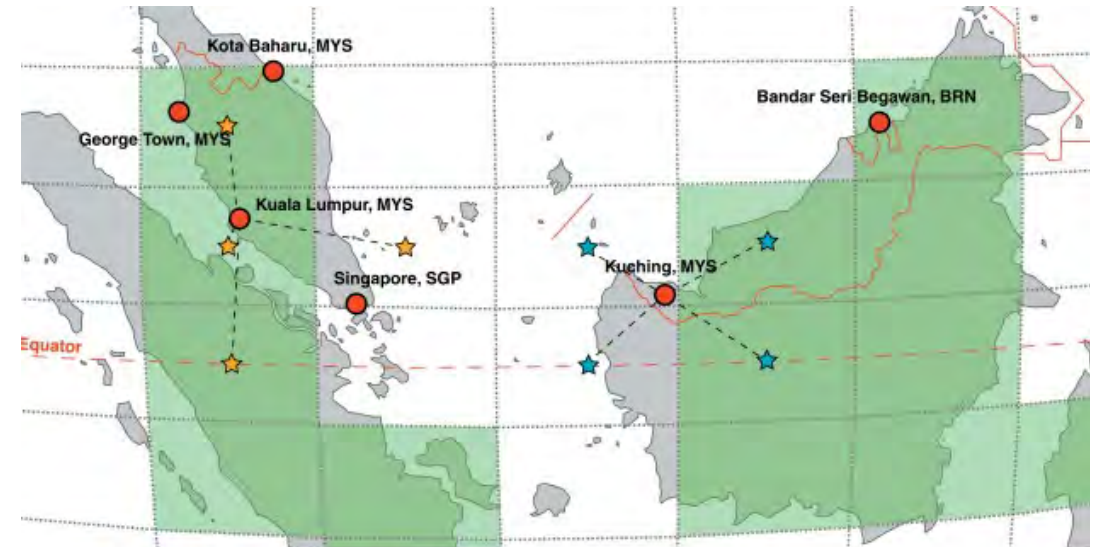
Browse Weather Data

Click on the markers in the map below to access weather data.



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](#)



CCWorldWeatherGen

Climate change world weather file generator

Version 1.8

Sustainable Energy Research Group

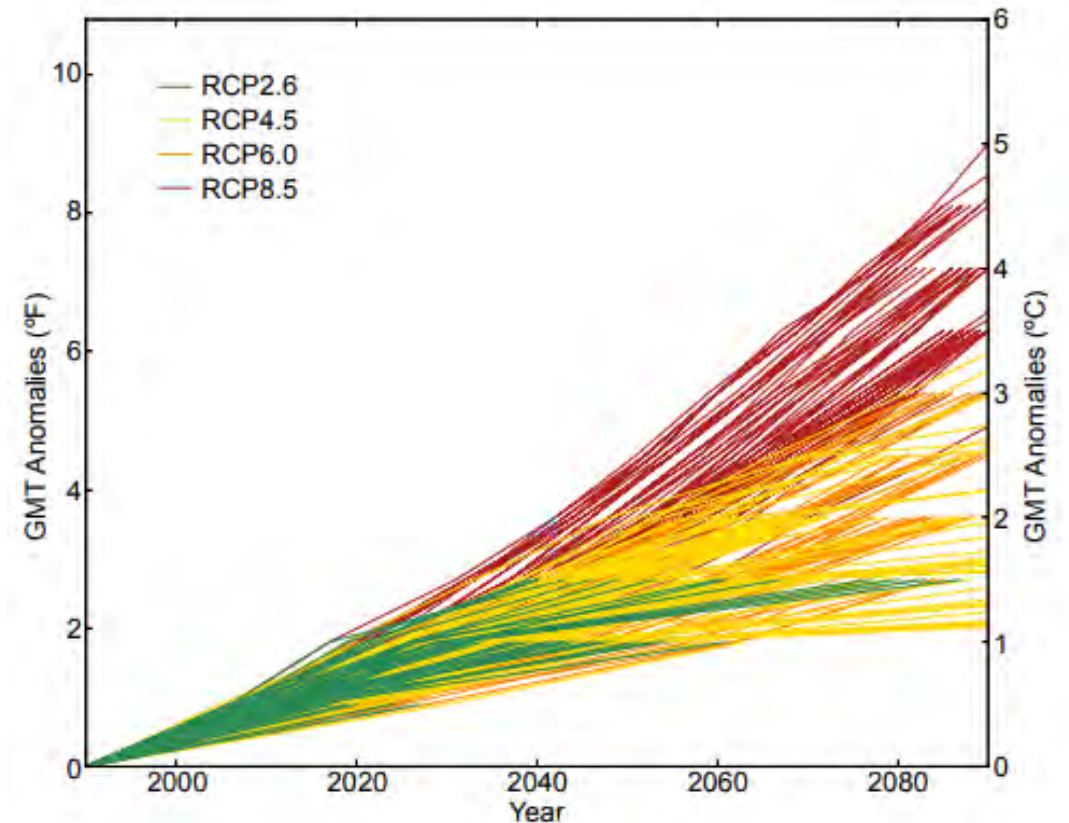
October 2013

UNIVERSITY OF
Southampton

Climate Science Special Report (CSSR)

U.S. Global Change Research Program CSSR 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.

WEATHERSHIFT™ v2.0

Heat Rain TopUp Design Days Library

Country: Canada

Location: Vancouver

Emission scenario: RCP 8.5

Warming percentile: 95% (most warming)

[View Future Weather](#)
or upload EPW file near Shift location

Buildings and infrastructure built today will experience significantly different weather patterns over the course of the 21st century due to the impact of climate change.

The WeatherShift™ tool uses data from global climate change modeling to produce EPW weather files adjusted for changing climate conditions. (EPW files contain hourly values of key weather variables for a typical year and are intended to be used for simulating building energy requirements.) The projected data can be viewed for three future time periods based on the emission scenario selected to the left.

* This site is preloaded with some EPW files provided to the public domain by the US Department of Energy. For all other shift locations - indicated by an * -- an EPW file must be uploaded as the basis for shifting.

[Purchase WeatherShift EPW Files from IES](#)

[Legal Notices](#) | [About](#) | [Authorized Users](#) | [Contact](#)

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

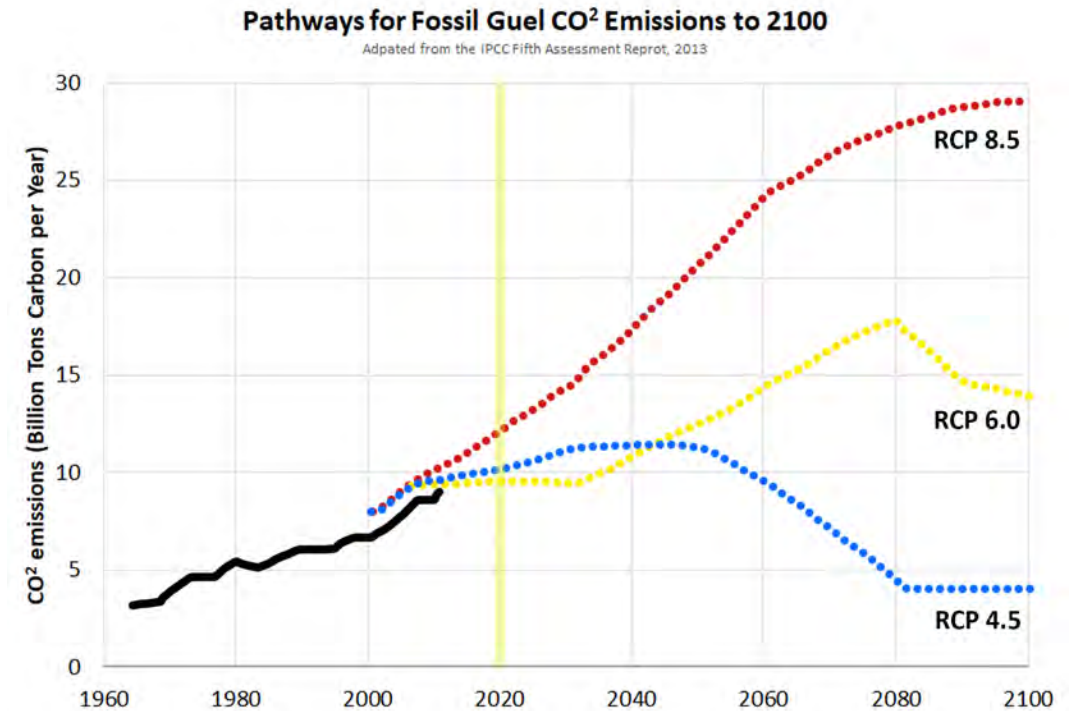
The background of the slide is a vibrant, abstract pattern of numerous arrows. These arrows, in various sizes and colors (including blue, green, yellow, orange, red, and pink), all point towards a central white circular area. The arrows are arranged in a radial pattern, creating a sense of convergence and focus on the center.

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.

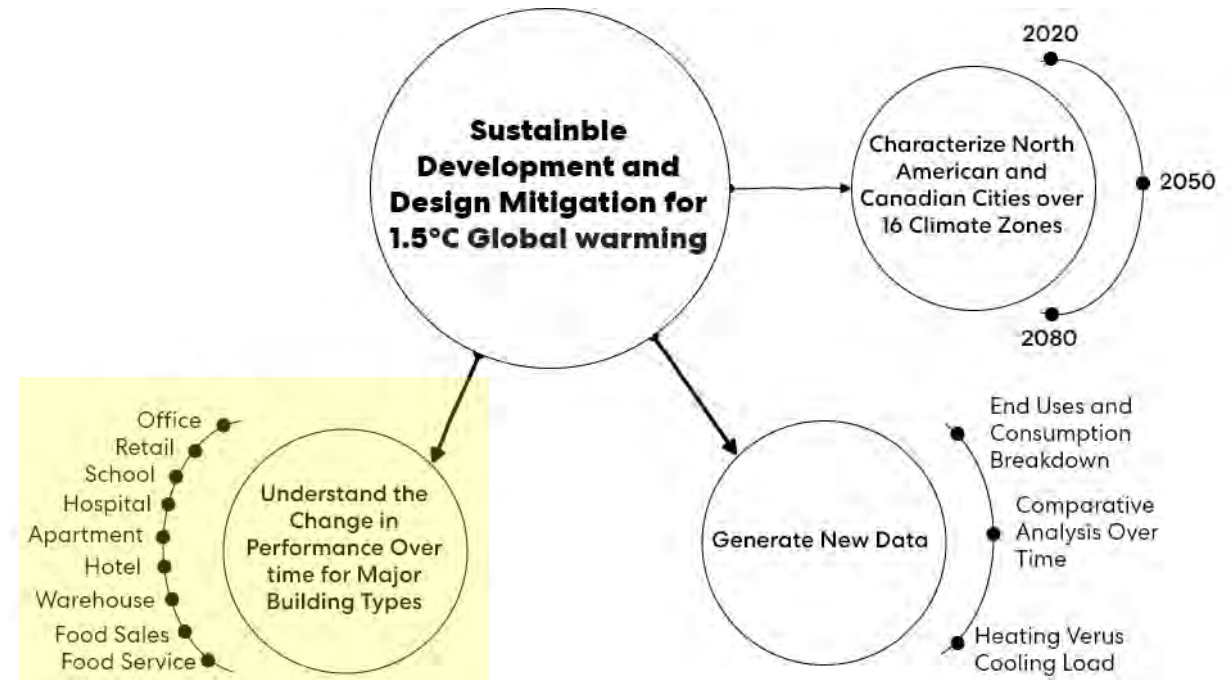
Define Scope

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 5-6°C* for additional analysis.

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

However, our 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

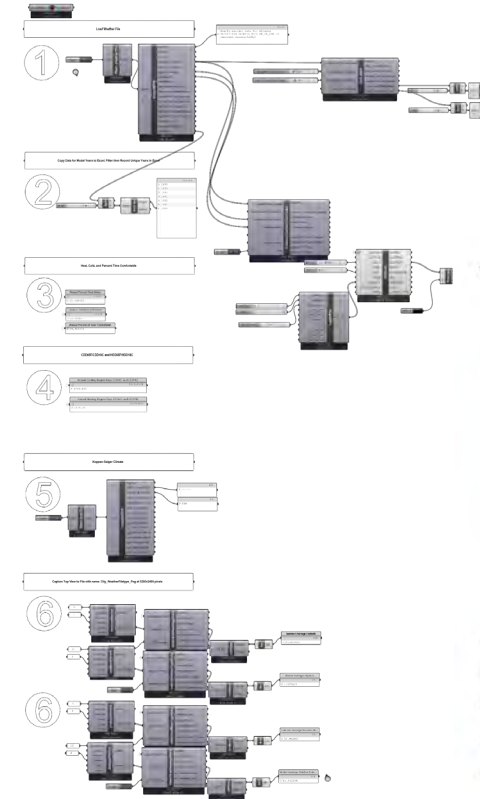
Thermal Comfort and Stress for Cities Comparison

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.

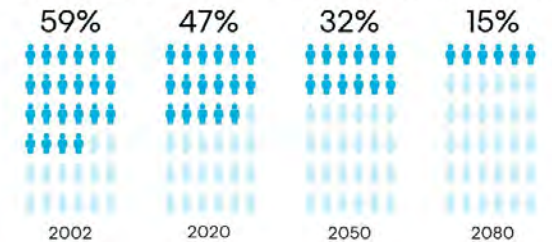
- The thermal comfort maps only report the data from weather file for temperatures, windspeed, and relative humidity.

Ladybug Thermal Comfort

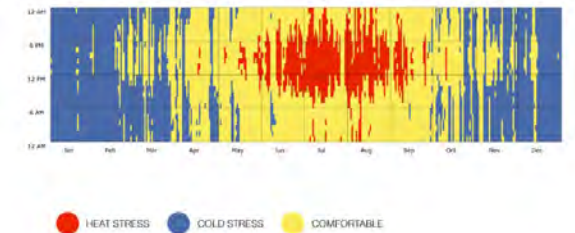
Outdoor Comfort with Universal Thermal Climate Index (UTCI)



WHAT WILL BE OUR DESIGN MITIGATION MEASURE TO ADAPT TO CLIMATE CHANGE?



HOW WILL OUR CLIMATE CHANGE SEASONALLY OVER TIME?



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.

