The Heat is On

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Interim analysis: the effect of heat stress on lives and livelihoods

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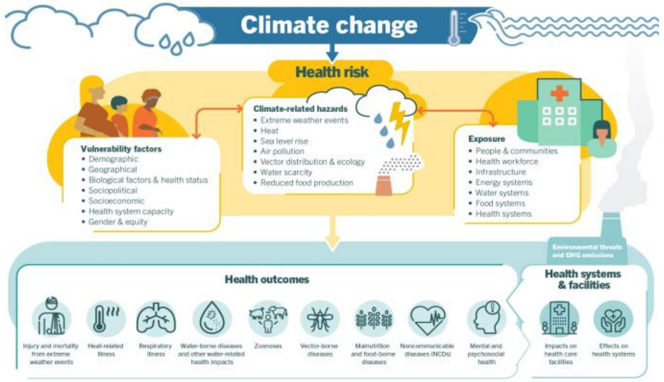
1. Introduction

"Climate change presents a fundamental threat to human health. It affects the physical environment as well as all aspects of both natural and human systems – including social and economic conditions and the functioning of health systems. It is therefore a threat multiplier, undermining and potentially reversing decades of health progress. As climatic conditions change, more frequent and intensifying weather and climate events are observed, including storms, extreme heat, floods, droughts and wildfires. These weather and climate hazards affect health both directly and indirectly, increasing the risk of deaths, noncommunicable diseases, the emergence and spread of infectious diseases, and health emergencies". Climate change (who.int)

Figure 1. Climate-sensitive health risks, their exposure pathways and vulnerability factors (WHO, 2023).



Heat is an important environmental and occupational health hazard. Increasingly, climate policy action on heat stress and health risks is considered a human right, and integral to safeguarding climate justice, especially of vulnerable groups in society.

Heat stress is the leading cause of weather-related deaths and can exacerbate underlying illnesses including cardiovascular disease, diabetes, mental health, asthma, particularly amongst the elderly. Heat stress can increase the risk of accidents, as well as the transmission of several infectious diseases. Although heat stress kills more people every year than other climate-related disasters, it is less scrutinized and discussed due to its chronic, slow-burn development that gradually intensifies over time, usually spanning multiple decades. Moreover, not everyone is exposed and harmed equally.

Vulnerability to heat is shaped by both physiological factors, such as age and health status, and exposure factors such as occupation and socio-economic conditions. High intensity and extended heat events (i.e., 'heat domes') cause high (senior) fatality. These life-threating events are often compounded by 'urban heat islands', i.e., spatial concentration of micro-climates and heat pockets in urbanized areas.

In this interim analysis, the effects of heat stress on the health of, especially, senior citizens and the vulnerable elderly are outlined. This preliminary analysis of stylized facts and initial findings is subject to change and relative uncertainties associated with climate and health data quality, as well as risks associated with (climate and health) forecasting.

(Heat and health (who.int), 2024; Home » Yale Climate Connections, 2024; National Institute of Environmental Health Sciences: Human Health Impacts of Climate Change (nih.gov))

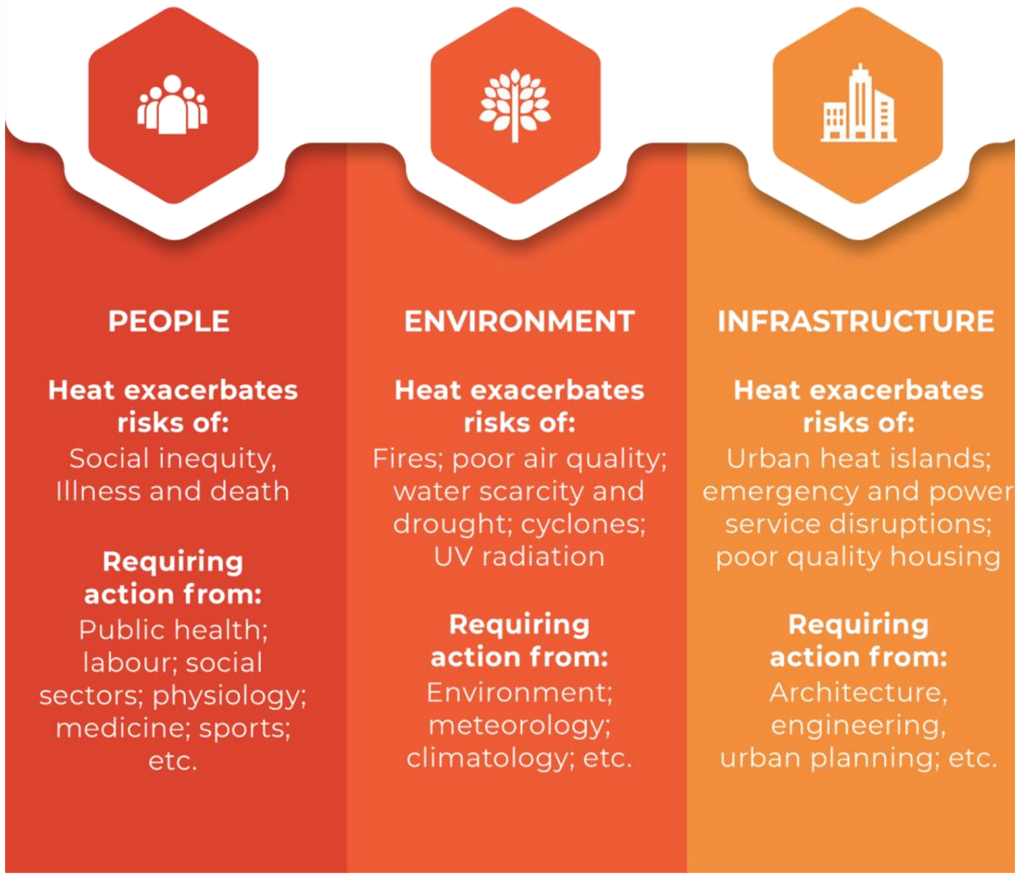
Heat is an 'All-of-Society' (AoS) Risk

Population ageing and the growing prevalence of non-communicable diseases (respiratory and cardiovascular diseases, diabetes, dementia, renal disease, and musculoskeletal disease) implies that over the past decades senior citizens have become more susceptible to adverse heat impacts.

The health hazards of heat are furthermore exacerbated due to a lack of climate-inclusive urban infrastructures to mitigate the accumulation and generation of heat, thereby resulting in elevated energy demand (and the risks of energy disruptions), as well as inappropriate housing (for senior citizens) that often amplify exposure to excess heat and air pollution.

Hence, heat and heat stress are an 'All-of-Society' (AoS) systemic risk of (I) ***People*** (residents and visitors), (II) ***Environment*** (climate and nature), and (III) ***Infrastructure*** (Urbanization, energy, and emissions).

Figure 2. Systemic risks of heat: people, environment, and infrastructure.



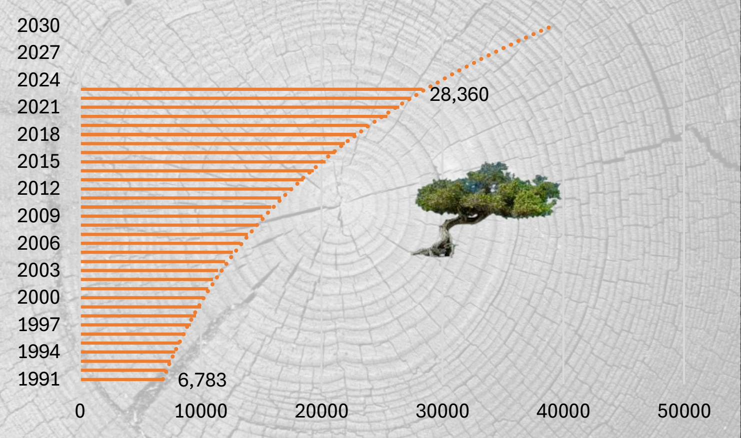
(Heat and health (who.int), 2024)

2. Demographics

Aruba is facing a – *rapidly accelerating* – aging population (+ 60 years). This generation 'Watapana' (Figure 3) has surged from an estimated 6,783 people in 1991 (10.3% of population) to 28,360 in 2023 (26.4% of population*), likely to expand to over 39,000 by 2030 (33% of projected population). In addition to the young children and pregnant women, the World Bank (2024) estimates that there are at least 36,000 senior citizens exposed to heat risks in Aruba.

