Climate Change, Indoor Environmental Quality, and Health

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William Fisk, Senior Scientist

Indoor Environment Group

Lawrence Berkeley National Laboratory

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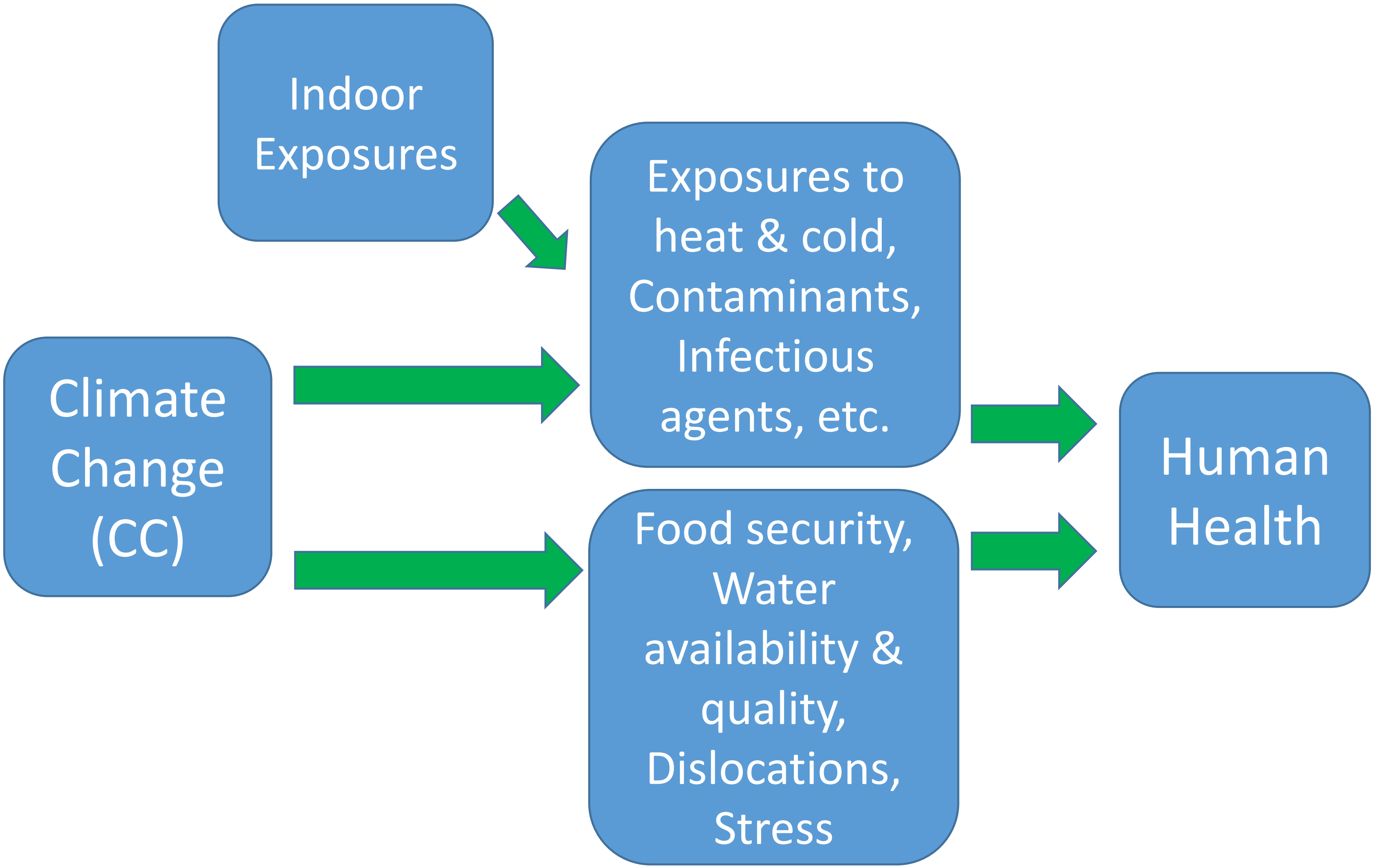
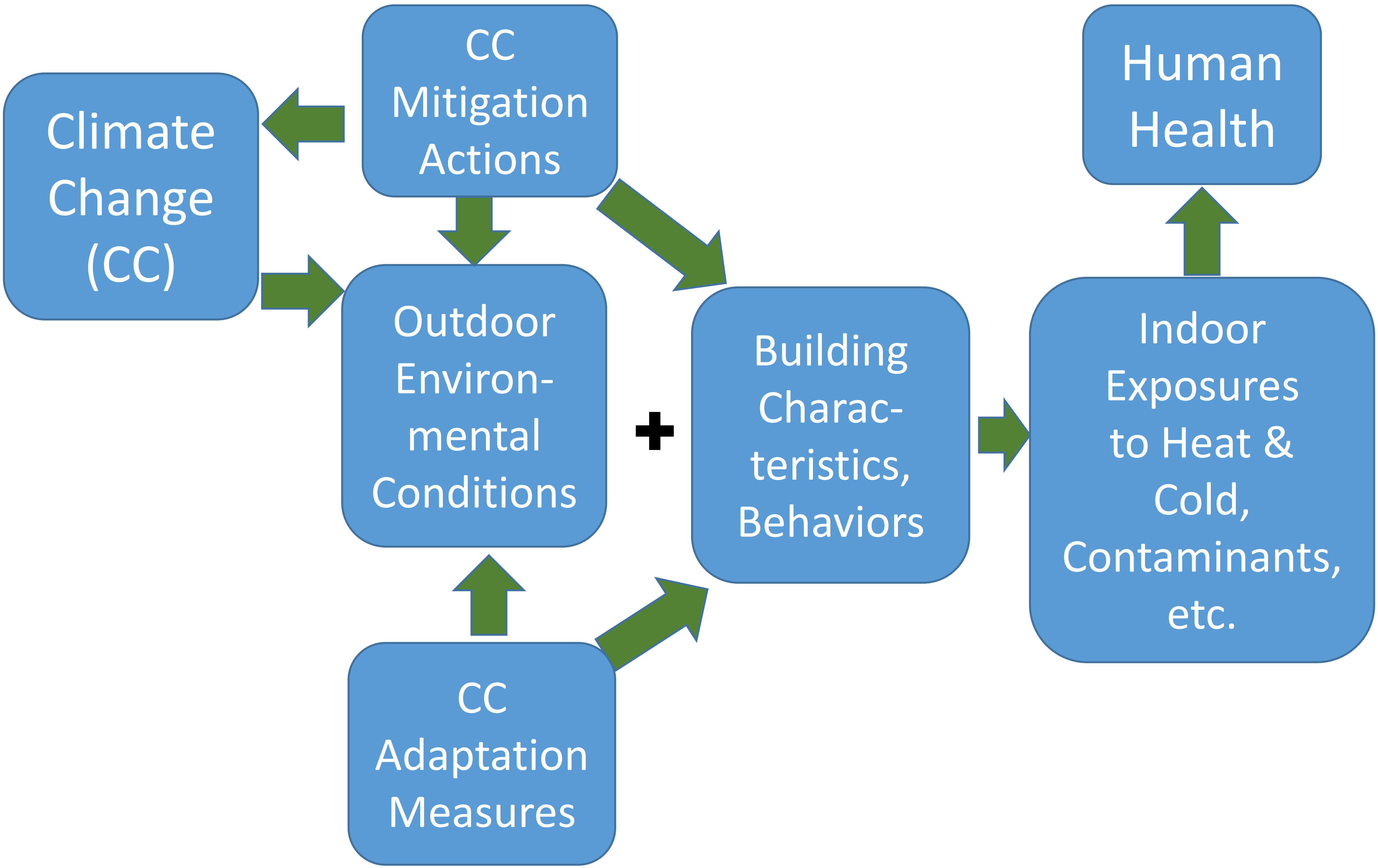
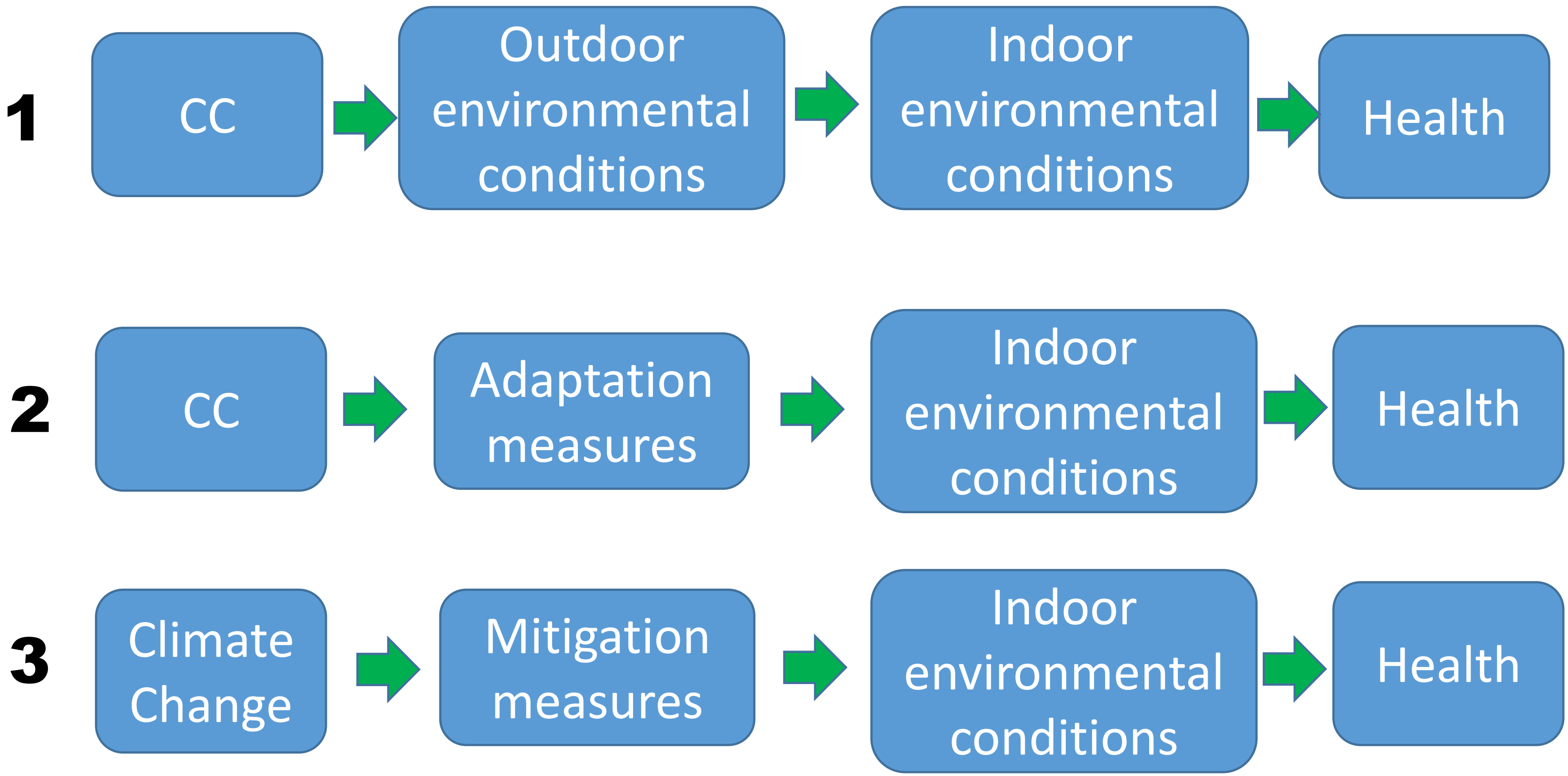
Context


