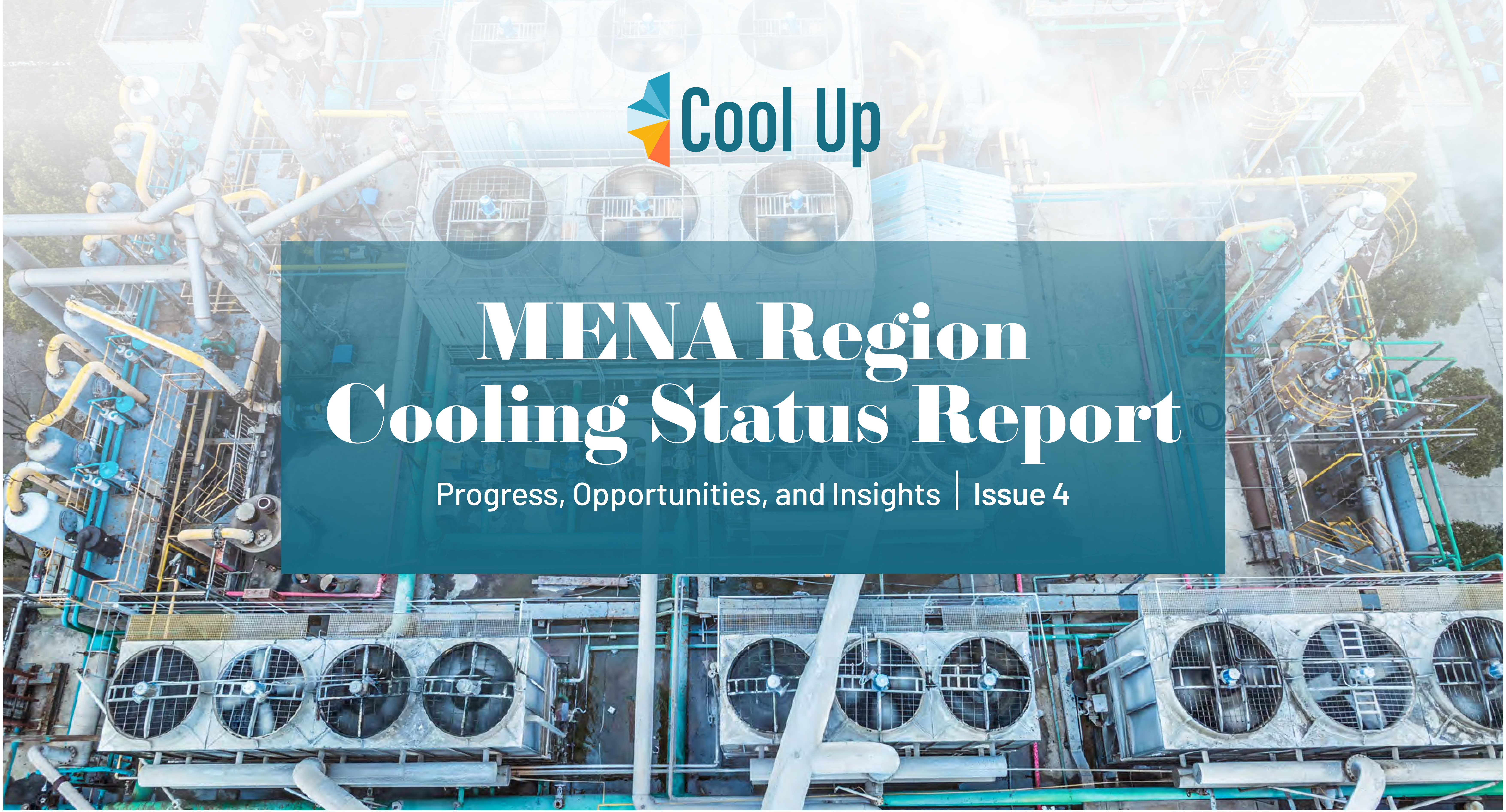


Cool Up

MENA Region Cooling Status Report

Progress, Opportunities, and Insights | Issue 4

www.cooluppprogramme.org
Newsletter
info@coolupprogramme.org
Linkedin: @Cool Up programme

Authors:

- Guidehouse Germany GmbH: Anna Runkel, Alexander Pohl, Eslam Mohamed Mahdy, Nesen Surmeli-Anac
- Öko-Recherche: Sinisa Prodanovic, Felix Heydel, Barbara Gschrey

Design: Guidehouse Germany GmbH: Anna Runkel, Alexander Pohl implemented by NETCOMPANY

Date: March 2026

Publisher

Guidehouse Germany GmbH
Bellevuestr. 3,
10785 Berlin, Germany
info@coolupprogramme.org
+49 30 297735790

Supported by:
Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag

IKI INTERNATIONAL CLIMATE INITIATIVE

The Cool Up programme is supported by the International Climate Initiative (IKI) of the Federal Government of Germany. Within the Federal Government, the IKI is anchored in the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN). The information and views set out in this publication are those of the authors and do not necessarily reflect the official opinion of the International Climate Initiative or Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety.

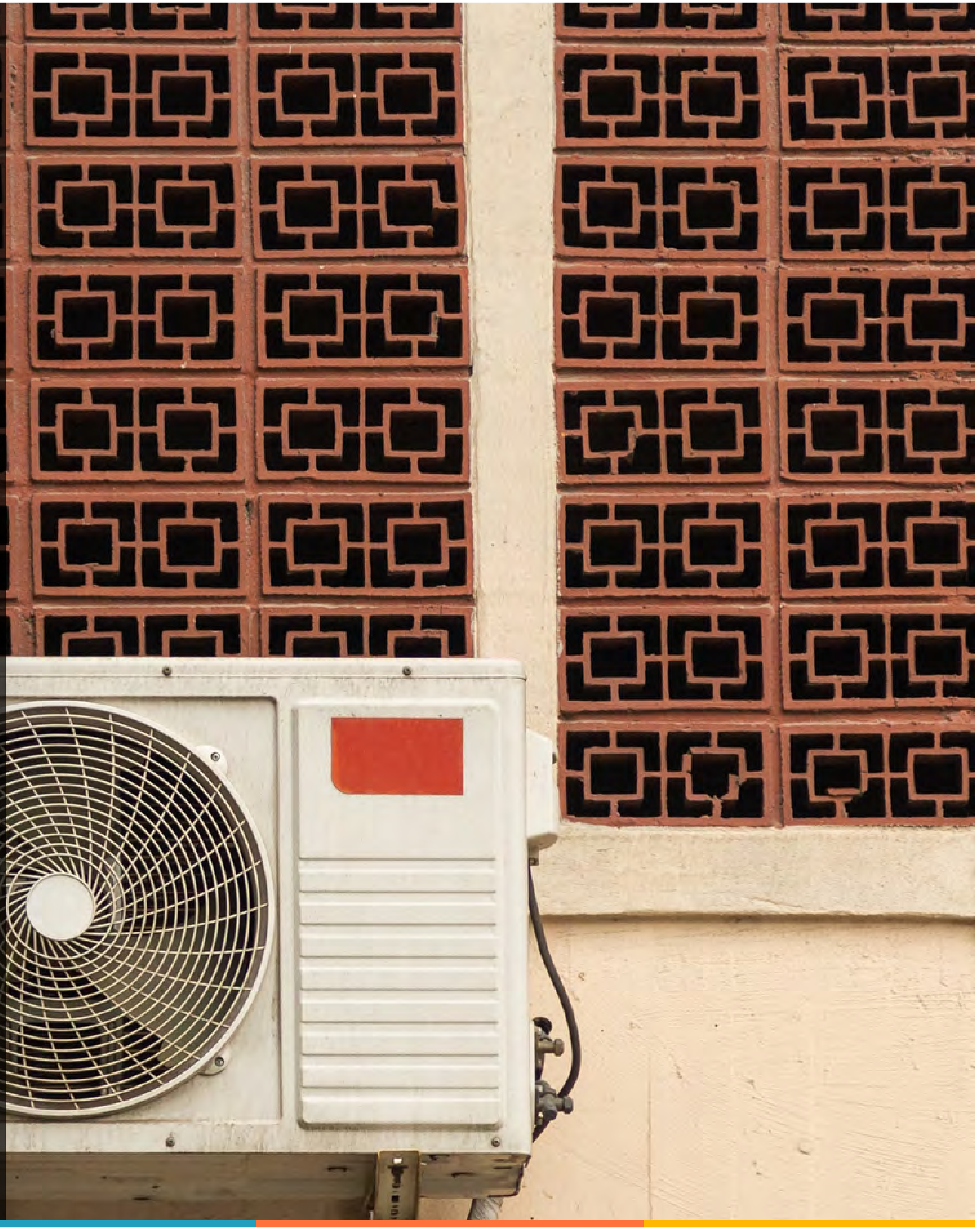
Contents

Foreword

Cooling in the Middle East, North Africa and Türkiye has moved from comfort to critical infrastructure: it underpins safe hospitals and schools, keeps food and medicines viable, stabilises summer power peaks and, when designed well, protects scarce water resources. This report treats cooling through three connected lenses—health, chemical safety and system performance—to help decision-makers act now on options that are already available and scalable.[1]

The health case is clear: heat is a leading weather-related killer and amplifies cardiovascular, respiratory, renal and mental-health risks, especially for elderly people and those with existing conditions.[2] The chemical-safety case is sharpening: a broadened OECD definition treats PFAS as a class, while drinking-water rules in Europe and the United States tighten monitoring and limits—signals that favour PFAS-free refrigerant pathways and disciplined end-of-life practices.[3] The policy case is practical: the EU F-gas Regulation (EU 2024/573) sets clear market guardrails that many regional manufacturers and buyers already follow.[4]

Against this backdrop, the report focuses on what to do next. It synthesises recent evidence and regional practice to explain why refrigerant choice matters, show how safe, efficient and PFAS-aware solutions can be deployed in high-ambient contexts, and outline pathways that align procurement, finance and skills with national health and climate goals.[5]



1 WHO, "Heat and health"; UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps — 2022 Assessment Report"

2 WHO, "Heat and health"

3 OECD, "A new OECD definition for per- and polyfluoroalkyl substances"; European Environment Agency, "Treatment of drinking water to remove PFAS (Signal)"; U.S. EPA, "Final PFAS National Primary Drinking Water Regulation"

4 EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

5 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps — 2022 Assessment Report"; WHO, "Heat and health"