Age vulnerabilities to heat exposure – Aruba (World Bank, 2024)	
Very young, < 5 years	Total: 6.06 thousand M: 2.96 thousand F: 3.1 Thousand
Seniors, +60 years	Total: 36.04 thousand M: 20.62 Thousand F: 15.41 Thousand

Figure 3. Generation Watapana: Number of +60 year-old residents (Aruba, 1991 – 2030p)



(CBS, 2023; LFS, 2024; Author's calculation)

*note: excluding unregistered or undocumented people, who are also considered a vulnerable socioeconomic group exposed to heat risks.

Tourists & Visitors

Aruba is experiencing an aging of tourism and respective visitors (+60 years). These 'Baby Boomers' and 'Silent' generations (Figure 4) are exposed to the adverse health risks of increasing heat and heat stress, both in their origin countries, as well as while visiting and vacationing on island.

In 2023:

- 290,857 visitors (and rapidly growing)
- At least 25% of total visitor market share
- Estimated potential tourism revenue impact: Afl. 873 million (14% of GDP)

Figure 4. Visitors by age (2023).

VISITORS BY AGE YTD DECEMBER 2023/2022 — 1,260,402 ARRIVALS — 14.5% GROWTH

	2022	Growth	2023	% Growth
0 - 11	76,122	8,352	84,474	11.0%
12-19	79,085	6,330	85,415	8.0%
20 - 29	145,842	5,700	151,542	3.9%
30 - 39	185,005	14,712	199,717	8.0%
40 - 49	181,882	25,469	207,351	14.0%
50 - 59	207,737	33,240	240,977	16.0%
60 - 69	150,529	40,277	190,806	26.8%
70 +	74,751	25,300	100,051	33.8%
Not Stated	44	25	69	56.8%
Total	**1,100,997**	159,405	**1,260,402**	**14.5%**

GENERATIONS YTD DECEMBER 2023/2022 — 1,260,402 VISITORS — 14.5% GROWTH

	2022	Growth	2023	% Growth	Marketshare 2022	Marketshare 2023
Gen A	59,671	6,945	66,616	11.6%	5.4%	5.3%
Gen Z	171,567	11,901	183,468	6.9%	15.6%	14.6%
Millennials	293,300	21,849	315,149	7.4%	26.6%	25.0%
Gen X	292,262	42,277	334,539	14.5%	26.5%	26.5%
Baby Boomers	259,448	65,461	324,909	25.2%	23.6%	25.8%
Silent Generations	24,706	10,946	35,652	44.3%	2.2%	2.8%
Age not specified	43	26	69	60.5%	0.0%	0.0%
Total	**1,100,997**	159,405	**1,260,402**	**14.5%**		

(ATA, 2024)

3. Intensifying temperature rise

Stylized facts and findings

Aruba has experienced accelerating temperature rise and heating since the early 1990's (Figure 5):

- Average air temperature has increased by at least 1.5c *above baseline 1951-1980*.
- Together with the increase in relative humidity, intensifying temperature rise amplifies heat risks.

Likewise, since the early 1990's, Aruba has experienced a significant growth in the mortality rate of elderly and senior fatalities (Figure 5). These include people over 60 years, with prevalence of morbidity (Mortality x morbidity (MM)).

Findings show (Figure 6):

- Significant and positive (non-linear/exponential) association between temperature rise and senior fatalities (between 1992 and 2023).
- Almost 50% of senior fatalities (in the past 30 years) is explained by intensifying temperature rise
- On average: +1c → +75 senior fatalities
- Historically: +.5c above baseline temperatures (1951-1980) significantly increases the risk of senior fatality.

Figure 5. Average Temperature Change (+Celsius; Baseline 1951-1980) and Mortality x Morbidity (+60 years). Past trends (1992-2023) and Projections (2030).

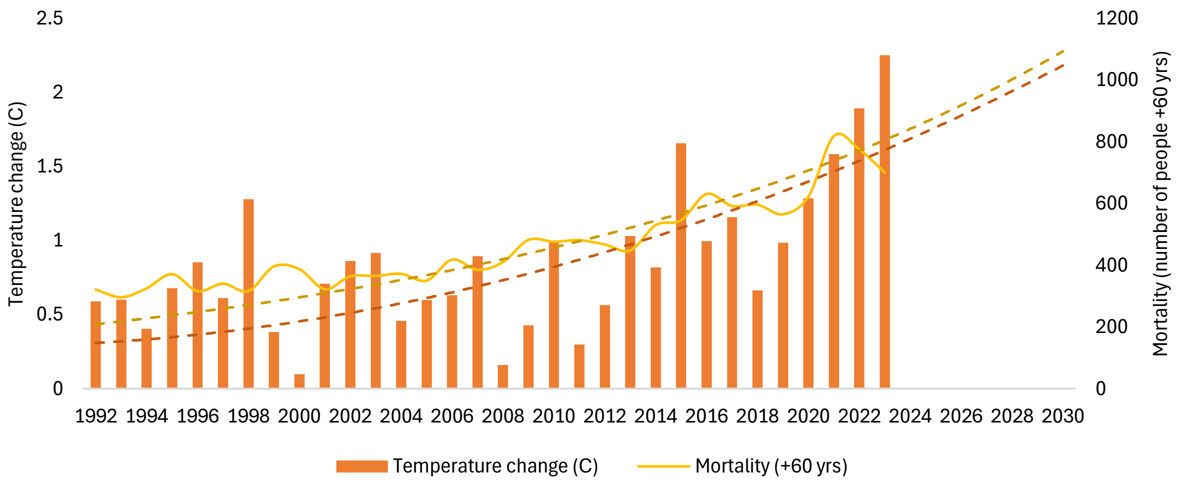
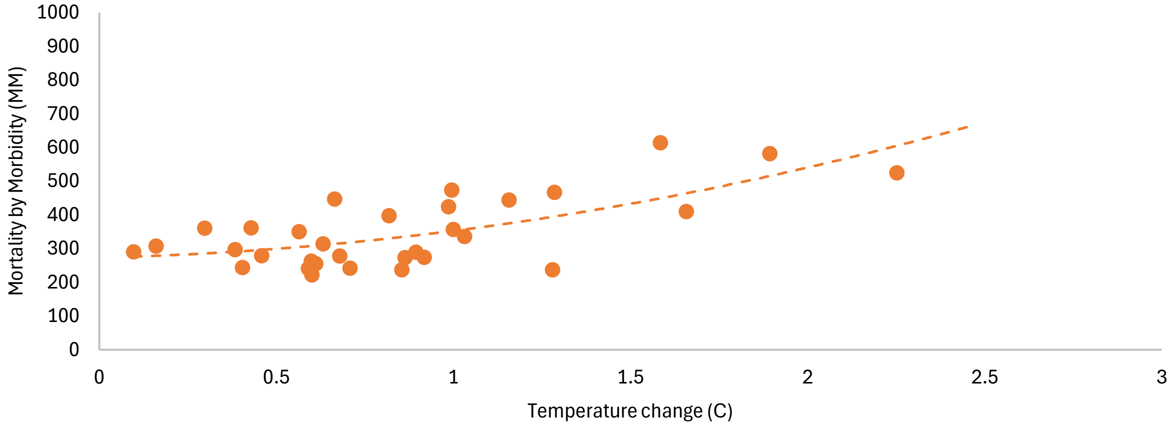


Figure 6. Relationship between relative temperature change and senior fatality.



(CBS, 2023; DMA, 2020; IMF, 2024; Author's calculation)

Past, Present, and Projected Trends in Average Mean Surface Air Temperature

The (temporal) extension of excessive heat periods (+30c) is expected in the next decade(s), thereby likely affecting senior health and fatality rates, without commensurate climate health policy adaptations.

Figure 7. Past trends in average mean surface temperature (Aruba, 1951-2020).