Indoor Exposures
Climate Change (CC)
Exposures to heat & cold, Contaminants, Infectious agents, etc.
Food security, Water availability & quality, Dislocations, Stress
Human Health

Linkage of Climate Change to Indoor Environmental Quality (IEQ) is Complex



Climate Change (CC) → Indoor Environmental Quality (IEQ) → Health: Three Pathways



Scope of Presentation

CC → outdoor environment → Indoor Environment

- Heat stress
- Ozone
- Wildfire smoke
- Dampness and mold from severe storms & flooding

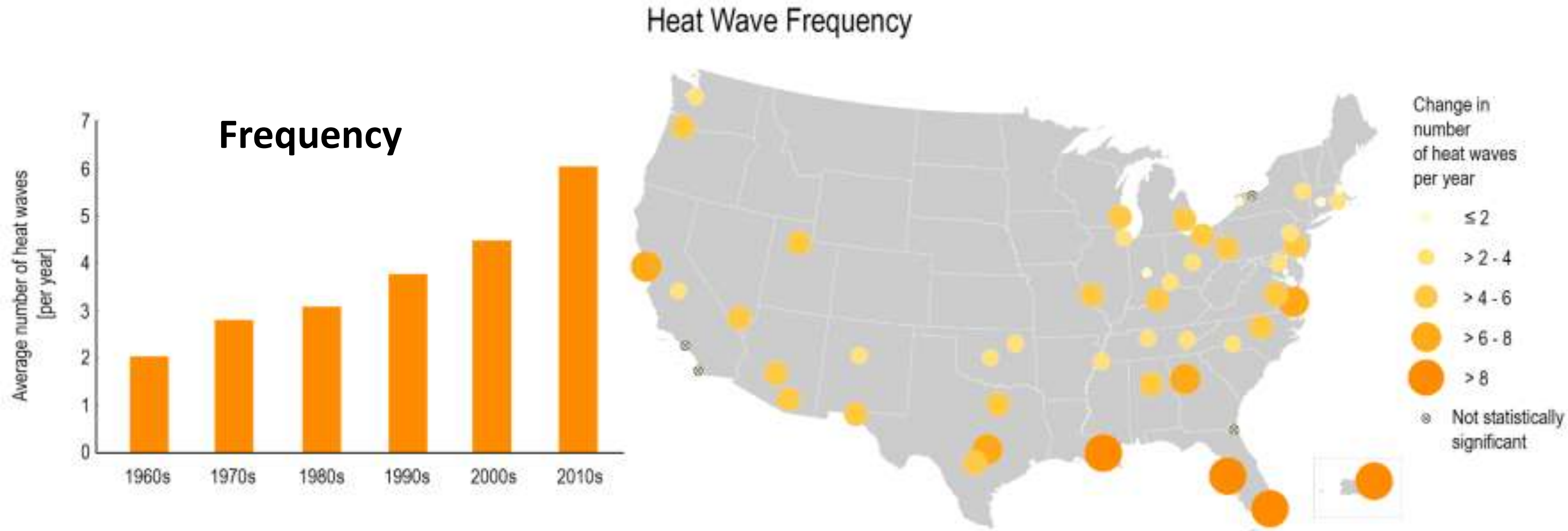
CC → adaptation measures → Indoor Environment

