Sustainable Cooling: A Global Challenge

Renaldi Renaldi
Lecturer in Thermal Engineering
renaldi@cranfield.ac.uk

Guest lecture – Institut Teknologi Sepuluh Nopember
10 June 2022

Contents

About the speaker - Background

Experience

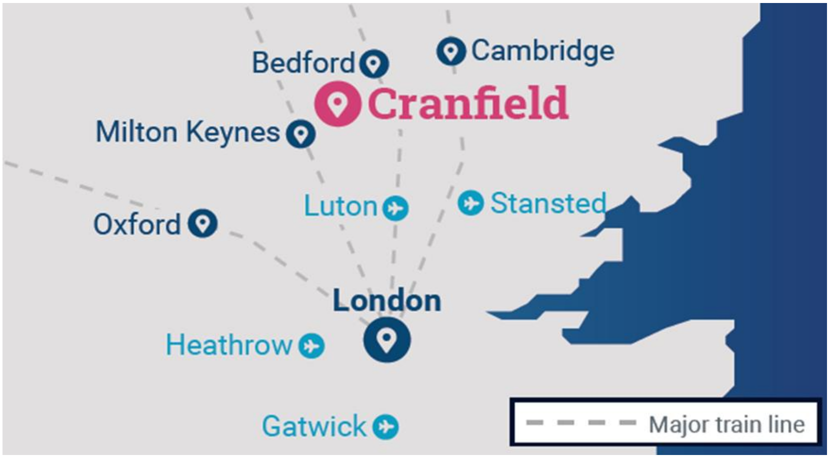
• Lecturer (Assistant Professor)	Cranfield University, UK
• Research Associate	University of Oxford, UK
• Research Associate	Newcastle University, UK

Education

• PhD (Energy Systems)	University of Edinburgh, UK
• MSc (Sustainable Energy)	TU Eindhoven, NL
• S.T. (Teknik Mesin)	Institut Teknologi Bandung

Cranfield University

- A specialist postgraduate University with distinctive characteristics.
- The largest number of postgraduate engineering students in the UK.
- Focused research themes:
  - Aerospace
  - Defence and Security
  - Energy and Power
  - Environment and Agrifood
  - School of Management
  - Manufacturing
  - Transport Systems
  - Water



Cranfield – Energy & Power

Centre for Energy Systems Strategy

Centre for Thermal Energy Systems and Materials

Centre for Renewable Energy Systems

Centre for Climate and Environmental Protection

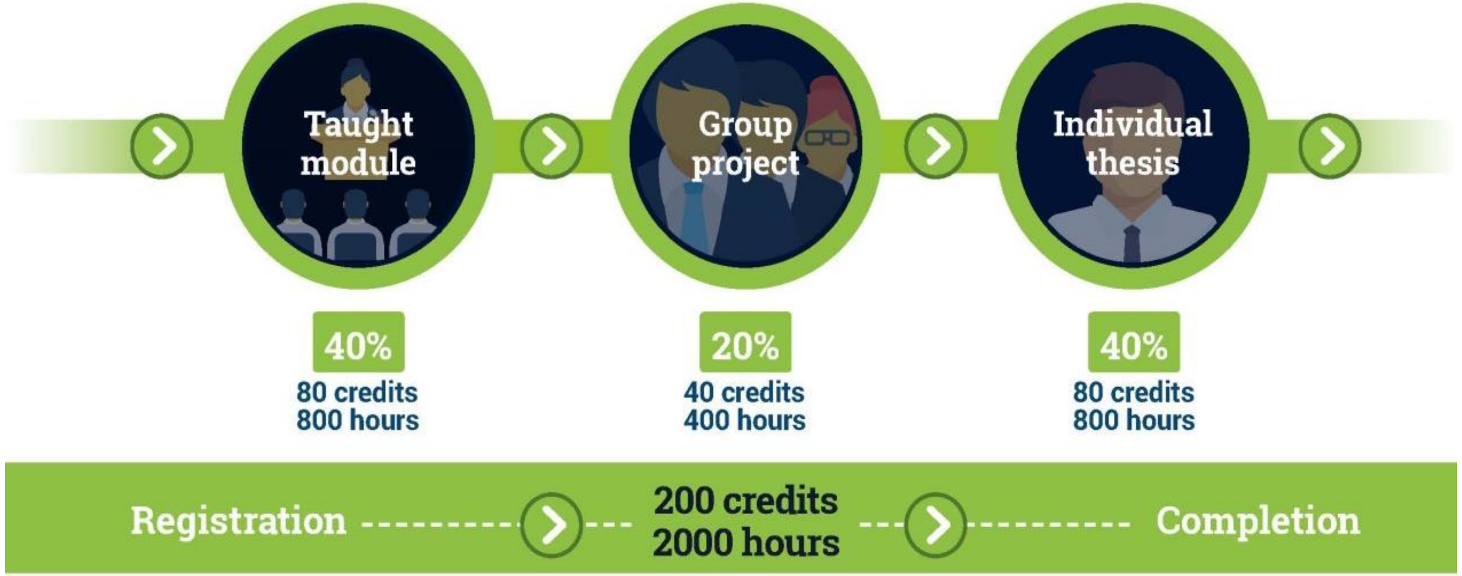
Energy & Power – MSc courses

- Advanced Chemical Engineering
- Advanced Digital Energy Systems
- Advanced Heat Engineering
- Advanced Mechanical Engineering
- Renewable Energy

Taught modules
October – February
- Lectures/seminars
- lab work
- Assignments
- private study

Group project
February - April
- Team work
- Multidisciplinary
- integrate subjects
- professional skills

Research thesis
April - September
- Scientific thesis
- research training
- externally linked and funded when possible



https://www.cranfield.ac.uk/themes/energy-and-power/courses

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Cranfield
Energy and Power

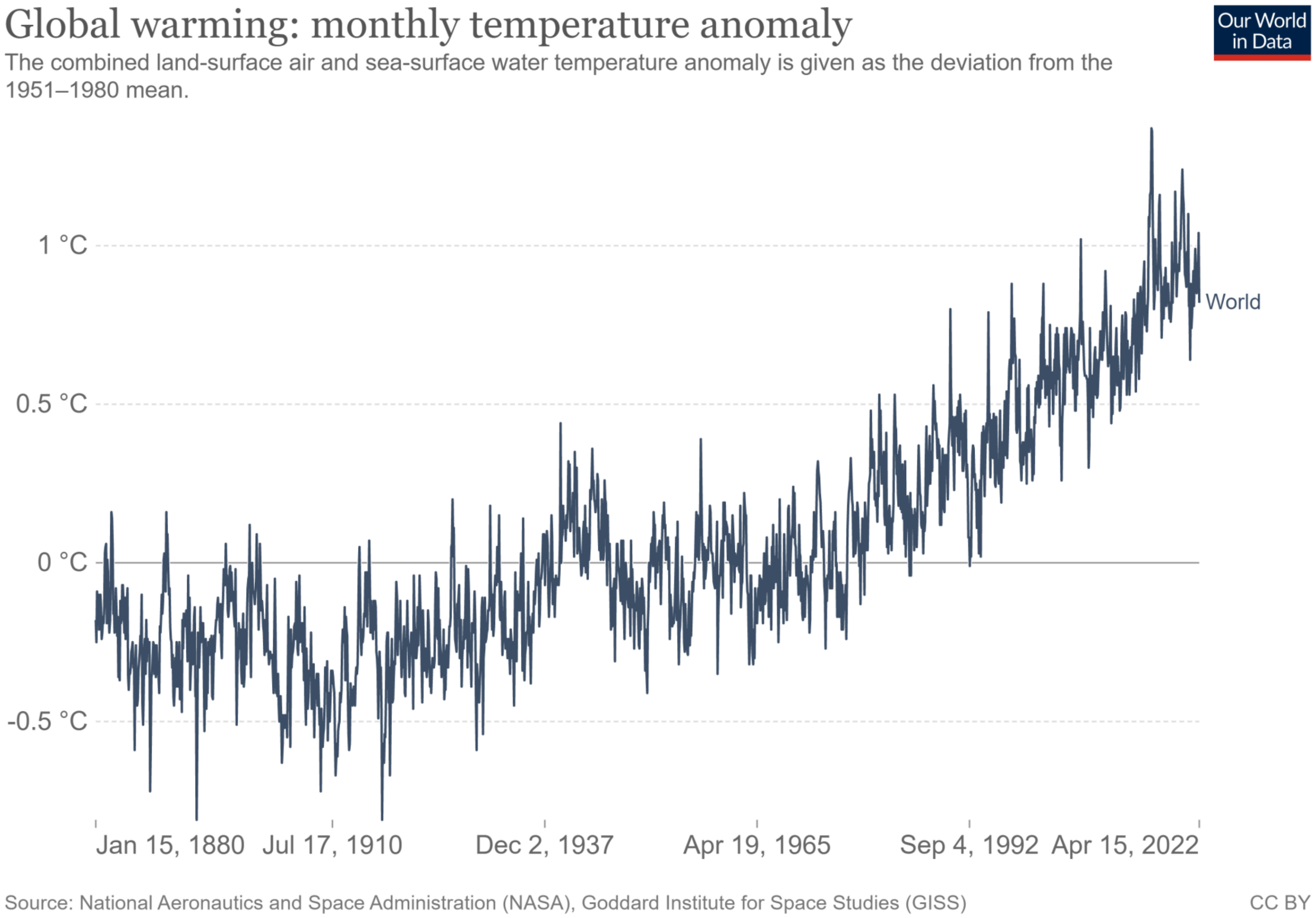
The Cool Coalition
@ActOnCooling

"I want to leave you with 3 figures: 3 billion more air conditioners will be installed by 2050, 1 billion people today do not have access to the cooling they need and 100 gigatonnes of emissions will be avoided if we solve the cooling problem."