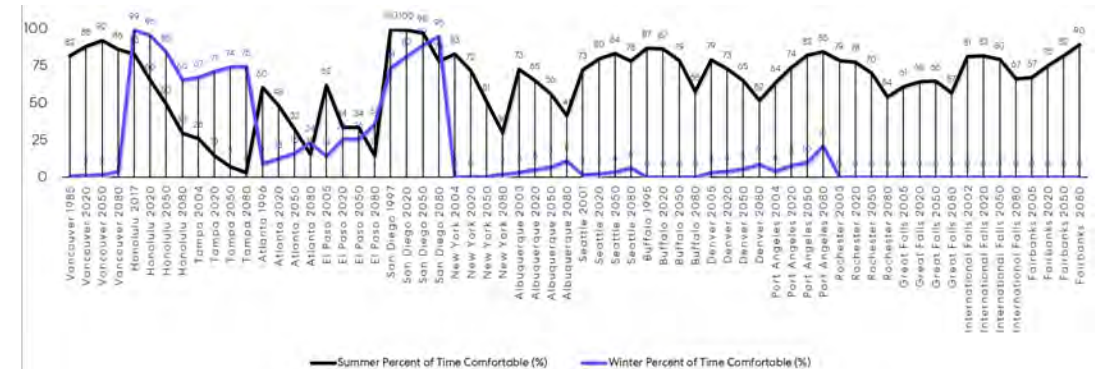


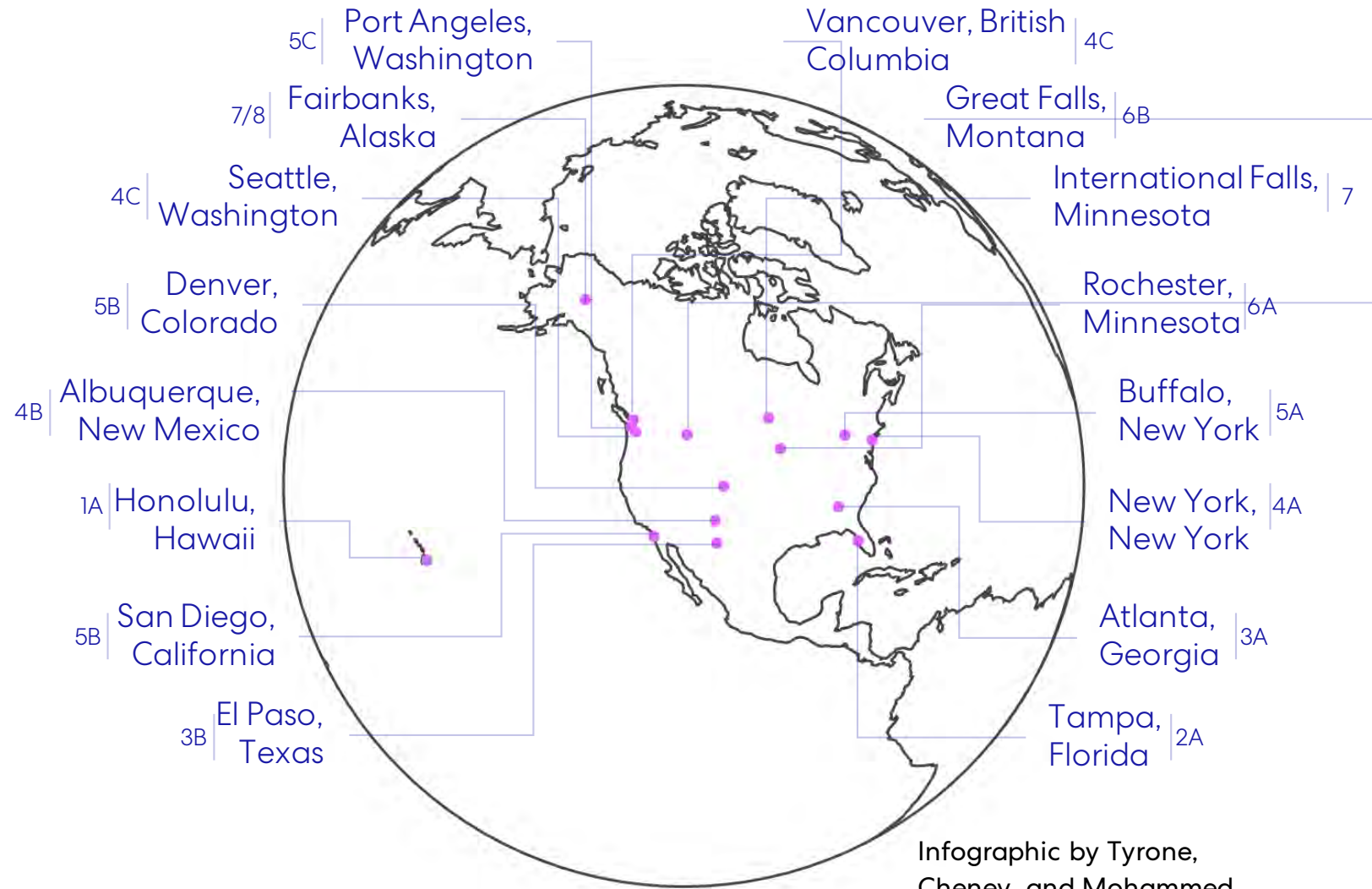
Chart by Tyrone, Cheney, and Mohammed

A photograph of a flooded urban area. In the foreground, a paved path and a grassy area are submerged in murky, brown water. Several ducks are swimming in the water. In the background, there are trees, a stone wall, and buildings, including a tall, modern apartment building on the right. The sky is overcast.

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:



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 9°C or 48°F and less than 26°C or 79°F.

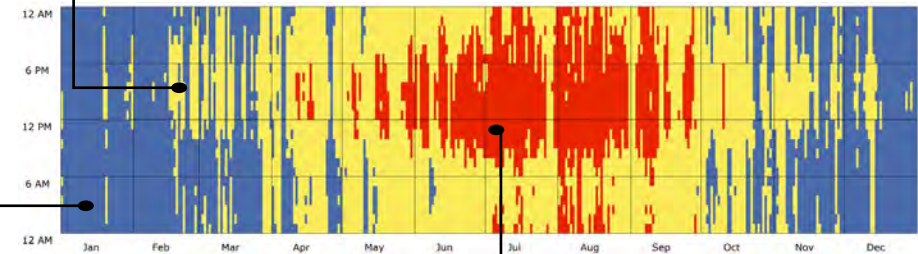
- Cold Thermal Stress or “BLUE” color or COLD!

- › The occupant in an exterior area would feel cold stress as the UTCI index is less than 9°C or 48°F.

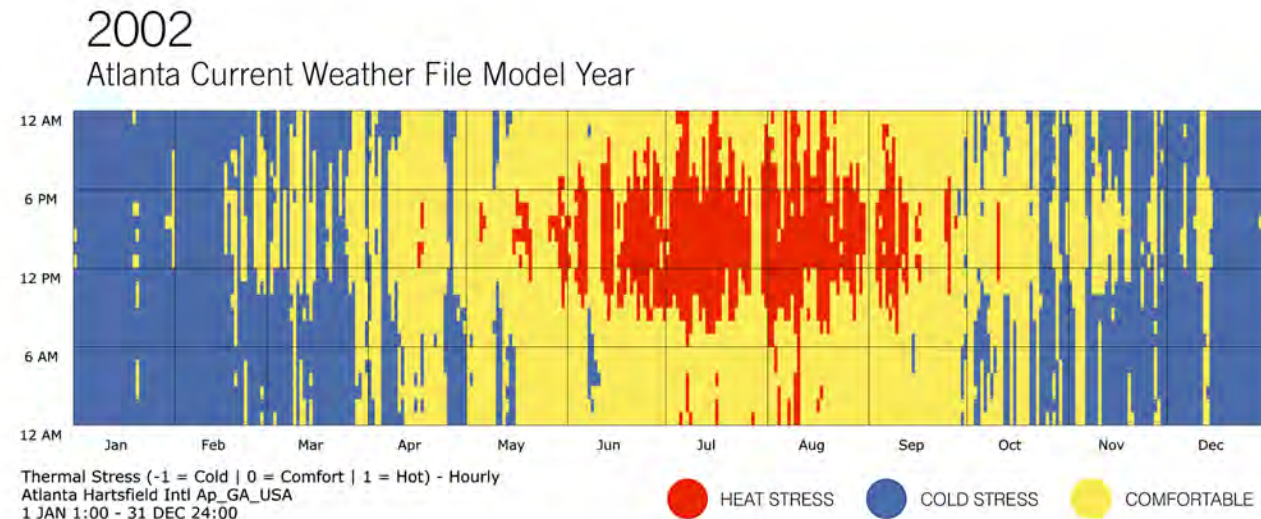
- Heat Thermal Stress or “RED” color or HOT!

- › The occupant in an exterior area would feel cold stress as the UTCI index is more than 26°C or 79°F.

Atlanta 2020 Weather File Transformation



FUTURE CLIMATE WEATHER PROJECTIONS

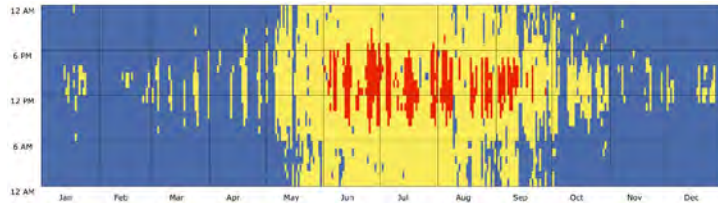


After comparing the changes annually in many different categories for each climate zone we map the freely available or current weather file climate zone per ASHRAE 169-2013 and then we plot the future weather projection climate for each of the locations from the change in heating and cooling degree days.

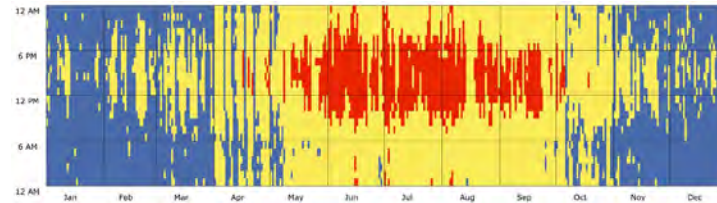
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

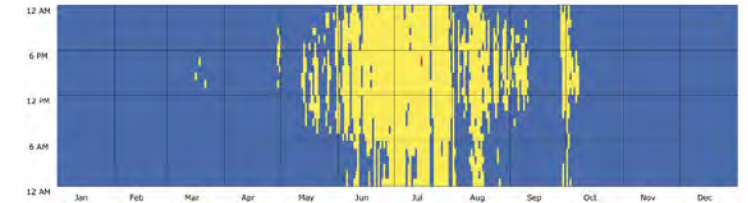
Denver 2005



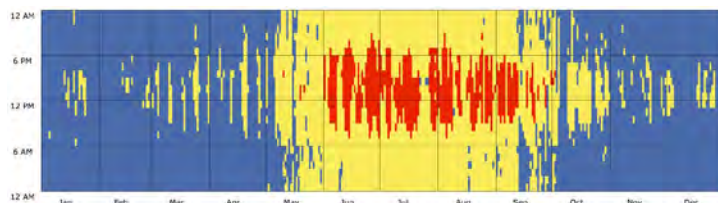
El Paso 2005



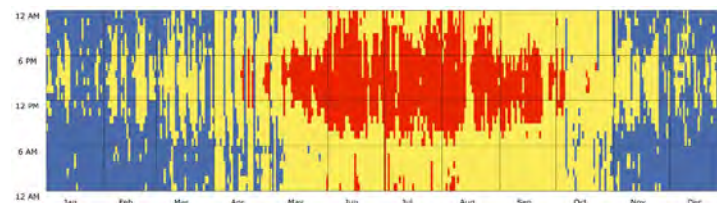
Fairbanks 2005



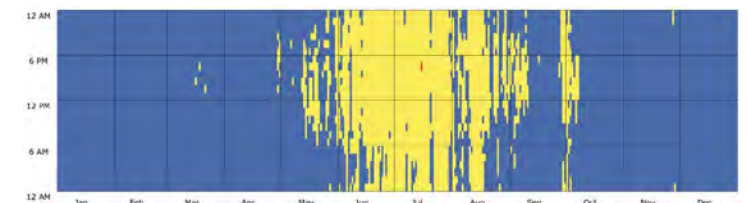
Denver 2020



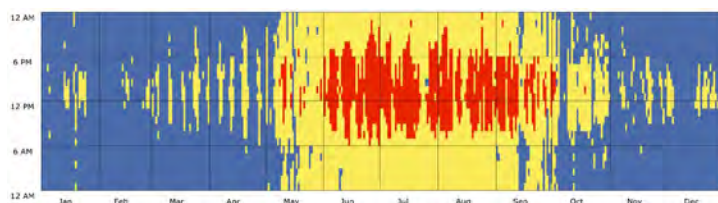
El Paso 2020



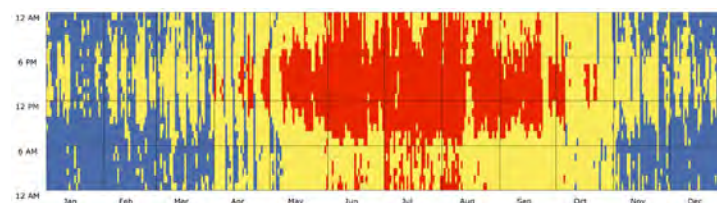
Fairbanks 2020



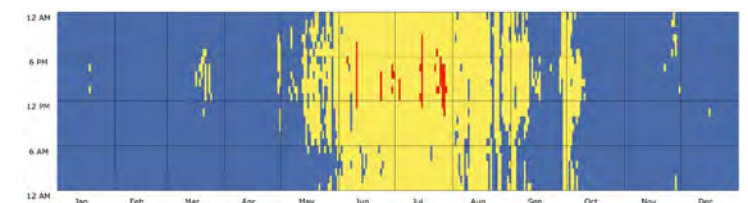
Denver 2050



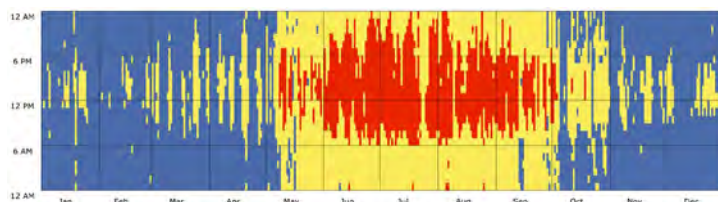
El Paso 2050



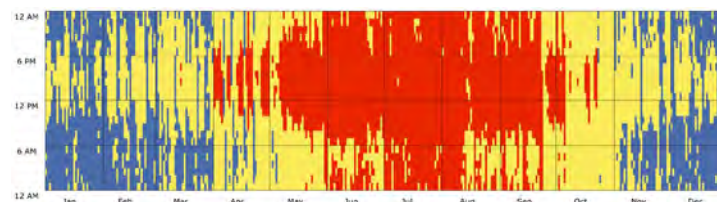
Fairbanks 2050



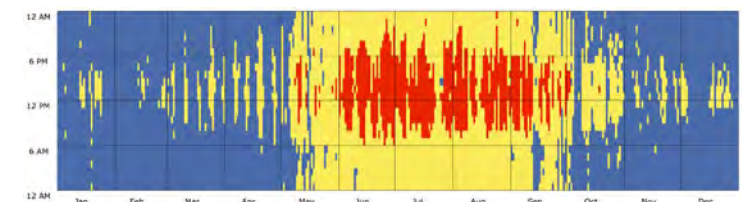
Denver 2080



El Paso 2080



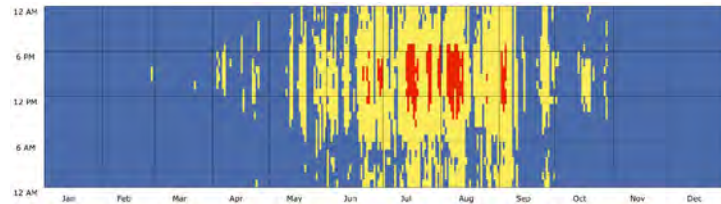
Fairbanks 2080



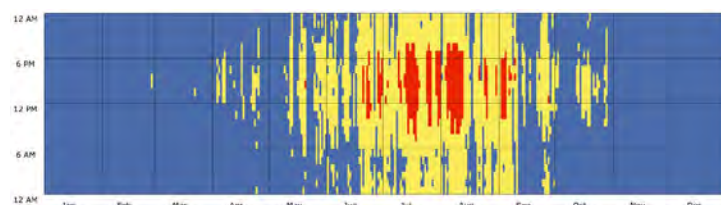
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