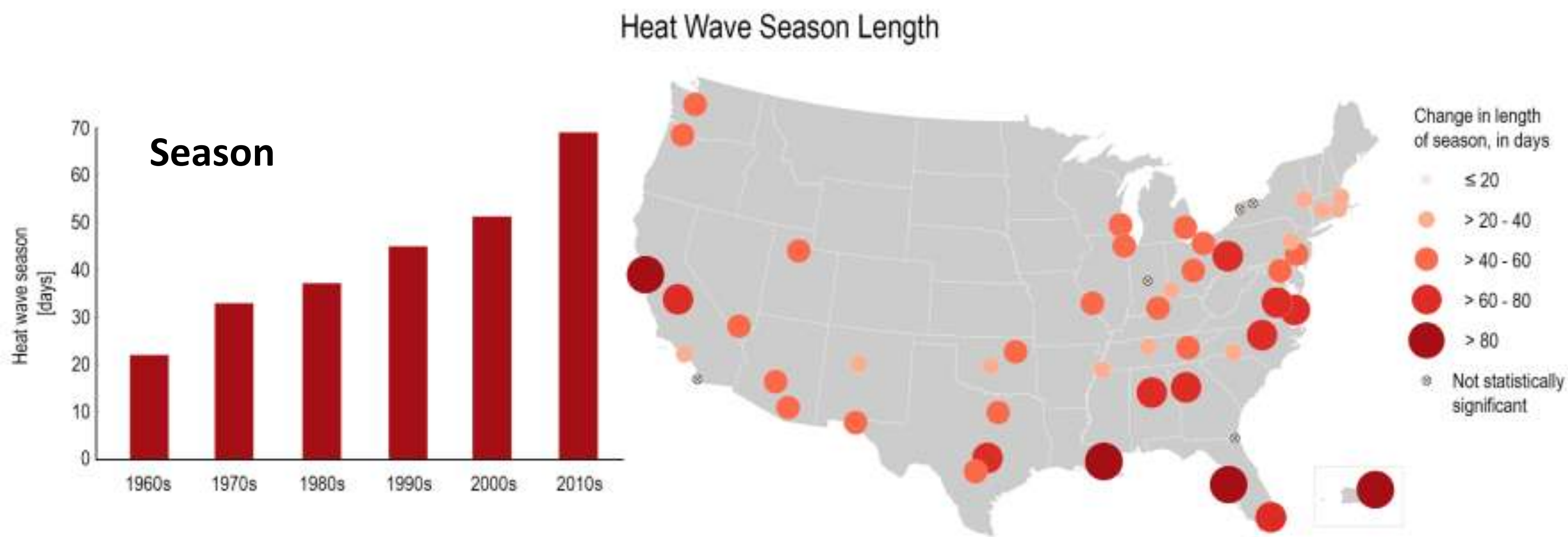
- Air conditioning

CC → mitigation measures → Indoor Environment

- Building energy efficiency

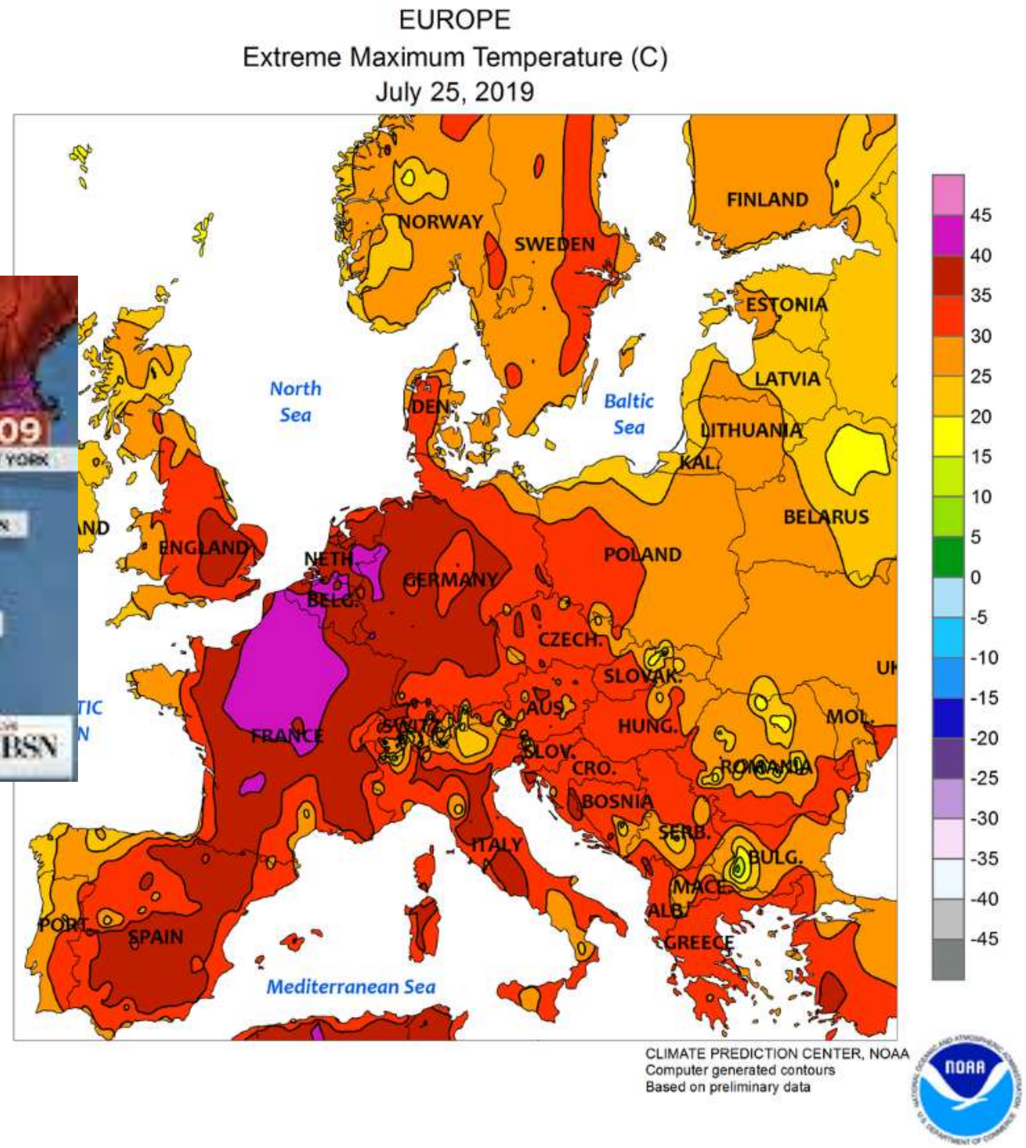
Heat Wave Characteristics in 50 Large U.S. Cities, 1961-2018