Executive Summary

Cooling demand in the MENA region and Türkiye is rising sharply as higher temperatures, rapid urbanisation, demographic growth, and increased reliance on mechanical air conditioning drive electricity consumption levels. [6] Electricity demand in the region has already tripled since 2000 and is projected to grow by about 50% by 2035, with cooling and desalination together expected to account for roughly two-fifths of additional demand.[7] Regional analysis under the Cool Up programme indicates that unitary air-conditioner stocks in MENA region and Türkiye could increase from about 35.6 million units in 2020 to more than 93 million units by 2050, unless efficiency measures and natural-refrigerant technologies scale rapidly.[8] Without strengthened policies, this trajectory risks locking in high electricity consumption, peak-load pressures, and refrigerant-related emissions across the region.[9]Health impacts from extreme heat are already severe and increasing. WHO

6 IEA, "The Future of Electricity in the Middle East and North Africa"; Cool Up, "MENA Region Cooling Status Report- Issue 2"

7 IEA, "The Future of Electricity in the Middle East and North Africa"

8 Cool Up, Status Update, "Where are Mena and Türkiye in the transition to sustainable cooling"

9 IEA, "The Future of Electricity in the Middle East and North Africa; Cool Up, MENA Region Cooling Status Report" – Issue 2; Cool Up, MENA Region Cooling Status Report – Issue 3

identifies climate change and rising temperatures as major drivers of heat-related illness and mortality, noting that heat stress is the leading cause of weather-related deaths and that heatwaves can trigger sharp increases in hospital admissions.[10] WHO also highlights that heat exacerbates cardiovascular, respiratory, renal, and mental-health conditions, particularly among older people, those with pre-existing diseases, and socially disadvantaged groups.[11] Global assessments suggest that heat-related mortality among people over 65 years has risen markedly over the last two decades and that about 37% of heat-related deaths in some locations are attributable to anthropogenic climate change.[12] In Cairo's informal settlements, a BMZ/Health vulnerability assessment found that many residents, including pregnant women and young children, already face dangerous indoor temperatures and heat-related health problems, with warming of up to 5.6 °C projected by the end of the century relative to 1990.[13] These findings underscore that access to safe, efficient cooling is increasingly a public-health imperative in the MENA region and Türkiye.[14]

PFAS add a long-term chemical-safety dimension to the cooling transition. The revised OECD definition underscores PFAS as a broad class of extremely persistent substances containing at least one fully fluorinated $-CF_3$ or $-CF_2-$ group.[15] Several fluorinated refrigerants, notably HFC-134a and HFO-1234yf, degrade in the atmosphere to TFA, a short-chain PFAS that is highly water-soluble and resistant to further breakdown.[16] Monitoring data from Europe show that TFA can account for a large share of PFAS in surface and drinking waters, prompting growing concern among water utilities and regulators.[17] The EU Drinking Water Directive now sets parametric values of 0.1 µg/L for a PFAS-20 subset and 0.5 µg/L for total PFAS from 2026, requiring expanded monitoring and, where necessary, treatment.[18]

In the United States, the Environmental Protection Agency has adopted enforceable maximum contaminant levels for several long-chain PFAS in public drinking-water systems at very low, parts-per-trillion concentrations.[19] For MENA, where desalinated water already supplies a significant share of municipal demand and volumes are projected to rise strongly, these regulatory trends highlight the importance of limiting PFAS-linked refrigerant pathways and developing PFAS and TFA monitoring frameworks.[20]

10 WHO, "Climate change, heat and health"

11 WHO, "Climate change and health"; WHO, "Climate change, heat and health"

12 Watts et al., "The 2020 report of the Lancet Countdown on health and climate change"

13 BMZ/Health, "A vulnerability assessment in Cairo, Egypt"

14 Greenpeace Research Laboratories, "Living on the Edge"; WHO, "Climate change, heat and health"; BMZ/Health, "A vulnerability assessment in Cairo, Egypt"

15 OECD, "A new OECD definition for per- and polyfluoroalkyl substances"

16 David et al., "Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East"

17 PAN Europe, "TFA in Water: Dirty PFAS Legacy Under the Radar"; PAN Europe, "TFA: The Forever Chemical in the Water We Drink"; ANSES, "PFAS: results of the national measurement campaign for drinking water"; Eurofins Scientific, "New report on TFA in surface- and groundwaters" ;KTH Royal Institute of Technology, "The potential dangers of TFA"

18 European Union, "Directive (EU) 2020/2184 on the quality of water intended for human consumption"

19 US EPA, "PFAS National Primary Drinking Water Regulation"

20 IEA, "The Future of Electricity in the Middle East and North Africa"; David et al., "Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East"; European Union, "Directive (EU) 2020/2184 on the quality of water intended for human consumption"; US EPA, "PFAS National Primary Drinking Water Regulation"

Refrigerant choice therefore matters for both climate and health outcomes. High-GWP HFCs such as R410A and R134a contribute substantially to cooling-related greenhouse-gas emissions and are being phased down under the Kigali Amendment, while several recent HFOs and HFC/HFO blends raise concerns about TFA formation and PFAS persistence.[21] Natural refrigerants such as CO_2 (R744), ammonia (R717), and hydrocarbons (e.g. propane R290) are PFAS-free and have very low or zero global-warming potentials, with growing evidence of competitive or superior efficiency in many applications, including high-ambient climates, when systems are properly designed and maintained.[22] International analyses indicate that combining improved cooling efficiency with a transition to low-GWP refrigerants could more than halve future cooling-related emissions compared to a baseline pathway, while reducing peak-load stress on power systems.[23] The report concludes that MENA region and Türkiye can treat the cooling transition as a combined health, climate, and chemical-safety opportunity. Key priorities include integrating cooling into heat-health and adaptation planning; implementing and enforcing stringent minimum energy-performance standards and refrigerant rules; accelerating the diffusion of PFAS-free natural-refrigerant solutions where feasible; building PFAS and TFA monitoring and regulatory capacities; and mobilising finance for efficient, PFAS-safe cooling in buildings, cold chains, and health facilities.[24] Positive examples such as emerging National Cooling Action Plans and alignment with international F-gas approaches in some countries demonstrate that policy frameworks for such a transition are already taking shape in the region and can be scaled in the coming decade.[25]

21 Cool Up, "MENA Region Cooling Status Report – Issue 2"; OECD, "A new OECD definition for per- and polyfluoroalkyl substances"; David et al., "Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East"

22 Cool Up, "MENA Region Cooling Status Report – Issue 2"; Cool Up, "MENA Region Cooling Status Report – Issue 3; IIFIIR, Snapshot of air conditioning in the MENA region and Türkiye"

23 IEA, "The Future of Electricity in the Middle East and North Africa"; Cool Up, "MENA Region Cooling Status Report – Issue 2"

24 Cool Up, "MENA Region Cooling Status Report – Issue 2"; Cool Up, "MENA Region Cooling Status Report – Issue 3"; WHO, "Climate change, heat and health"; OECD, "A new OECD definition for per- and polyfluoroalkyl substances"; European Union, "Directive (EU) 2020/2184 on the quality of water intended for human consumption"; US EPA, "PFAS National Primary Drinking Water Regulation"

25 Cool Up, MENA Region Cooling Status Report – Issue 2; Cool Up, MENA Region Cooling Status Report – Issue 3

1. How are cooling markets and policies evolving?

This year's regional picture is unambiguous: cooling has become one of the defining forces shaping the MENA region and Türkiye's power systems, urban health, and investment needs. Electricity demand across the Middle East has already roughly tripled since 2000 and forward-looking assessments indicate around an additional 50% increase by the mid-2030s, with air-conditioning and desalination together driving a large share of incremental consumption and peak load.[26] In practical terms, this means refrigerant and cooling technology choices are no longer an afterthought at equipment level—they now influence peak capacity, grid adequacy and long-run system costs.[27]

On the ground, the market remains dominated by vapour-compression systems. In residential and small commercial segments, R410A and increasingly R32 underpin unitary split and multi-split AC portfolios, while VRF solutions continue to gain share in larger buildings thanks to zoning flexibility and strong part-load performance.[28] At the same time, natural refrigerants gain market share: CO_2 (R744) systems in supermarkets and distribution centres, NH_3 (R717) in industrial cold stores and process cooling, and hydrocarbons (e.g., R290) in plug-in cabinets and piloted split prototypes—each within well-defined safety envelopes that require certified installation, charge-limit compliance, and appropriate ventilation.[29]

26 IEA, "Electricity demand is surging across the Middle East and North Africa, driven by cooling and desalination needs"; IEA, "The Future of Electricity in the Middle East and North Africa"

27 IEA, "The Future of Electricity in MENA"

28 Cool Up, "MENA Region Cooling Status Report – Issue 3"; UNEP/TEAP RTOC, "2022 Assessment"

29 UNEP/TEAP RTOC, "2022 Assessment"; Cool Up, "Mena Region Cooling Status Report - Issue 3"

Policy is catching up—and, in places, pulling ahead. Regionally, ratifications of the Kigali Amendment keep advancing; most notably, Saudi Arabia joined in 2025 as the 166th Party, reinforcing a common trajectory to phase down high-GWP HFCs.[30] Governments are also moving from planning to execution on National Cooling Action Plans (NCAPs) and Kigali Implementation Plans (KIPs). Jordan closed out ~30 measures in its NCAP spanning minimum energy-performance standards (MEPS) to labelling, refrigerant management, cold-chain reliability, capacity building and financing mechanisms—one of the most concrete roadmaps in the region.[31] Regionally, RCREEE convened a Cairo workshop in October 2025 to codify best practice for NCAP implementation—recommendations included multi-stakeholder national cooling committees, explicit alignment with NDCs and National Adaptation Plans, monitoring frameworks, and finance options.[32] Alongside NCAPs, countries are also operationalising the Kigali Amendment through Kigali Implementation Plans (KIPs), which are approved and supported under the Multilateral Fund for the Implementation of the Montreal Protocol. KIPs set out the overarching strategy and concrete actions needed to meet HFC consumption control targets under the Kigali Amendment. KIPs typically combine policy and regulatory measures, technical assistance, training, awareness raising, coordination, reporting and monitoring, and where relevant technology conversions. They are also supported by Multilateral Fund financing to help countries deliver the transition and meet HFC phase down obligations in practice.[33]External regulatory shifts will also shape regional choices. The EU's revised F-gas Regulation (Regulation (EU) 2024/573) tightens the quota scheme, extends placing-on-market bans across multiple equipment classes through 2025–2033, and sets a pathway to an HFC phase-out by 2050.[34] For exporters based in the MENA region and Türkiye exporting to the EU, this raises compliance pressure and strengthens the case for PFAS-free naturals and high-efficiency designs. In parallel, the Global Cooling Pledge (COP28) establishes collective targets to halve average efficiency gaps for new ACs by 2030 and cut cooling-related emissions by ≥ 68% by 2050, while expanding access—offering a broad benchmark many governments in and around the region reference.[35]