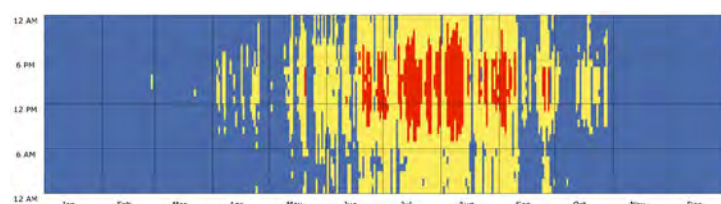
Great Falls 2005



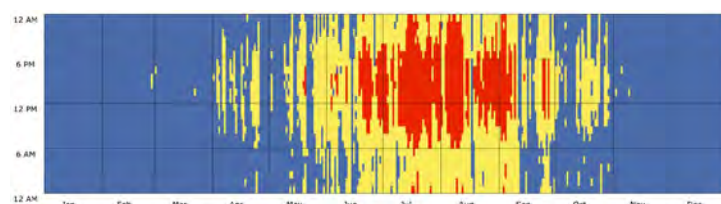
Great Falls 2020



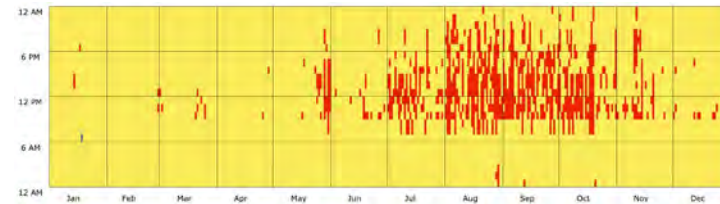
Great Falls 2050



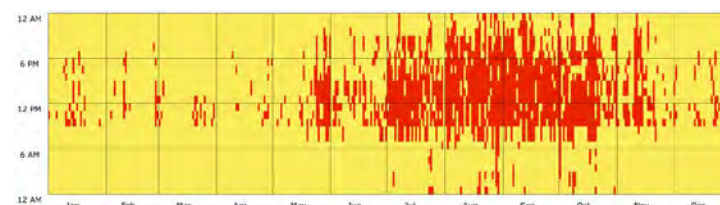
Great Falls 2080



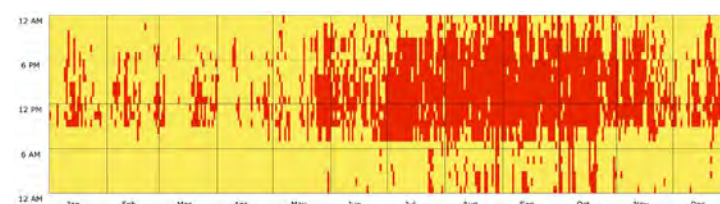
Honolulu 2017



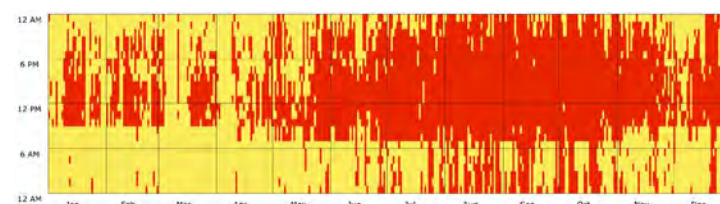
Honolulu 2020



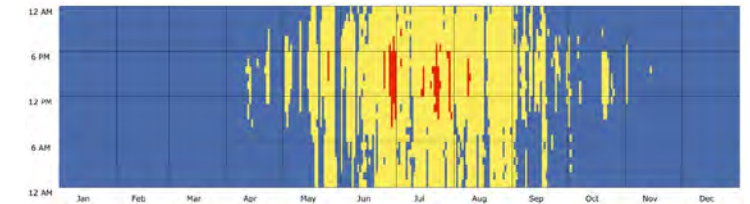
Honolulu 2050



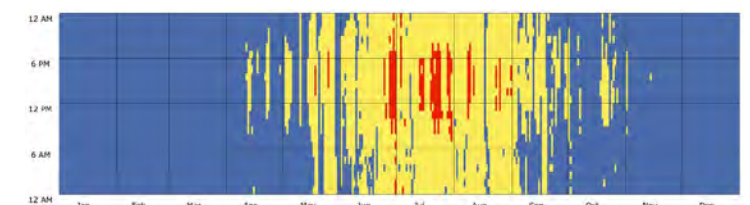
Honolulu 2080



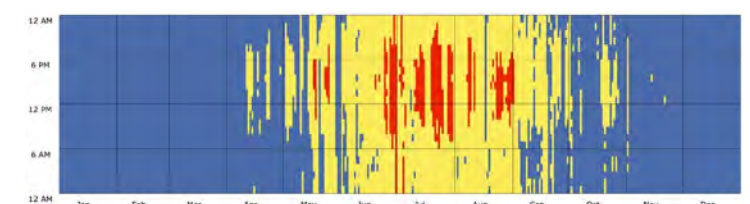
International Falls 2002



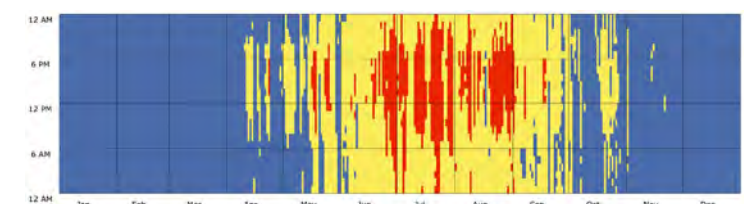
International Falls 2020



International Falls 2050



International Falls 2080



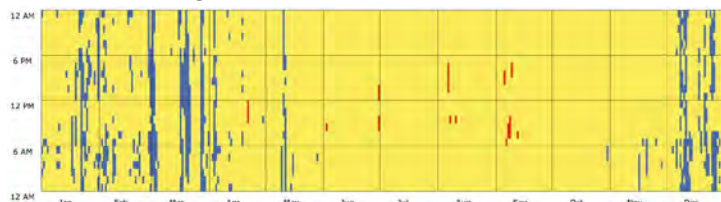
Infographic by Tyrone, Cheney, and Mohammed