🎙 Noah Horowitz, @CleanCoolCollab

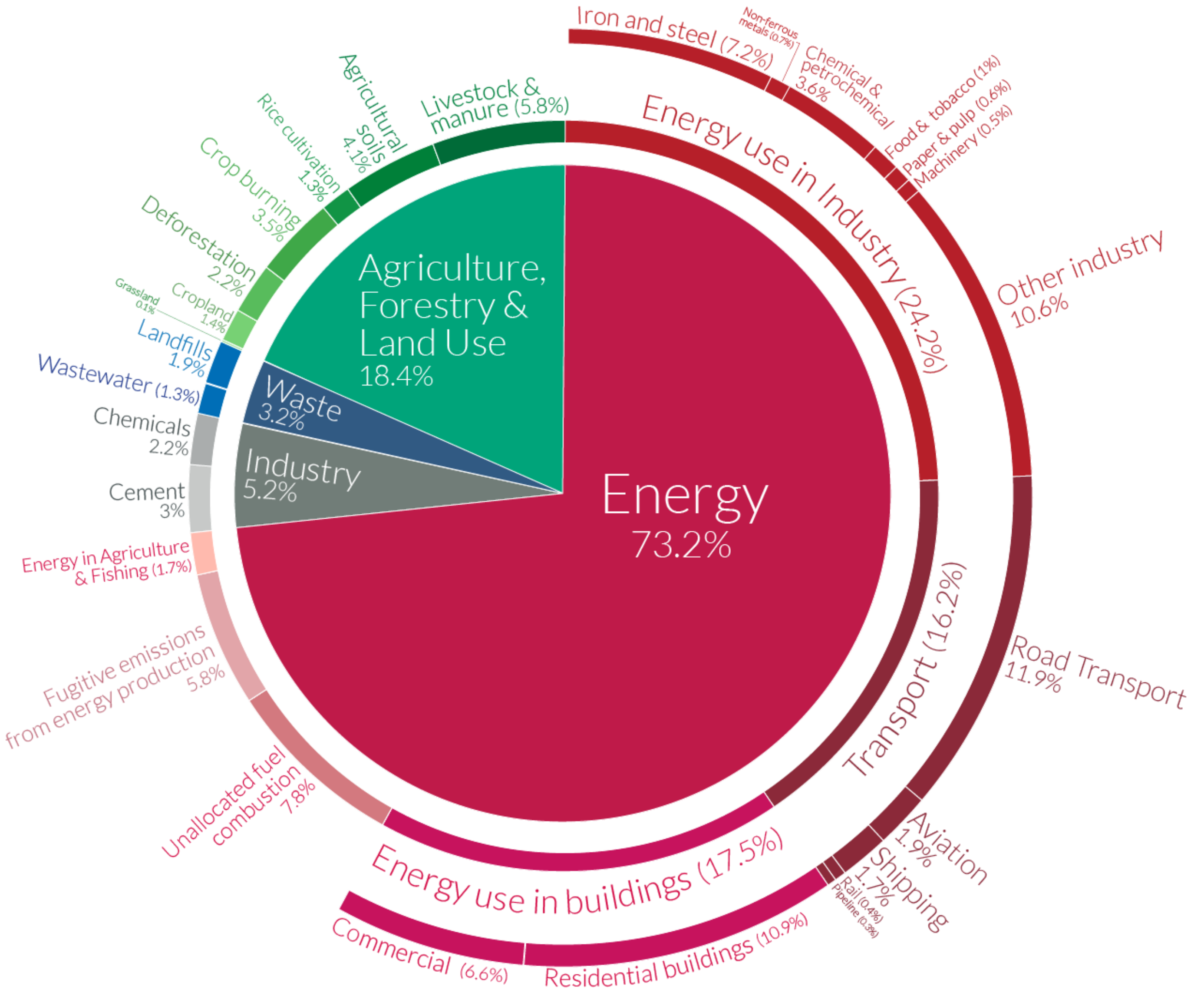
11:46 AM · Jun 8, 2022 · Twitter Web App

Climate change



Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.



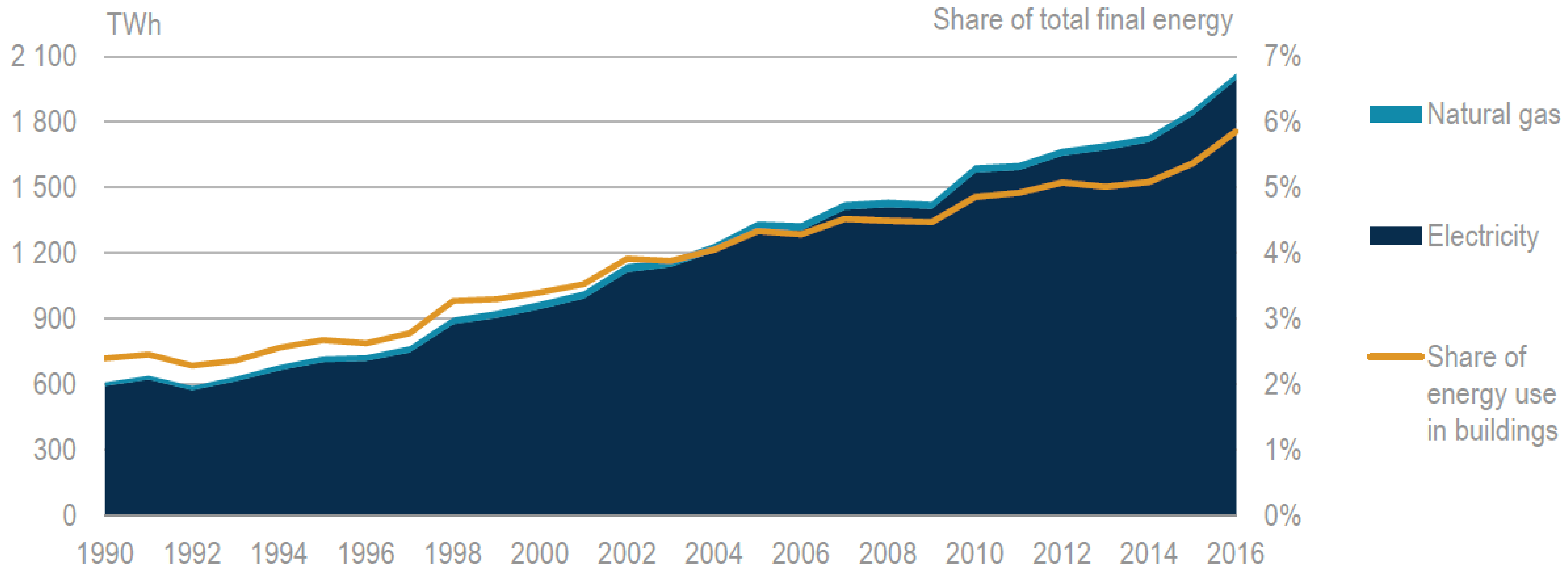
Our World in Data

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).

Cooling demand - Global

Figure 1.8 • World energy consumption for space cooling in buildings



IEA (2018) The Future of Cooling: Opportunities for energy efficient air conditioning

Cooling demand - Global

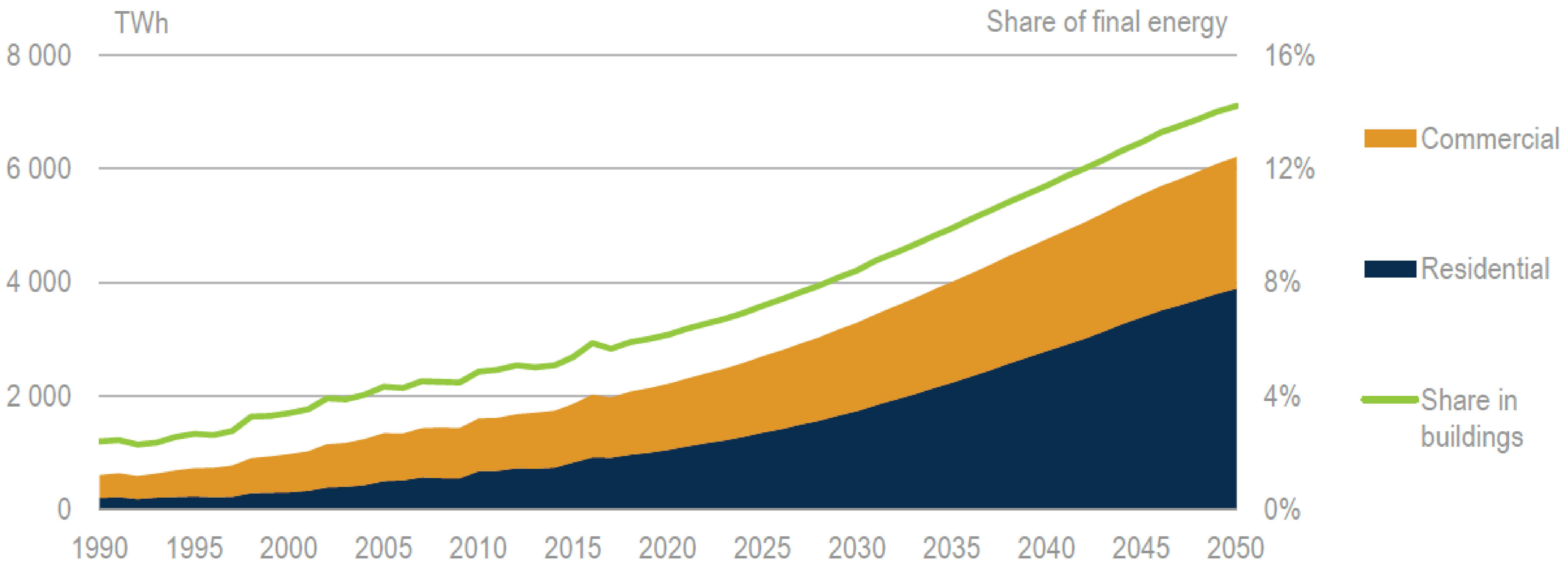
Table 1.2 • World final energy consumption for space cooling in buildings by country/region