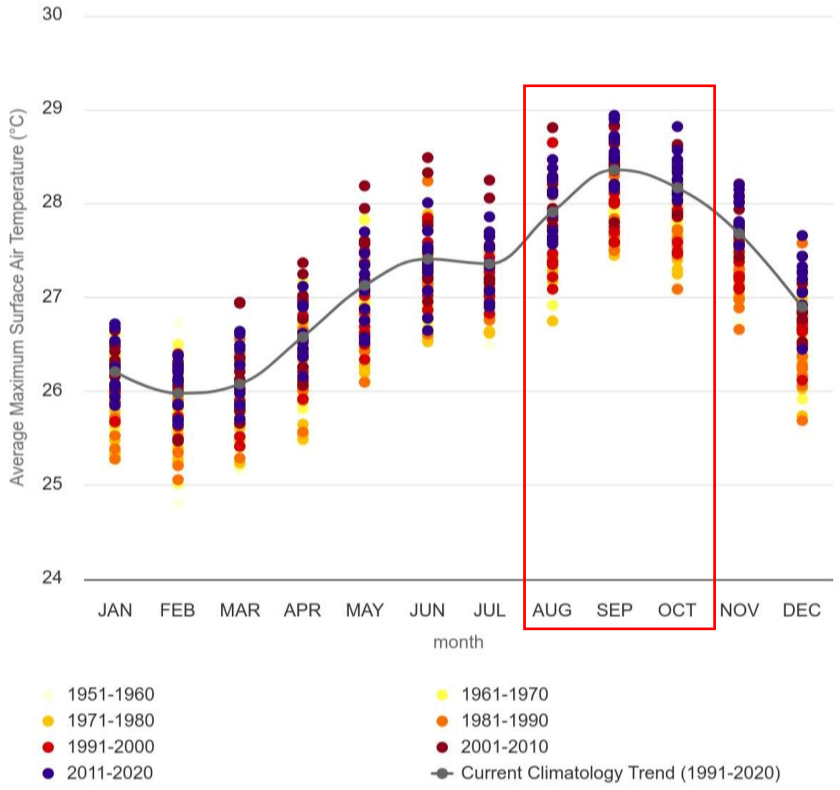
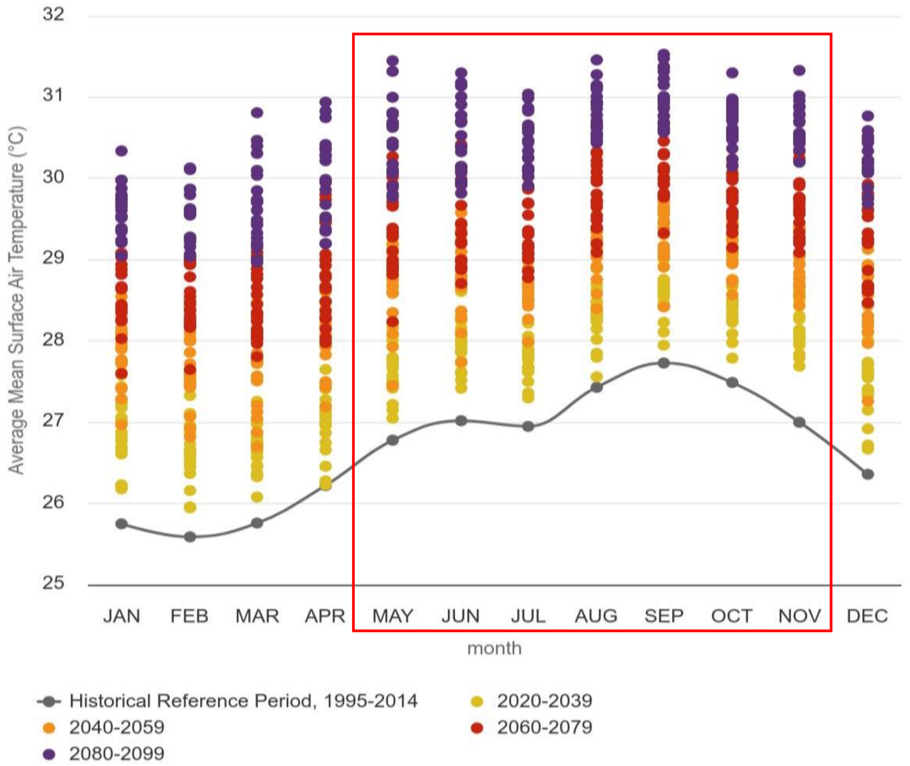


Figure 8. Projected trends in average mean surface temperature (Aruba, 2020 - 2099).



(World Bank, 2024)

Heat and Heat Index:

Increasing heat risks and the potential formation of heat domes are likely to intensify in the future, thereby extending the traditional 'heat wave' in Aruba.

**The perception of heat is subjective and can be affected by various factors such as age and health conditions. A higher relative humidity (RH) affects normal body cooling by reducing the rate of evaporation of sweat. The human body cools itself through perspiration, where heat is removed from the body as a result of the evaporation of sweat. The lower rate of evaporation subsequently lowers the rate at which the body cools, increasing the perception of heat. This perception of heat is what the heat index measures.*

(https://www.calculator.net/heat-index-calculator.html?airtemperature=35&airtemperatureunit=celsius&humidity=75&ctype=1&x=Calculate).

Heat is a function of different dynamic environmental and weather conditions, including, e.g.,

- Temperature (Air and Ocean)
- Humidity (Relative)
  - Increases (perceived) heat, heat stress, as well as health-related heat risks.
  - Rising average mean humidity from 75.6 (1951-1980) to 77.9 (1991-2020)
- Heat index*: 30c @ 78% humidity = 40c (104f)
  - Heat risk warning: *Extreme caution - at this condition, heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.*
- Wind (speed) and cloud (coverage)
- Duration: 'Heat waves' vs. 'Heat domes'
  - 3 days to extended periods of more than 2 weeks.
  - Increasing likelihood of heat dome formation in Aruba between May and November (2021-2040).

Figure 10. Projected heat risk period from temperature, humidity, and duration - Aruba.

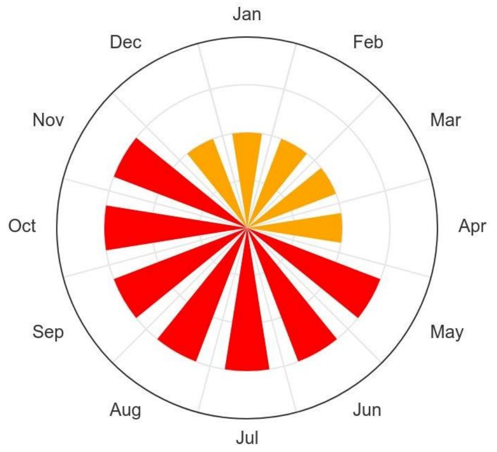


Figure 9. Aruba seasonal cycle and duration of consecutive heat waves and humidity (Heat index > 35c).

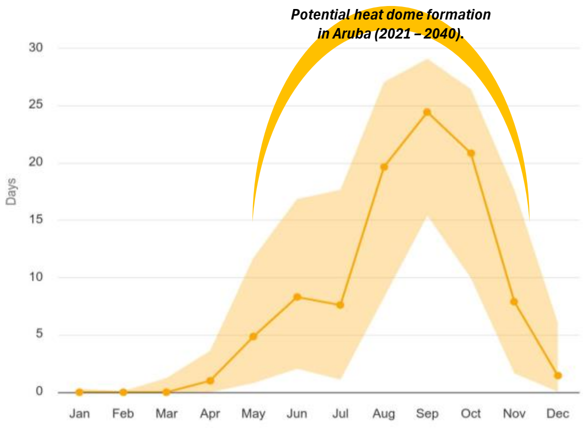
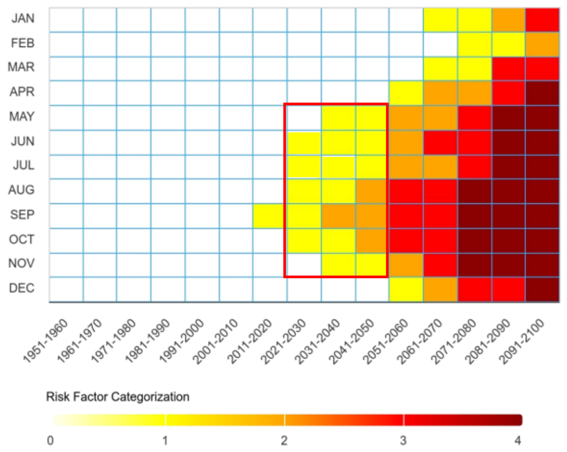


Figure 11. Projected map of heat risk index by month and year (past, present, and projections for Aruba).