30 IIR, "Saudi Arabia ratifies Kigali"

31 Cool Up, "MENA Region Cooling Status Report – Issue 3"

32 RCREEE, "NCAP workshop press release"

33 UNDP, "Kigali Implementation Plans"

34 EUR-Lex, "Regulation (EU) 2024/573"

35 UNEP, "Global Cooling Pledge"

Technologically, the context of high-ambient temperatures matters to varying extent in the MENA region and Türkiye. Experience shows that propane and CO_2 transcritical systems can deliver strong performance in Gulf and Levant climates when designs incorporate parallel compression, ejectors and adiabatic gas coolers, while NH_3 continues to anchor efficient industrial applications and is being explored in large chilled-water and district-cooling contexts.[36] R32 is increasingly used as a transitional option in single and multi-split portfolios due to its GWP of about 675 and favourable thermodynamic properties, but its GWP remains far higher than that of natural refrigerants such as CO2 (GWP 1), ammonia (GWP 0) and propane (GWP 3). As a flammable refrigerant, R32 requires equipment designed for flammable refrigerants, appropriate ventilation and technician training.[37]

Across the policy, technology and market landscape, one through-line stands out: the choices made during the second half of the 2020s will lock in efficiency, peak demand profiles, refrigerant-related emissions and chemical-safety outcomes for decades. With electricity systems already feeling summer peaks dominated by cooling, and with desalination adding material shares in coastal countries, steering demand growth through MEPS, building-fabric upgrades, smarter controls and refrigerant transitions is now a grid-stability and public-health imperative—not merely a climate ambition.[38] Aligning NCAP execution, F-gas compliance, and Global Cooling Pledge targets with PFAS-aware refrigerant strategy—prioritising sustainable cooling technologies where feasible, and managing the adoption of flammable refrigerants safely where chosen—offers a coherent pathway to meet the region's fast-rising cooling needs while safeguarding water, health and investment objectives.[39]

Taken together, these trends underline that cooling in MENA region and Türkiye can no longer be treated solely as an energy or equipment issue. Rising peak loads, tighter grids and expanding cooling stocks intersect directly with human exposure to heat, particularly in dense urban areas and in settings where access to reliable cooling is uneven. Against this background, the implications of cooling for public health move from a secondary consideration to a core policy concern.

36 UNEP/TEAP RTOC, "2022 Assessment"

37 UNEP/TEAP RTOC, "2022 Assessment"; Cool Up, "MENA Region Cooling Status Report - Issue 3"

38 IEA, "Electricity demand is surging across the Middle East and North Africa, driven by cooling and desalination needs"; IEA, "The Future of Electricity in the Middle East and North Africa"

39 UNEP/TEAP RTOC, "2022 Assessment"; UNEP, "Global Cooling Pledge"

2. How does cooling become public health infrastructure?

Across the region, the role of cooling in protecting health is becoming increasingly clear. Hospitals, schools, workplaces and homes are already experiencing the compounding effects of extreme heat, urban form and unequal access to safe, efficient temperature control. Recent public-health guidance issued by the WHO for national and local public-health institutions underscores three realities. First, heat stress is now the leading cause of weather-related mortality, with exposure growing rapidly as heatwaves become more frequent, longer and more severe; heat-related mortality among people aged 65 and over has risen markedly in the last two decades.[40] Second, vulnerability is shaped not only by physiology but by where and how people live and work: dense urban areas with poor ventilation and limited green space amplify health risks by sustaining high night-time indoor temperatures.[41] Third, because heat affects everyday function—sleep quality, cognitive performance, hydration status, chronic disease control—cooling is, in practice, a public-health intervention.[42]

The clinical and epidemiological burden is broad. Extended periods of hot days and nights increase cardiovascular, respiratory and renal events; emergency admissions rise during heatwaves, and mortality spikes among older adults and those with chronic conditions.[43] In many cities across the MENA region and Türkiye, heat episodes also coincide with elevated air-pollution exposures, further increasing cardiopulmonary risks.[44] For households, sustained indoor temperatures above thermal-comfort thresholds impair sleep and thermoregulation, particularly in small apartments with low insulation and inadequate cross-ventilation; the housing guidance highlights the co-benefits of building-fabric improvements (e.g., shading, reflective roofs, insulation) for indoor air quality (IAQ) and energy use.[45] For clinical facilities, reliable cooling stabilises operating theatres, server rooms and pharmacy stores—failure during heatwaves compromises patient safety and service continuity.[46]

40 WHO, "Heat and health"

41 WHO, "Heat and health"; WHO, "Housing and health guidelines"

42 WHO, "Heat and health"

43 Ibid.

44 Ibid.

45 WHO, "Housing and health guidelines"

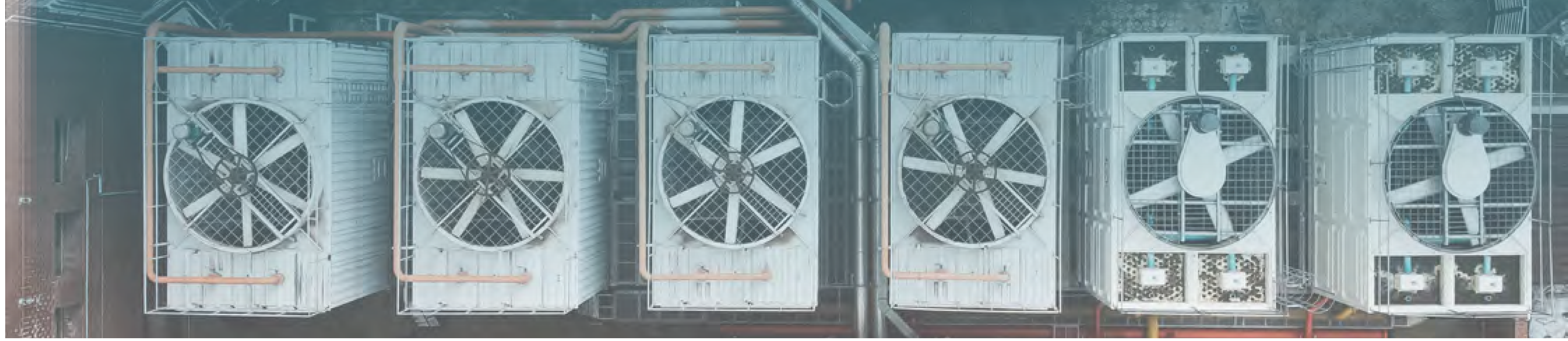
46 WHO, "Heat and health"

Workplaces face a distinct but related set of challenges. Field and factory evidence shows that heat exposure undermines work capacity, productivity and safety: accident rates increase, while heat exhaustion and heatstroke become more common without protective measures such as shaded rest areas, hydration, ventilation and access to mechanical cooling.[47] Aggregate modelling indicates that by 2030, the world could lose around 2.2% of total working hours due to heat stress—equivalent to tens of millions of full-time jobs— with the Arab States and Africa among the most exposed regions.[48] In MENA region and Türkiye, where construction, agriculture, tourism and light manufacturing employ substantial shares of the workforce, these losses translate to real income, safety and productivity impacts—making occupational cooling and work-rest cycles core to heat-health action plans.[49]

47 ILO, "Working on a warmer planet"; ILO, "Heat at work: Implications for safety and health"h

48 ILO, "Working on a warmer planet"; ILO, "Heat at work: Implications for safety and health"

49 ILO, "Heat at work: Implications for safety and health"



Cooling, however, is not risk-free when systems are substandard or poorly maintained. IAQ deteriorates with clogged filters, microbial growth in ducts, and inadequate ventilation—factors known to exacerbate asthma, respiratory infections and general discomfort.[50] Where refrigerants (e.g., R32, HCs) are used, safe design and servicing protocols—ventilation, detector deployment, technician training—are essential to reduce risks without sacrificing efficiency (UNEP/TEAP RTOC, 2022 Assessment). These fundamentals are not optional: they are part of risk management and a prerequisite for trust in mechanical cooling.[51]

Water interfaces add another dimension to health resilience. In many MENA countries, desalination is central to drinking-water supply. Regulatory trajectories outside the region are moving fast: the EU's recast Drinking Water Directive introduces parametric values of 0.5 µg/L for PFAS total and 0.1 µg/L for a PFAS-20 subset from 2026, while the US EPA has finalised enforceable Maximum Contaminant Levels of 4 ppt for PFOA/PFOS and 10 ppt for PFNA/PFHxS/HFPO-DA, plus a Hazard Index for mixtures.[52] Although the health chapter is not about chemicals per se, these water limits matter wherever HFC/HFO degradation products such as TFA can enter water cycles; they reinforce the case for PFAS-free natural refrigerants in public facilities and for routine monitoring around desalination intakes.[53]

50 WHO, "Housing and health guidelines"

51 WHO, "Housing and health guidelines"; UNEP/TEAP RTOC, "2022 Assessment"

52 EEA, "Treatment of drinking water to remove PFAS (Signal)"; US EPA, "Final PFAS National

53 EEA, "Treatment of drinking water to remove PFAS (Signal)"; US EPA, "Final PFAS National Primary Drinking Water Regulation"

A local case illustrates how cooling as health intervention plays out in practice. A qualitative vulnerability and adaptation assessment in three informal settlements of Greater Cairo—Ezbet El-Nasr, Khosoos, Markaz El-Abhath—documented high night-time indoor temperatures, sleep disruption, dehydration and exacerbations of chronic disease among pregnant women and mothers of young children.[54] The study reported projected warming of up to +5.6 °C by 2100 relative to 1990 and highlighted limited access to efficient cooling in small dwellings with poor insulation.[55] The recommendations were straightforward and replicable: envelope upgrades, shading/greening, targeted provision of efficient, safe cooling for vulnerable households, and community cooling centres—with attention to technician skills, IAQ and refrigerant safety[56]. As municipalities design Heat-Health Action Plans, Cairo's experience underlines that equity and access—not only the physics of cooling—determine health outcomes during heat events.[57]