	TWh				% of total building final energy use in 2016
	1990	2000	2010	2016	
United States	339	448	588	616	10.6%
European Union	63	100	149	152	1.2%
Japan	48	100	119	107	9.5%
Korea	4	17	34	41	8.5%
Mexico	7	16	23	37	9.8%
China	7	45	243	450	9.3%
India	6	22	49	91	3.4%
Indonesia	2	6	14	25	3.0%
Brazil	10	19	26	32	7.7%
South Africa	4	6	6	8	2.8%
Middle East	26	49	97	129	9.3%
World	608	976	1 602	2 021	5.9%

IEA (2018) The Future of Cooling: Opportunities for energy efficient air conditioning

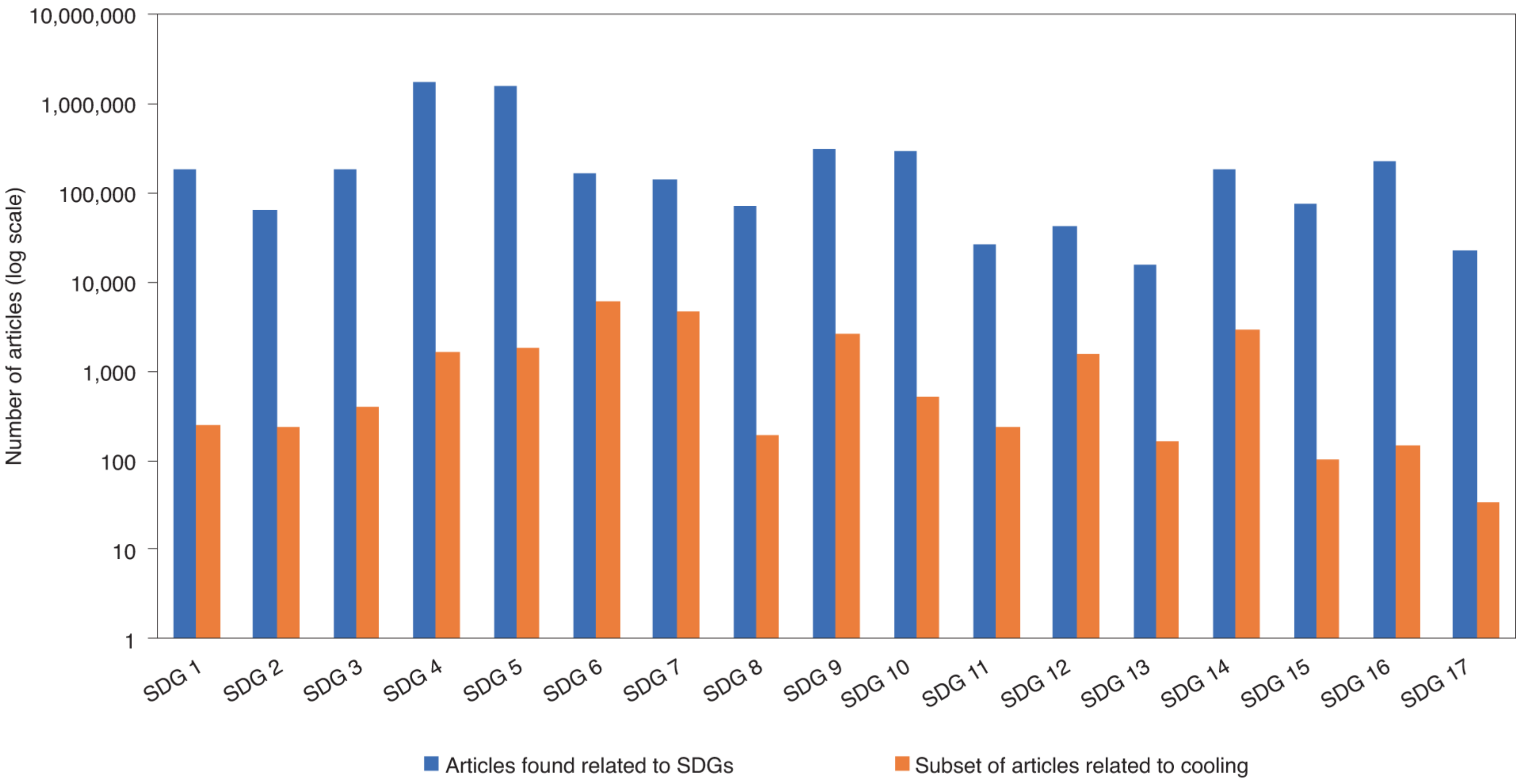
Cooling demand - Projections

Figure 3.5 • World energy use for space cooling by subsector in the Baseline Scenario



IEA (2018) The Future of Cooling: Opportunities for energy efficient air conditioning

Cooling & Sustainable Development Goals (SDGs)



nature sustainability

PERSPECTIVE

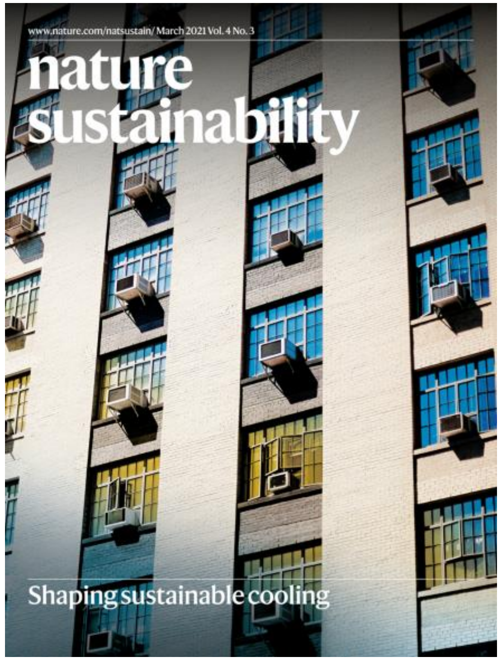
https://doi.org/10.1038/s41893-020-00627-w

Check for updates

Cooling for sustainable development

Radhika Khosla[1,2], Nicole D. Miranda[1,3], Philipp A. Trotter[1,2,4], Antonella Mazzone[1,2], Renaldi Renaldi[1,3], Caitlin McElroy[1,2], Francois Cohen[1,2,5], Anant Jani[1], Rafael Perera-Salazar[1,6] and Malcolm McCulloch[1,3]

The unprecedented rise in cooling demand globally is a critical blind spot in sustainability debates. We examine cooling as a system comprised of active and passive measures, with key social and technical components, and explain its link to all 17



Khosla, R., Miranda, N. D., Trotter, P. A., Mazzone, A., **Renaldi, R**., McElroy, C., ... & McCulloch, M. (2021). Cooling for sustainable development. *Nature Sustainability*, *4*(3), 201-208.

Cooling & Sustainable Development Goals (SDGs)

SDG	Exemplary linkages between the SDG and cooling[a]
1. No poverty	Increased extreme heat without cooling provisions is linked to lower productivity from land and income, exacerbating poverty especially in developing countries. Reduced cooling from decreased urban green spaces is also linked to increased income poverty.
2. Zero hunger	Cooling enables food production and delivery via the cold chain as well as from cooling techniques that support food production in greenhouses and aquaponic systems.
3. Good health and well-being	Cooling reduces the health burden of severe exposure to heat, especially with climate change impacts of rising temperatures. In addition, heat has an impact on infant well-being.
4. Quality education	Cognitive faculties are impaired by extreme temperatures, and heat has a negative effect on productivity and learning outcomes which are mitigated by cooling.
5. Gender equality	Household food-related activities are often women's responsibilities, and the opportunities from cooling and refrigeration enable women to undertake small businesses and reduce time spent on daily food provision.
6. Clean water and sanitation	Industrial processes (for example, thermoelectric power plants) require vast amounts of water for cooling with important implications and choices for water availability and quality.
7. Affordable and clean energy	Active space cooling and refrigeration have a very large electricity demand and influence clean energy system design (including via solar cooling technologies). Cooling is also required to generate clean energy, for instance via solar concentrated power.
8. Decent work and economic growth	Cooling reduces the negative health impacts on the economy and on worker productivity, especially in light of negative climate change impacts.

Khosla, R., Miranda, N. D., Trotter, P. A., Mazzone, A., **Renaldi, R**., McElroy, C., ... & McCulloch, M. (2021). Cooling for sustainable development. *Nature Sustainability*, *4*(3), 201-208.

Indonesia?