(WB, 2024. Based on the compounded risk categorization (0-4) of (a) average (air) temperature, (b) humidity-based heat, and (c) vulnerable -aging- population).

Heat Snapshot: March – May 2024

Total days > 32c (Air temperature): **31**
Heat Index Temperature: **43c**
Heat warning: **Danger**

WARNING	HEAT INDEX	HEALTH IMPACT
Safe	< 26	No adverse effects expected due to heat
Caution	27- 32	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	33 - 40	Heat stroke, heat cramps or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	41 - 51	Heat cramps or heat exhaustion likely and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	52 - 92	Heat stroke highly likely
Beyond human threshold*	<93	Values beyond human resistance to heat

Figure 13. Average high and low daily temperatures (Weatherspark.com; Aruba, Mar-May, 2024).

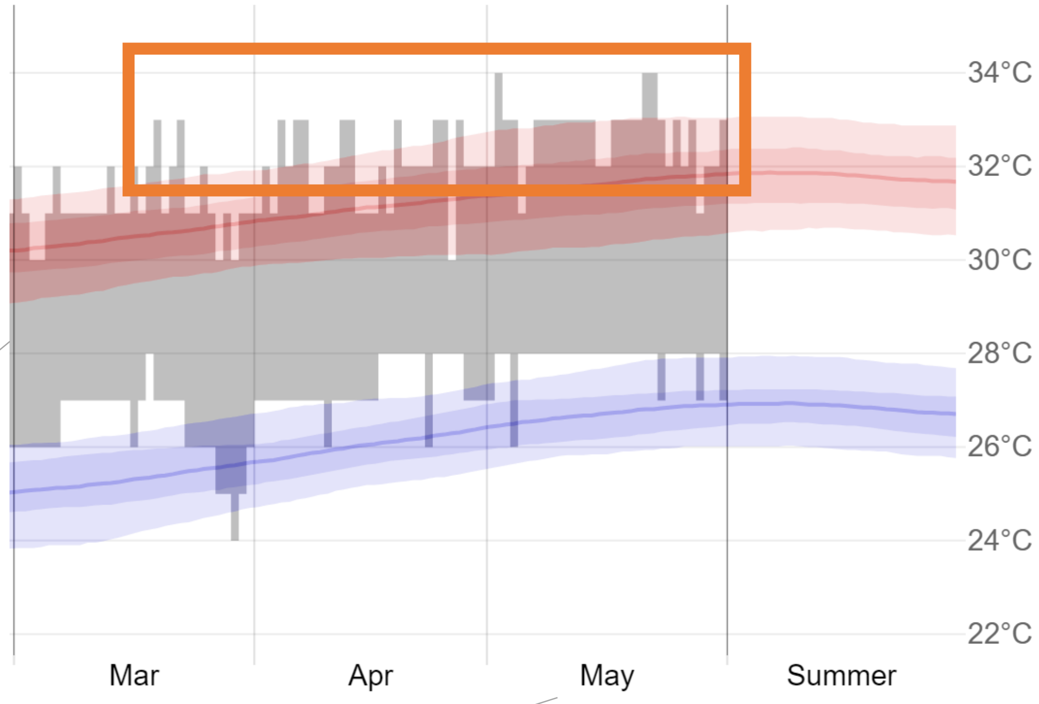
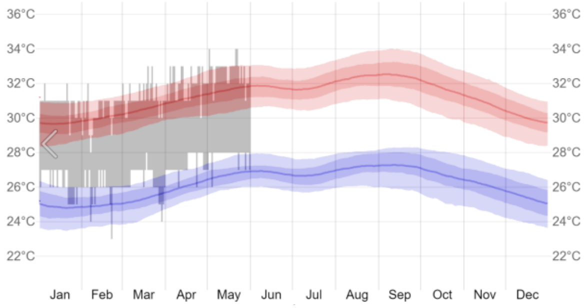


Figure 12. Average high and low daily temperatures (Weatherspark.com; Aruba, Jan-May, 2024).



At this level:
- Heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.
- Poor air quality is likely (if GHG emissions elevated).

Heat at this level is a **major risk** to individuals who are (1) exposed to the sun, (2) active, (3) of age (or very young), and/or (4) have previous medical conditions.

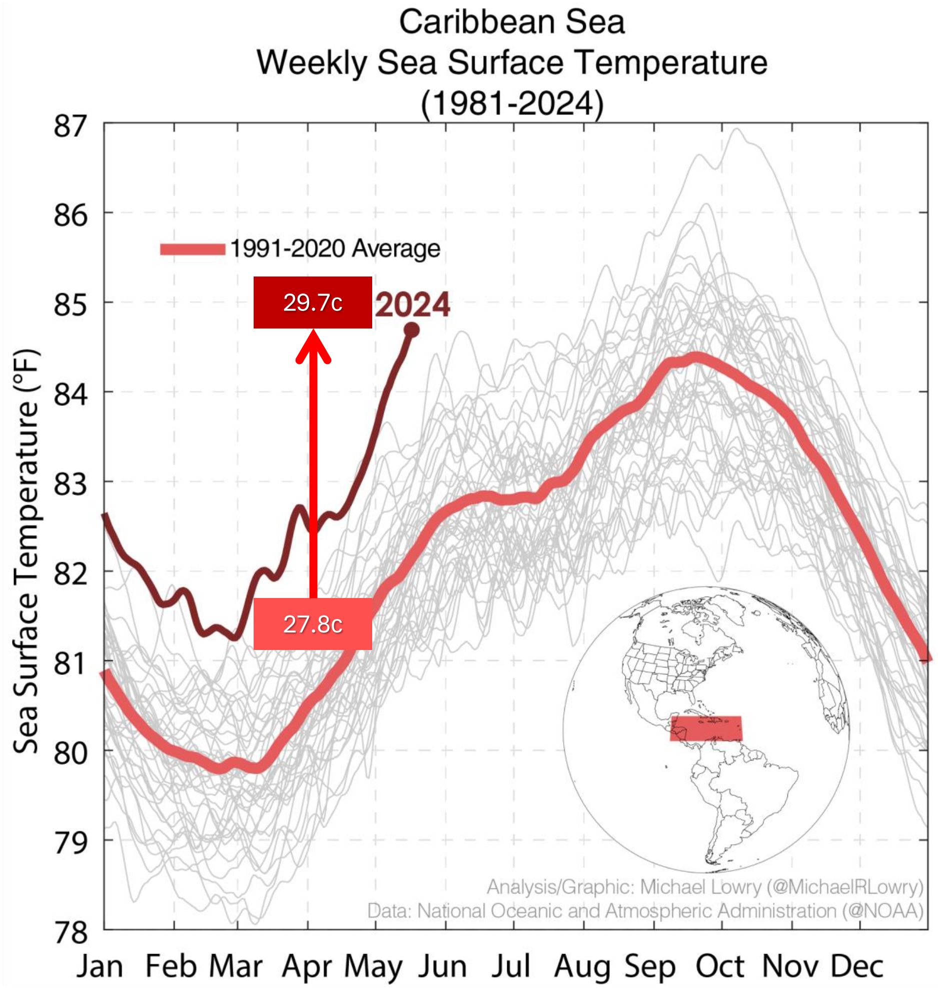
Industries affected: Construction, Transportation, Tourism, Health, and Agriculture.

4. Environmental impacts: Ocean and Sea Surface Temperature (SST)

As of May 2024, the average SST is +1.5c above 1991-2020 baseline level. Together with high(er) air temperatures and humidity, higher SST creates conditions for rapid intensification of tropical disturbances and hurricanes, sea level rise, storm surges, as well as loss of marine life and biodiversity. The amalgam of these SST stressors have profound implications for ocean ecosystems and the services they provide. When water temperatures warm, tropical rainfall increases by a factor of five. This amplifies the risk of storm and rain flooding in coastal areas and communities across the Caribbean.