Source: US Global Change Research Program

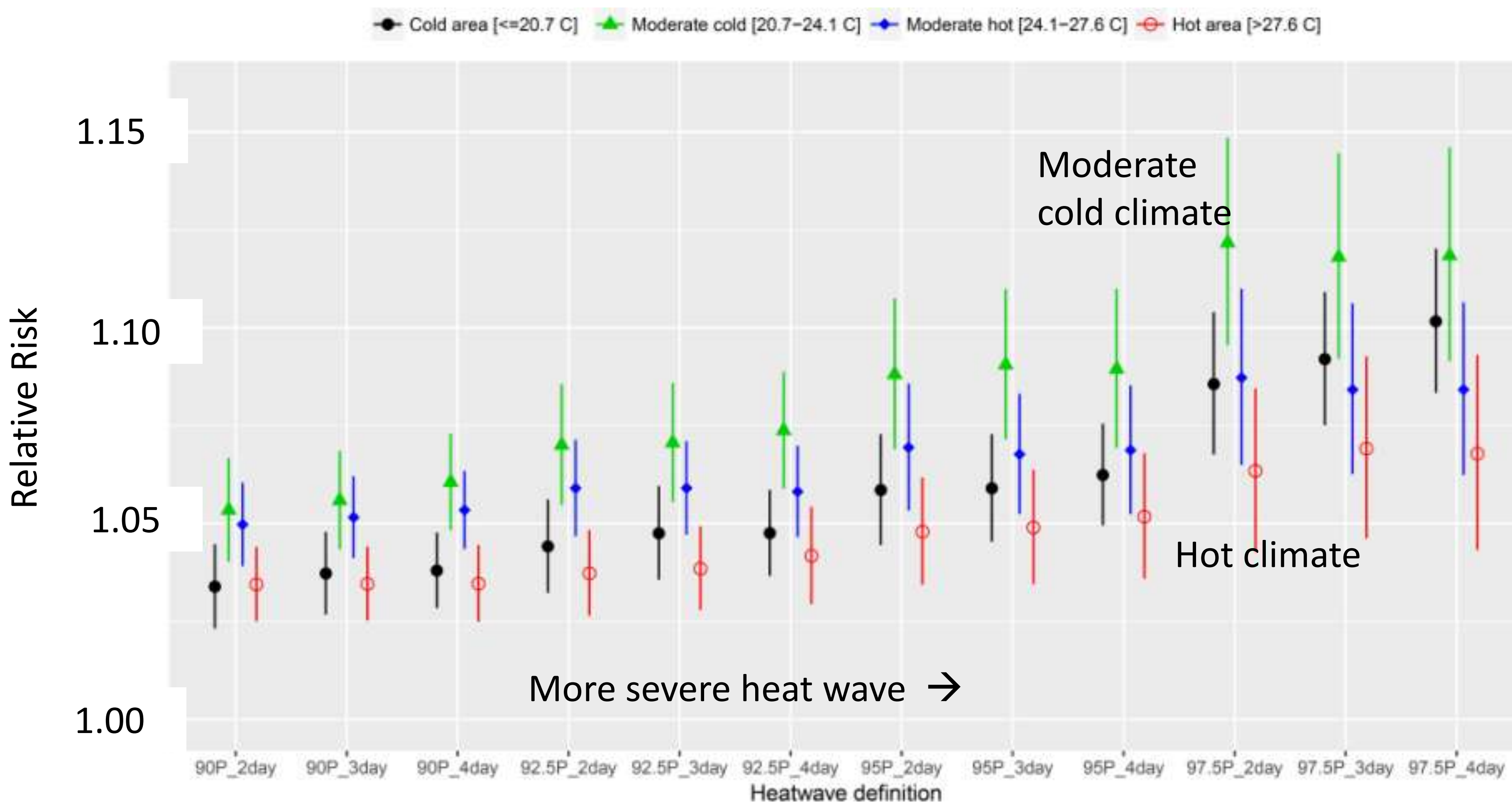
Heat Waves in 2019



Effects of Extreme Heat

- Illness, hospitalizations, and deaths
- Tens of thousands of premature deaths linked to heat waves in 2003 in Europe and 2010 in Russia

How Heat Waves Affect Mortality



Source Guo et al EHP 2017

Predicted Net Effects of more Extreme Hot Days and Fewer Extreme Cold Days on Mortality for 33 Metropolitan Areas in US

Green House Gas Emissions	Net Mortality Increase in 2100*	Mortality Increase Scaled to full US Population
Business as usual	5915	17,700
Large reduction	1888	5660

*Source: Mills et al. Climate Change 2015

Evidence of Importance of Indoor Heat Exposures

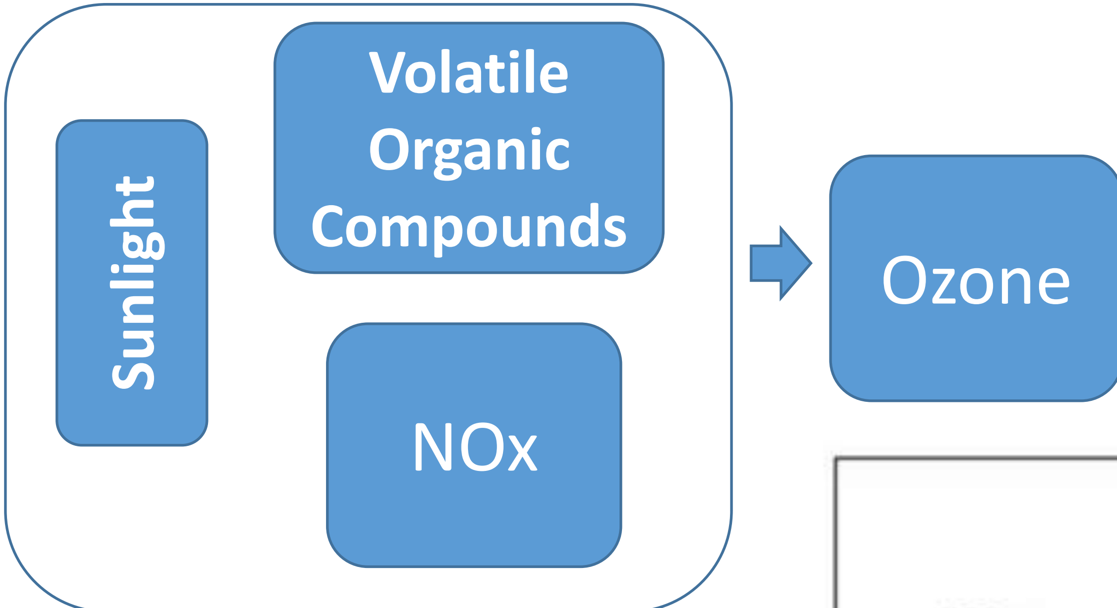
- In developed world, people are indoors ~ 90% of the time.
- In US, people age ≥ 65 are indoor at home 81% of time
- In Northern Europe, elderly with coronary heart disease are indoors at home 88% of time
- Heat waves preferentially affect elderly and those with poor health
  - 61% of excess deaths had age >75, France 2006 heat wave
  - 80% of excess deaths had age > 55, France 2006 heat wave
- Living on top floor, poor thermal insulation, lack of air conditioning increase the risk of death in a heat wave
- **Thus, data suggest many, perhaps most, heat waves deaths occur in elderly population exposed to high heat indoors**

Indoor Heat Stress Mitigation Options

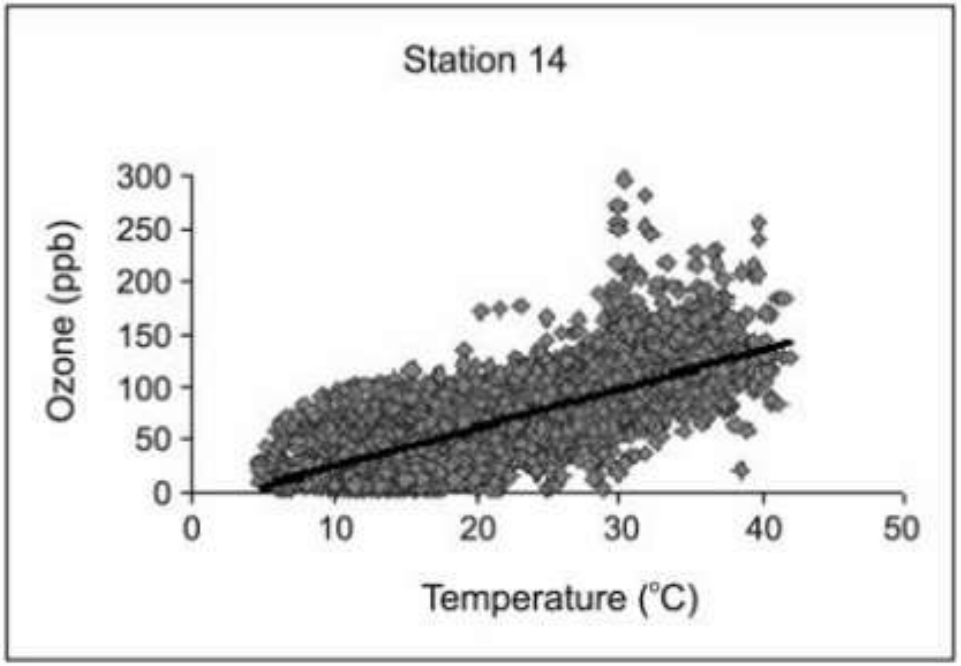
- Air conditioning
- Roof and attic insulation*
- Cool roof surfaces (reflect sunlight)*
- Window shading*
- Education and behavior changes*

*Highly desirable measures to implement even without climate change

Tropospheric Ozone Increases with Temperature



Example of trend of urban ozone with temperature*



*source: Stathopoulou et al J. Earth System Sci 2008

Ozone Health Consequences

- Respiratory symptoms (wheeze, cough, shortness of breath), asthma attacks
- Worldwide ~ 150,000 premature deaths linked to ozone pollution*
- Elderly & people with COPD and cardiovascular disease are most affected