54 GIZ, "Protecting Health from Heat Stress in Informal Settlements of the Greater Cairo Region"

55 Ibid.

56 Ibid; WHO, "Housing and health guidelines"

57 WHO, "Heat and health"

For health systems, prioritising resilience at facilities is non-negotiable. In practical terms, this means combining efficient central plants (or appropriately sized distributed systems) with backup power, thermal storage, smart controls, preventive maintenance, and passive measures—reflective roofs, shading, insulation, operable windows—so that wards, theatres and pharmacies remain within safe temperature bands even under grid stress.[58] In the cold chain, unbroken temperature control for vaccines and essential medicines prevents wastage and efficacy loss, with direct benefits for disease burden and cost.[59] Because health facilities are anchor institutions, their adoption of PFAS-free natural refrigerants—CO_2 for refrigerated storage, NH_3 for central plants where appropriate, R290 for small cabinets—can accelerate market capacity and de-risk compliance with evolving F-gas and PFAS rules.[60]

Finally, the workforce and community lens deserves emphasis. Heat-health action plans should integrate early-warning systems, clinical protocols, public communication, surveillance and guaranteed access to cooling for vulnerable groups.[61] In workplaces, enforceable standards for rest cycles, hydration, shade, ventilation and mechanical cooling—paired with training and monitoring—reduce incidents and preserve productivity.[62] In homes and schools, building-fabric upgrades lower indoor temperatures and energy use, while appliance standards and maintenance protect IAQ and safety (WHO, Housing and health guidelines). Across these settings, treating cooling as health infrastructure aligns public-health, grid and environmental objectives: safe, clean, and accessible cooling for all.[63]

While access to cooling is central to protecting health, the characteristics of cooling systems themselves—efficiency, refrigerant type, safety profile and lifecycle management—shape whether health benefits are delivered sustainably. The choice of refrigerant, in particular, links health outcomes to climate impacts, system performance and chemical safety, making it a strategic decision rather than a purely technical one.

58 WHO, "Heat and health"; WHO, "Housing and health guidelines"

59 WHO, "Heat and health

60 UNEP/TEAP RTOC, "2022 Assessment"; EEA, "Treatment of drinking water to remove PFAS (Signal)"

61 WHO, "Heat and health"

62 ILO, "Heat at work: Implications for safety and health"

63 WHO, "Heat and health"; UNEP/TEAP RTOC, "2022 Assessment"

3. Why Refrigerant Choice Matters

Refrigerant selection is one of the most consequential decisions in the regional cooling transition because it determines direct emissions, electricity use, regulatory exposure and chemical-safety outcomes for decades of asset life. In the MENA region and Türkiye—where summer peaks are increasingly defined by air-conditioning and where desalination is integral to water supply—choosing the right refrigerant is no longer a narrow technical choice. It is a systems lever that shapes grid adequacy, health protection and long-term compliance.[64] From a climate perspective, HFCs such as R410A and R134a have high global-warming potentials (GWPs) and are the principal target of the Kigali phasedown and tightening regional rules. Two broad replacement pathways now dominate equipment portfolios. The first uses lower-GWP refrigerants, notably R32 (difluoromethane), or selected HFO/HFC blends. These options can slightly reduce GWP versus R410A and deliver seasonal efficiency in unitary, multi-split and VRF systems. The second pathway adopts natural refrigerants—CO_2 (R744), NH_3 (R717) and hydrocarbons such as R290—which combine ultra-low or zero GWP with mature safety regimes and expanding high-ambient design patterns.[65]

Natural refrigerants address climate and chemical-safety together. CO_2 (R744) has matured rapidly at high ambient temperature conditions: modern packs with parallel compression, ejectors and adiabatic gas coolers now deliver strong efficiency in Gulf and Levant supermarkets and distribution, often with heat-recovery co-benefits. NH_3 (R717) remains the industrial benchmark for large cold stores and process cooling around the world; safety focuses on toxicity containment, detection and ventilation—well codified in industrial standards and increasingly familiar to regional contractors. R290 is now ubiquitous in plug-in cabinets and heat pumps and is advancing in split-AC pilots; it offers high efficiency and very low GWP, provided charge limits, electrical protection and ventilation are respected and installers are trained for the safe installation of refrigerants.[66]

Policy and water signals favour future-proof choices. The EU's F-gas Regulation (EU 2024/573) tightens HFC quotas, extends placing-on-market bans across multiple equipment classes through 2025–2033, and sets a pathway to an HFC phase-out by 2050—trajectory shifts that Original Equipment Manufacturers (OEMs) and buyers in the MENA region and Türkiye already track to preserve market access and avoid stranded assets.[67] In parallel, drinking-water rules respond to PFAS concerns. The EU Drinking Water Directive introduces 0.5 µg/L for PFAS total and 0.1 µg/L for a PFAS-20 subset from 2026, while the US EPA has finalised MCLs of 4 ppt (PFOA/PFOS) and 10 ppt (PFNA/PFHxS/HFPO-DA) with a Hazard Index for mixtures. As several HFC/HFO refrigerants can degrade atmospherically to trifluoroacetic acid (TFA)—an ultrashort-chain PFAS that is mobile in water—these rules strengthen the case for PFAS-free natural refrigerants in public infrastructure and for disciplined end-of-life handling of any fluorinated systems.[68]

64 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report"; Cool Up Programme / Guidehouse, "MENA Region Cooling Status Report – Issue 3"

65 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report"

66 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report"

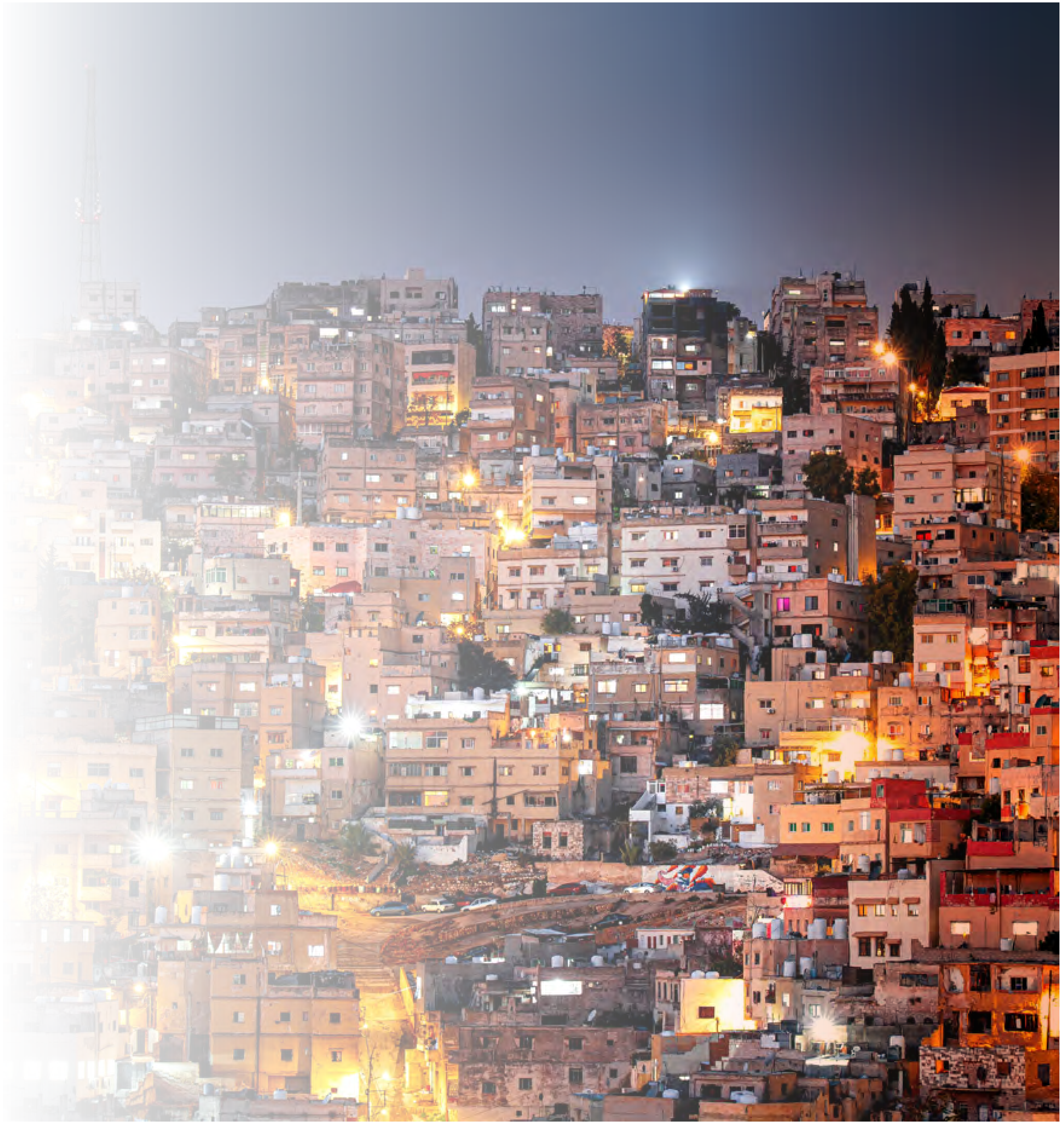
67 EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

68 European Environment Agency, "Treatment of drinking water to remove PFAS (Signal)"; U.S. Environmental Protection Agency, "Final PFAS National Primary Drinking Water Regulation"

Translating strategy into procurement is straightforward. For hospitals, schools, public buildings, retail and cold stores, make R744/R717/R290 the default wherever technically feasible. Where flammable refrigerants solutions are selected for transitional or site-specific reasons, require documented safety cases (ventilation, leakage risk assessment, detection, emergency procedures). In all cases, embed end-of-life recovery and reclamation clauses to avoid water-quality liabilities and to protect against tightening PFAS restrictions.[69] Pair procurement with system-level efficiency: envelope upgrades, right-sizing, high-SEER (Seasonal Energy Efficiency Ratio) equipment, part-load control, heat recovery and thermal storage often deliver larger gains than the refrigerant alone, especially on grids that struggle with summer peaks.[70]

For financiers and portfolio owners, refrigerant choice is also a risk-management lever. Natural refrigerants minimise exposure to future PFAS restrictions, reduce dependence on shrinking HFC quotas and lower stranded-asset risk as bans tighten. Flammable refrigerants can be used effectively when the safety case and service-quality provisions are robust and auditable. Either way, aligning efficiency, chemical safety and market access creates durable value in a region where cooling demand will keep rising and where water and grid constraints are structural.[71]