Exterior Thermal Comfort Maps

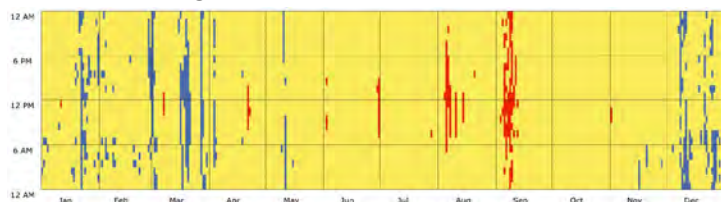
San Diego 1997



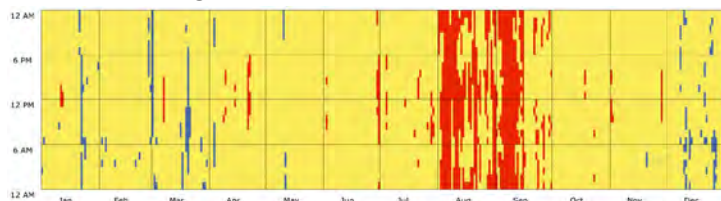
San Diego 2020



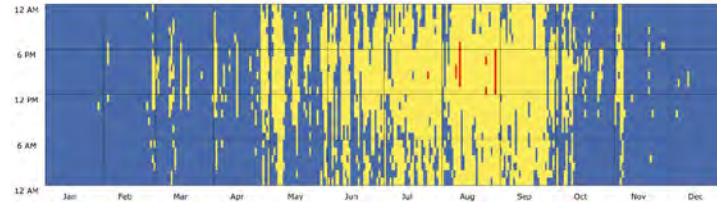
San Diego 2050



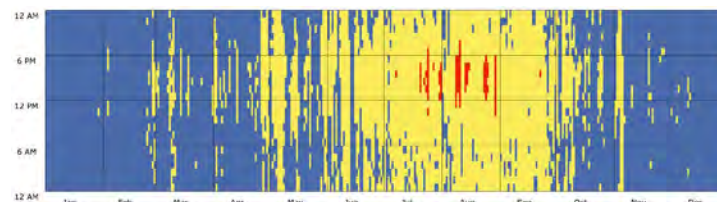
San Diego 2080



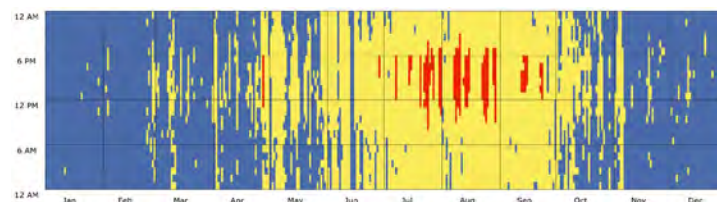
Seattle 2001



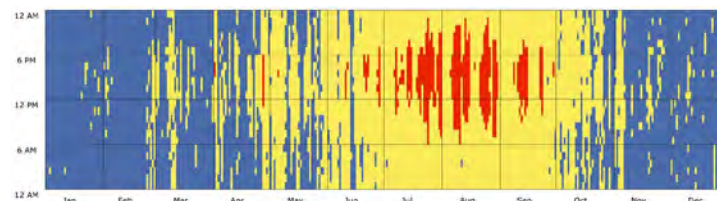
Seattle 2020



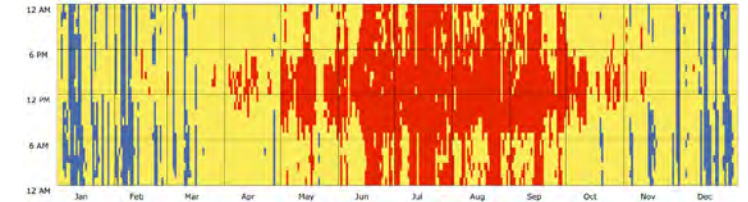
Seattle 2050



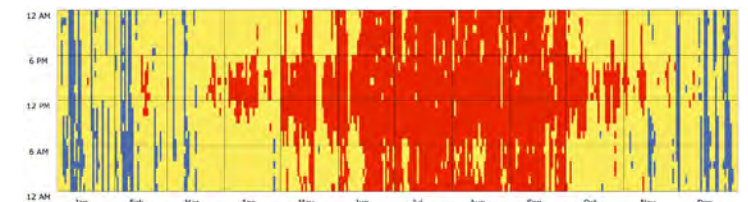
Seattle 2080



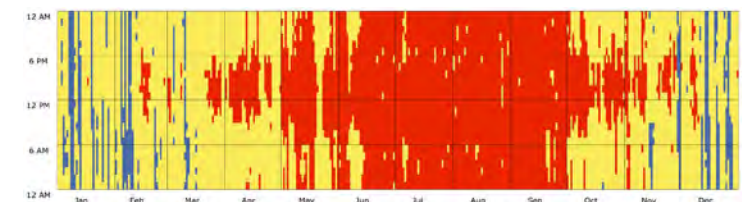
Tampa 2004



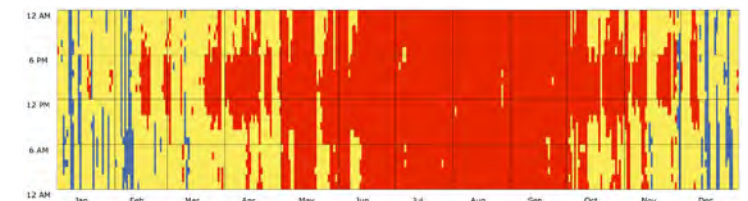
Tampa 2020



Tampa 2050

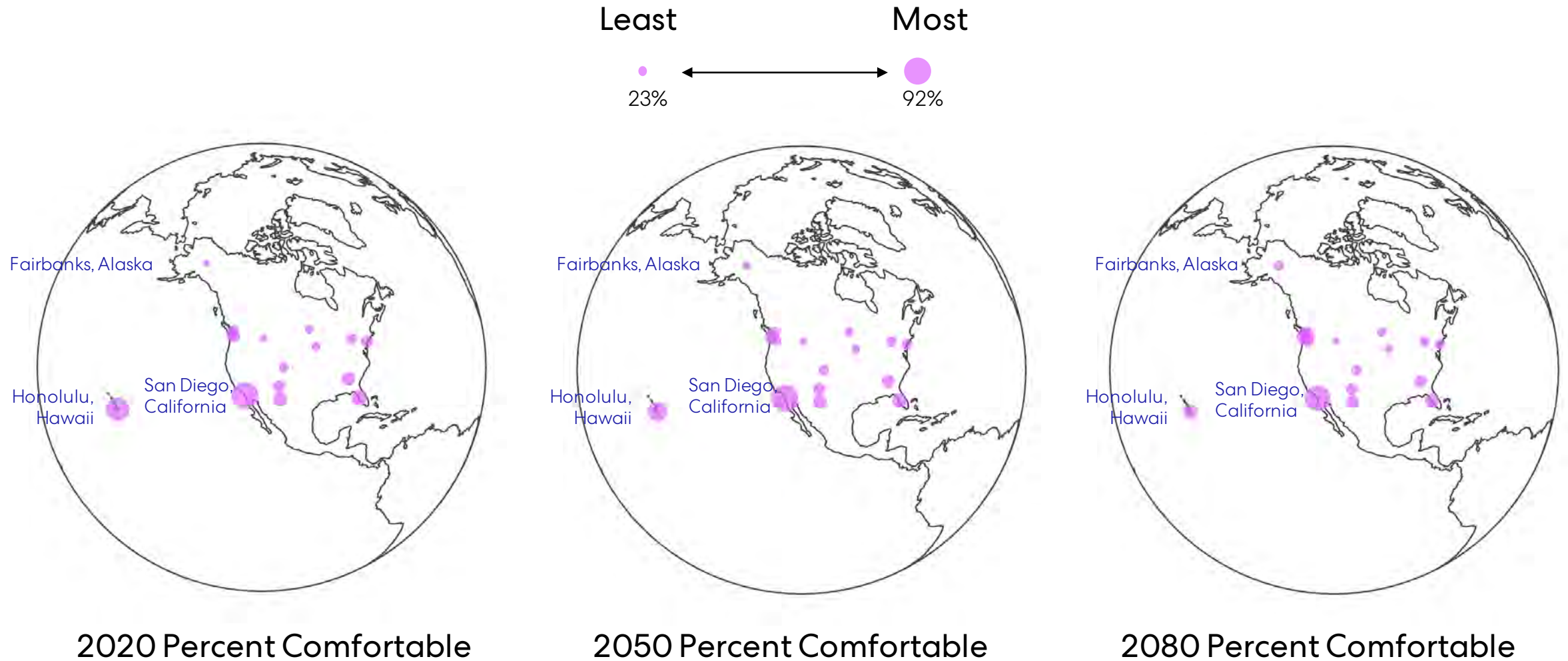


Tampa 2080



Infographic by Tyrone, Cheney, and Mohammed

Annual Exterior Thermal Comfort Design Summary

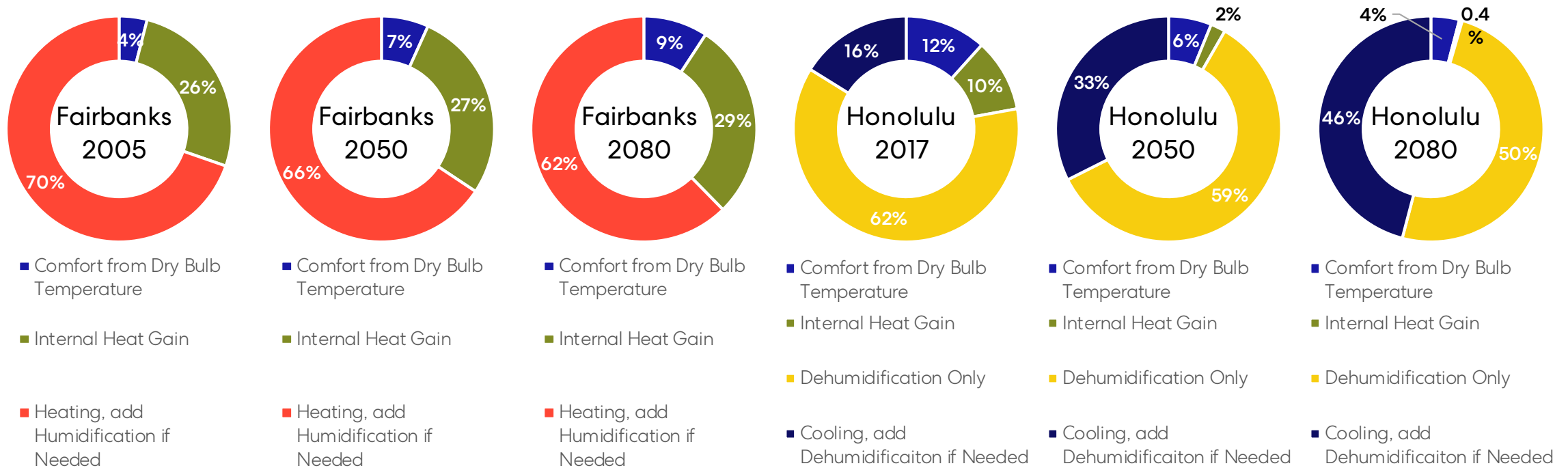


Infographic by Tyrone, Cheney, and Mohammed

Climate Design Strategies for Indoor Thermal Comfort

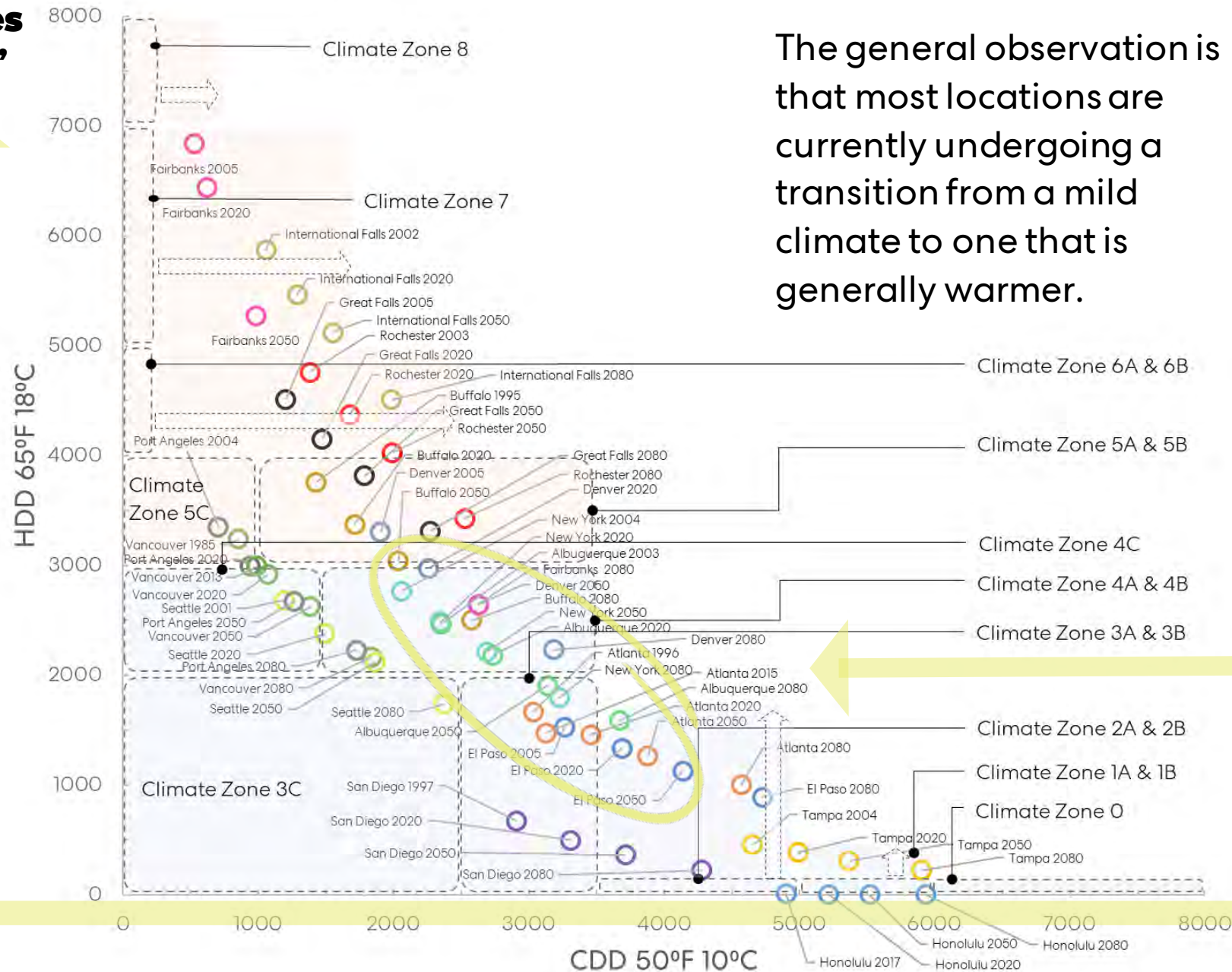
Fairbanks climate will over-time require slightly less emphasis on well-insulated walls and insulated glazing units with low U-value and high SHGC to retain internal heat gain from occupants and equipment.

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



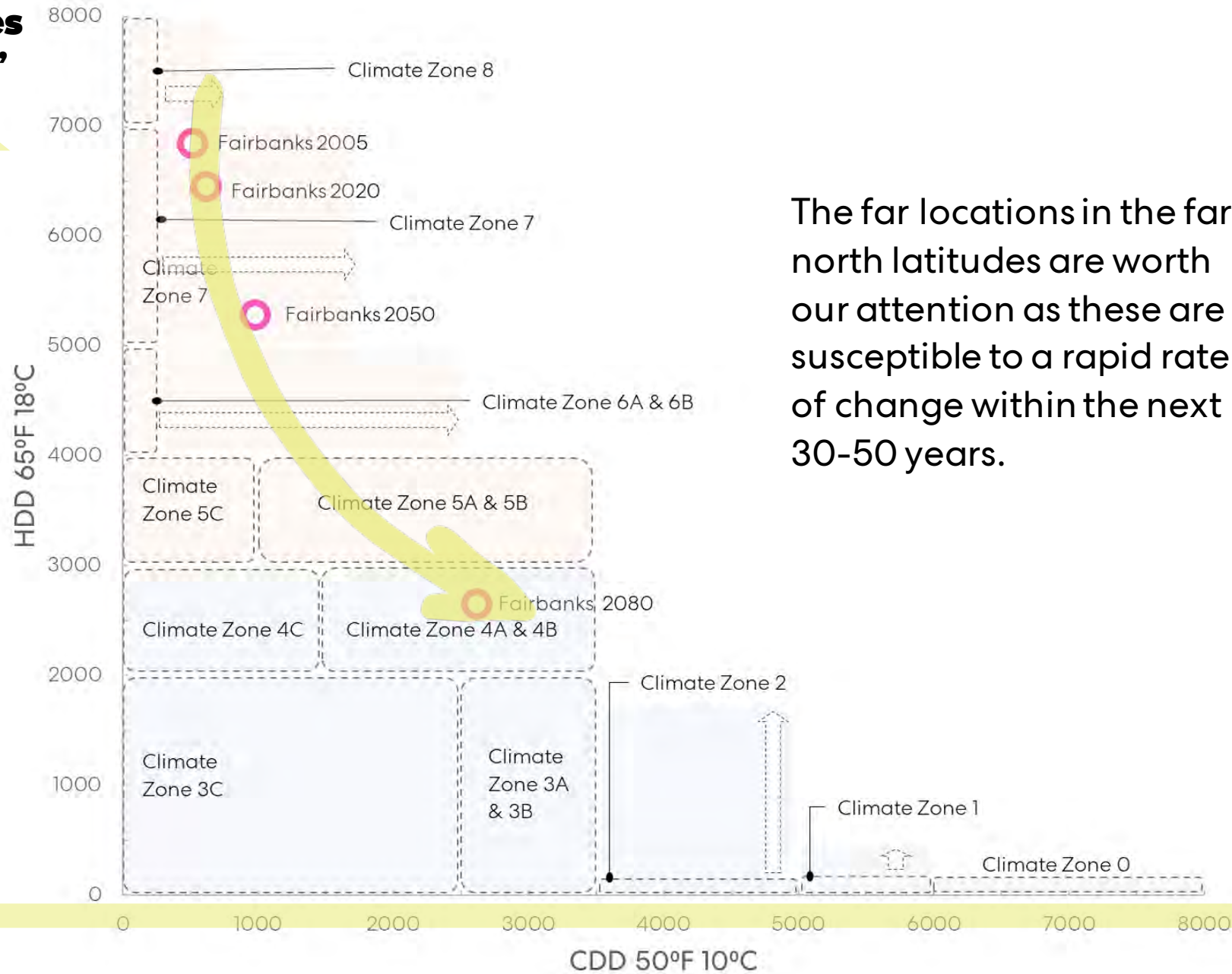
**Cold
Climates
“Arctic”**

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

**Cold
Climates
“Arctic”**



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.