Source: Lim et al. Lancet 2012

Projected Changes in Health Effects of Ozone from Climate Change*

Location	Time period	Increased health effects
50 US Cities	2050s vs. 1990s	Total mortality in summer increases 0.11 to 0.27% Summer hospital admissions increase 0.24% to 1.6% from COPD, age > 65 0.8% to 2.1% from respiratory effects, age > 65 2.1% from asthma, age ≤ 64
27 European Countries	2021-2050 vs. 1961 - 1990	8.6% to 13.7% increase in annual ozone-related mortality 8.2% to 12.4% increase in annual ozone-related hospitalizations

***for sources s**ee Fisk, Building and Environment 2015

Increase Ozone: Indoor Environment Implications

Indoor ozone
<
outdoor ozone

People indoors 90% of time,

Lower breathing rates when indoors

→

25% to 60% of ozone inhalation occurs indoors

more for those most susceptible

Indoor Ozone Mitigation Options

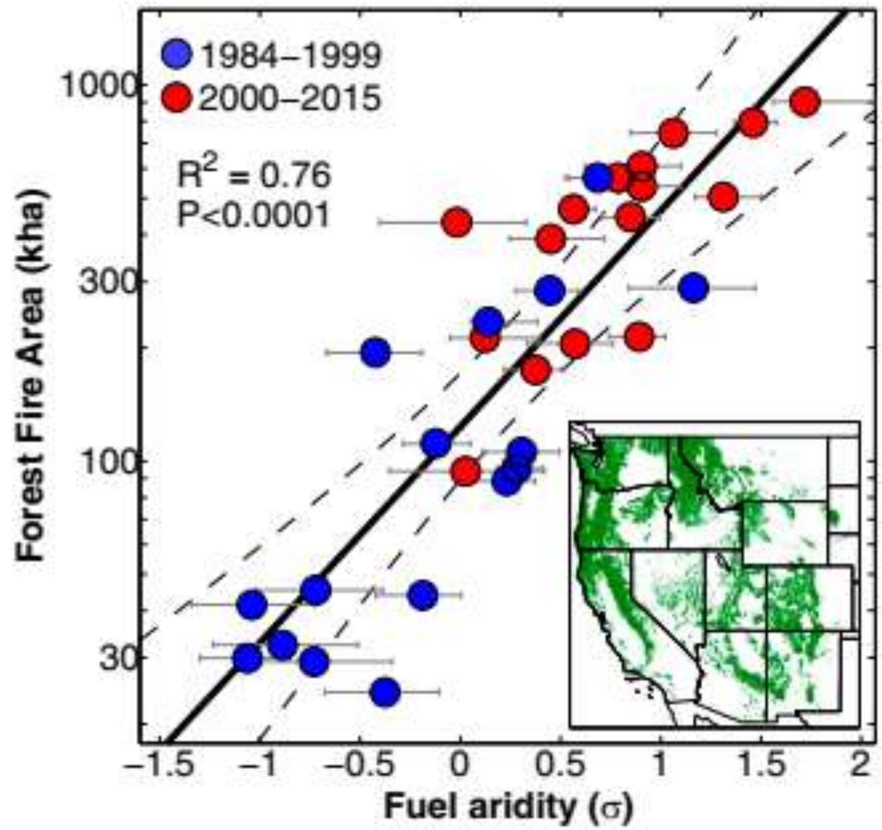
- Closed windows and air conditioning
- More air-tight building envelopes
- Filters containing activated carbon, although effectiveness of many commercial products not verified

Climate Change and Wildfires

Prior fire suppression increased fuel loads

Climate change → increased fuel aridity

More wildfires and larger area burned

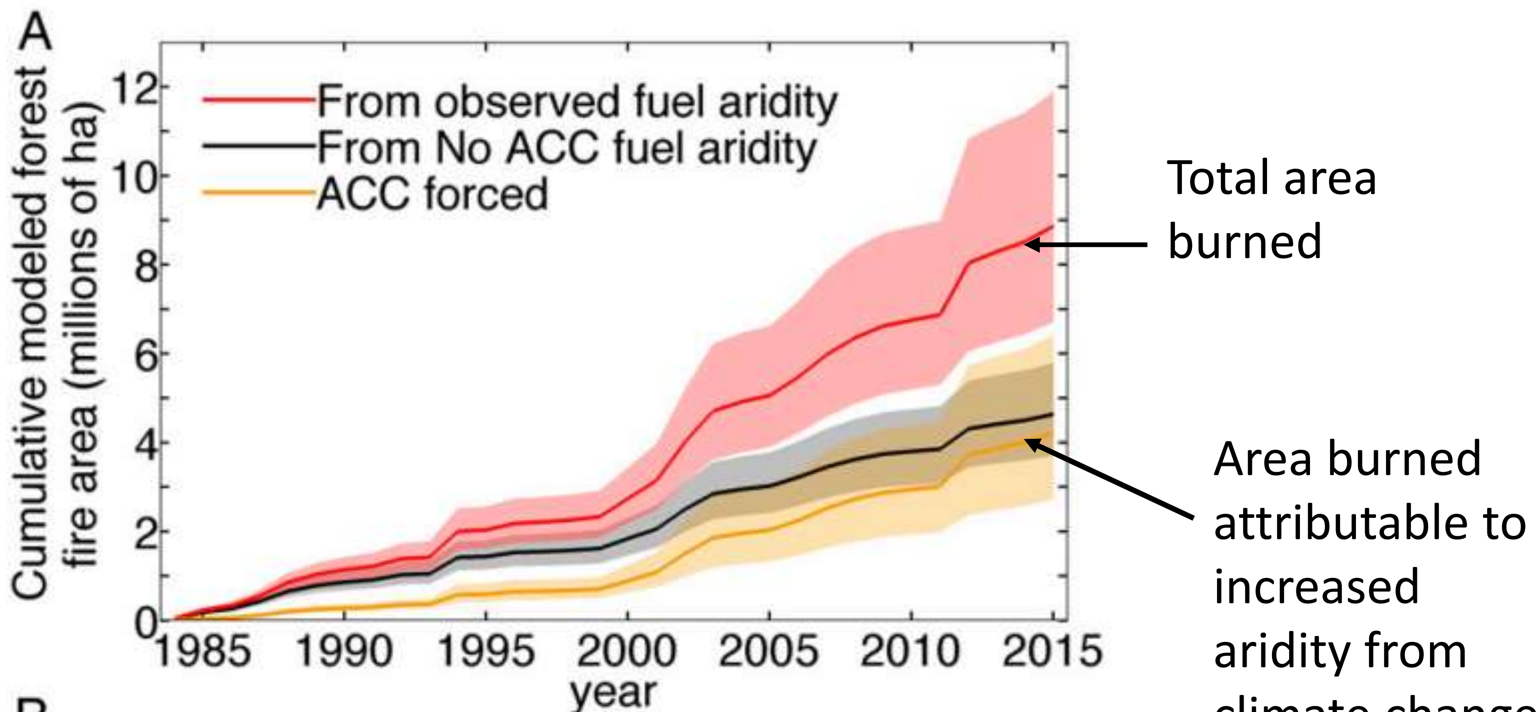


Source: Abatzoglou PNAS 2016

Effect of Climate Change on Western US Wildfires

Added 4.4 (2.7 to 6.5) million ha or 10.4 (6.7 to 16.0) million acres of western forest fire for 1984-2015

- About half of total area burned
- Approximately equal to combined areas of Massachusetts and Connecticut



Source: Abatzoglou PNAS 2016

How Wildfires Affect Outdoor Particles*

- Estimated that wildfires increase summertime mean PM2.5 levels in western US by 30% to 40%
- 2003 southern CA wildfire
  - PM2.5 was ~ 90 µg m^{-3} in heavy smoke areas and 75 µg m^{-3} in light smoke areas, ~ 20 µg m^{-3} during non fire periods
- In October and November 2018, some bay area locations had PM2.5 > 200 µg m^{-3}
- During an extreme extended term fire in Indonesia, highly affected areas had > 1000 µg m^{-3} for several days