In short, refrigerant choice matters because it decides how the cooling transition balances emissions stemming from cooling, system performance, compliance and health protection. Prioritising PFAS-free natural refrigerants wherever feasible and embedding quality from design to end-of-life will future-proof investments for the MENA region and Türkiye's reality.[72]



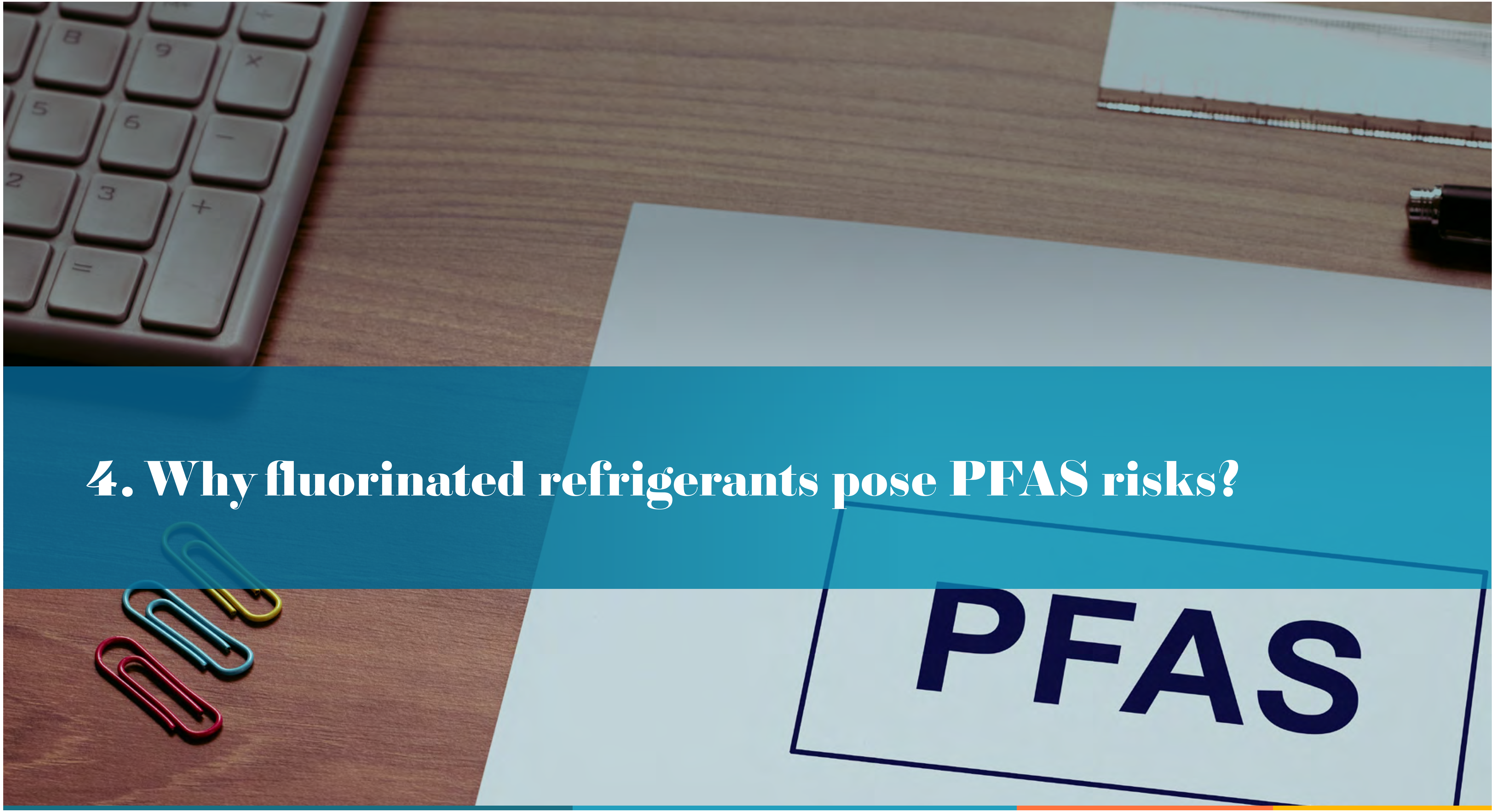
69 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report"; EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

70 Cool Up, "MENA Region Cooling Status Report – Issue 3"

71 EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"; European Environment Agency, "Treatment of drinking water to remove PFAS (Signal)"

72 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report"; EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

4. Why fluorinated refrigerants pose PFAS risks?



Chemical safety has moved from a background compliance task to a strategic consideration for every cooling decision in the MENA region and Türkiye. The reason is twofold. First, PFAS are now treated as a class under a broadened structural definition that captures legacy and emerging chemistries; the OECD recommends identifying PFAS as any fluorinated substance containing at least one fully fluorinated methyl or methylene carbon (–CF_2 or –CF_3–), simplifying policy and procurement across thousands of compounds.[73] Second, several HFC/HFO refrigerants, along with fluorinated coatings and elastomers used in cooling equipment, link to PFAS life-cycle pathways—notably the atmospheric formation of trifluoroacetic acid (TFA), an ultrashort-chain PFAS that is highly mobile in water and not readily removed by conventional treatment.[74]

73 OECD, "Reconciling Terminology of the Universe of PFAS"

74 PAN Europe, "TFA: The Forever Chemical in the Water We Drink"; UNEP/TEAP RTOC, "2022 Assessment Report"

In practical terms, PFAS interfaces with cooling in four places. Certain materials and components rely on PFAS-containing fluoropolymers and elastomers (e.g., wire coatings, seals, hoses, printed circuit boards), chosen for their heat and chemical resistance.[75] Lubricants and surface treatments may include PFAS, especially where low friction, non-wetting and thermal stability are required.[76] Some fluorinated refrigerants (notably certain HFOs and some HFCs) form trifluoroacetic acid (TFA) as an atmospheric breakdown product. TFA is highly persistent and water-soluble and has been increasingly detected in precipitation, surface water, groundwater, and desalination influent.[77] At the food-chain level, recent assessments show that TFA is not only present in aquatic environments but can also accumulate in soils, plant material and cereal-based products, including wheat-derived foods and wines. This reflects its role as a highly stable degradation product originating from multiple fluorinated chemical uses, and aligns with scientific reviews documenting TFA's widespread environmental occurrence and persistence.[78] And at end-of-life, poor recovery and disposal allow PFAS-containing materials and fluids to enter waste streams and leach into water bodies[79].

75 OECD, "Reconciling Terminology of the Universe of PFAS"

76 UNEP/TEAP RTOC, "2022 Assessment Report"

77 PAN Europe, "TFA: The Forever Chemical in the Water We Drink"

Regional data underline why monitoring matters. A baseline study of Saudi Red Sea coastal lagoons measured Σ12 PFAS up to 956 ng/L in areas influenced by treated wastewater and historical firefighting-foam use.[80] Pan-African reviews synthesise drinking-water concentrations ranging ~0.03–200 ng/L, surface-water concentrations up to ~788 ng/L, and wastewater concentrations up to ~507 ± 258 ng/L, while highlighting scarce routine monitoring and limited data for North Africa.[81] Even where measured PFAS levels are below emerging health thresholds, the persistence and mobility of TFA makes this relevant to long-term water-resource management.[82]

78 PAN Europe, "Unseen and Unregulated: TFA, the 'forever chemical' in Europe's Cereals; Freeling & Björnsdotter, Assessing the environmental occurrence of the anthropogenic contaminant TFA"

79 UNEP/TEAP RTOC, "2022 Assessment Report"

80 Ali et al., "PFASs in contaminated coastal marine waters of the Saudi Arabian Red Sea"

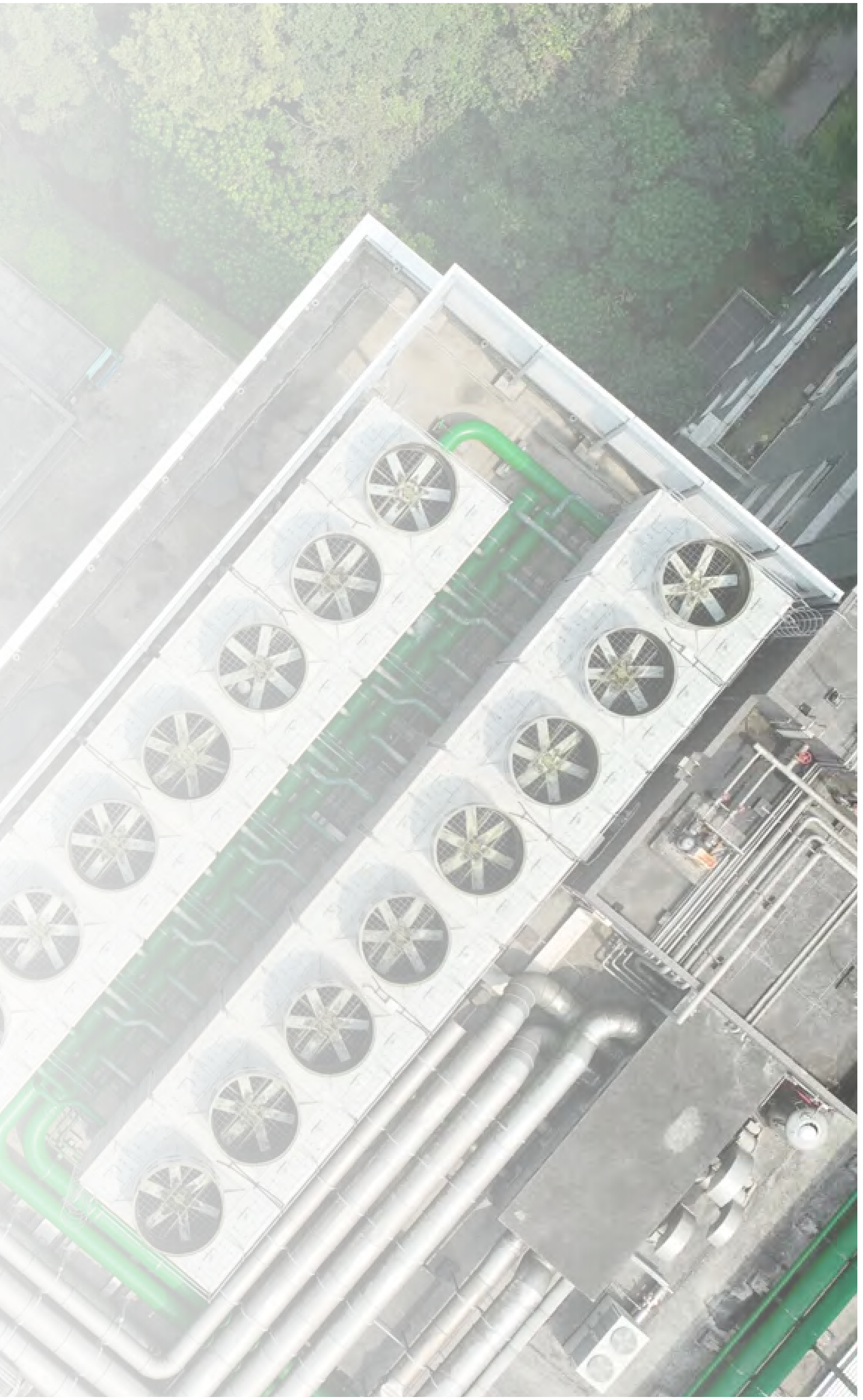
81 Umejuru et al., "PFAS in the African Continent"