Kompas.com / Regional

6 Kota Terpanas di Indonesia, Surabaya Nomor 1

Kompas.com - 31/12/2021, 06:00 WIB

Cuaca Terik, Ciputat Pegang Rekor Suhu Terpanas di RI

CNN Indonesia

Kamis, 12 Mei 2022 09:36 WIB

Cooling Degree Days

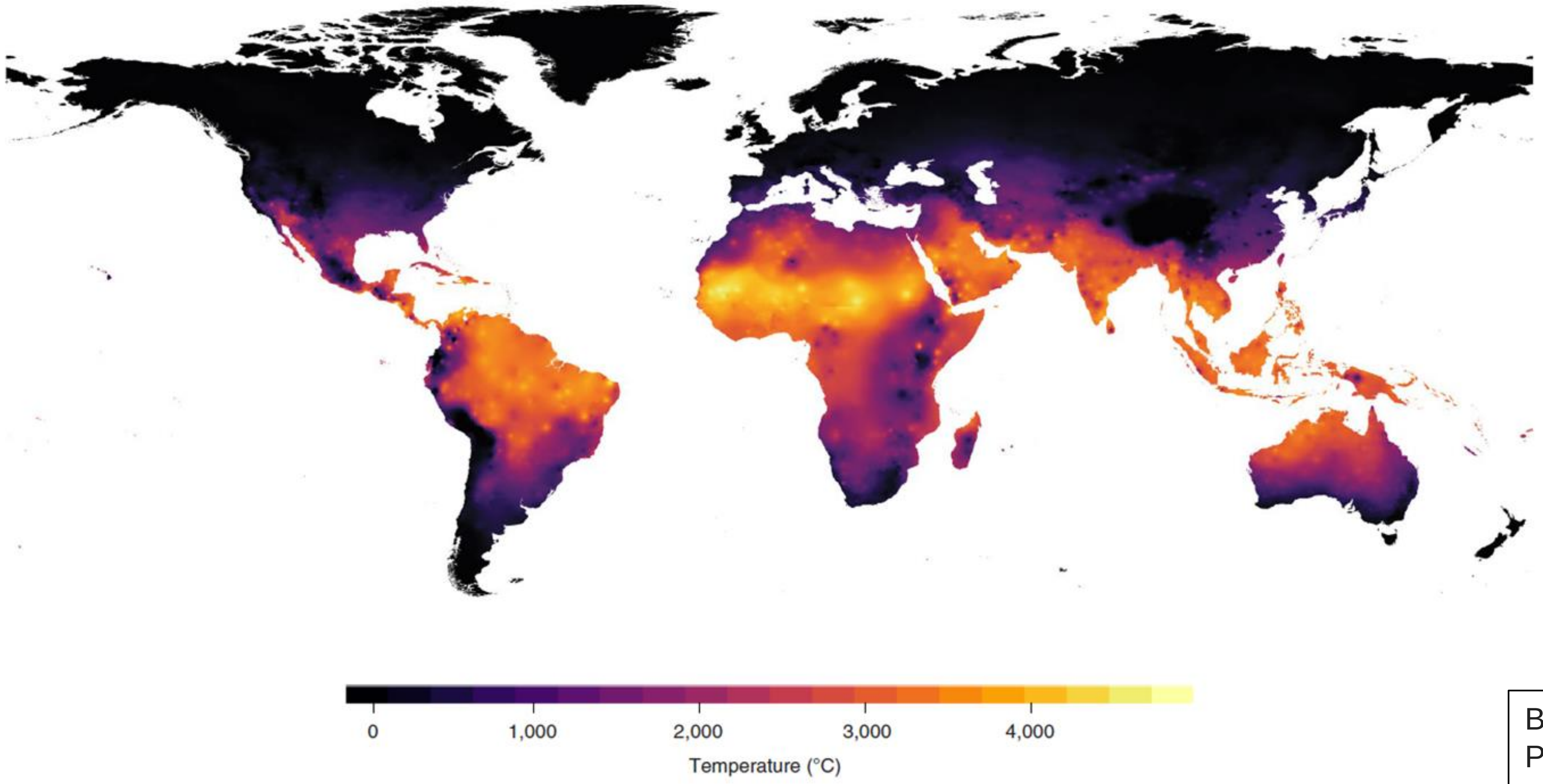


Fig. 1 | Global CDDs. Average annual CDDs for the period 2009–2018. We calculated CDDs as the sum of the daily mean temperatures above 18.3 °C (65 °F). The underlying temperature data were drawn from 14,500+ land-based monitoring stations tracked by the US National Climatic Data Center.

Biardeau, L. T., Davis, L. W., Gertler, P., & Wolfram, C. (2020). Heat exposure and global air conditioning. *Nature Sustainability*, *3*(1), 25-28..

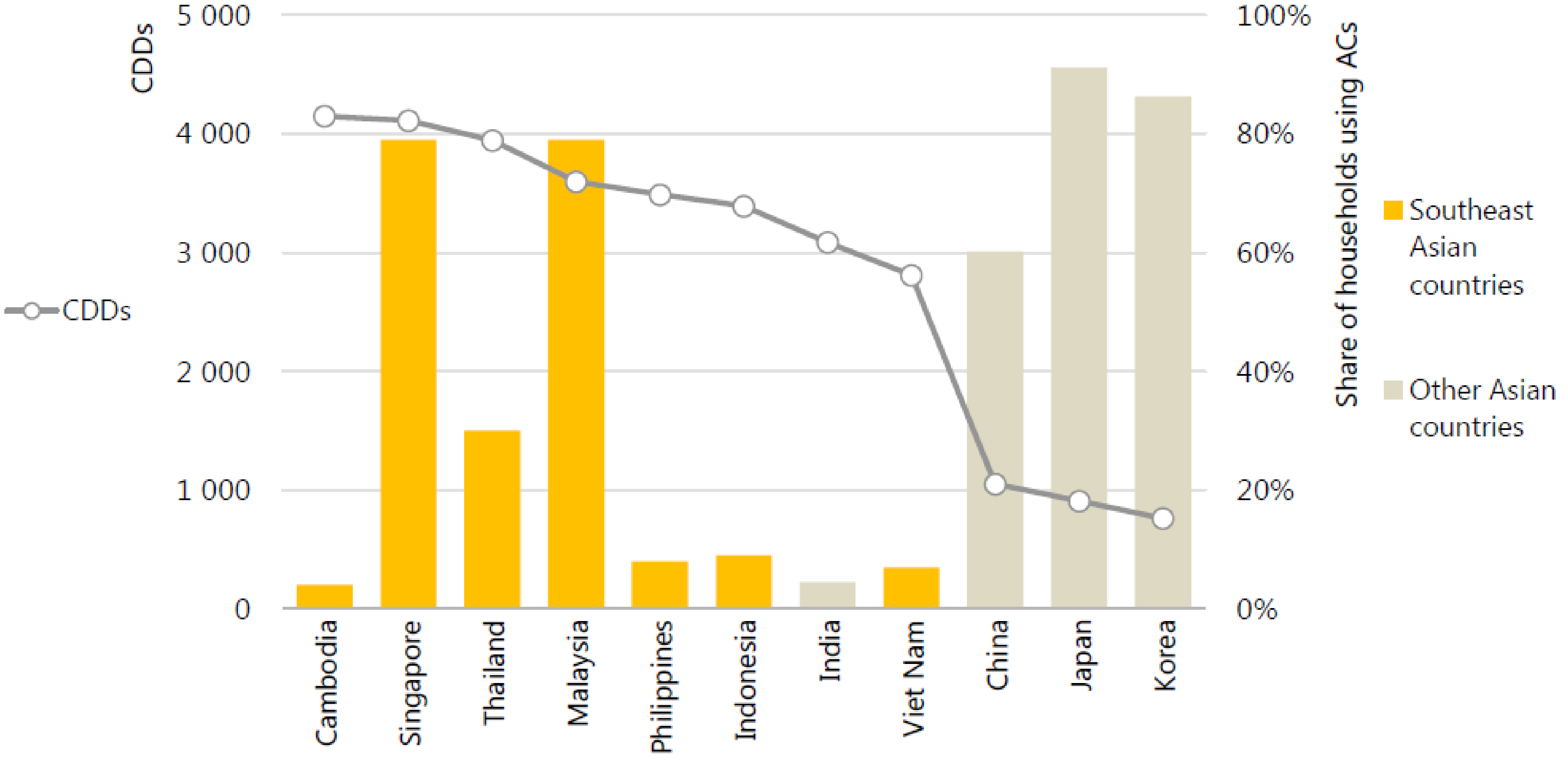
Cooling Degree Days

	Country/city	Population (in millions)	Population-weighted annual CDDs	Product of population and CDDs (in billions)	Global share (%)
Top ten countries					
1	India	1,309	2,848	3,728	28
2	China	1,397	1,009	1,410	10
3	Indonesia	258	3,284	848	6
4	Nigeria	181	3,429	621	5
5	Pakistan	189	2,504	474	4
6	Brazil	206	2,108	434	3
7	Bangladesh	161	2,644	426	3
8	Philippines	102	3,266	332	2
9	United States	320	867	277	2
10	Vietnam	94	2,777	260	2

Biardeau, L. T., Davis, L. W., Gertler, P., & Wolfram, C. (2020). Heat exposure and global air conditioning. *Nature Sustainability*, *3*(1), 25-28..