Infographic by
Tyrone, Cheney,
and Mohammed

**Hot
Climates
“Sahara”**



05 Buildings and Climate

Heating/Cooling Ratio - Hospital

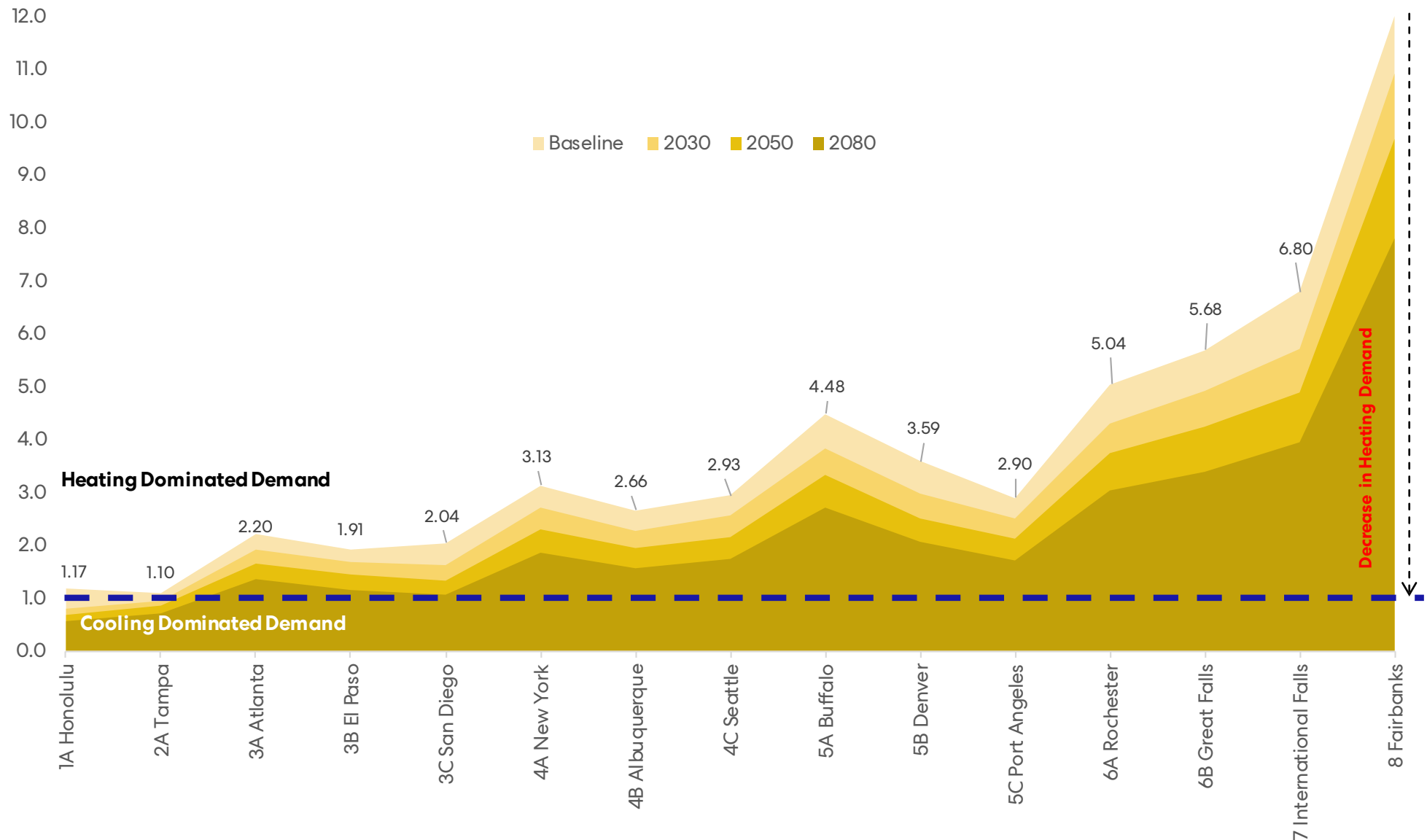


Chart by Tyrone,
Cheney, and
Mohammed

Heating/Cooling Ratio – Highrise Apartment

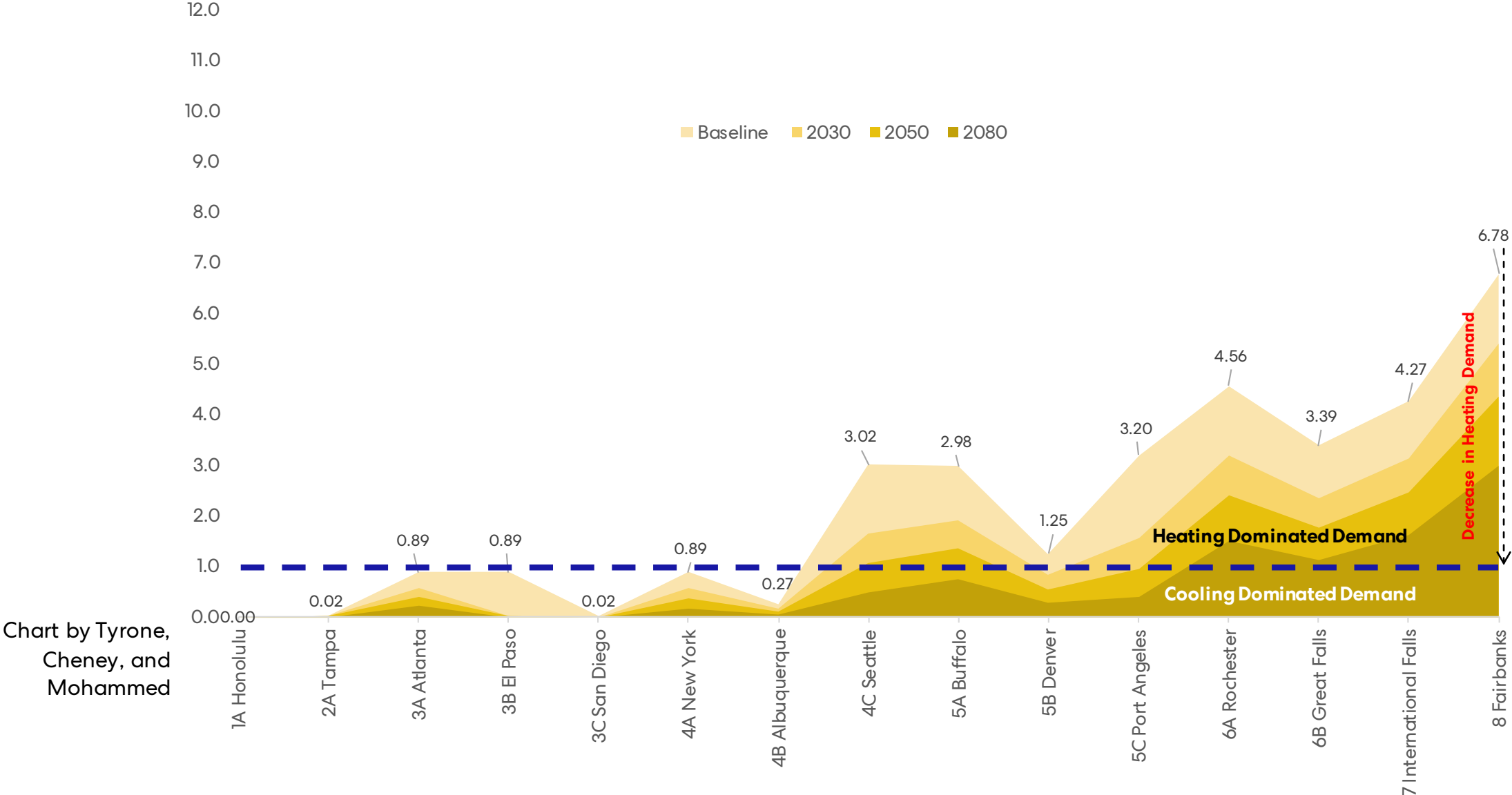


Chart by Tyrone, Cheney, and Mohammed

Heating/Cooling Ratio – Hotel

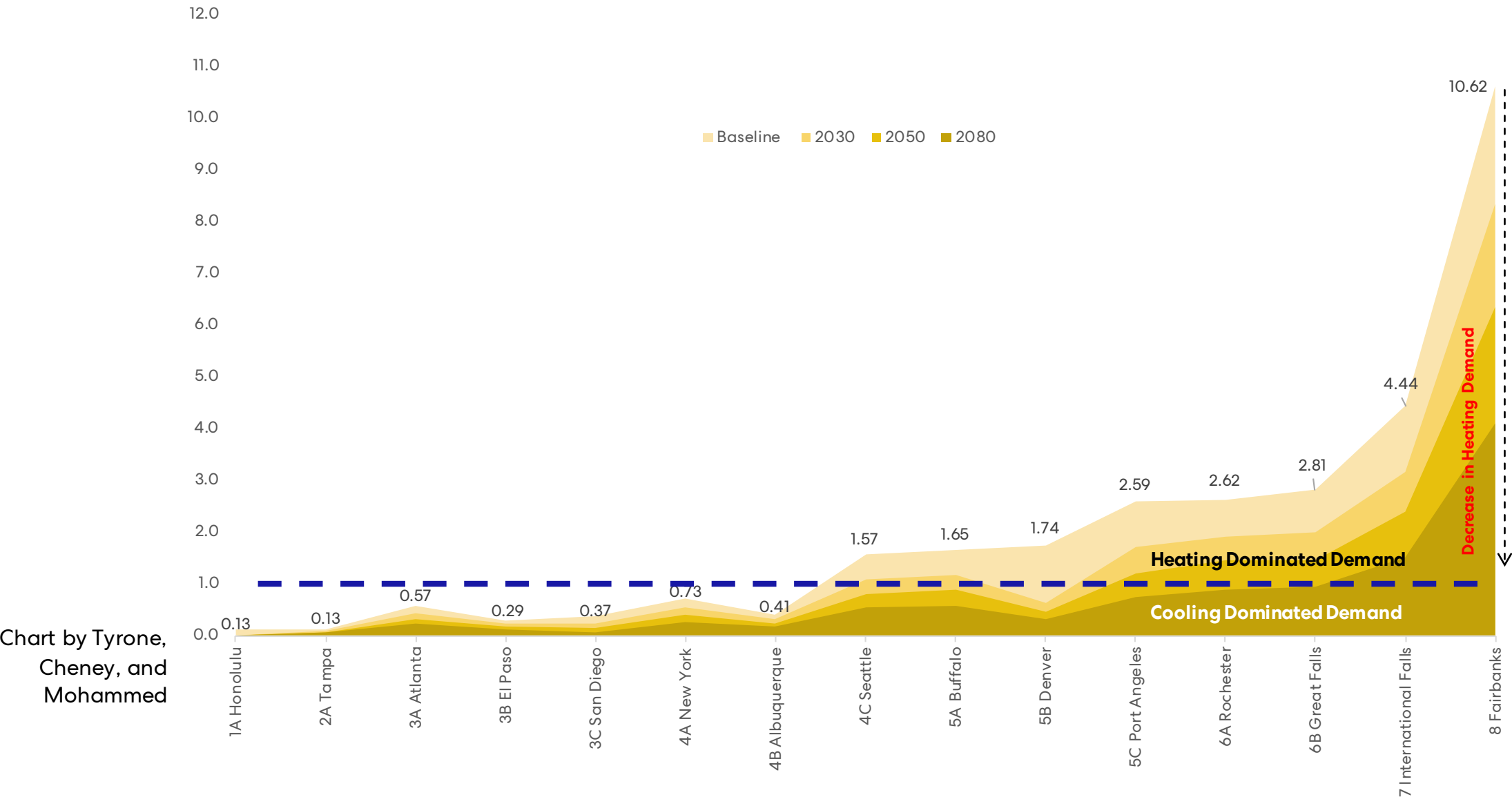


Chart by Tyrone,
Cheney, and
Mohammed

Heating/Cooling Ratio – Office

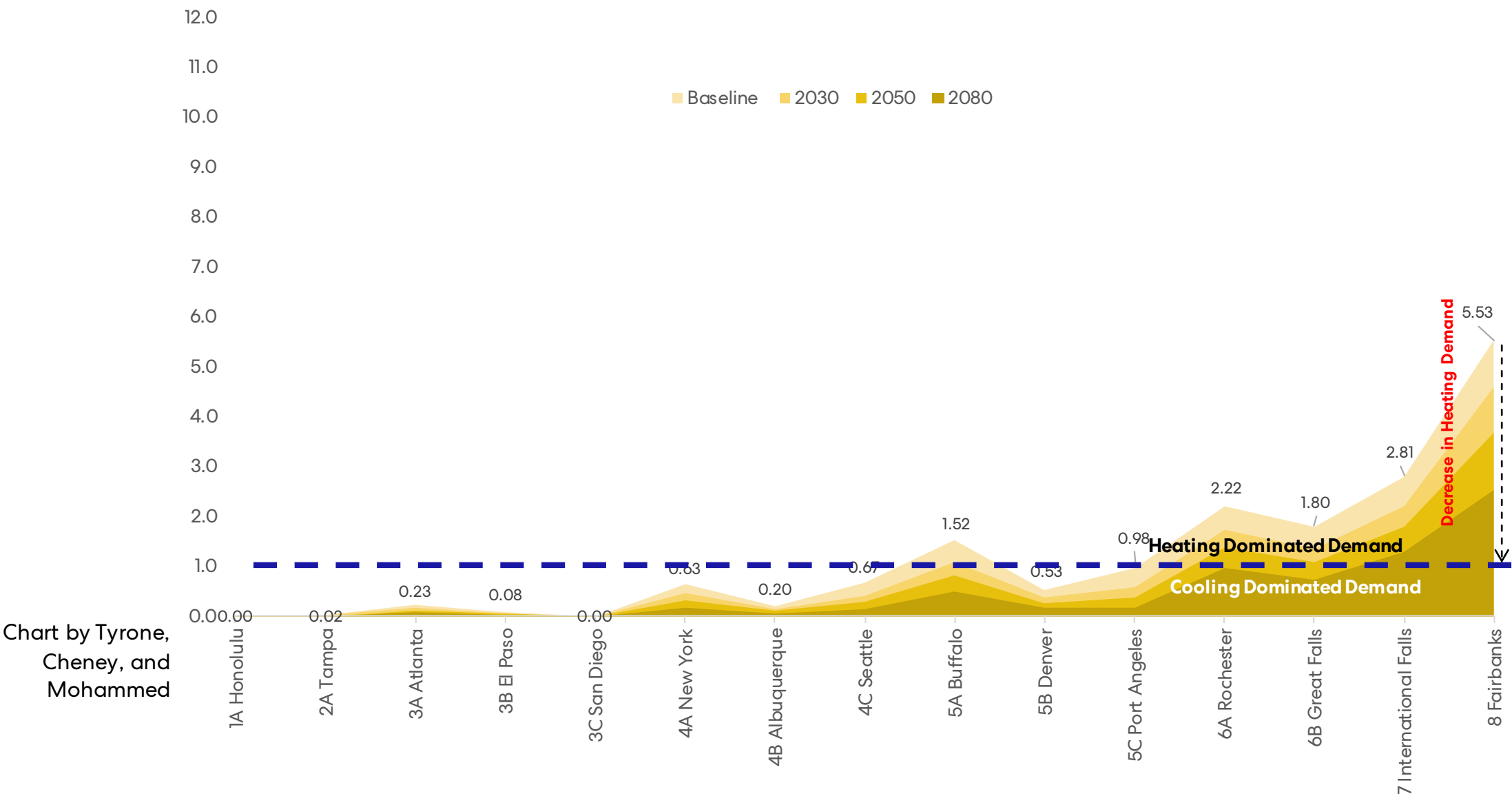


Chart by Tyrone,
Cheney, and
Mohammed

Heating/Cooling Ratio – Primary School

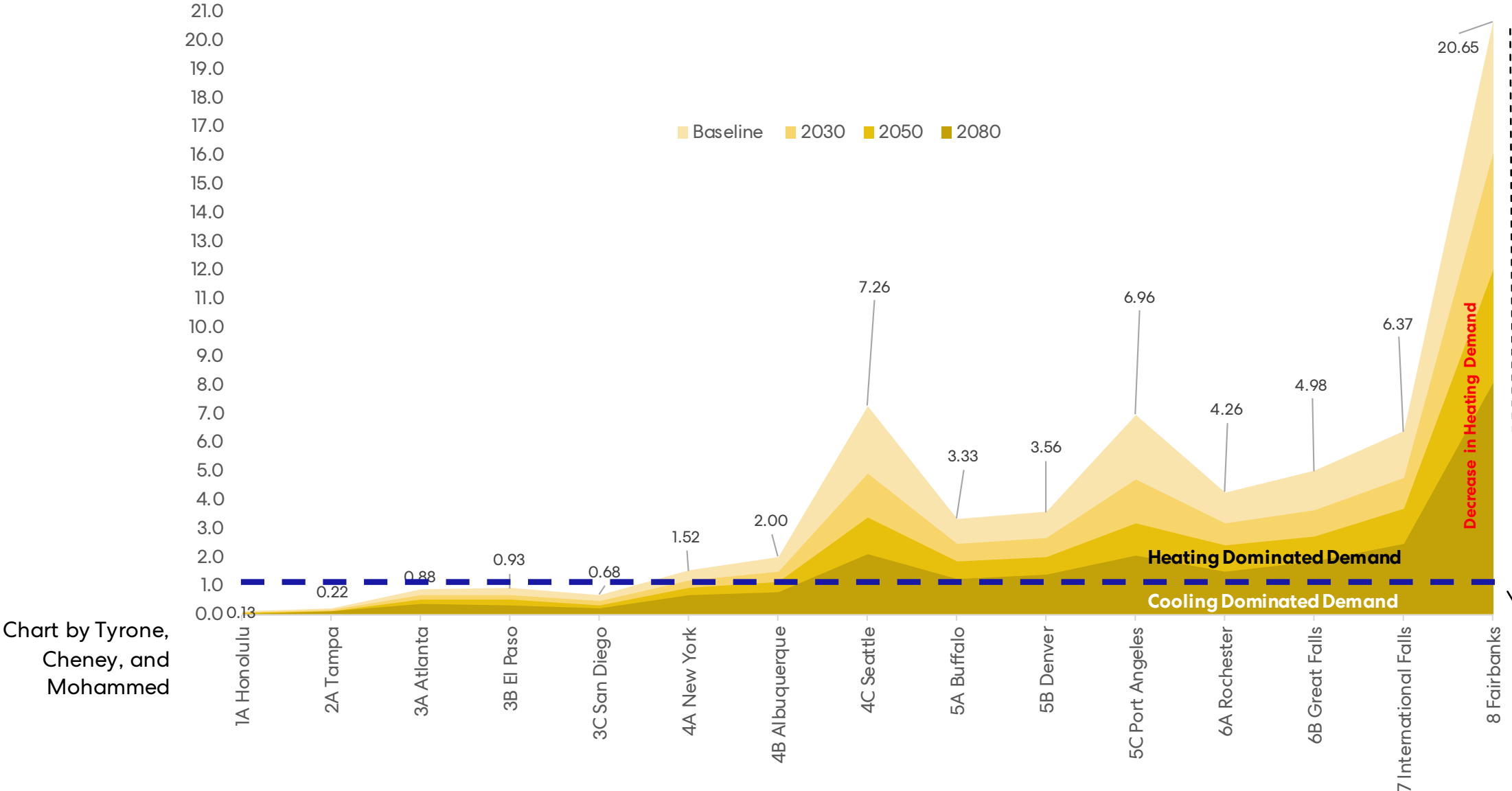


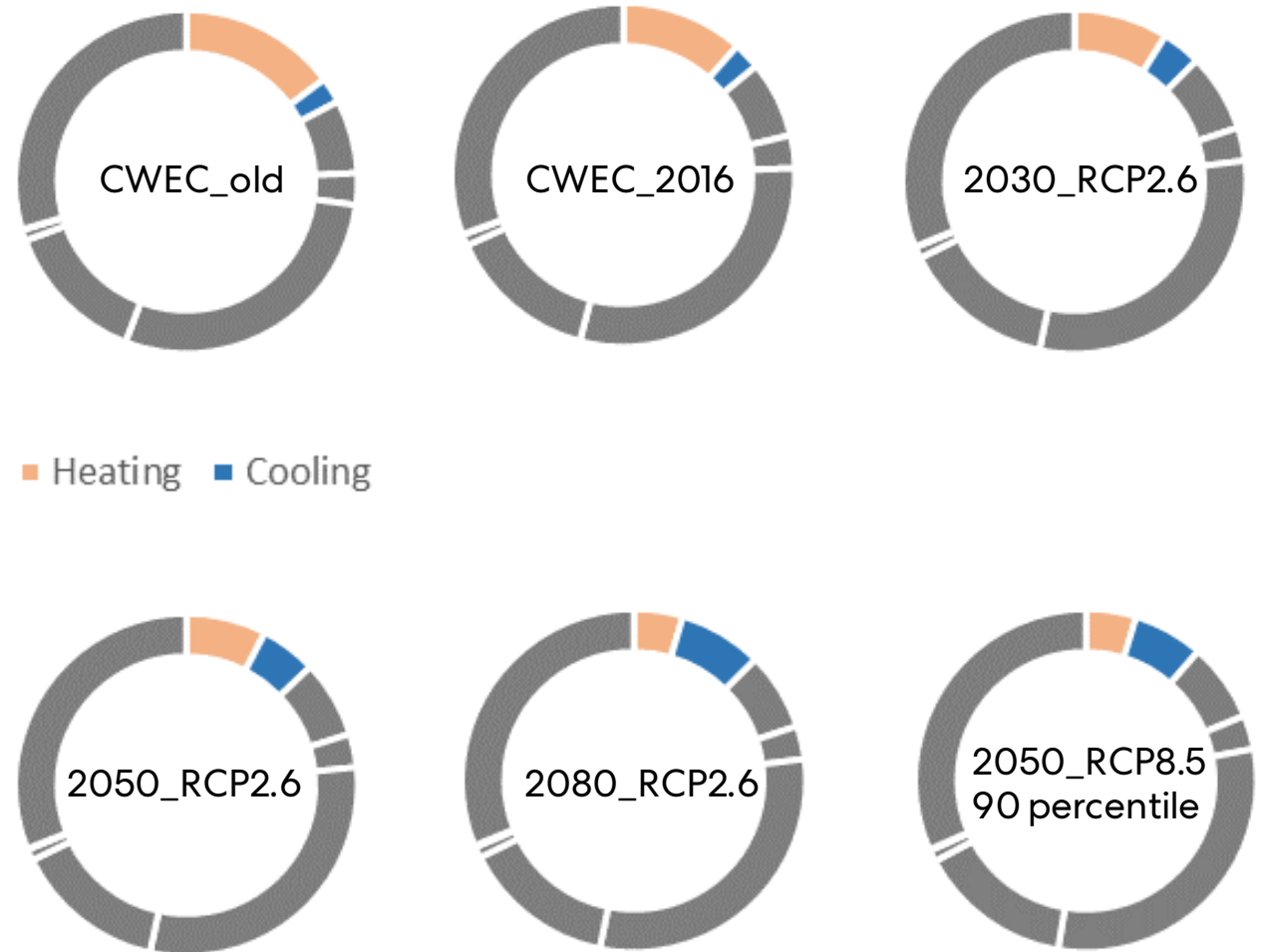
Chart by Tyrone, Cheney, and Mohammed

06 Case Study

Vancouver, British Columbia

Vancouver Case Study

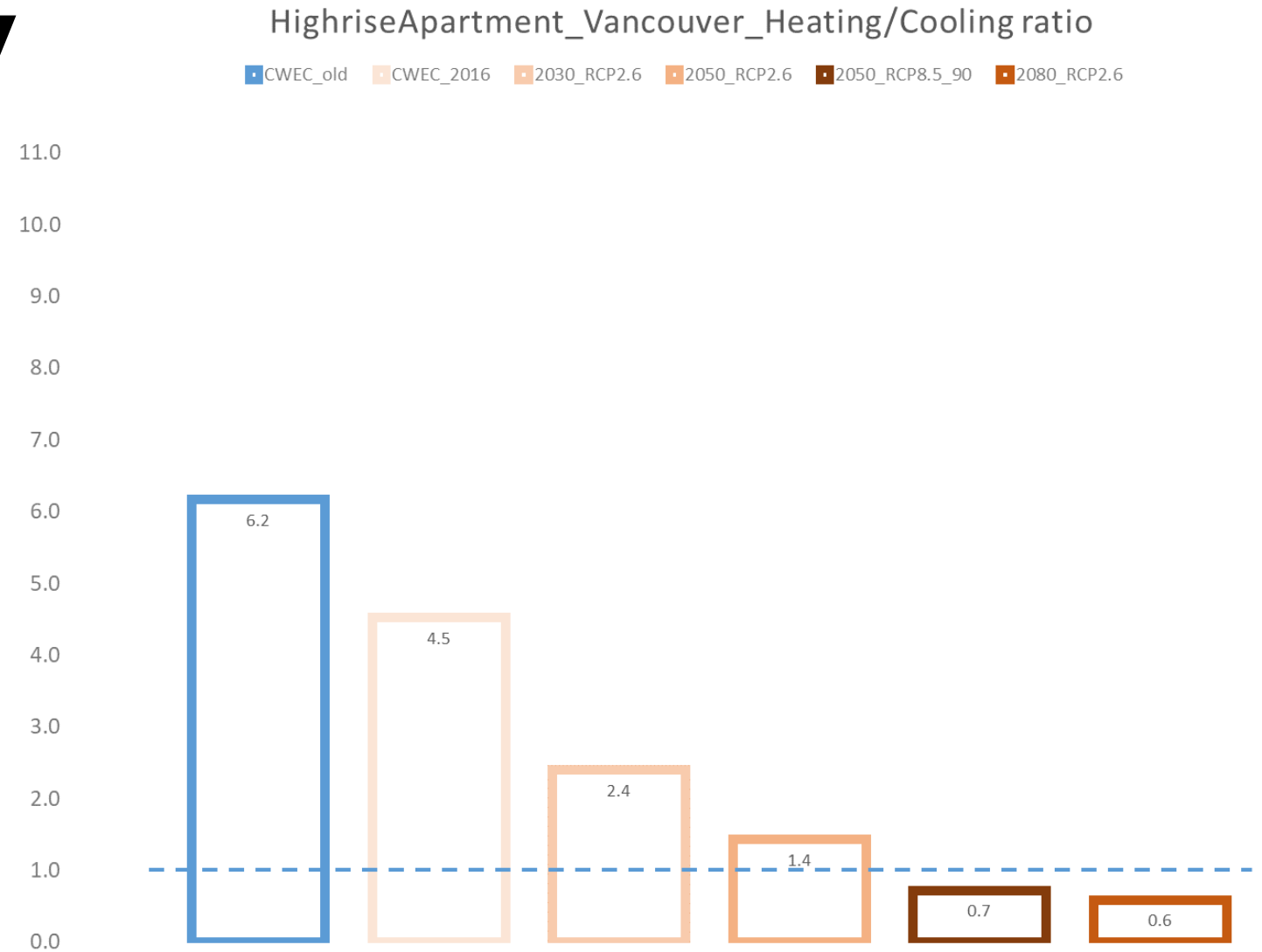
- **Highrise Apartment** in Vancouver will definitely switch from heating energy dominated to cooling energy dominated;