82 PAN Europe, "TFA: The Forever Chemical in the Water We Drink"; EEA, "Treatment of drinking water to remove PFAS (Signal)"

Regulation is tightening quickly outside the region, and that trajectory is instructive. In the EU, the recast Drinking Water Directive introduces parametric values of 0.5 µg/L for PFAS total and 0.1 µg/L for a PFAS-20 subset from 2026.[83] In the United States, the US EPA has finalised enforceable Maximum Contaminant Levels of 4 ppt for PFOA/PFOS and 10 ppt for PFNA/PFHxS/HFPO-DA, plus a Hazard Index for mixtures.[84] On chemicals policy, the REACH universal PFAS restriction dossier—updated in August 2025—widens scope and evaluates derogations and sector conditions; it is now under RAC/SEAC review, with opinions to inform a Commission decision.[85] For MENA region and Türkiye, these developments set external compliance baselines for import/export and public procurement—especially for hospitals, schools and water utilities—and they signal where OEM portfolios are likely to pivot.

What does this mean for refrigerant strategy? From a chemical-safety perspective, natural refrigerants—CO_2 (R744), NH_3 (R717) and hydrocarbons such as R290—avoid PFAS at source and deliver ultra-low or zero GWP. By contrast, HFO/HFC blends can offer strong efficiency and lower GWP, but do not remove PFAS/TFA concerns and may add end-of-life handling complexity—points that carry weight where water systems are stressed and monitoring capacity is limited.[86] Technician training, effective leakage control and proper recovery practices play a key role in reducing refrigerant emissions. By improving containment, these measures also lower the risk of forming trifluoroacetic acid (TFA), a per- and polyfluoroalkyl substance (PFAS), from fluorinated refrigerants that may degrade into TFA. Consequently, emission-reduction measures traditionally applied to HCFCs and HFCs should also be applied to HFOs and HFO blends where degradation to TFA is expected or cannot be ruled out.[87]

Procurement and operations can translate policy into practice. For public buildings, health facilities and retail anchors, specifying PFAS-free naturals wherever technically feasible reduces future regulatory and treatment liabilities and aligns with external water rules.[88] Installation and servicing should adopt leak-tight practices, detector deployment, ventilation and charge-limit compliance, with certified technicians for flammable refrigerants classes; these measures are routine in high-performing markets and offer measurable reductions in direct emissions and IAQ risks.[89]



Wherever flammable refrigerants are selected, procurement should require flammable refrigerants-ready designs, documented risk assessments and training, so that efficiency gains are realised without compromising safety.[90] And because the data gap persists in many countries, stakeholders should build PFAS/TFA monitoring around desalination intakes and urban water sources, using EU DWD parameters as design targets and publishing results to strengthen public trust.[91]

83 EEA, "Treatment of drinking water to remove PFAS (Signal)"

84 US EPA, "Final PFAS National Primary Drinking Water Regulation"

85 ECHA, "ECHA publishes updated PFAS restriction proposal"; European Commission (DG CLIMA), "F-gas legislation documentation"

86 UNEP/TEAP RTOC, "2022 Assessment Report"; PAN Europe, "TFA: The Forever Chemical in the Water We Drink"

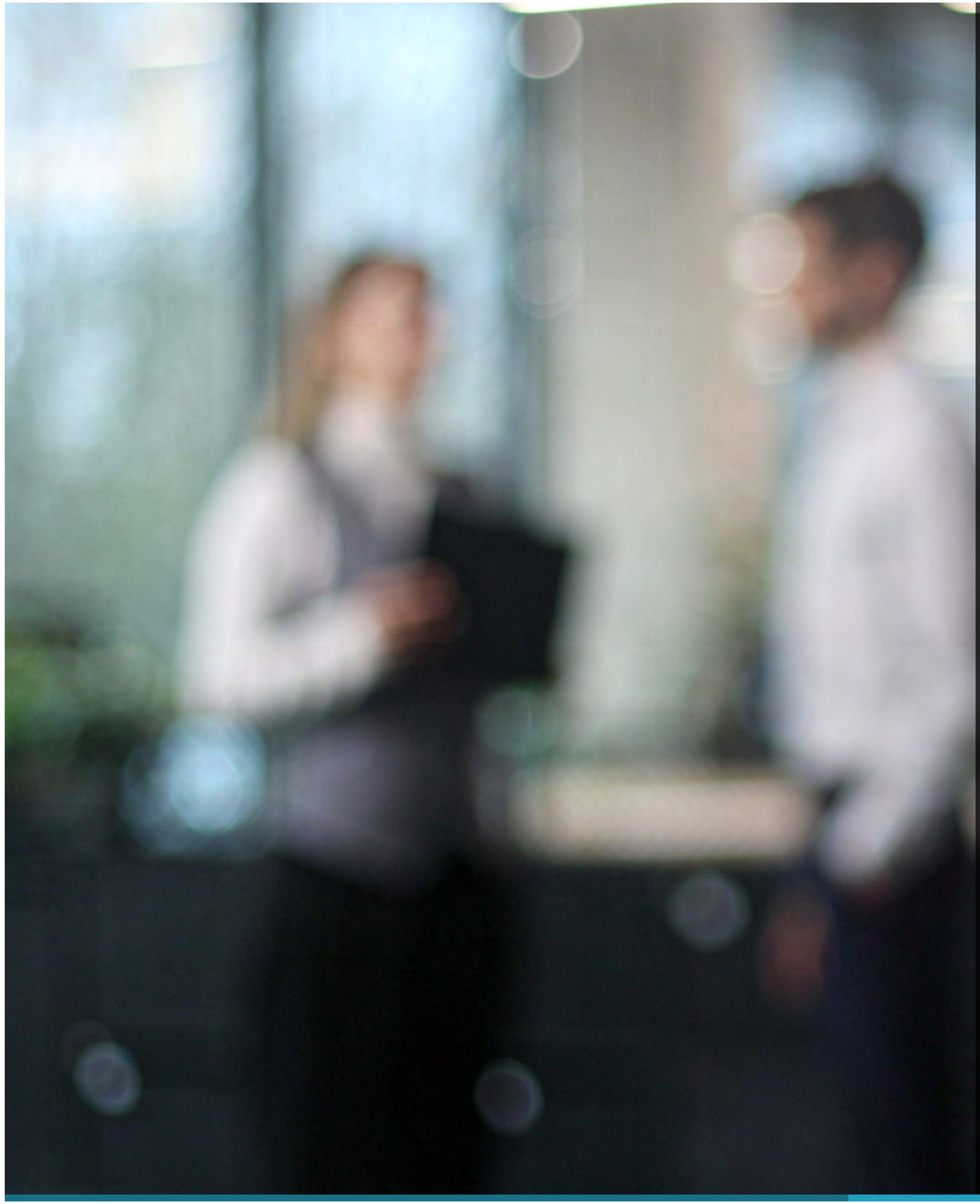
87 EUR Lex. "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

88 EEA, "Treatment of drinking water to remove PFAS (Signal)"; US EPA, "Final PFAS National Primary Drinking Water Regulation"

89 UNEP/TEAP RTOC, "2022 Assessment Report"

90 UNEP/TEAP RTOC, "2022 Assessment Report"

91 EEA, "Treatment of drinking water to remove PFAS (Signal)"



5. Interview: Prof. Dr. Michael Kauffeld, Karlsruhe University of Applied Sciences

The Cool Up programme interviewed Prof. Dr. Michael Kauffeld, Professor at Karlsruhe University of Applied Sciences, to discuss the environmental implications of per- and polyfluoroalkyl substances (PFAS) and trifluoroacetic acid (TFA), the links between fluorinated refrigerants and persistent degradation products, as well as the opportunities and challenges associated with transitioning to natural refrigerants in the MENA region. This interview builds directly on the findings of the Cool Up MENA Region Status Report, which highlights rising global attention to PFAS and, in particular, TFA, and their relevance for the Refrigeration, Air Conditioning and Heat Pump (RACHP) sector. To provide a clearer and more accessible perspective for policymakers, implementers and practitioners in the MENA region, the conversation explores the environmental implications of fluorinated refrigerants, the formation of TFA, and practical pathways towards a safe, energy-efficient transition to natural refrigerants.

Prof. Dr.-Ing. habil. Michael Kauffeld is a mechanical engineer with a PhD in refrigeration engineering and 40 years of experience in refrigeration, air conditioning and heat pump technologies with a focus on natural refrigerants. Since 2002, he has been Professor of Refrigeration at Karlsruhe University of Applied Sciences, where his work focuses on sustainable refrigeration, natural refrigerants, and ice slurry technology. Prior to joining academia, he worked in industry and at several research organisations in Germany, Denmark, and the United States. Since 1997, he has been a member of the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC).

Experience over the past decades shows that natural refrigerants can often match or even outperform systems based on HFCs or HFOs.

Cool Up:
To set the scene, could you start by explaining what PFAS are, why they are referred to as "forever chemicals", and where they are commonly used?

Prof. Dr. Michael Kauffeld:
PFAS comprise a very large family of fluorinated chemicals with numerous variants. Many of these substances have extremely long environmental lifetimes, whether in the atmosphere, soil or water, which is why they are often referred to as "forever chemicals". We encounter them in many everyday applications, including non-stick cookware coatings, water and grease repellent food packaging, membranes in outdoor clothing, certain pesticides and a range of technical components such as gaskets.