Share of AC - Indonesia

Cooling degree days and share of households using air conditioning systems by country, 2017

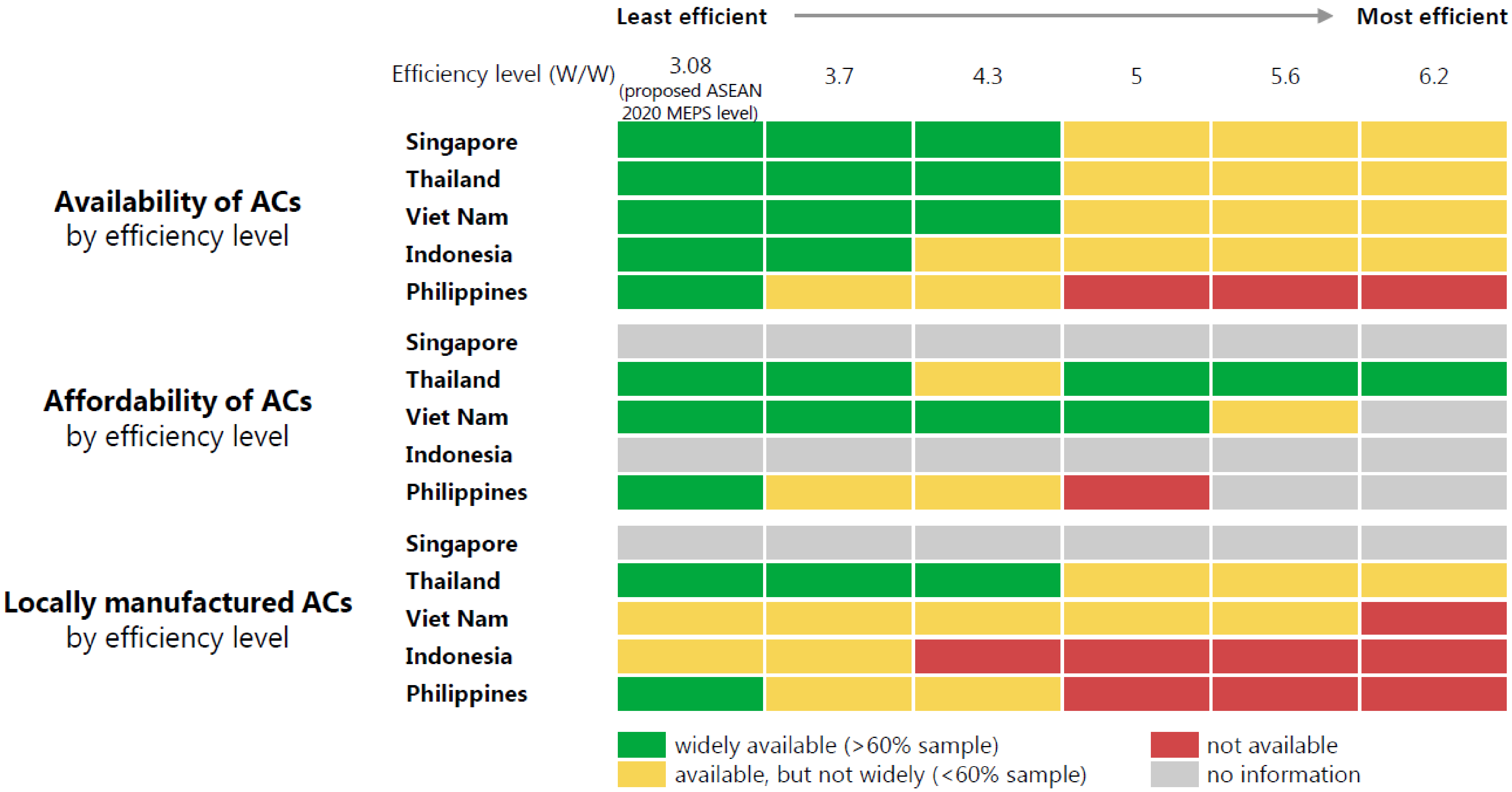


Note: CDDs = Cooling degree days; ACs = Air conditioners

Source: IEA (2019) Southeast Asia Energy Outlook

Efficiency of AC - Indonesia

Results of air conditioning market analysis in selected Southeast Asian countries



Sources: IEA analysis based on information from CLASP, the Kigali Cooling Efficiency Program and the National registration databases of Indonesia and Singapore

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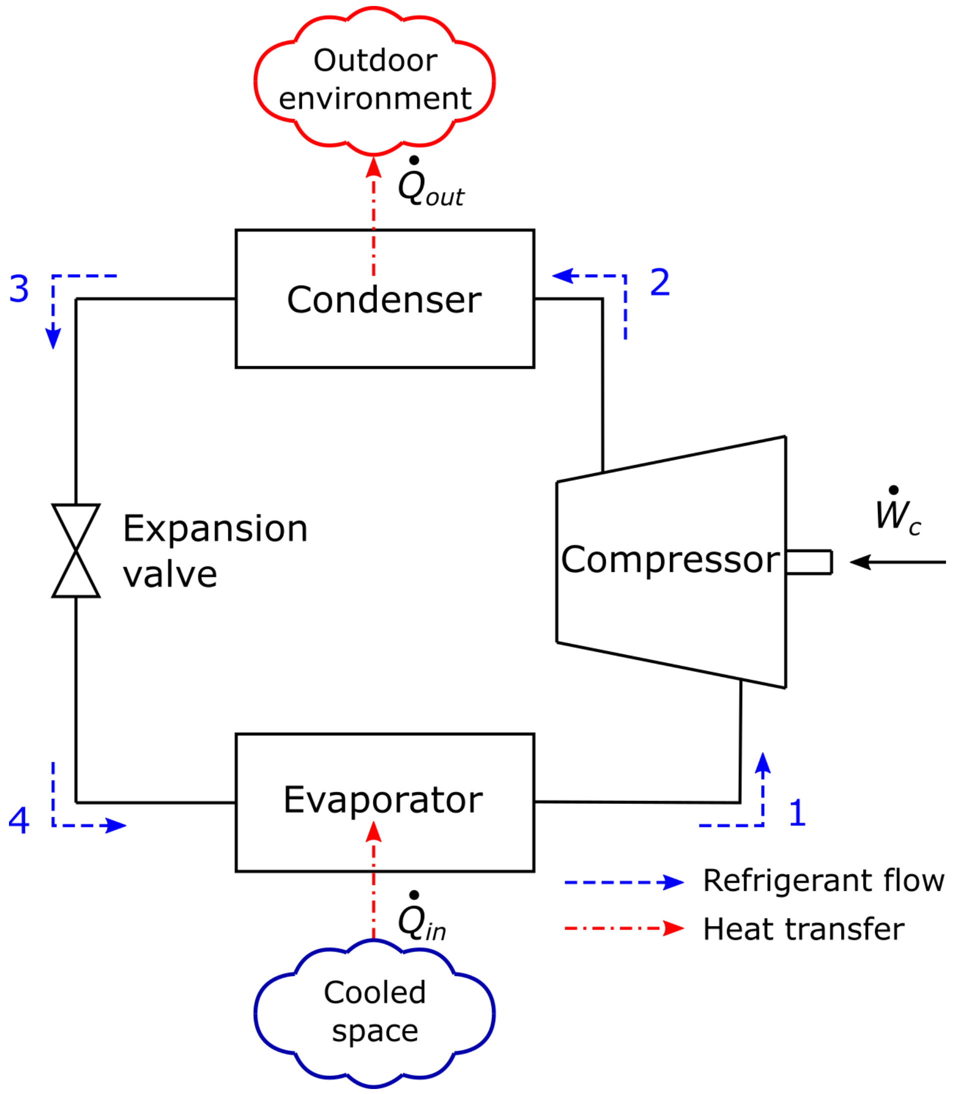
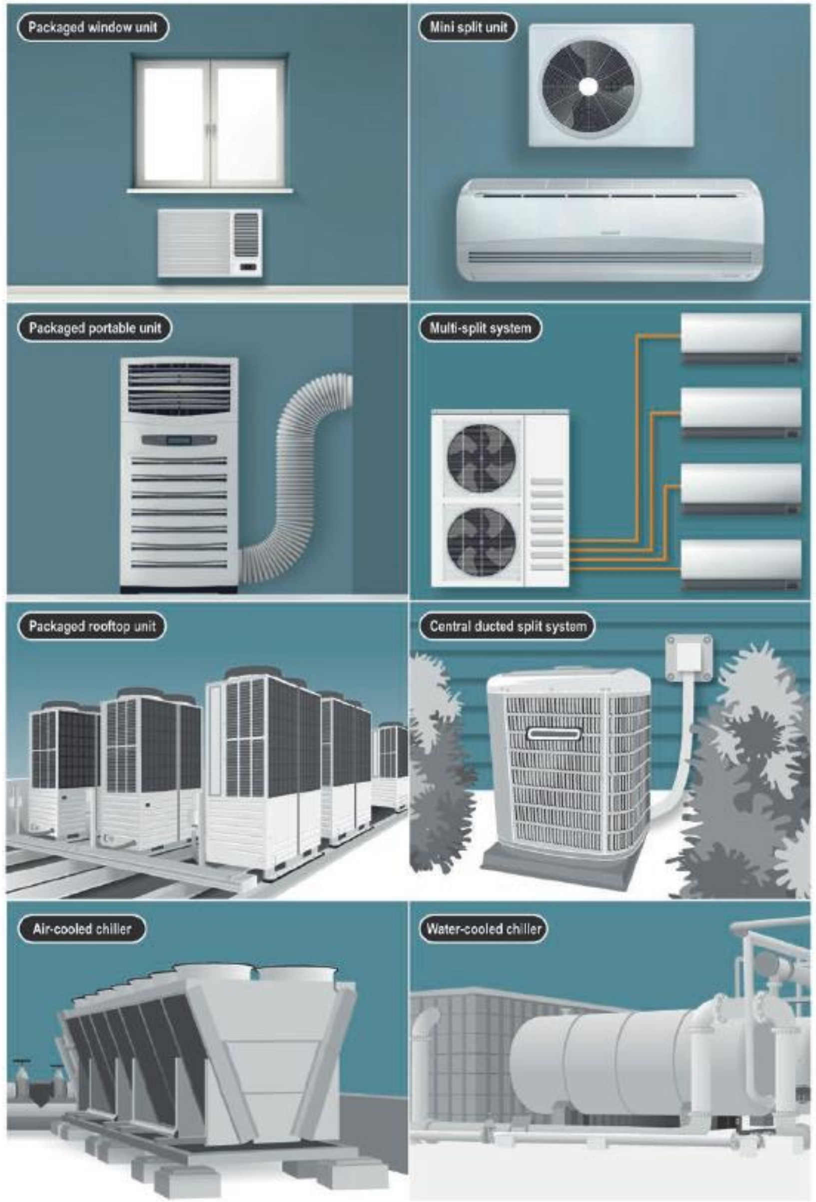
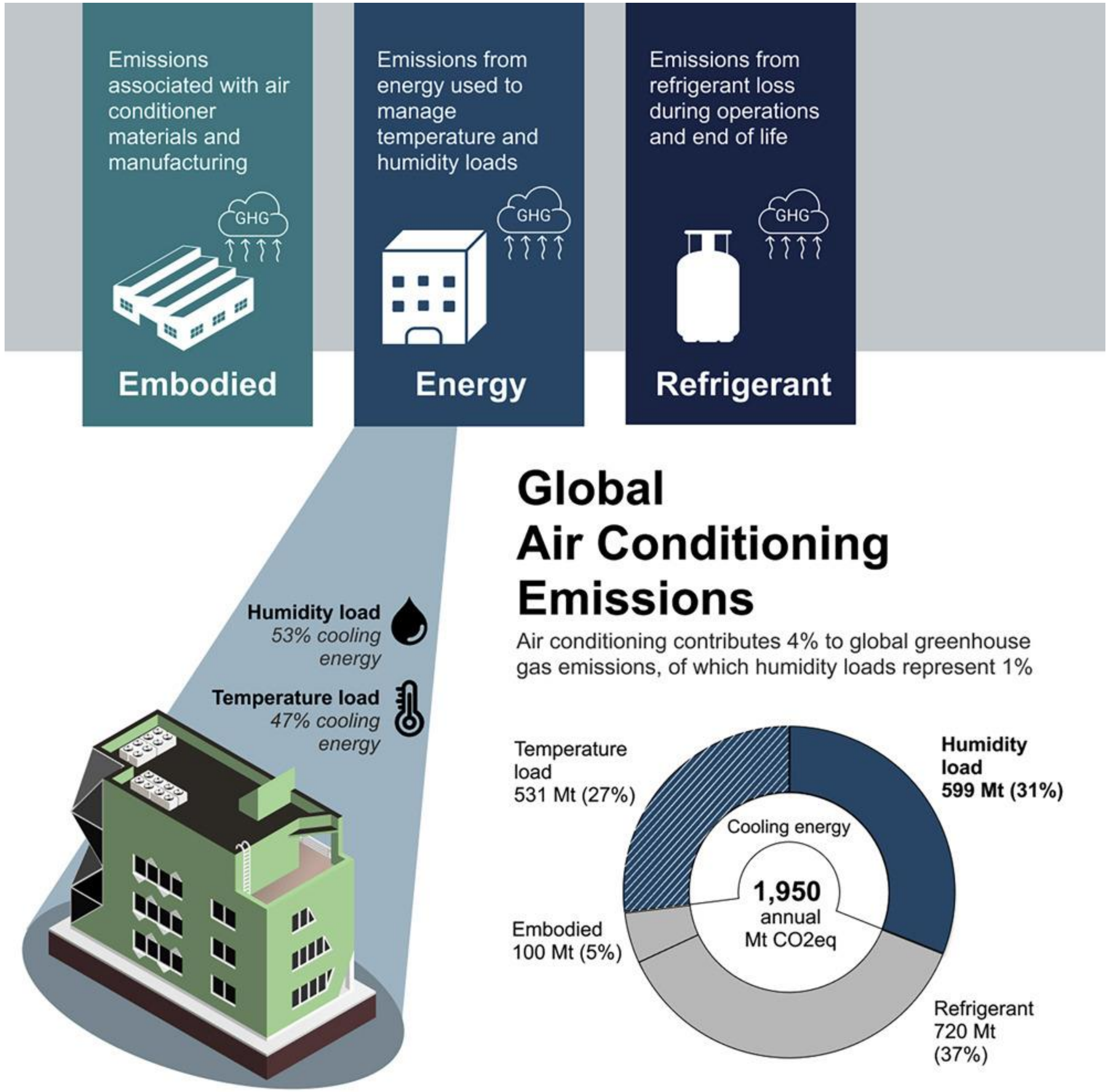
- Introduction
- Global cooling challenge
- **Technological landscape**
- Potential solutions
- Discussions