- If RCP increases too quick, in 2050 at RCP8.5, the heating/cooling ratio will be close to 2080 at RCP2.6.



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

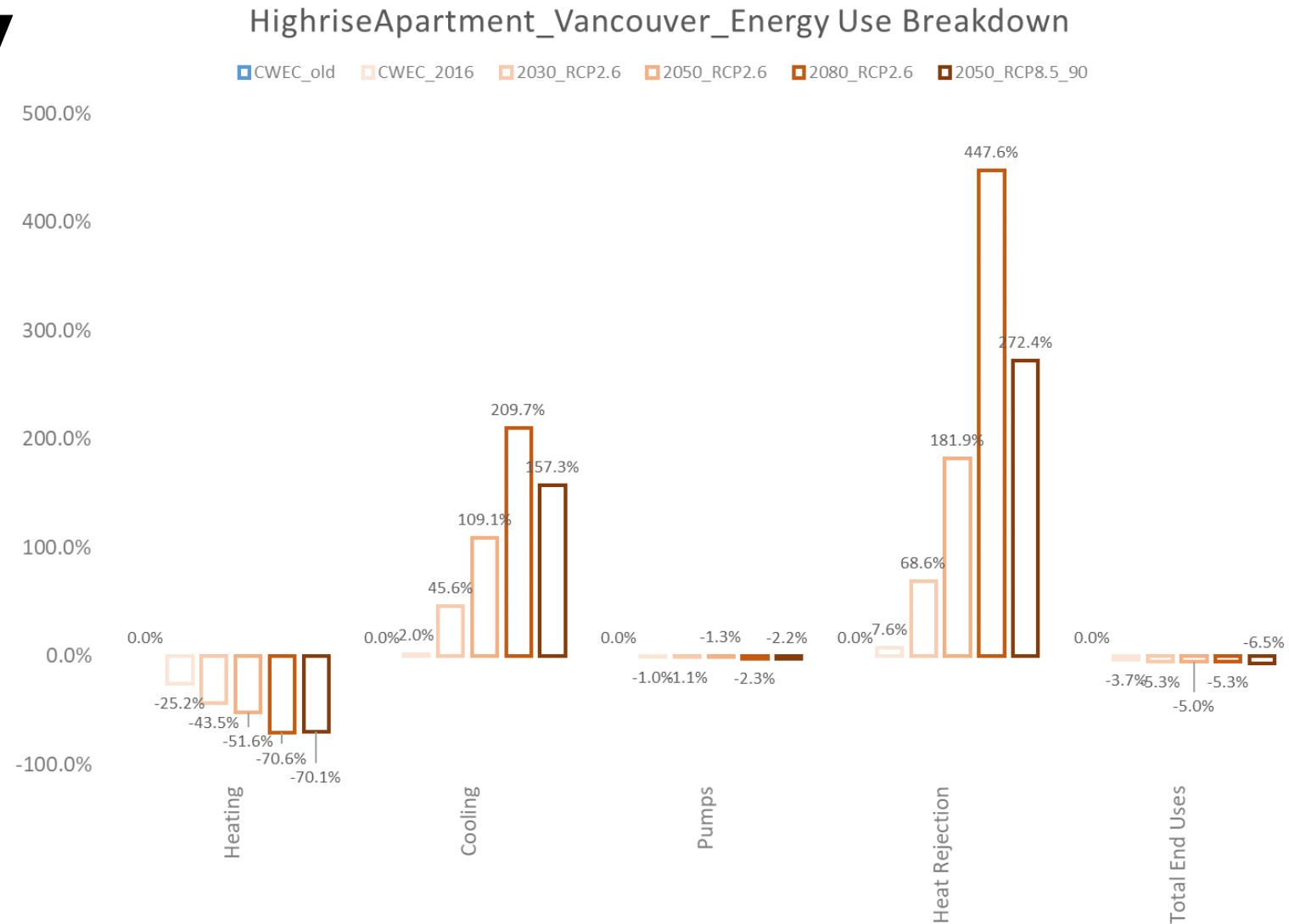
- **Highrise Apartment** in Vancouver Heating/cooling ratio maximum difference is **5.6** (CWEC_old vs. 2080_RCP2.6);



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

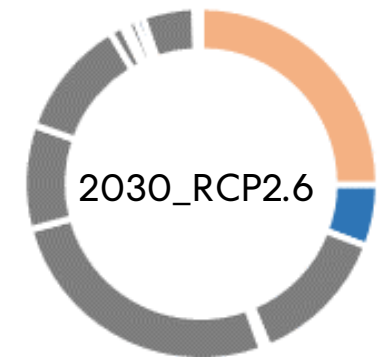
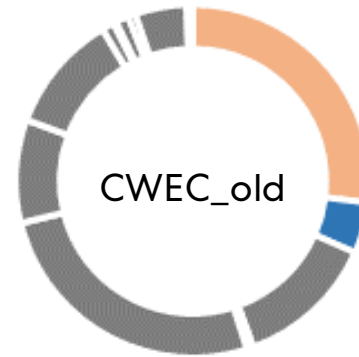
- **Highrise Apartment** in Vancouver overall building energy use will decrease up to 6.5%. The climate change concerns will mainly be associated with thermal comfort, cooling equipment size, etc.;



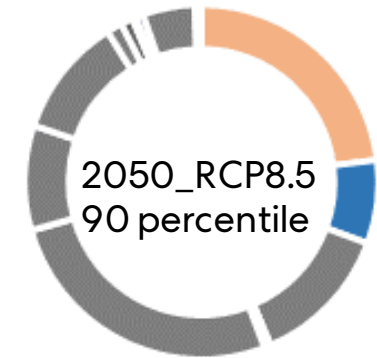
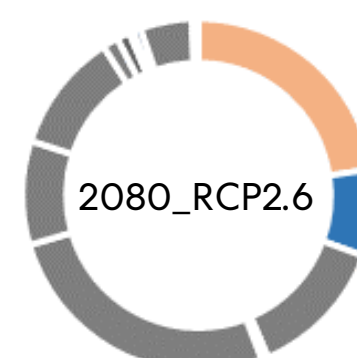
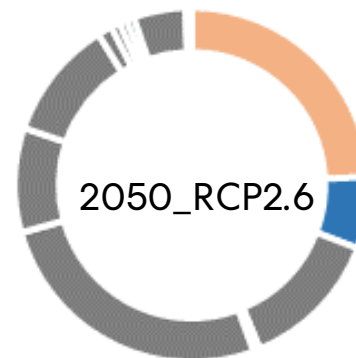
Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