With the advent of the transition from El Niño to La Niña (70% chance of occurring in second half of 2024), there are severe health repercussions, as the onset of more precipitation and warmer temperatures provides a fertile ground for the accelerated spread of viral and communicable diseases.

Figure 14. Caribbean sea surface temperature (1981-2024).



(yaleclimateconnections.org, 2024)

The Impact on Nature:
Ocean heat stress and coral bleaching

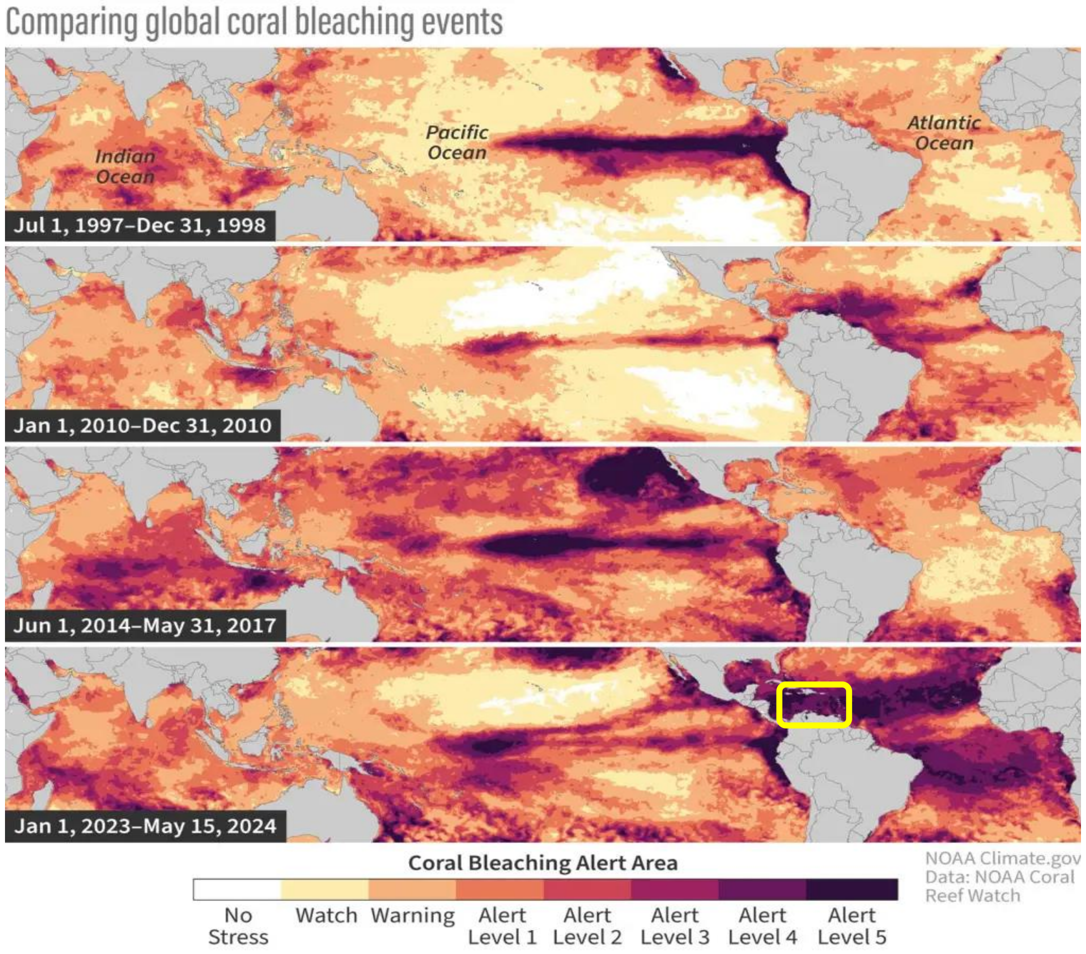
Nature and oceans are increasingly exposed to heat stress. The adverse impact on marline life, and consequently, the loss of biodiversity and ecosystems services is well known and documented.

In 2023, some of the worst coral heat stress and coral bleaching were recorded in the Caribbean. The lengthening duration of heat stress (i.e., ocean heat domes), as confirmed by NOAA in April 2024, is once again threatening the survival and recovery of Caribbean corals in 2024.

Based on previous estimates of the value of ecosystem services in Aruba (Wolfscompany, 2018), it is projected that at least Afl. 600 mln. in marine services is at stake and exposed to the adverse impacts of heat stress.

Note: Map series comparing the coral bleaching year-to-date 2024 (bottom map) to previous global events in 1998 (topmost map), 2010, and 2014-2017. Each map shows the location and intensity of coral heat stress during the peak of the events.

Figure 15. Global coral bleaching events (1997 – 2024).

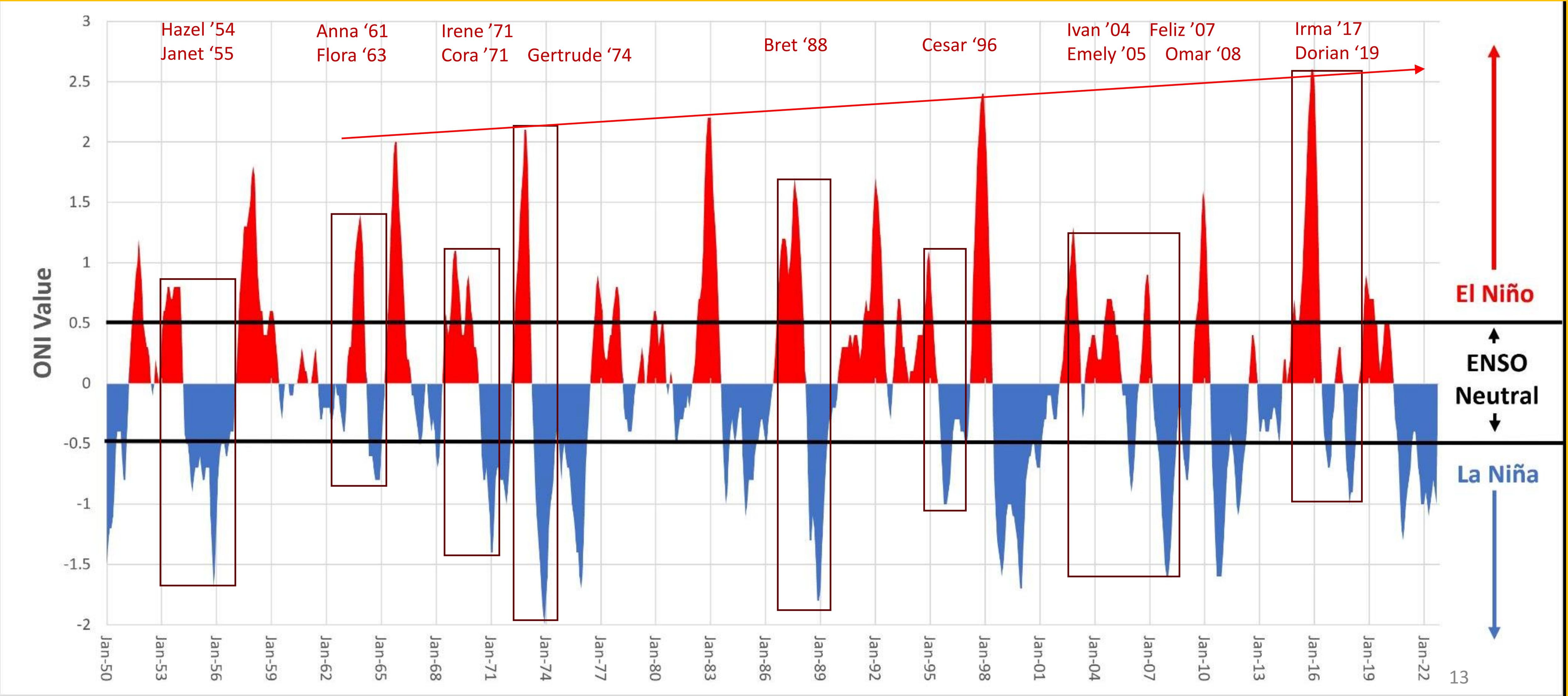


(yaleclimateconnections.org, 2024)

Rapid transitions from El Niño to La Niña (1950 – 2021) and Extreme Weather Shocks

The accelerated transition from N-to-N (70% in 2024) sets the scene for extreme weather intensification in the Caribbean with profound impacts for both vulnerable communities and vital (coastal) infrastructures, including Aruba's health and senior care services.