Incumbent: Vapour compression cycle



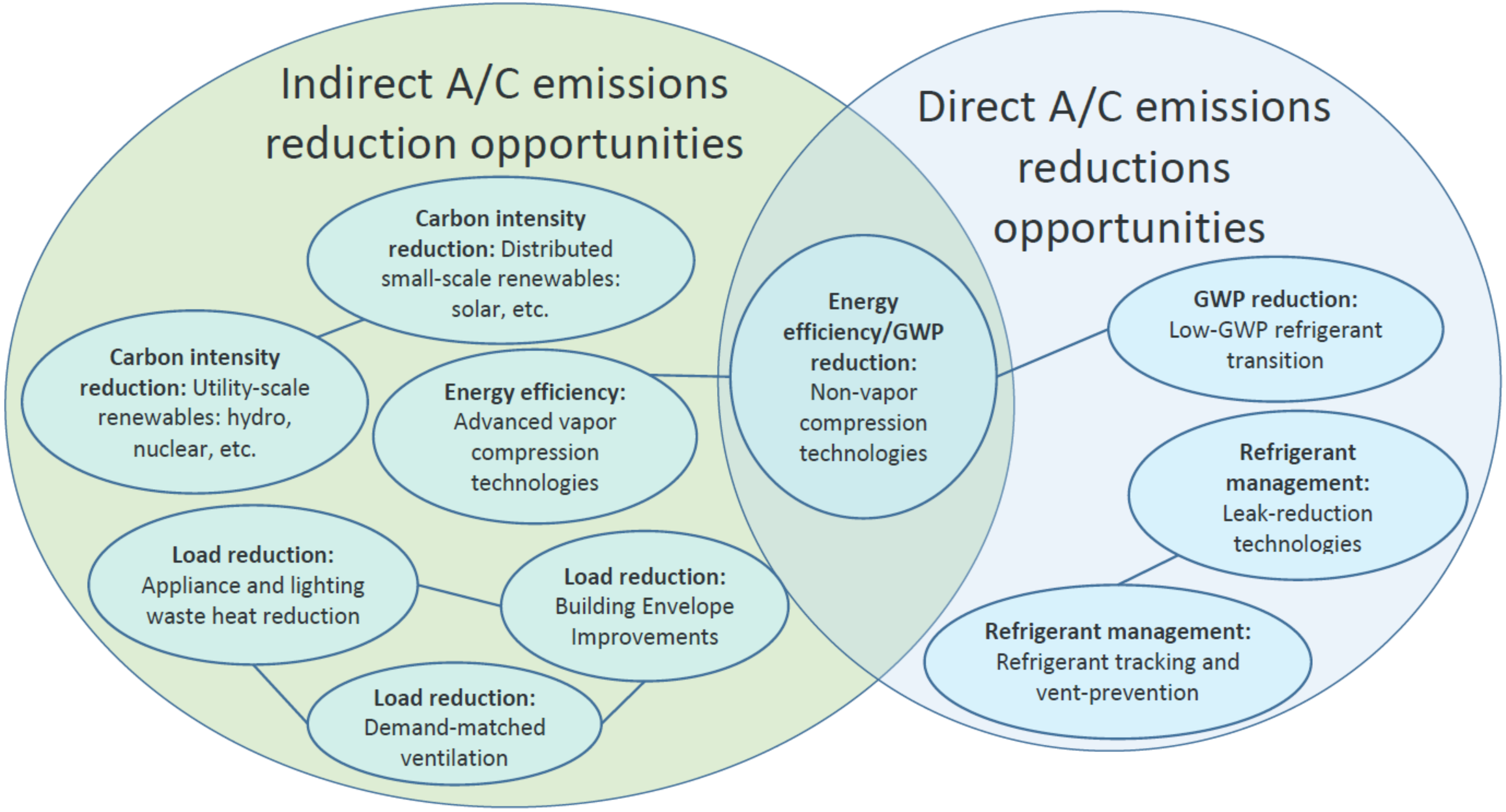


Emissions from air conditioners



Woods, J., James, N., Kozubal, E., Bonnema, E., Brief, K., Voeller, L., & Rivest, J. (2022). Humidity's impact on greenhouse gas emissions from air conditioning. *Joule*.