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



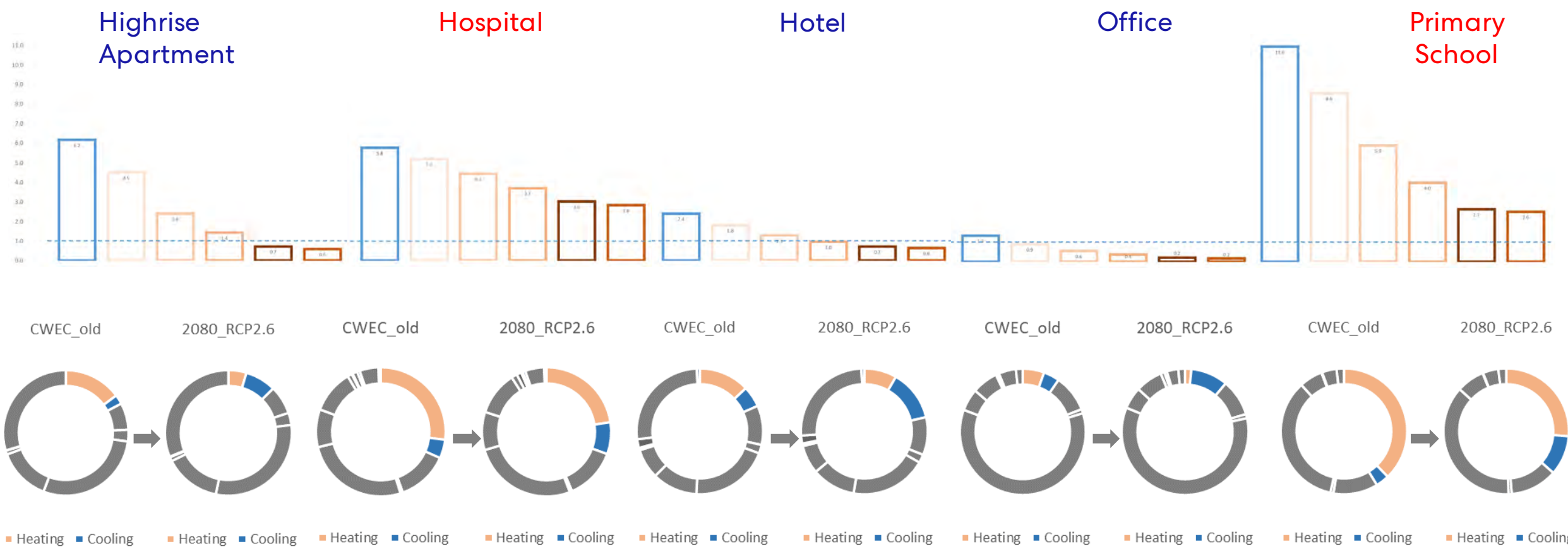
■ Heating ■ Cooling



Infographic by Tyrone, Cheney, and Mohammed

Vancouver Case Study

CWEC_old CWEC_2016 2030_RCP2.6 2050_RCP2.6 2050_RCP8.5_90 2080_RCP2.6



Infographic by Tyrone, Cheney, and Mohammed

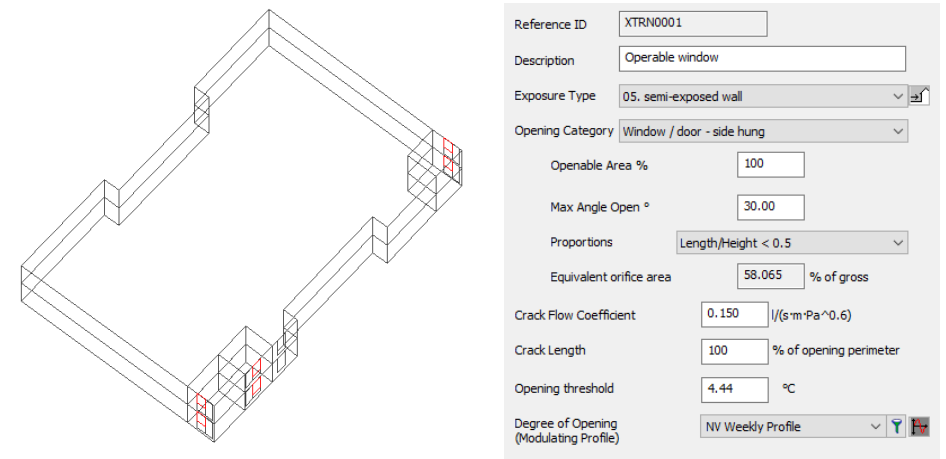
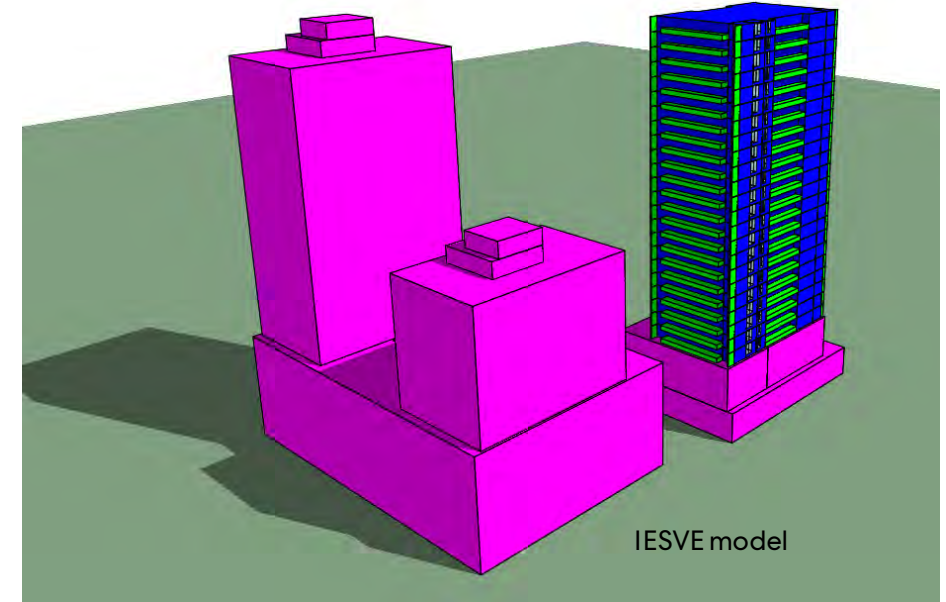
Vancouver Case Study



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)



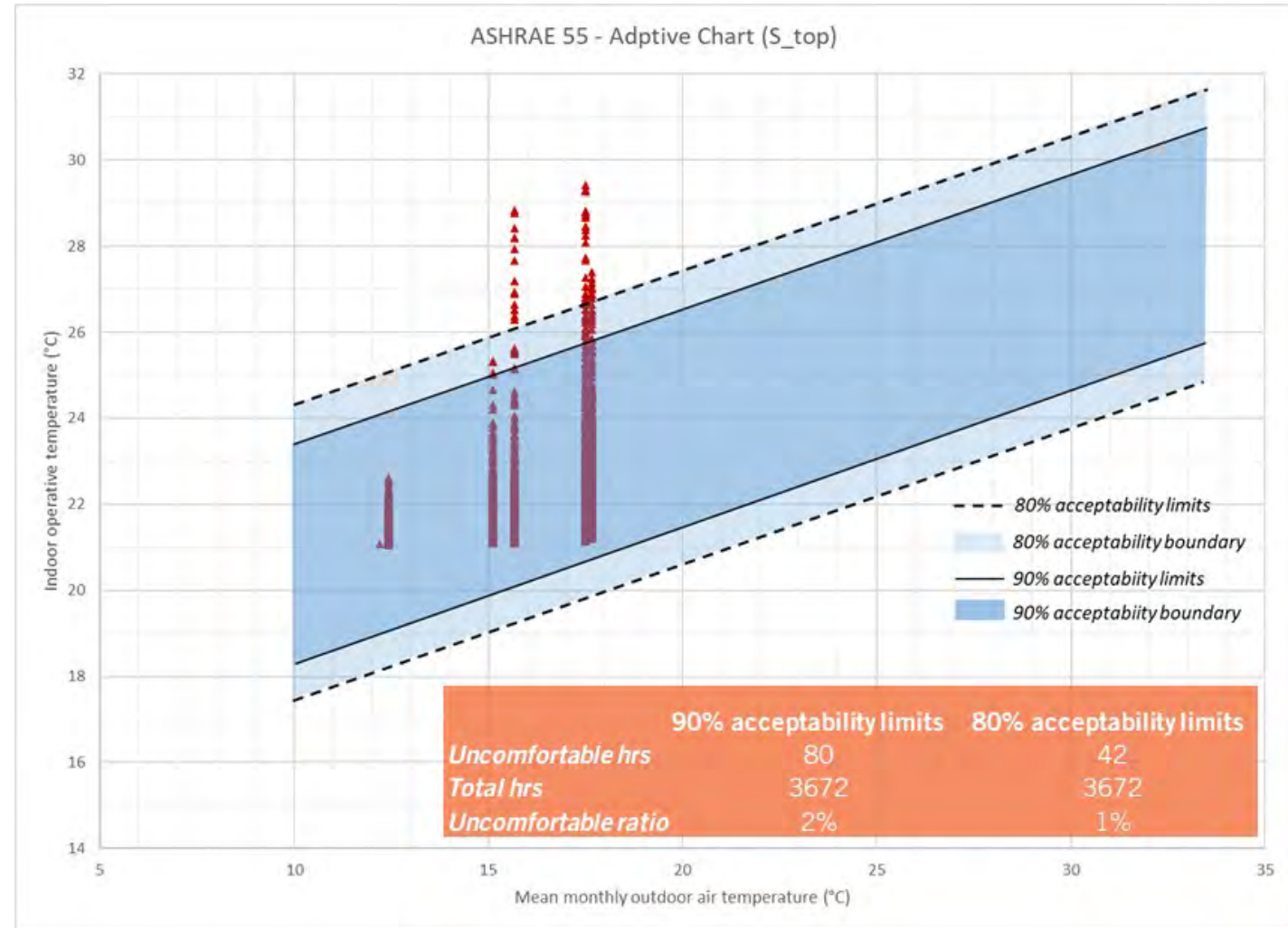
Infographic by Tyrone, Cheney, and Mohammed

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. (°C)
May	12
June	15
July	17
August	18
September	16



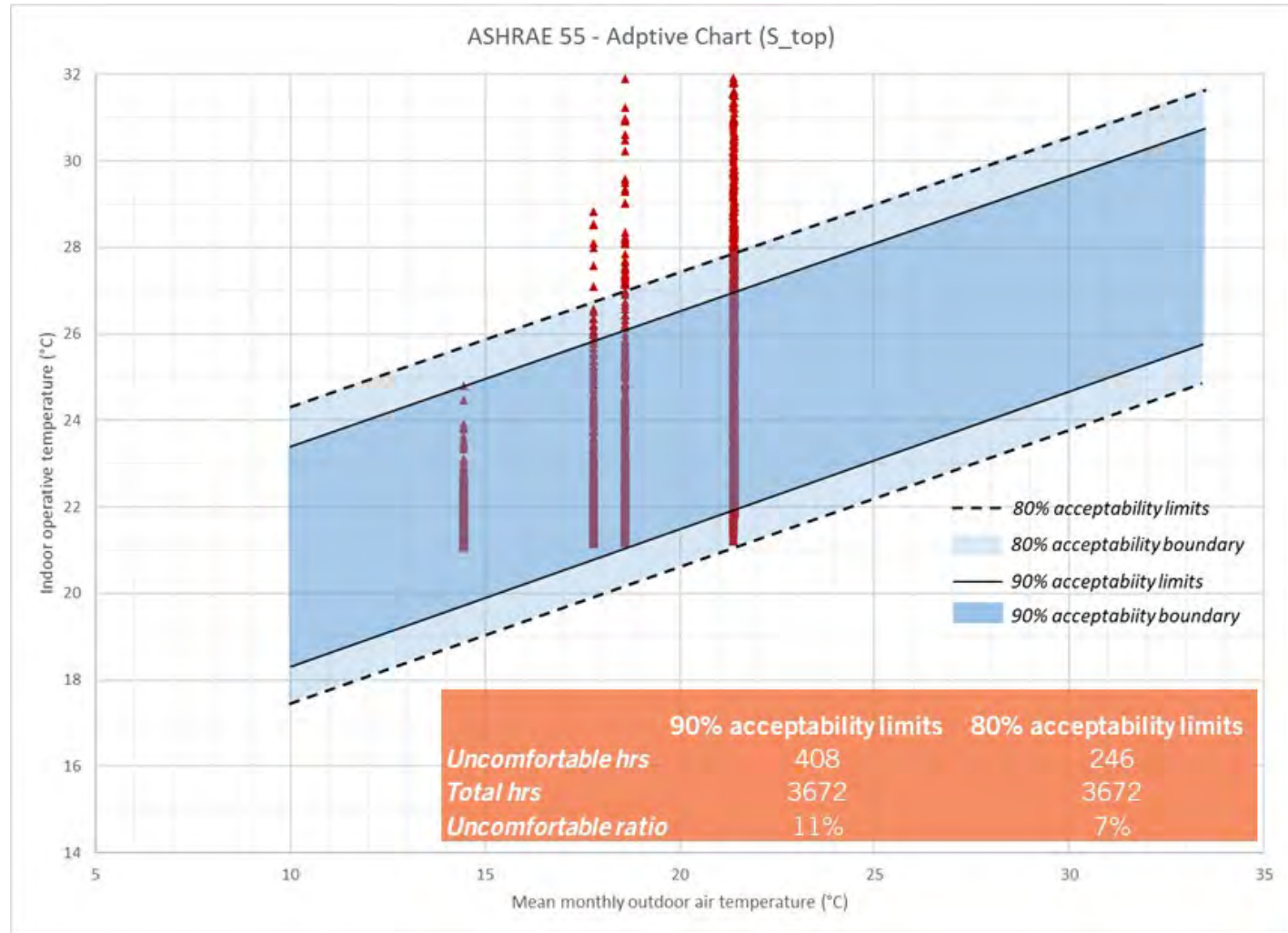
Infographic by Tyrone, Cheney, and Mohammed

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. (°C)
May	14
June	18
July	21
August	21
September	19