***for sources s**ee Fisk, Building and Environment 2015

Example Health Consequences of Wildfires

Location	Duration	Health Consequences
S. California	1.5 month with 55 to 70 μg m^{-3}	Asthma admissions increased 26% at 55 μg m^{-3} and 34% at 70 μg m^{-3} Acute bronchitis admissions increased 9.6% per 10 μg m^{-3} of PM2.5 133 (26 to 262) excess cardio-respiratory deaths
Kuala Lampur Malaysia	Several months , PM10 > 166 μg m^{-3} on 20 days, PM10 > 245 μg m^{-3} on 8 days	When PM10 > 210 μg m^{-3} 70% increase in non traumatic death for age 65-74 19% increase in non traumatic death for all ages

*__for sources s__ee Fisk, Building and Environment 2015

Most Exposure to Wildfire Smoke Occurs Indoors, Particularly at Home

- With windows closed, indoor particle concentration increases in homes during wildfires are estimated to be 33% to 80% of increases outdoors
- People are indoors ~ 90% of the time. Roughly 65% of inhalation intake of wildfire particles occurs indoors
- Elderly, infants, and those with cardiac and respiratory disease are most affected by wildfire smoke. In US, people age ≥ 65 are indoor at home 81% of time.
- If wildfire health effects vary linearly with particle levels, most of the health effects are a consequence of indoor exposures

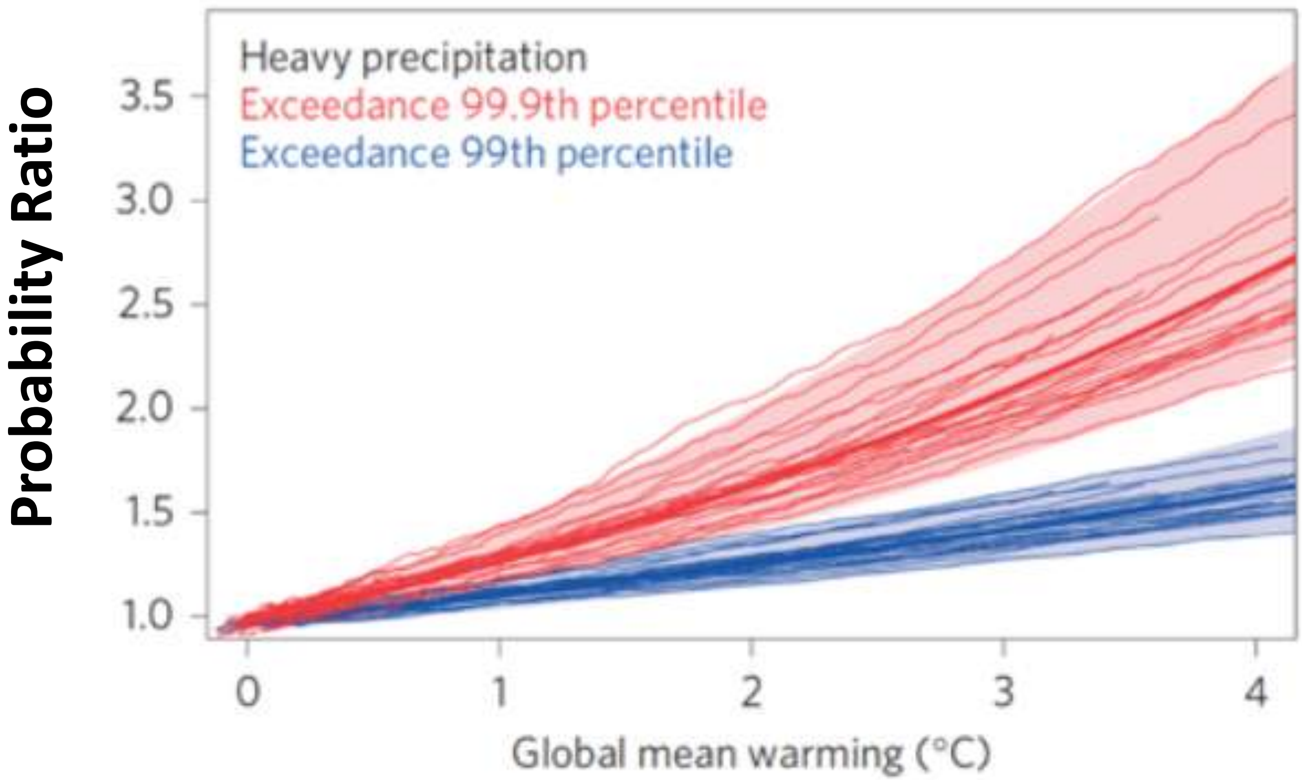
Mitigation Measures for Indoor Wildfire Smoke

- **Stay indoors and keep windows closed during wildfires^**
  - **Air conditioning facilitates closed windows during hot weather**
- **Use n95 masks**
- **Operate particle filtration systems during wildfire periods^, In six home filtration scenarios the following are model predictions:***
  - **PM2.5 intake reduced 11% to 62% for age > 65, 6% to 39% for all ages**
  - **Wildfire-related hospital admissions are decreased 11% to 63% and deaths are decreased 7% to 39%**
  - **For age > 65, hospital admissions are decreased by 20% to 105% of the increase without extra filtration, deaths are decreased 12% to 65%**
  - **Portable HEPA filter units and high efficiency filters in forced air systems that operate continuously are most effective**
  - **Interventions that target homes with residents with age > 65 are much more cost effective**

*Source: Fisk and Chan, Indoor Air 2017

^Highly desirable measures to implement even without climate change

Climate Change Increases Periods of Heavy Precipitation



Exceeds 99.9th percentile of pre-industrial daily precipitation

Exceeds 99th percentile of pre-industrial daily precipitation

Source: Hoegh-Guldberg et al. (2018) Impacts of 1.5 ^{o}C warming on natural and human systems. In: Global warming of 1.5 ^{o}C. An IPCC special report ……
https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf

Climate Change and Predicted Sea Level Rise by 2100 compared to 1986-2005

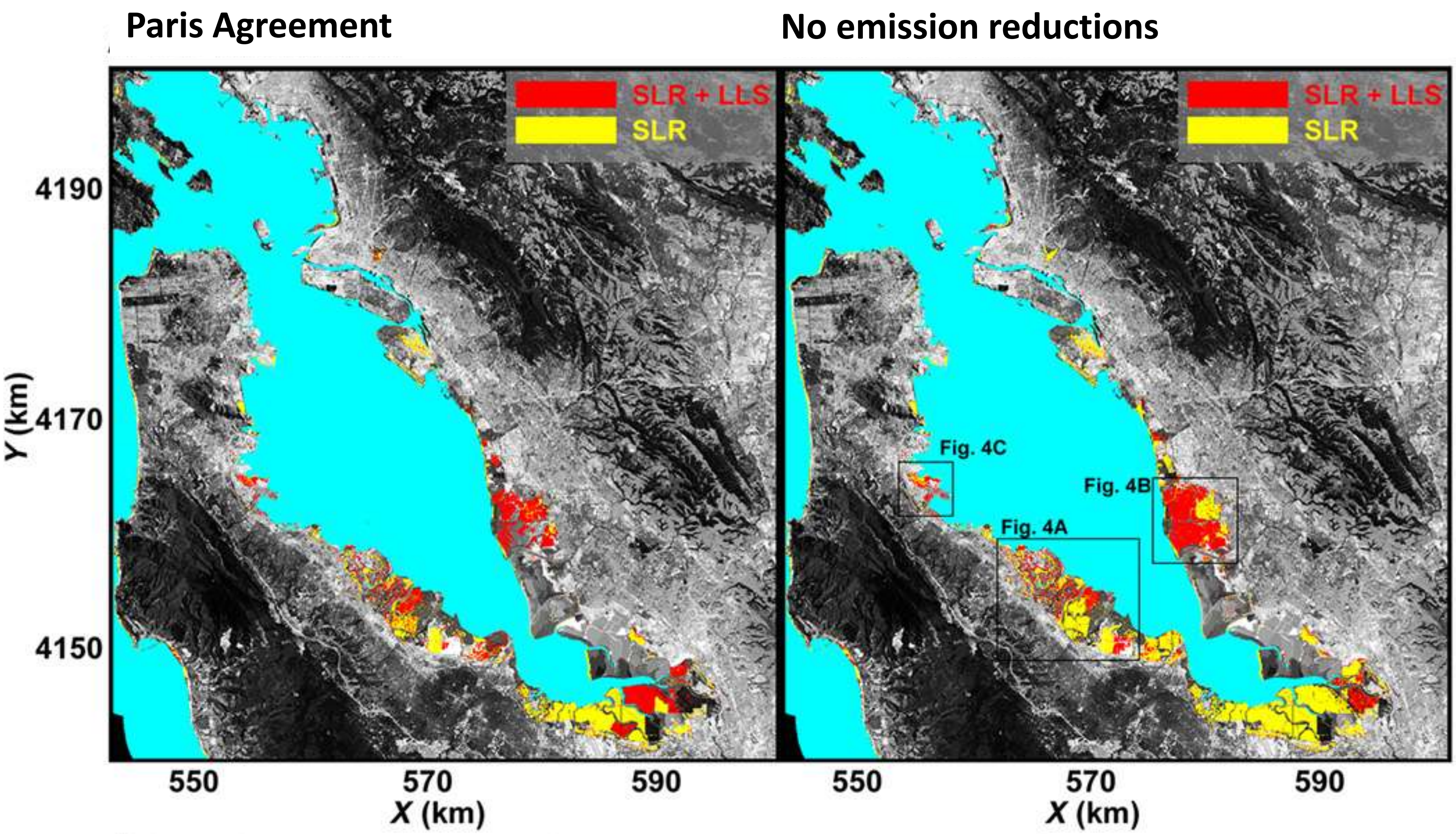
From IPCC

- 0.2 to 0.8 m sea level rise (1.5 ^{o}C warming)
- 0.3 to 1.0 m sea level rise (2 ^{o}C warming)

- At least a quadrupling of years in 21st century with 1-in-100-year floods was projected at 7 of 9 locations analyzed

Source: Hoegh-Guldberg et al. (2018) Impacts of 1.5 ^{o}C warming on natural and human systems. In: Global warming of 1.5 ^{o}C. An IPCC special report ……
https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf

Predicted Bay Area Regions Inundated by Flooding in 2100



Source: Manoochehr Shirzaei, and Roland Bürgmann Sci Adv 2018;4:eaap9234

Severe Storms and Sea Level Rise are Expected to Affect and Indoor Dampness and Mold

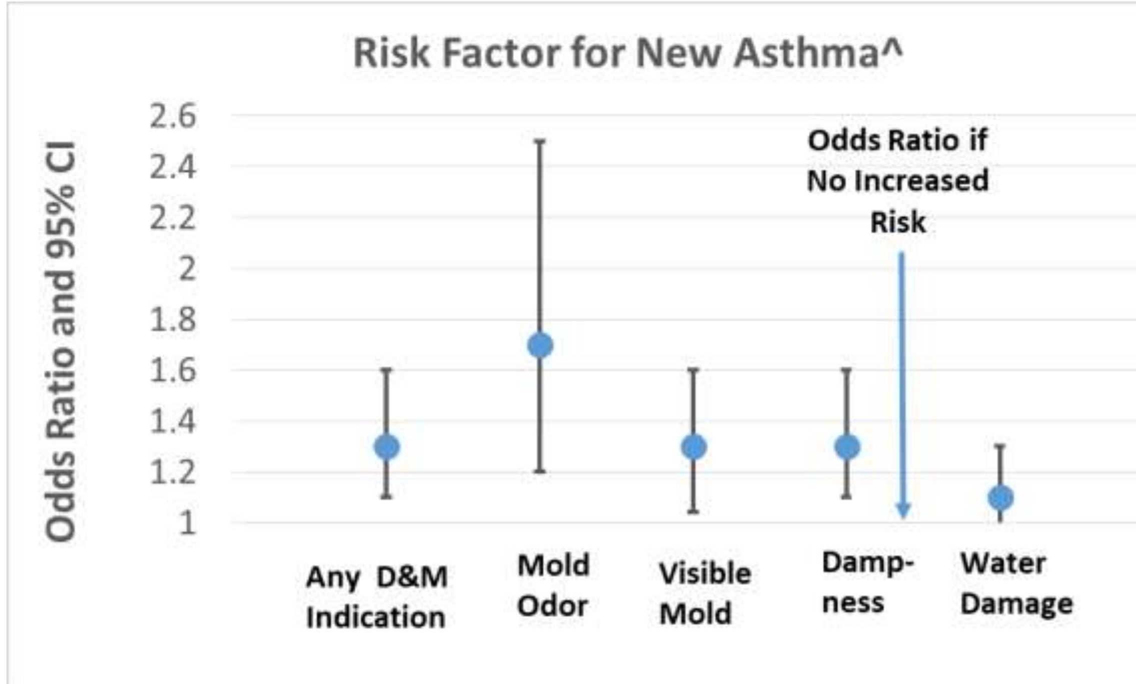
Expect increased dampness and mold in buildings, but magnitude of increase has not been quantified

- More buildings exposed to coastal flooding
- Increased water penetration and building damage from severe storms

Health Risks from Dampness and Mold in Homes

Odds ratios for health effects in damp or moldy homes

- **Upper Respiratory Symptoms OR = 1.70 (1.44 – 2.0)***
- **Cough OR = 1.67 (1.49 – 1.86)***
- **Wheeze OR = 1.50 (1.38 – 1.64)***
- **Current asthma OR = 1.56 (1.30 – 1.86)***
- **Rhinitis OR = 2.1 (1.6 – 2.8)^**
- **New asthma OR = 1.3 (1.1 – 1.6)^**
- **Respiratory infections OR = 1.44 (1.31 – 1.59)#**



*Fisk et al. Indoor Air 2007 ^Quansah et al. PLoS One 2012 #Fisk et al. Environmental Health 2010

Examples of Projected Health-Related and Economic Consequences of an Increase in Dampness and Mold

If CC Increases Dampness and Mold in U.S. Homes by 25%

1.2 million additional cases of current asthma

2% to 5% increase in common respiratory Infections

Unquantified increased in remediation and repair costs

Source: Fisk et al. (2015) Indoor Air

Reducing Indoor Environment Effects of Severe Storms and Sea Level Rise

- Improved building maintenance*
  - Roof repair or replacement
  - Fix leaky windows and walls

- Building design and construction changes*
  - Elevating buildings above grade in flood prone zones
  - Mold resistant building materials
  - Better drainage away from foundation
  - Storm-resistant designs

- Land use changes*
  - Reduce new construction in flood-prone regions

*Highly desirable measures to implement even without climate change

Increased Use of Air Conditioning: A Climate Change Adaptation Measure

Expected indoor environmental quality improvements

- Increased thermal comfort during hot weather
- Avoided heat stress illness or premature mortality
- Reduced indoor levels of pollutants from outdoor air (because windows more often closed)

Expected indoor environmental quality worsening

- Increased indoor levels of pollutants from indoor sources
- Mold & bacteria often grow on wetted surfaces of air conditioners – a potential source of exposures
- In offices, air conditioning, compared to natural ventilation, is associated with increase in "sick building syndrome" symptoms

Increased Building Energy Efficiency: A Climate Change Mitigation Measure

Building energy efficiency is key to climate change mitigation

- 30% to 40% of CO_2 emissions in US and Europe are attributable to building energy use

Common building energy efficiency measures

- Sealing leaks in building envelopes
- Thermal insulation
- Energy efficient windows
- Energy efficient appliances and lighting systems

Indoor environment improvement measures are sometimes combined with energy efficiency retrofits

- Bathroom and kitchen exhaust fans
- Adding continuous mechanical ventilation systems
- Fixing water leaks

Expected Influence of Building Energy Efficiency Measures on Indoor Environmental Quality