Figure 16. ENSO Oceanic Niño Idex (Niño 3.4 Region, Jan, 1950 – Jan, 2022).



https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

5. Infrastructure and Urbanization

Since the early 1990's, Aruba has experienced a rise in urbanization and energy consumption, as well as increasing levels of GHG emissions; the latter are a significant contributor to (air) pollution and subsequent health-related risks.

The rate of urbanization (i.e., built infrastructure) amplifies the effects of temperature, relative humidity, and heat. More importantly, in addition to (temporal) heat waves and domes, increasing urbanization spurs the (*spatial*) formation of '***urban heat islands***', thereby increasing mean temperatures (by 3c on average).

The compounding impact of an aging population, temperature rise, and the formation of heat domes and heat islands, as well as increasing GHG emissions have a significant impact on the health and fatality of senior citizens; 8 in 10 senior fatalities are attributed to the cumulative and compounding impact of the aforementioned factors. Furthermore, the coastal proximity of urban heat islands is an exacerbating climate risk in Aruba, due to the impact of storm surge floodings, in addition to gradual sea level rise.

Note: Structures such as buildings, roads, and other infrastructure absorb and re-emit heat more than natural landscapes and nature-based ecosystems. Urban areas, where these structures are highly concentrated and nature is limited, become "islands" of higher temperatures. These "pockets of heat" are referred to as "heat islands." Humid regions and urban centers with larger and denser populations experience the greatest temperature and heat differences (https://www.epa.gov, 2023).

Figure 17. Urbanization & GHG emissions (Aruba, 1992 – 2022; World Bank, 2024).

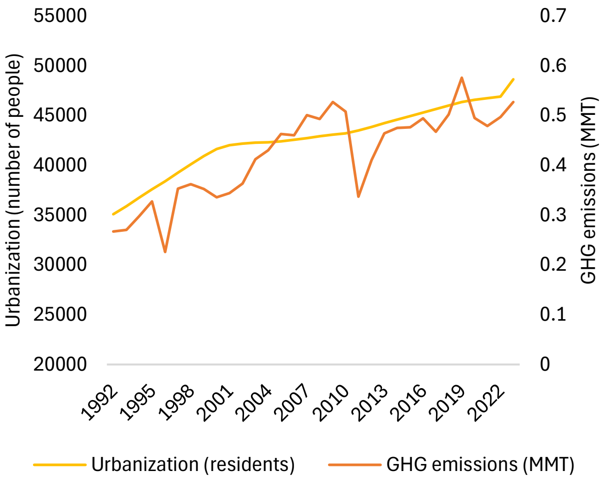


Figure 18. Urbanization & temperature change (Aruba, 1992 – 2022; World Bank, 2024; IMF, 2024).

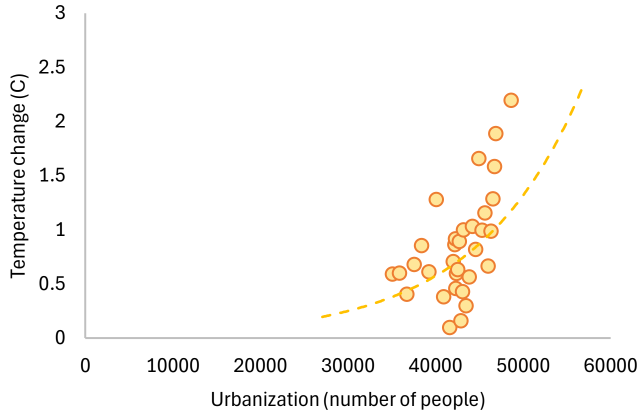


Figure 19. Potential formation and concentration of urban heat islands in Aruba (2024).

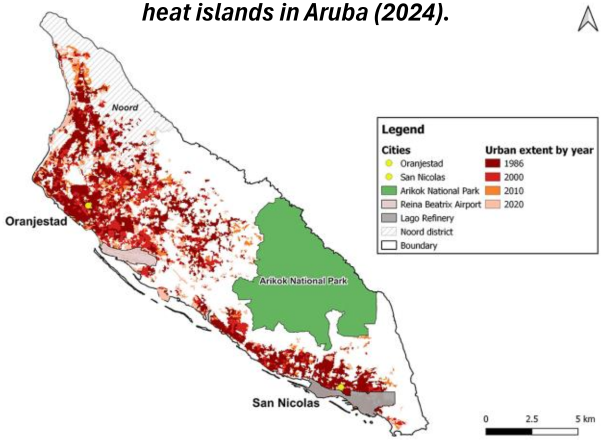
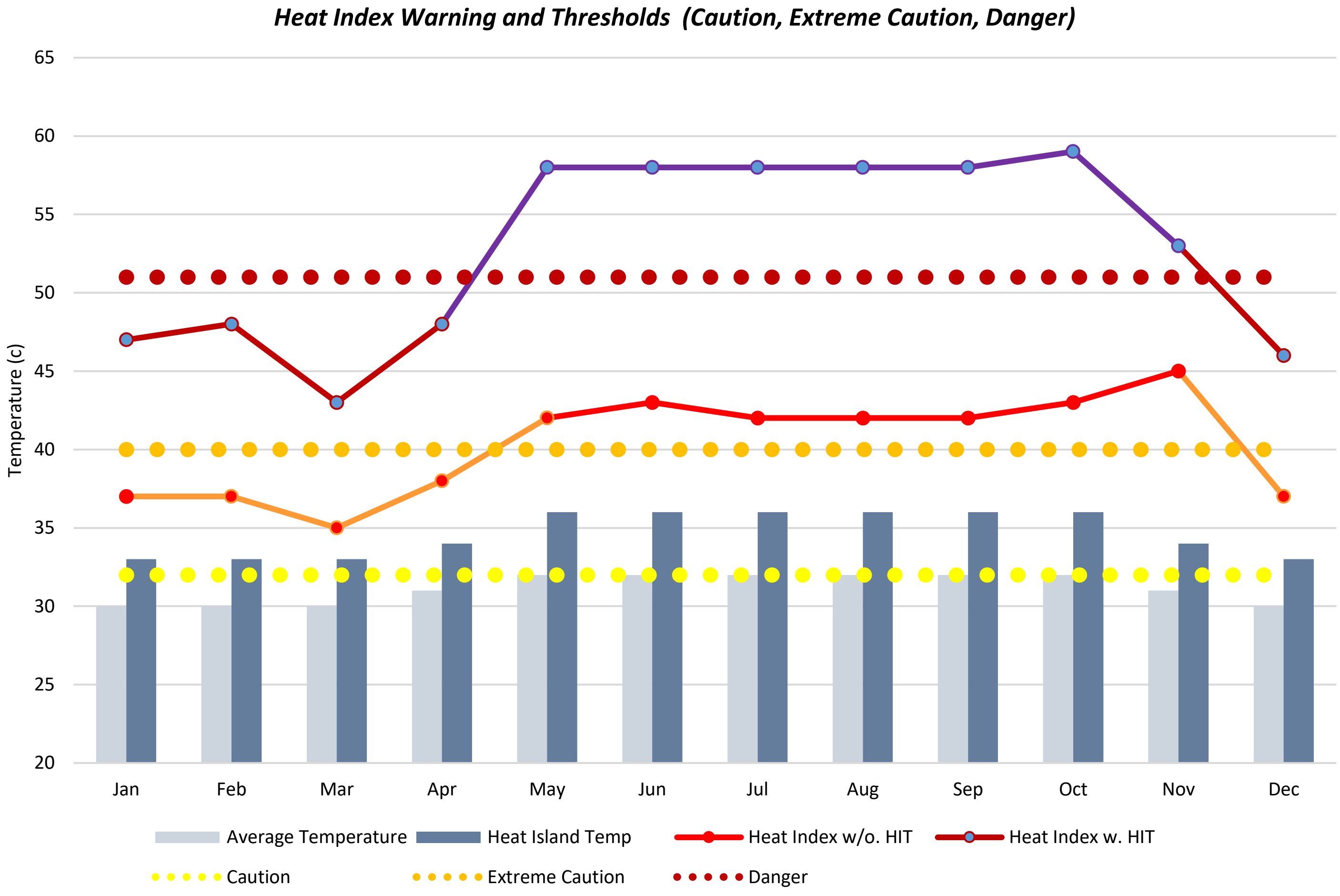


Figure 20. Average Air and Heat Island Temperature (HIT).
Heat Index with and without HIT (Aruba, 2023).