In the RACHP sector, PFAS arise in two principal ways: firstly, through certain solid materials used within systems; and secondly, and far more critically, through fluorinated refrigerants. Certain HFC and HFO refrigerants, such as R134a or R125 are PFAS because they contain at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any H/Cl/Br/I attached to it). When these refrigerants are released into the atmosphere, they degrade into persistent PFAS, most notably TFA, which has now become a central topic in environmental and chemical safety discussions.

Cool Up:
Could you explain how specific refrigerants, particularly HFCs and HFOs, are linked to the formation of TFA?

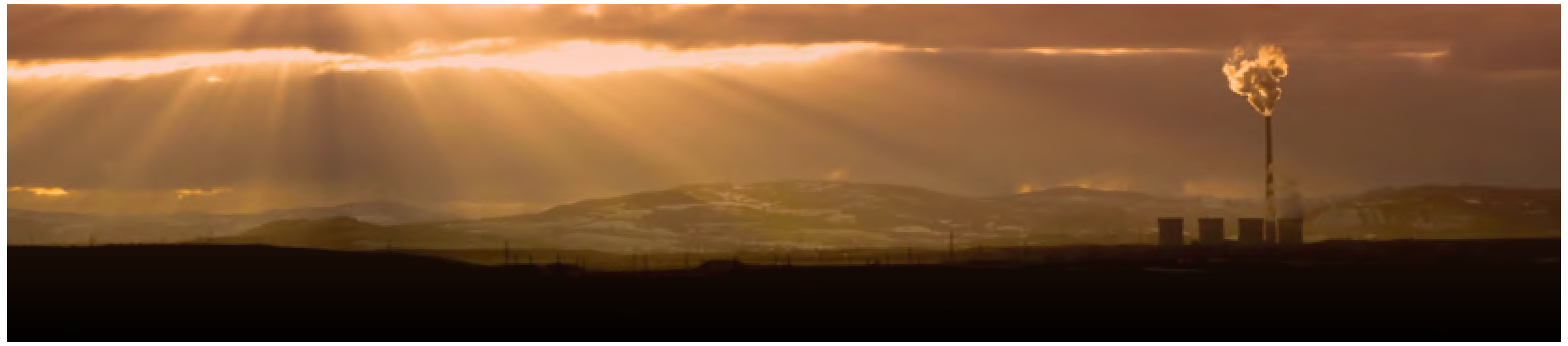
Prof. Dr. Michael Kauffeld:
TFA is a short-chain PFAS that forms when certain fluorinated refrigerants break down in the atmosphere. The HFC R134a, which was widely used in mobile air-conditioning systems for many years, produces TFA only partially (22.2%) and degrades slowly due to its long atmospheric lifetime of approximately 13.5 years. By contrast, the HFO R1234yf, introduced as a low-GWP alternative, breaks down within 12 days and converts entirely into TFA.

This distinction is critical. Long-lived HFCs degrade far from the emission source, sometimes after years of atmospheric transport. Fast-degrading HFOs, however, generate TFA locally, leading to higher and more concentrated deposits near cities and traffic corridors. Modelling studies indicate that where R1234yf is used extensively, TFA concentrations may increase several hundred-fold. This differs markedly from HFCs such as R134a, whose longer atmospheric lifetimes disperse their degradation products globally rather than concentrating them in specific regions.

Cool Up:
Based on current evidence, where is TFA found in the environment, and what concerns arise from its presence?

Prof. Dr. Michael Kauffeld:
TFA binds readily to water and is removed from the atmosphere through rain, fog, or snow, eventually entering surface waters and groundwater. Measurements from water bodies and even beverages show steadily increasing concentrations over recent decades. When we examine older samples, such as wines from the 1950s, archived groundwater, or Antarctic ice cores, we find no detectable TFA before the mid-1980s. The increase coincides with the introduction and expanded use of fluorinated refrigerants and certain pesticides, the latter representing an additional TFA source in agricultural regions.

At higher concentrations in animal studies, TFA has shown effects on the liver and on fetal development. Two major concerns follow: firstly, TFA's resistance to natural degradation means it accumulates in aquatic systems over very long periods, and secondly, we lack a clear understanding of the mixture, or "cocktail", effects of TFA with other PFAS. Because TFA is such a small molecule, reverse osmosis is currently the only broadly effective treatment method, but it is energy-intensive, costly, and not feasible on an environmental scale. While drinking water can be treated, natural ecosystems cannot, meaning that once TFA enters groundwater, it persists for centuries.



Cool Up:
Are PFAS free alternatives available, and how can they be used safely in practice?

Prof. Dr. Michael Kauffeld:
Yes, we have long-established, PFAS-free alternatives. Natural refrigerants such as hydrocarbons, ammonia, and CO_2 are widely applied across many system types. Hydrocarbons like propane and isobutane offer high efficiency and broad applicability. Ammonia provides excellent efficiency for industrial refrigeration systems where trained personnel are present. CO_2 has now become the mainstream option in European supermarkets, particularly following design improvements tailored to warm climates. Water and air also serve niche applications.

However, safety must be engineered into every system. This requires adherence to standards, appropriate charge limits, effective ventilation, leak detection, and thorough commissioning and maintenance procedures. Technician training is essential, with appropriate engineering measures and the right skills, safe deployment is fully achievable.

Many of these substances have extremely long environmental lifetimes, whether in the atmosphere, soil or water, which is why they are often referred to as "forever chemicals".

Cool Up:
Let's talk about efficiency. How do systems using natural refrigerants perform energetically compared with HFC- and HFO-based systems?

Prof. Dr. Michael Kauffeld:
Experience over the past decades shows that natural refrigerants can often match or even outperform systems based on HFCs or HFOs. In many unitary applications, switching from HFCs to hydrocarbons can deliver efficiency gains in the range of 10–15%, particularly when heat-exchanger design is optimised and tailored to the refrigerant.

Ammonia remains the most efficient option for a wide range of large-scale industrial systems and chillers. Its thermodynamic properties give it a clear performance advantage in settings where trained personnel are available to operate and maintain the equipment safely.

CO_2 supermarket systems were initially viewed as challenging in high-ambient-temperature contexts. However, system design has evolved substantially. Today, CO_2 installations frequently match or even surpass the performance of legacy R404A systems across Europe — including warmer regions — thanks to targeted design improvements that address earlier limitations.

Cool Up:
Could you elaborate on how the persistence of TFA, together with current industry dynamics, influences the transition away from fluorinated refrigerants?

Prof. Dr. Michael Kauffeld:
From a policy perspective, the crucial issue is the contrast between the behaviour of HFOs in the atmosphere and the persistence of their degradation product, TFA, in groundwater. While HFOs break down quickly in the atmosphere resulting in low global warming potential (GWP), TFA remains in water for extremely long periods, which underscores the need for precautionary regulation targeting substances whose breakdown leads to persistent PFAS.

Industry dynamics also play a significant and long-standing role. Historically, transitions between refrigerant classes have been closely linked to patent cycles and associated commercial interests. The current resistance to accelerating the shift towards natural refrigerants reflects the commercial value of HFO-related intellectual property, which continues to influence market behaviour and slows progress towards PFAS-free solutions.

Cool Up:
To wrap up, what would be your key message to policymakers and practitioners in the MENA region?

Prof. Dr. Michael Kauffeld:
My main recommendation is to leapfrog directly from HFCs to natural refrigerants, thereby avoiding additional TFA burdens. TFA levels in most MENA countries are still comparatively low, which presents a unique opportunity to prevent long-term contamination by transitioning straight to PFAS-free solutions.

To support this shift, it is essential to establish standards and codes adapted to high-ambient-temperature conditions, ensure reliable access to suitable system components, and provide structured, hands-on training for installers, technicians, and service providers. With clear policy direction and the right implementation support, this transition is entirely achievable. Preparing supply chains and scaling training programmes will help ensure safe and efficient operation from day one. The region can draw on European experience while also developing its own strong market capacities and ecosystems. Ghana, for example, just issued a refrigerant label for air conditioners (ACs) and refrigerators / freezers also emphasizing the PFAS and TFA issue associated with certain HFCs.[92]

Cool Up:
Thank you, Prof. Dr. Kauffeld, for these insights and for helping move the conversation towards natural refrigerants as an essential part of future-proof cooling solutions.

92 Environmental Protection Authority; "Refrigerant Label"

6. Pathways and Conclusion

The MENA region and Türkiye can steer fast-rising cooling demand toward health resilience, grid stability and chemical safety by treating refrigerant choice and system efficiency as one policy lever. Aligning national roadmaps with the Kigali phasedown and the EU F-gas Regulation (EU 2024/573) gives clear market guardrails, while public-health guidance confirms that access to safe, reliable cooling is now essential infrastructure.[93] Updating MEPS and labels, enforcing market surveillance, and setting timelines that withdraw high-GWP refrigerants will accelerate uptake of PFAS-free naturals—CO_2, NH_3, R290—in supermarkets, public buildings and industry. Where flammable refrigerant options (e.g., R32) are retained, efficiency gains must be paired with documented flammable refrigerants safety—ventilation, detection and certified servicing—so performance is achieved without compromising risk management.[94]

Mainstreaming cooling in health and adaptation policy is the second lever. Hospitals, clinics and schools should combine envelope upgrades and passive measures with efficient plants using naturals to stabilise services during heatwaves and improve indoor air quality. Procurement can lock this in by making PFAS-free solutions the default in new builds and retrofits and by requiring end-of-life recovery to avoid future water-quality liabilities. Tightening drinking-water parameters for PFAS in the EU and final US EPA MCLs underscore why refrigerant decisions matter in water-stressed countries; monitoring TFA and other PFAS at desalination intakes provides early warning and targets mitigation.[95]

Finance and capacity complete the pathway. Blended finance and utility programmes can scale district cooling, thermal storage and deep retrofits, while technical training across flammable refrigerants classes embeds quality from design to maintenance. Country examples such as Jordan's National Cooling Action Plan show how multi-measure packages—standards, finance, skills and technology—can move from pilots to portfolios; regional platforms such as RCREEE already convene implementation exchanges to spread lessons across energy, environment, water, housing and health.[96] Compliance and collaboration then close the loop: integrating PFAS/TFA monitoring, publishing results, and tracking the updated REACH PFAS restriction process will de-risk imports, exports and public tenders and reinforce the case for naturals in public infrastructure.[97]

Choosing PFAS-free naturals wherever feasible, managing flammable refrigerants safely where selected, and embedding quality from design to end-of-life aligns efficiency, emissions, market access and health protection for the region's high-ambient reality. With standards that pull the market forward, procurement that rewards best-in-class solutions, finance that unlocks system upgrades and collaboration that sustains momentum, MENA region and Türkiye can deliver safe, clean and accessible cooling at the speed public health now requires.[98]

93 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps — 2022 Assessment Report"; EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"; WHO, "Heat and health"; WMO, "2024 State of Climate Services"

94 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps — 2022 Assessment Report"; EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

95 European Environment Agency, "Treatment of drinking water to remove PFAS (Signal)"; U.S. Environmental Protection Agency, "Final PFAS National Primary Drinking Water Regulation"

96 Ministry of Environment (Jordan), "National Cooling Action Plan of Jordan"; RCREEE, "Press Release: Regional Workshop on Best Practices on Implementing National Cooling Action Plans"

97 European Chemicals Agency, "ECHA publishes updated PFAS restriction proposal"

98 UNEP/TEAP RTOC, "Refrigeration, Air Conditioning and Heat Pumps — 2022 Assessment Report"; EUR-Lex, "Regulation (EU) 2024/573 on fluorinated greenhouse gases"

References

Ali, Aasim M.; Higgins, Christopher P.; Alarif, Walied M.; et al. "Per and polyfluoroalkyl substances (PFASs) in contaminated coastal marine waters of the Saudi Arabian Red Sea: a baseline study." 2020. https://link.springer.com/article/10.1007/s11356-020-09897-5 . Accessed 4 December 2025.