Measure	Expected IEQ Effect
Envelope sealing to reduce air leakage	Reduced indoor concentrations of outdoor air pollutants Increased indoor concentrations of pollutants from indoor sources and soil beneath house Indoor humidity reduced in summer in air conditioned houses Indoor humidity increased in winter Sealing materials can be sources of air pollutants Reduced drafts
Thermal insulation	Some insulation systems reduce air leakage Generally increased thermal comfort Reduced or increased potential for overheating Insulation can be source of air pollutants
Window replacement	Often reduces air leakage Improved thermal comfort

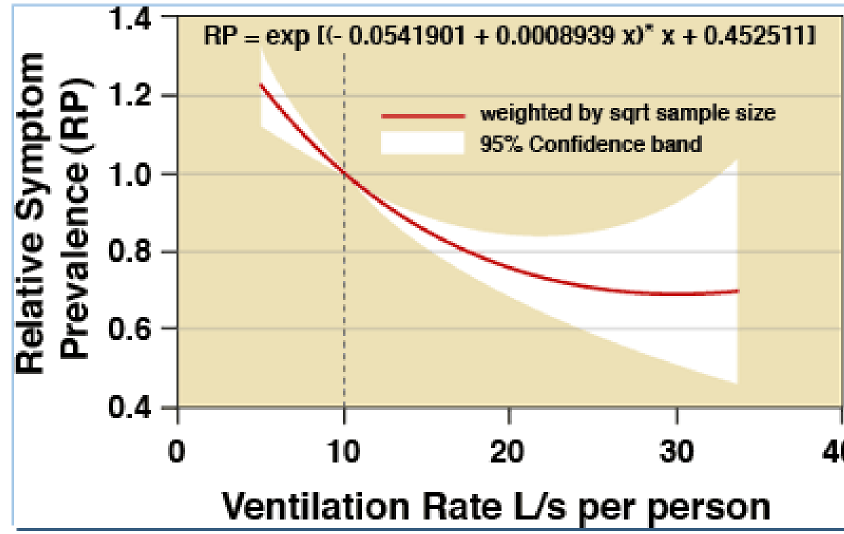
Building Energy Efficiency Often Reduces Ventilation Rates: What are the Empirically Documented Effects of Ventilation Rates (VRs)

In Offices, lower VRs associated with:

- increased sick building symptoms
- decreased task performance

In Schools, lower VRs associated with:

- reduced student performance and test scores
- increased absence

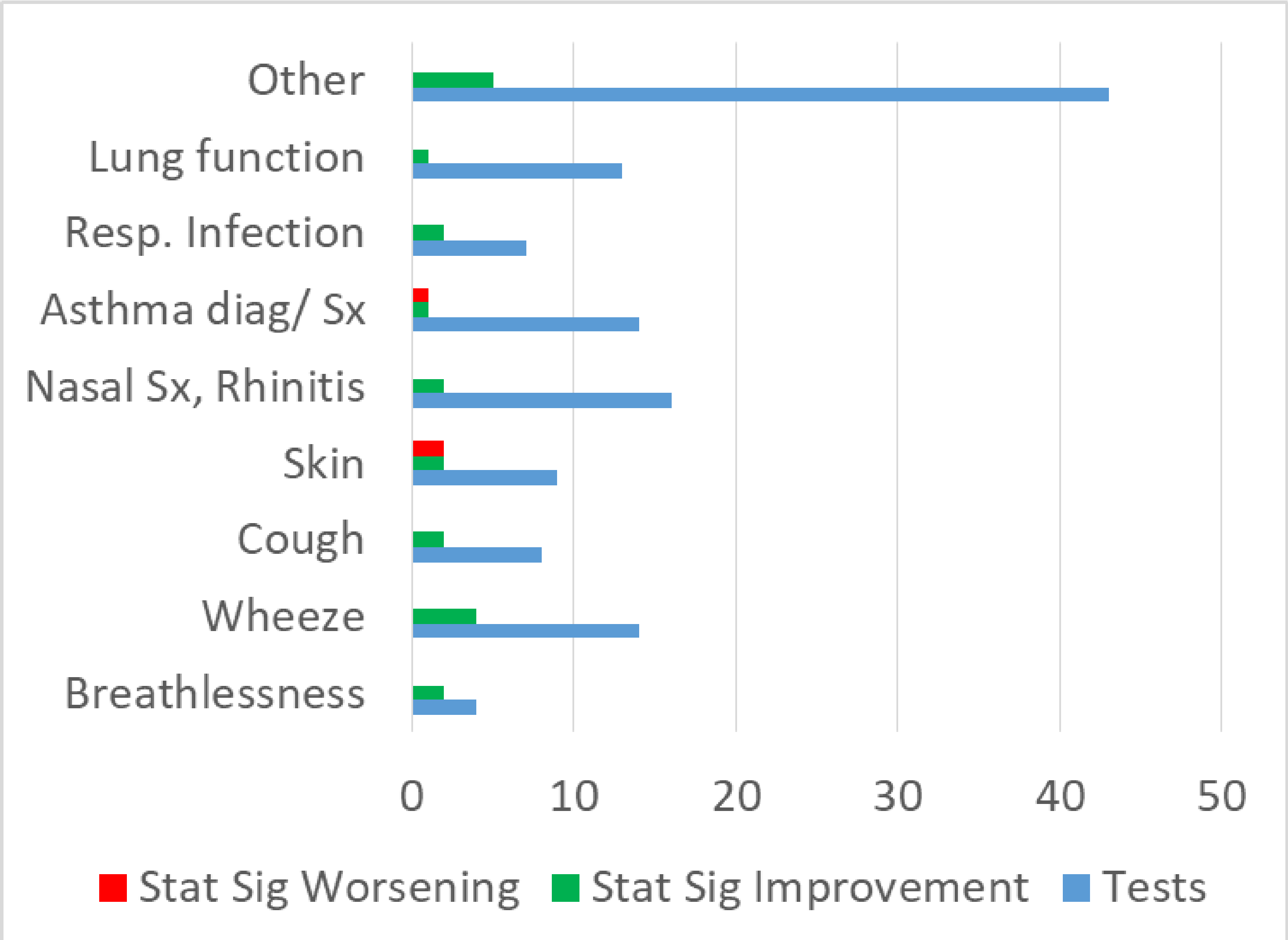


Statistical Analyses of 8 Office Studies with 43 Data Points

For sources, see www.iaqscience.lbl.gov

With Increased VR in Homes

A Small Fraction of Tests Indicate Statistically Significant Change in Health



Source: Fisk (2018) Indoor Air Journal, review of 20 studies

How Home Energy Retrofits Affect IAQ and Health

Preliminary Results of Ongoing Review of Published Empirical Data (39 studies)

- **Indoor radon concentrations tend to increase**
- In approximately equal number of studies, indoor formaldehyde concentrations increased and decreased, although increases are more often statistically significant
- In approximately equal numbers of studies, indoor concentrations of VOCs other than formaldehyde, particles, and NO_2 increase and decrease
- **Self reported thermal comfort typically improves, although most data are from studies aiming to improve warmth in cold homes**
- Self reported asthma symptoms have increased and decreased and changes are typically not statistically significant
- **Self reports of dampness and mold have tended to decrease**

Conclusions

Climate-change-related changes in heat waves, precipitation, sea level, wildfires, and ozone are projected to adversely affect indoor environmental conditions & human health

- Changes in building features and operation can reduce adverse effects
- Many of the mitigation measures are highly desirable irrespective of climate change

Air conditioning use will increases as an adaptation measure

- Expected to increase thermal comfort and reduce heat stress illness
- Indoor pollutants will be both positively and negatively affected

- Building energy efficiency (EE) is a critical climate change mitigation measure (preliminary findings)
  - On average, EE retrofits associated with increased indoor radon concentrations
  - No clear overall effects of EE retrofits on indoor levels of volatile organic compounds, particles, or NO_2
  - On average, EE retrofits are associated with improvements in self-reported thermal comfort in winter
  - No clear overall effects of EE retrofits on self-reported asthma symptoms

More Information

- www.indoorairscience.lbl.gov

- Fisk, W.J. (2015) Building and Environment 86: 70-80.
- Institute of Medicine (2011) Climate change, the indoor environment, and health. Washington DC, National Academies Press. Nap.edu