In 2023, urban heat islands amplified the effect of heat, and consequently, health-related risks of heat stress, especially for elderly. These effects were particularly pronounced between May and November 2023.

In conjunction with extended (temporal) heat domes, elevated (spatial) urban heat islands are likely a recurring – and intensifying – phenomenon in the decade(s) to come, thereby warranting the need for a localized heat warning system, calibrated to geo-spatial and geo-temporal indicators, and customized to vulnerable communities in Aruba.

6. Industry heat exposure and vulnerability

Over the past decades, and consistent with previous global studies (IMF, 2017), findings indicate that with every +1c rise in temperature (Aruba between 1992 and 2023), economic contracted by, on average, 4.4% (Figure 21). Output and productivity losses were especially significant after +0.6c increase. The long-run impact of accelerated temperature rise on output loss is estimated to be at least twice as high (Bilal & Kanzig, 2024).

Based on the latest 2019 national account estimates of the CBS (2024), it is projected that at least 40% of GDP (+ Afl. 2,4 billion) is exposed to extreme and chronic industry heat stressors. Critical heat-exposed industries include, e.g., agriculture, manufacturing, utilities, construction, transportation, tourism, education, health, and household activities.

However, whereas numerous sectors of the Aruban economy are exposed by differentiated degrees, not all industries are equally sensitive and vulnerable to heat stress. The latter is influenced by several interrelated factors, including:

- Demographics, lifestyle, and health of industry workforce
- Occupational hazards of industry
- Intensity of (outdoor) weather exposure
- Extent of regulation and enforcement of heat risk labor regulation.

Figure 21. Relationship between temperature rise (c) and output loss (real GDP/capita rate) (Aruba, 1991 – 2023; IMF, 2024).

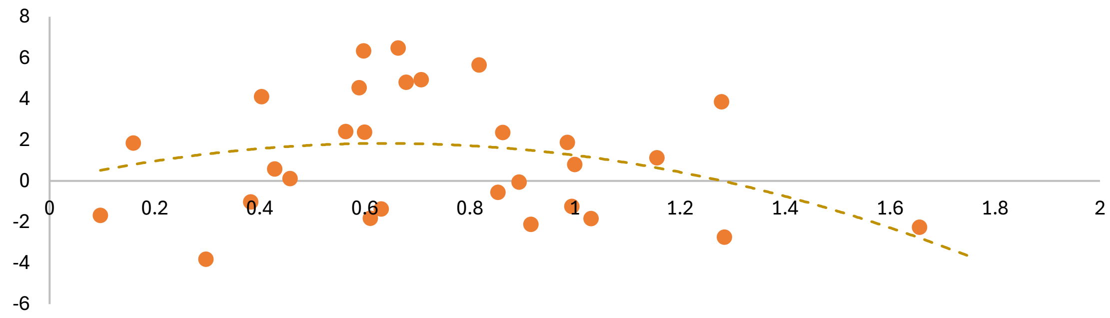
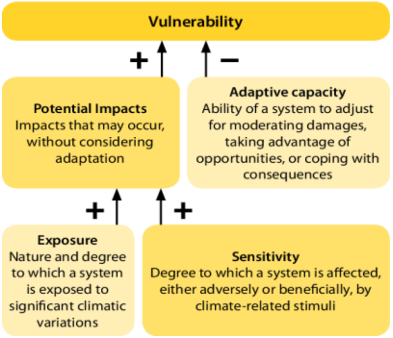


Table 1. Industry Heat Exposure and Output Loss.

Industries	2018	2019	2019 % of total GDP
Agriculture, forestry and fishing; mining and quarrying	1.31	1.68	0.03
Manufacturing	189.13	155.76	2.56
Electricity, gas, steam and air conditioning supply/Water supply; sewerage, waste management and remediation activities	192.21	239.91	3.95
Construction	284.74	295.58	4.86
Wholesale and retail trade; repair of motor vehicles and motorcycles	552.08	573.01	9.43
Transportation and storage	288.94	295.82	4.87
Accommodation and food service activities	1,011.44	1,029.40	16.94
Information and communication	165.04	167.69	2.76
Financial and insurance activities	405.93	443.28	7.29
Real estate activities	581.95	549.11	9.03
Professional, scientific and technical activities	141.28	137.43	2.26
Administrative and support service activities	278.66	306.99	5.05
Public administration and defence; compulsory social security	628.75	620.09	10.20
Education	136.82	145.92	2.40
Human health and social work activities	234.72	234.06	3.85
Arts, entertainment and recreation	161.76	164.80	2.71
Other service activities	42.91	45.75	0.75
Activities of households as employers	45.33	47.77	0.79
Total	5,343.00	5,454.04	89.73
Total taxes less subsidies on products	521.37	624.43	10.27
Nominal gross domestic product at market prices	5,864.38	6,078.47	
Compounded heat risk economic exposure		***2,445.89***	***40.24***

Figure 22. The relationship between heat exposure, heat sensitivity, and heat impacts.



Industry Heat Exposure & Sensitivity

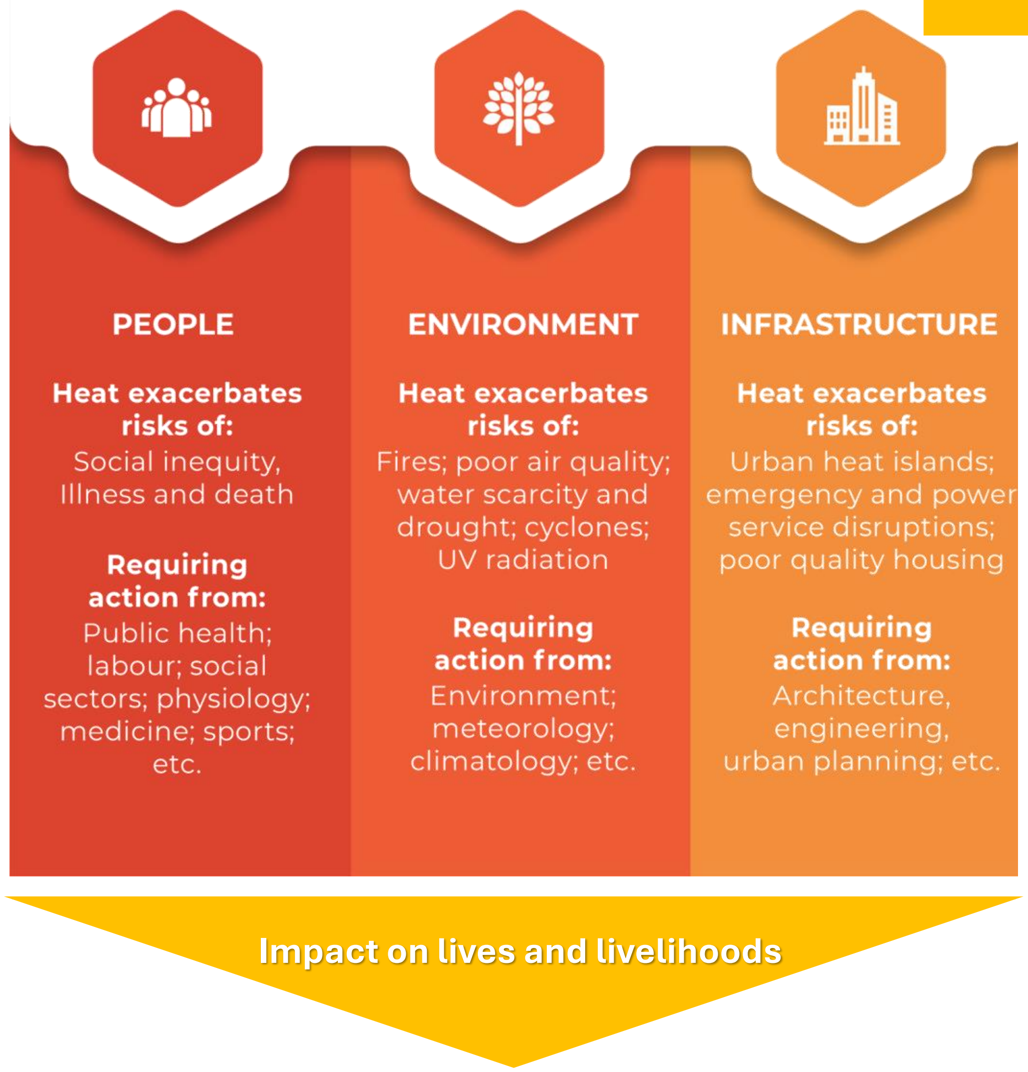
Using a conservative average Industry Heat Exposure (IHE) of 50% (per annum*), different levels of Industry Heat Sensitivity (IHS) produce varying levels of Industry Heat Vulnerability (IHV) and potential output losses (under a 'business-as-usual' scenario without requisite adaptive capacity and policy measures). Findings (Table 2) indicate that the output losses from industry heat exposure and sensitivity ranges from Afl. 12 mln. to Afl. 611 mln. For example, in the case of an average 50% IHE and an average 50% IHS, the heat-induced economic losses would amount to an estimated Afl. 611 mln. (based on 2019 nominal GDP estimates (CBS, 2024).