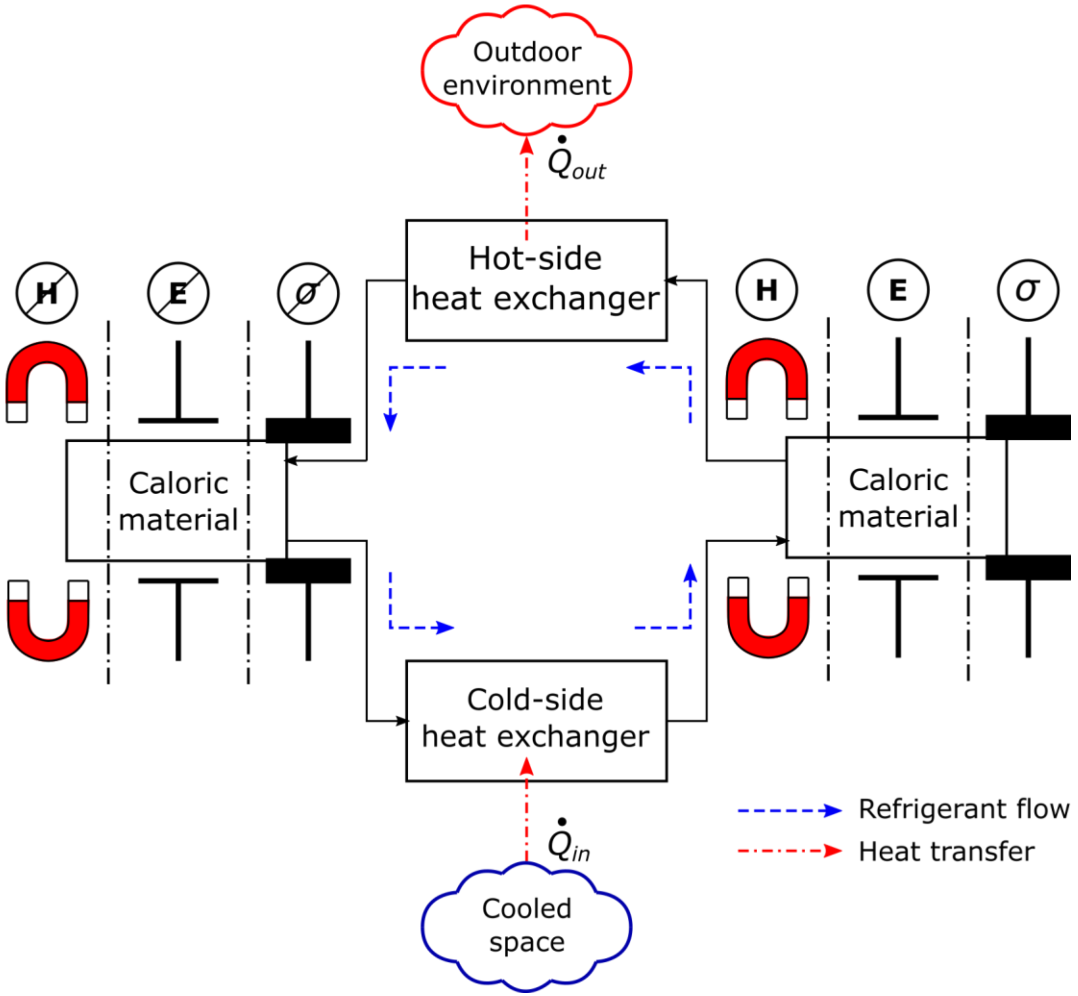
Emissions reduction opportunities



Goetzler, W., Guernsey, M., Young, J., Fujrman, J., & Abdelaziz, A. (2016). *The future of air conditioning for buildings* (No. DOE/EE-1394). Navigant Consulting, Burlington, MA (United States).

Non-vapour compression technologies

- Not-in-kind Cooling Technologies
  - Solid-state
    - Magnetocaloric
    - Elastocaloric/thermoelastic
    - Electrocaloric
    - Thermoelectric
    - Thermionic
    - Thermotunneling
  - Electro-Mechanical
    - Bernoulli heat pump
    - Brayton cycle
    - Pulse-tube
    - Thermoacoustic
    - Vortex-tube
    - Critical flow cycle
    - Evaporative cooling
    - Membrane heat pump
  - Thermally Driven
    - Liquid desiccant
    - Solid desiccant
    - Absorption
    - Adsorption
    - Duplex-Stirling
    - Vuilleumier
    - Ejector cooling



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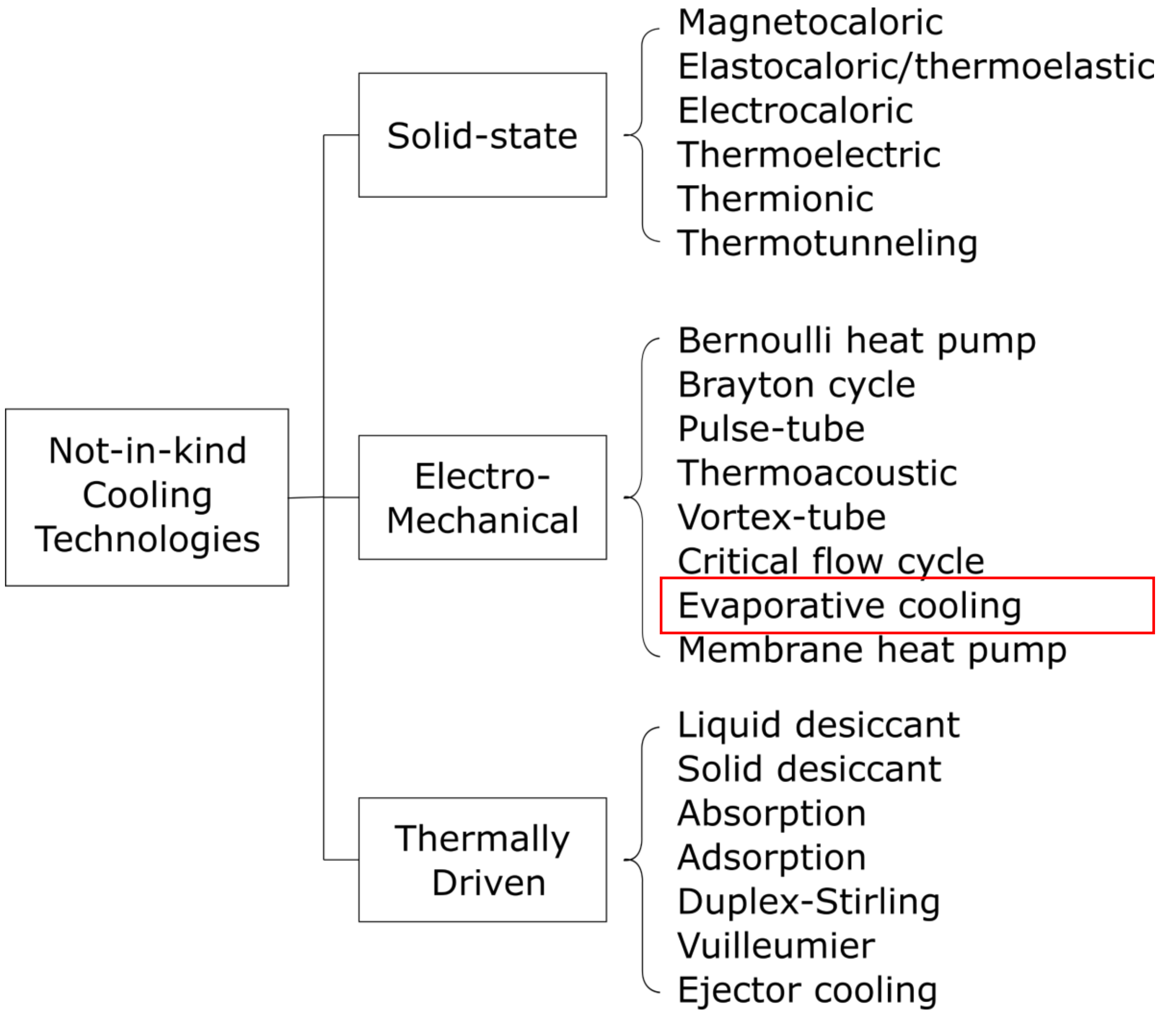
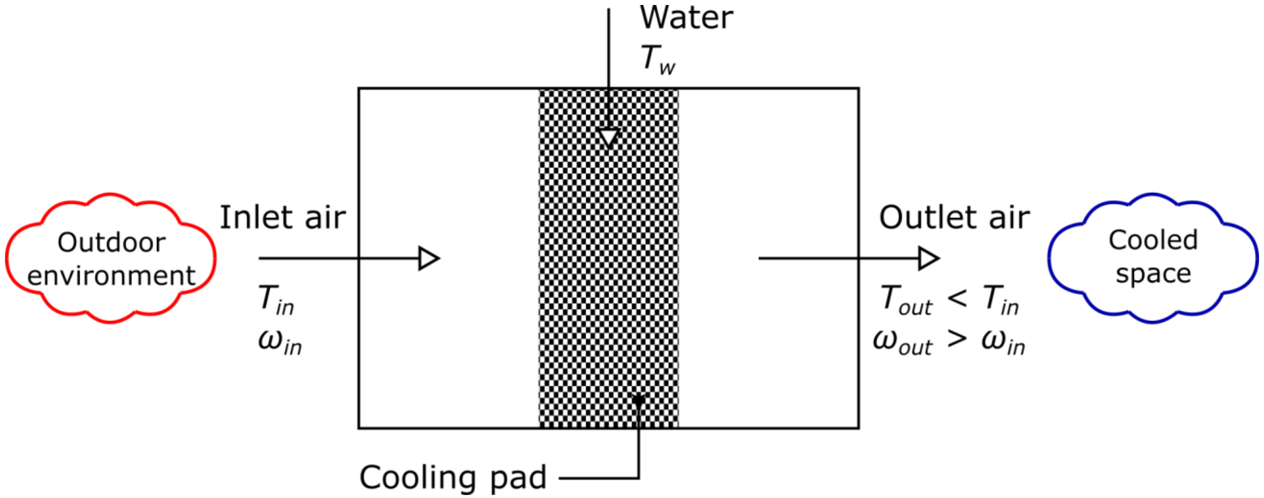
Non-vapour compression technologies