ANSES. „PFAS: results of the national measurement campaign for drinking water." 2025. https://www.anses.fr/en/content/pfas-results-national-measurement-campaign-drinking-water . Accessed 06 December 2025.

BMZ / Health. „A vulnerability assessment in Cairo, Egypt." 2024. https://health.bmz.de/toolkits/climate-health/vulnerability-assessments/a-vulnerability-assessment-in-cairo-egypt/ . Accessed 3 December 2025.

Cool Up programme. „MENA Region Cooling Status Report – Issue 2." 2023. https://www.coolupprogramme.org/wp-content/uploads/2023/12/Cool-Up_MENA-Region-Cooling-Status-Report_Issue-2.pdf . Accessed 14 December 2025.

Cool Up programme. "MENA Region Cooling Status Report — Issue 3." 2024. https://www.coolupprogramme.org/wp-content/uploads/2024/12/Cool-Up_MENA-Region-Cooling-Status-Report_Issue-3.pdf . Accessed 15 December 2025.

Cool Up programme, "Status Update, Where are Mena and Türkiye in the transition to sustainable cooling." https://www.coolupprogramme.org/wp-content/uploads/2024/03/Where-are-MENA-and-Turkiye-in-the-transition-to-sustainable-cooling.pdf. Accessed 17 December 2025.

Daikin Industries, Ltd. "R 32: The Most Balanced Refrigerant for Stationary Air Conditioners and Heat Pumps." 2025. https://www.daikin.com/csr/information/refrigerant/hfc32 . Accessed 18 December 2025.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). "Protecting Health from Heat Stress in Informal Settlements of the Greater Cairo Region — Final report." 2017. https://www.humanitarianlibrary.org/sites/default/files/2023/09/Protecting%20Health%20from%20Heat%20Stress%20In%20Informal%20Settlements%20of%20the%20Greater%20Cairo%20Region.pdf. Accessed 05 December 2025.

European Environment Agency. "Treatment of drinking water to remove PFAS (Signal)." 2025. https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/treatment-of-drinking-water-to-remove-pfas-signal. Accessed 18 December 2025.

Environmental Protection Authority. "Refrigerant Label." 2026. https://www.epa.gov.gh/new/refrigerant-label/. Accessed 2 March 2026.

European Commission (DG CLIMA). "Fgas legislation documentation." 2024–2025. https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/documentation/f-gas-legislation_en. Accessed 18 December 2025.

European Union. „Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption." 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020L2184. Accessed 13 December 2025.

Eurofins Scientific. „New report on TFA in surface and groundwaters." 2024. https://www.eurofins.se/tjaenster/miljoe-och-vatten/nyheter-miljo/new-report-on-tfa-in-surface-and-groundwaters/ . Accessed 25 October 2025.

EUR Lex. "Regulation (EU) 2024/573 on fluorinated greenhouse gases." 2024. https://eur-lex.europa.eu/eli/reg/2024/573/oj/eng. Accessed 18 December 2025.

Freeling, F., and M.K. Björnsdotter. "Assessing the environmental occurrence of the anthropogenic contaminant trifluoroacetic acid (TFA). Current Opinion in Green and Sustainable Chemistry." 2023. https://www.sciencedirect.com/science/article/abs/pii/S2452223623000561. Accessed 12 December 2025.

International Energy Agency. "Electricity demand is surging across the Middle East and North Africa, driven by cooling and desalination needs." 2025. https://www.iea.org/news/electricity-demand-is-surging-across-the-middle-east-and-north-africa-driven-by-cooling-and-desalination-needs. Accessed 16 December 2025.

International Energy Agency. „The Future of Electricity in the Middle East and North Africa." 2025. https://iea.blob.core.windows.net/assets/a205959d-3d98-4abb-ac0e-fb97b3b05a8d/TheFutureofElectricityintheMiddleEastandNorthAfrica.pdf. Accessed 18 December 2025.

International Institute of Refrigeration. "Saudi Arabia joins global effort against climate change as 166th country to ratify the Kigali Amendment." 2025. https://iifiir.org/en/news/saudi-arabia-joins-global-effort-against-climate-change-as-166th-country-to-ratify-the-kigali-amendment. Accessed 15 December 2025.

International Institute of Refrigeration. „Snapshot of air conditioning in the MENA region and Türkiye." 2023. https://iifiir.org/en/news/snapshot-of-air-conditioning-in-the-mena-region-and-turkiye. Accessed 18 December 2025.

International Labour Organization. "Heat at work: Implications for safety and health — A global review of the science, policy and practice." 2024. https://www.ilo.org/media/578371/download. Accessed 17 December 2025.

International Labour Organization. "Working on a warmer planet: The effect of heat stress on productivity and decent work." 2019. https://www.ilo.org/publications/major-publications/working-warmer-planet-effect-heat-stress-productivity-and-decent-work. Accessed 18 December 2025.

KTH Royal Institute of Technology. „The potential dangers of TFA." 2015. https://www.energy.kth.se/polopoly_fs/1.1117740.1636469950!/Kyla%202015%2007%20-%20TFA%20ENG.pdf. Accessed 18 December 2025.

LG Electronics. "R 32 VRF Transition — Navigating the Refrigerant Shift." 2025. https://media.us.lg.com/m/5aab7399268433db/original/R-32-VRF-Transition-Article-02-2025.pdf. Accessed 7 December 2025.

David, Liji M.; Barth, Mary, et al. „ Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East." 2021. https://acp.copernicus.org/articles/21/14833/2021/. Accessed 5 December 2025.

OECD. „A new OECD definition for per- and polyfluoroalkyl substances." No. 61, 2021. https://www.oecd.org/chemicalsafety/risk-management/a-new-oecd-definition-for-per-and-polyfluoroalkyl-substances-pfas.pdf. Accessed 18 December 2025.

Organisation for Economic Co operation and Development. "Reconciling Terminology of the Universe of Per and Polyfluoroalkyl Substances: Recommendations and Practical Guidance." 2021. https://one.oecd.org/document/ENV/CBC/MONO(2021)25/en/pdf. Accessed 18 December 2025.

PAN Europe. „TFA in Water: Dirty PFAS Legacy Under the Radar." PAN Europe Report, 2024. https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/TFAinWater_Report_27052024.pdf . Accessed 06 December 2025.

PAN Europe. „TFA: The Forever Chemical in the Water We Drink." PAN Europe Report, 2024. https://www.pan-europe.info/resources/reports/2024/07/tfa-forever-chemical-water-we-drink . Accessed 06 December 2025.

PAN Europe, "Unseen and Unregulated: TFA, the 'forever chemical' in Europe's Cereals." 2025. https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/04122025_%20Report_TFA%20in%20cereals%20report.pdf. Accessed 10 December 2025.

RCREEE. "Press Release: Regional Workshop on Best Practices on Implementing National Cooling Action Plans." 2025. https://rcreee.org/press-release-regional-workshop-on-best-practices-on-implementing-national-cooling-action-plans/ . Accessed 18 Dec 2025.

UNEP/TEAP RTOC. "Refrigeration, Air Conditioning and Heat Pumps – 2022 Assessment Report." 2023. https://ozone.unep.org/system/files/documents/RTOC-assessment%20-report-2022.pdf. Accessed 18 December 2025.

United States Environmental Protection Agency. „ Final PFAS National Primary Drinking Water Regulation." 2024. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas. Accessed 18 December 2025.

United Nations Environment Programme. "Global Cooling Pledge." 2023. https://www.unep.org/resources/report/global-cooling-pledge. Accessed 18 December 2025.

U.S. Environmental Protection Agency. "Final PFAS National Primary Drinking Water Regulation." 2024. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas. Accessed 18 December 2025.

Umejuru, Emmanuel Christopher; Street, Renee; Edokpayi, Joshua N. "A Comprehensive Review of the Occurrence, Distribution, Characteristics and Fate of PFAS in the African Continent." 2024. https://link.springer.com/article/10.1007/s42250-024-01048-4. Accessed 18 December 2025.

Umweltbundesamt (Germany). "EU Regulation concerning fluorinated greenhouse gases." 2024. https://www.umweltbundesamt.de/en/topics/climate-energy/fluorinated-greenhouse-gases-fully-halogenated-cfcs/statutes-regulations/eu-regulation-concerning-fluorinated-greenhouse. Accessed 18 December 2025.

United Nations Development Programme "Kigali Implementation Plan." https://www.undp.org/chemicals-waste/flagship-cooling/kip. Accessed 15 Dec 2025

Watts, N., M. Amann, N. Arnell, et al. „The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises." 2021. 129–170. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32290-X/fulltext. Accessed 18 December 2025.

World Health Organization. „Climate change, heat and health." 2024. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health. Accessed 18 December 2025.

World Health Organization. „Climate change." 2023. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health. Accessed 18 December 2025.

World Health Organization. "Heat and health." 2024. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health. Accessed 13 December 2025.

World Health Organization. "WHO Housing and health guidelines." 2018. https://iris.who.int/bitstream/handle/10665/276001/9789241550376-eng.pdf. Accessed 18 December 2025.

World Meteorological Organization. "2024 State of Climate Services (WMO No. 1363)." 2024. https://library.wmo.int/viewer/69061/. Accessed 18 December 2025.