*Based on the assumption of heat exposure of 6 months per year

Table 2. Industry Heat Exposure (%) and Potential Output Loss (Afl. Mln.) due to Industry Heat Sensitivity (%).

Industries	2019 (Nominal GDP)	**Average Industry Heat Exposure (IHE at 50%)**	**Industry Heat Sensitivity (IHS in %)**				
			1	*10*	*25*	35	50
Agriculture, forestry and fishing; mining and quarrying	1.68	0.84	0.0084	0.084	0.21	0.29	0.42
Manufacturing	155.76	77.88	0.77	7.78	19.47	27.25	38.94
Electricity, gas, steam and air conditioning supply/Water supply; sewerage, waste management and remediation activities	239.91	119.955	1.19	11.99	29.98	41.98	59.97
Construction	295.58	147.79	1.47	14.77	36.94	51.72	73.89
Transportation and storage	295.82	147.91	1.47	14.79	36.97	51.76	73.95
Accommodation and food service activities	1029.40	514.7	5.14	51.47	128.67	180.14	257.35
Education	145.92	72.96	0.72	7.29	18.24	25.53	36.48
Human health and social work activities	234.06	117.03	1.17	11.70	29.25	40.96	58.51
Activities of households as employers	47.77	23.885	0.23	2.38	5.97	8.35	11.94
Industry Heat Exposure and Sensitivity Loss (in Afl. mln.)	***2445.90***	***1222.95***	***12.23***	***122.30***	***305.74***	***428.03***	***611.48***
Nominal gross domestic product (in Afl. mln.)	6078.47						

7. Conclusion



Key Lessons

Heat is an 'All-of-Society' (AoS) risk that requires a 'Whole-of-Society' (WoS) response.

The preliminary evidence indicates that rising temperatures as well as heat systems, e.g., heat domes and heat islands, have a significant adverse affect on senior fatality and industry productivity, thereby endangering both lives and livelihoods in Aruba, intensifying at great expense.

In order to safeguard lives and livelihoods, a **WoS response begets strengthening ecosystem-based resilience of people, environment, and infrastructure**, including:

(I) *Concerted and coordinated action across multiple sectors and institutions*, as well as

(II) *Comprehensive foresight and prudence, including intelligent and advance warning systems of (extreme) temperature, as well as heat domes and the amplifying effect of urban heat islands*.

The adverse health impacts of heat are predictable and largely preventable with specific public health, senior affairs, nature, urban planning, and other multi-sectoral policies and interventions. Climate action combined with comprehensive preparedness and proactive risk management saves lives now and in the future.

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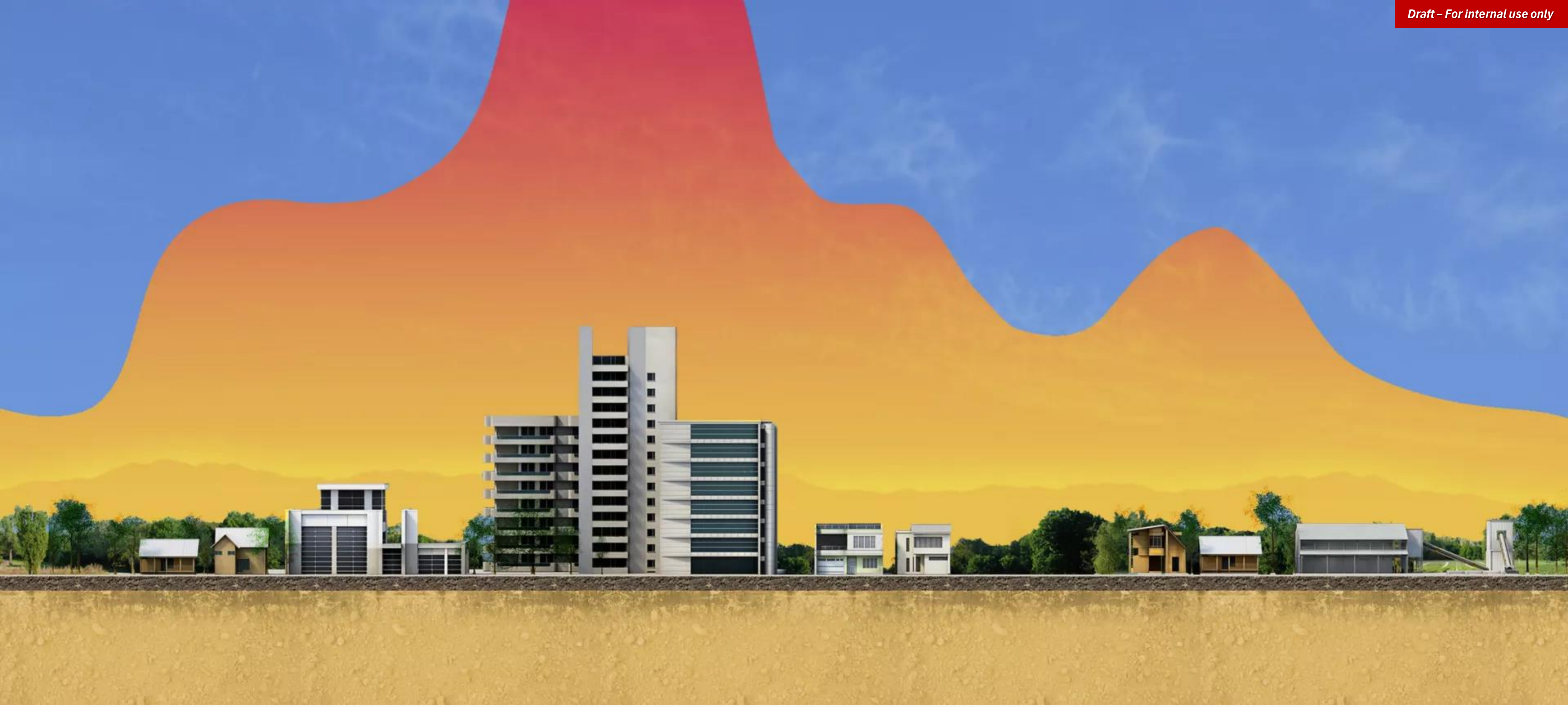

The Heat is On

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