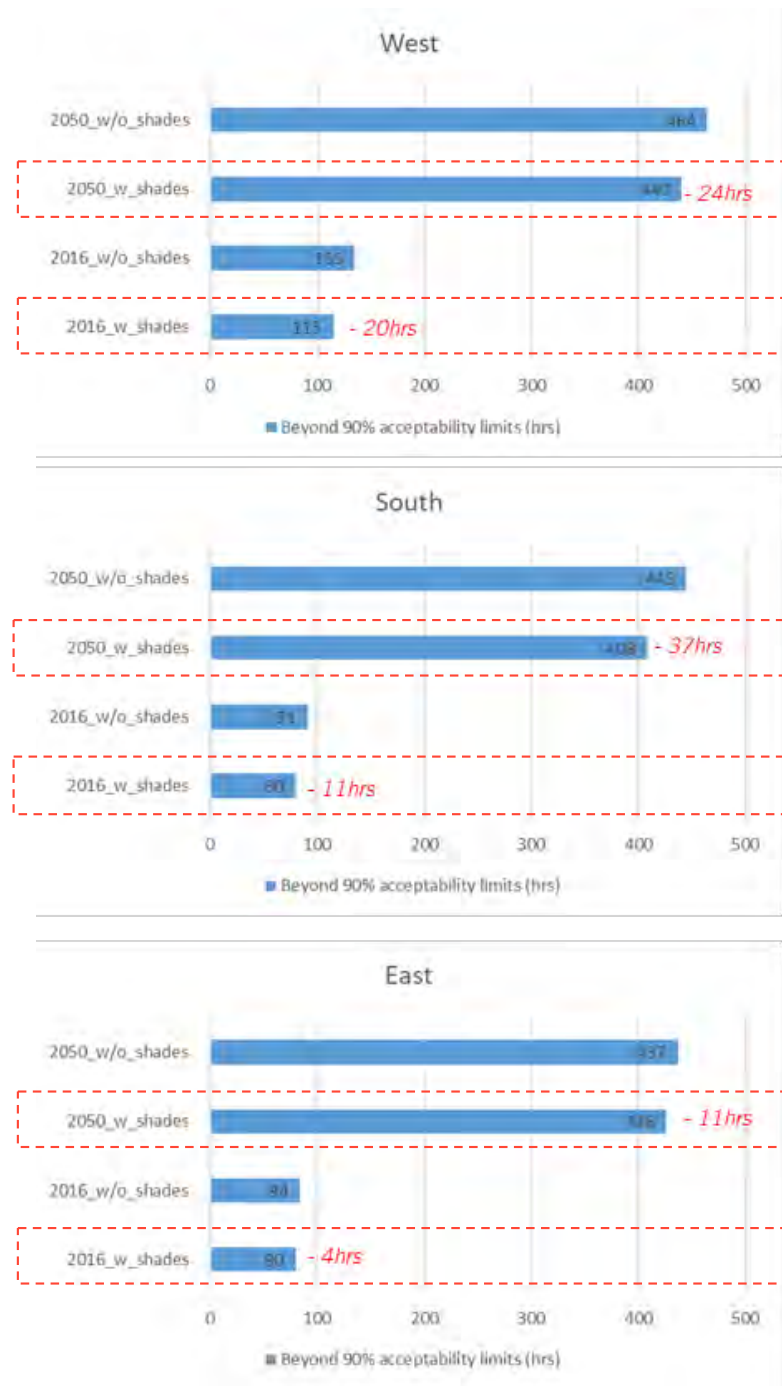


Infographic by Tyrone, Cheney, and Mohammed

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 1.5°C and found the following takeaways:

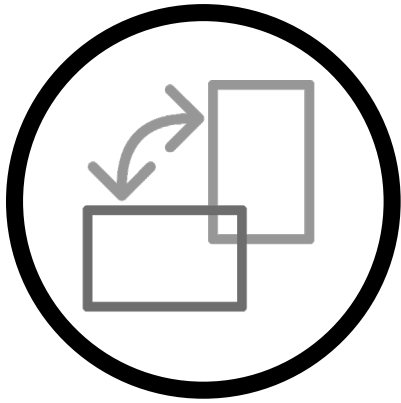
- **Very Cold Climates like Fairbanks, Alaska**
 - There were more hours where the mechanical system does not adequately manage heating or cooling setpoints
- **Cool Humid Climates like Buffalo, New York**
 - The mechanical systems were less effective at removing heat gain through the glazing system. 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

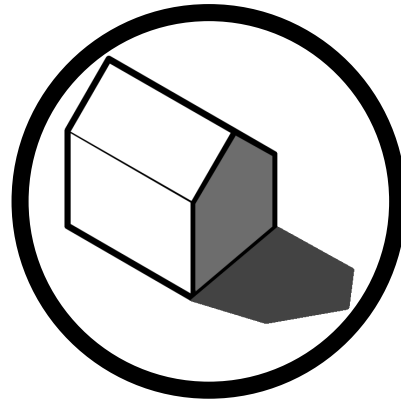
- **Temperate Climates like Cool and Dry**
 - Buildings in temperate climate zones are more sensitive to climate change and more vulnerable to the switch of heating/cooling plants;
- **Vancouver Case Study**
 - In Vancouver, high-rise apartments, hotels, and offices are more likely to switch the heating/cooling 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

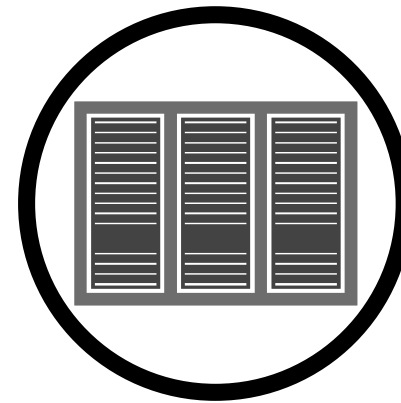
Infographic by Tyrone, Cheney, and Mohammed



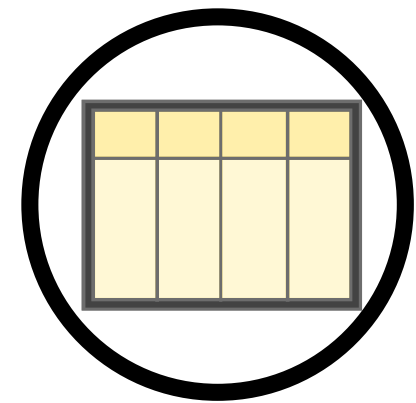
Orientation



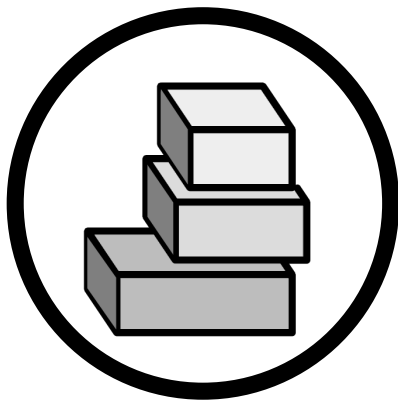
Self-shading



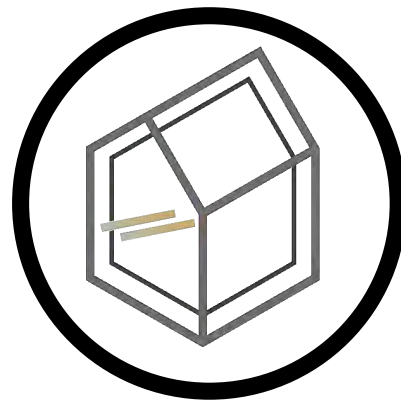
Shading Devices



Low-emissive glazing



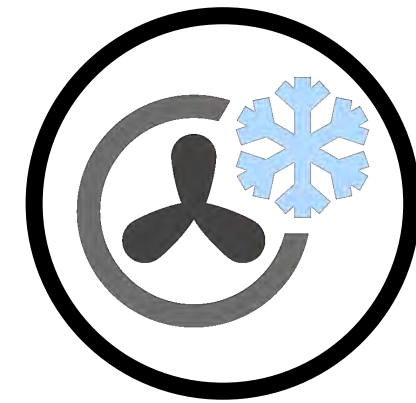
Massing



High Thermal Mass



Evaporative Cooling

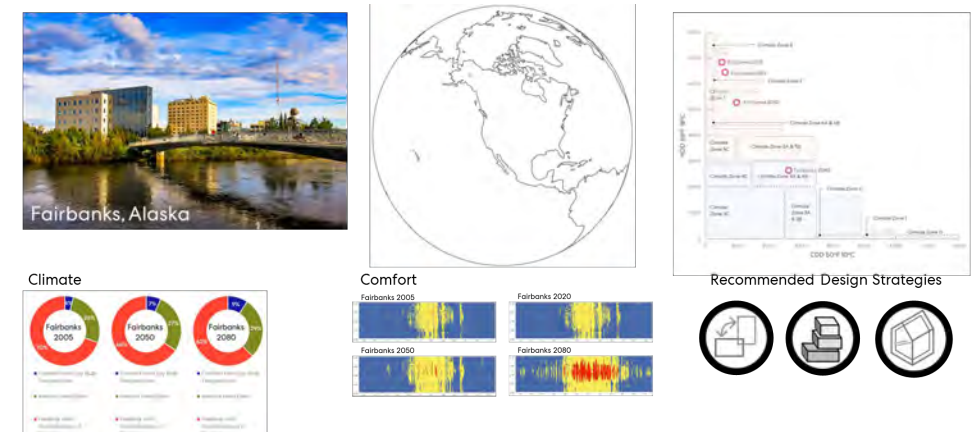


Active Cooling

Deliverables

We studied the impacts of available and current weather files with transformed ones to approximate a 1.5°C 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

A speedometer with a blue needle pointing towards the top. The background is dark with blurred numbers and units. The text "08 Limitations | Future Work" is overlaid in white.

08 Limitations | Future Work

MPH
km/h

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:

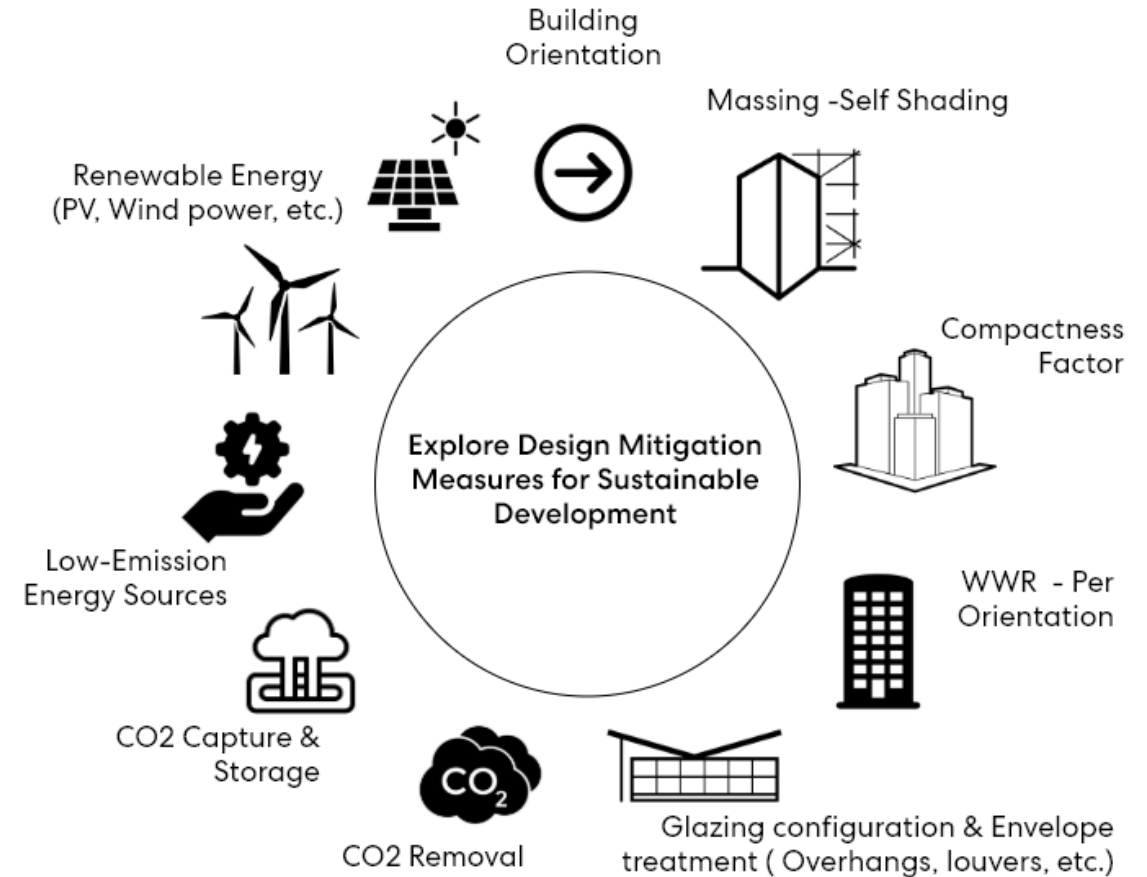
- Secondary School
- Quick Service Restaurant
- Full-Service Restaurant
- Outpatient Health Care

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

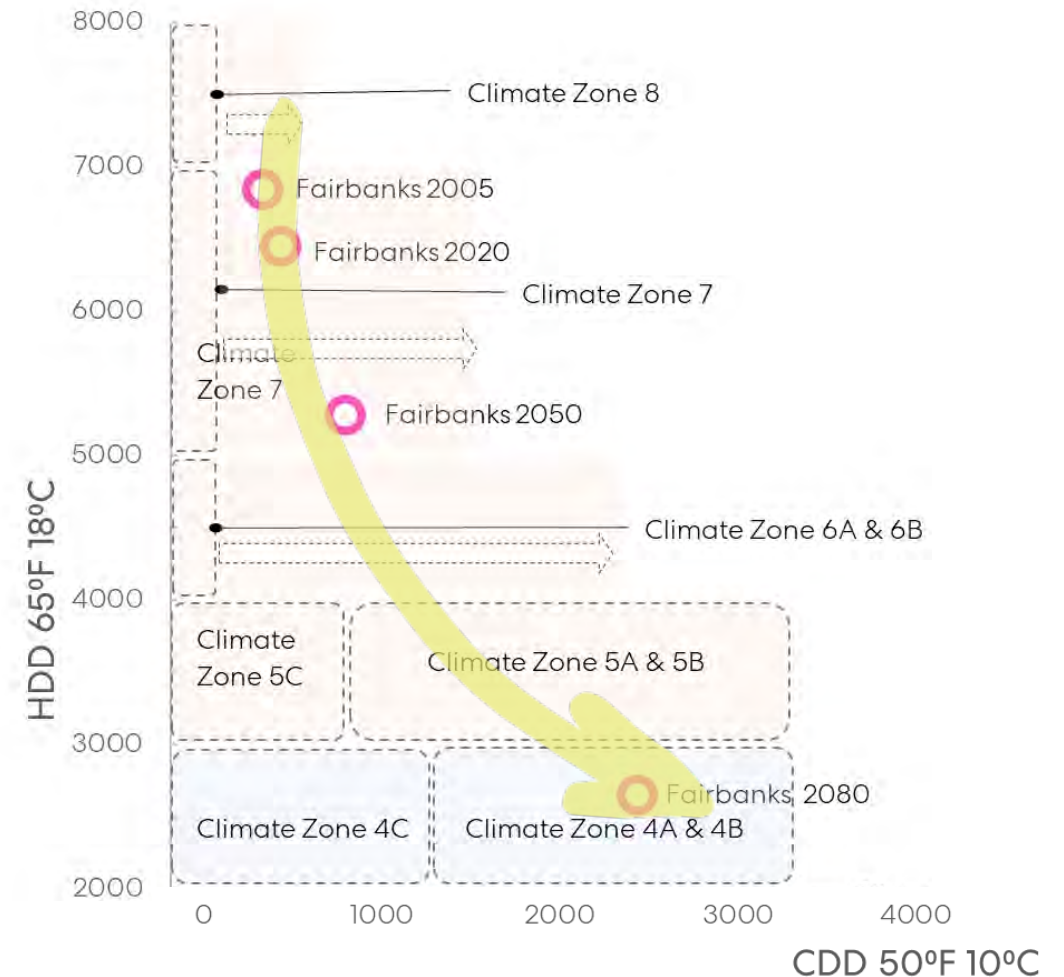
The next steps will consider extending the case studies to understand the relative **trade-offs** between enhanced energy efficiency, building massing and orientation, glazing configuration and window to wall ratio, envelope insulation, low-emission energy sources, renewable energy, carbon dioxide capture 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!