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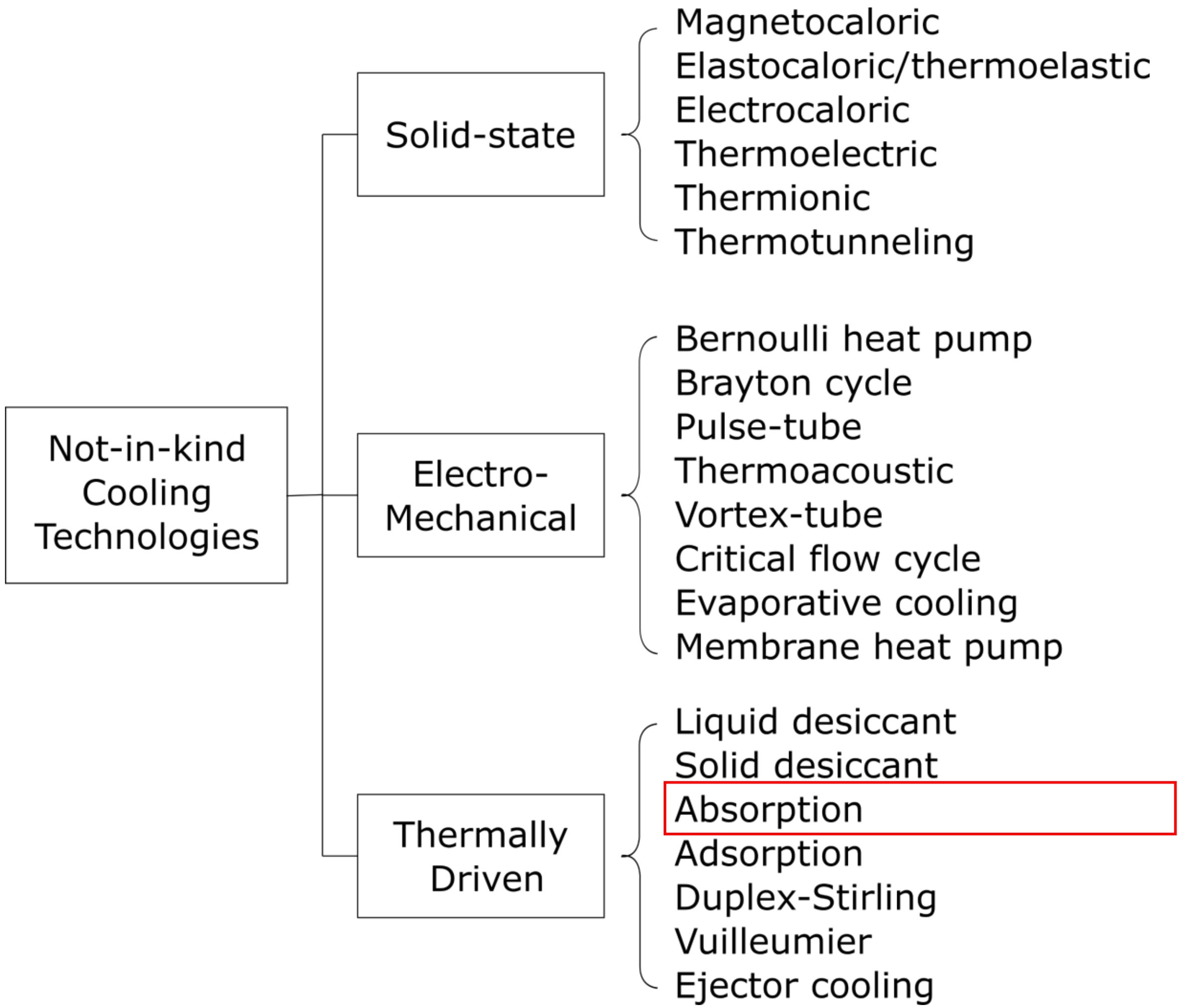
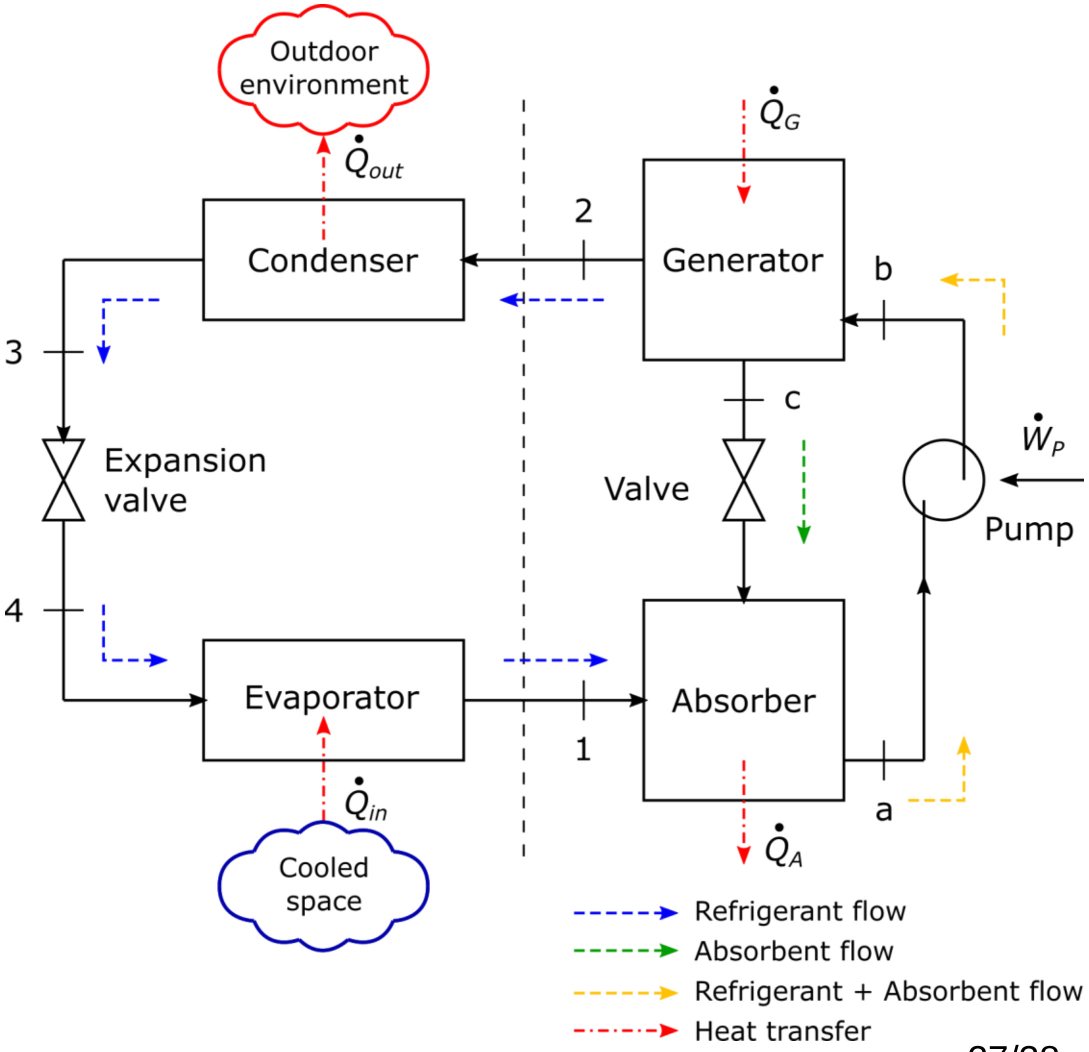
Non-vapour compression technologies





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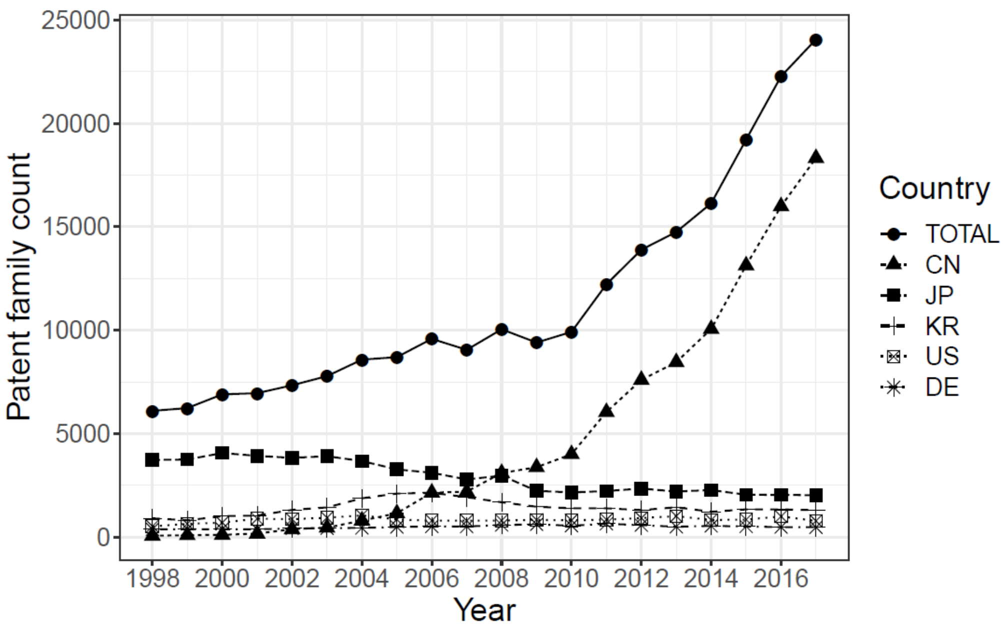
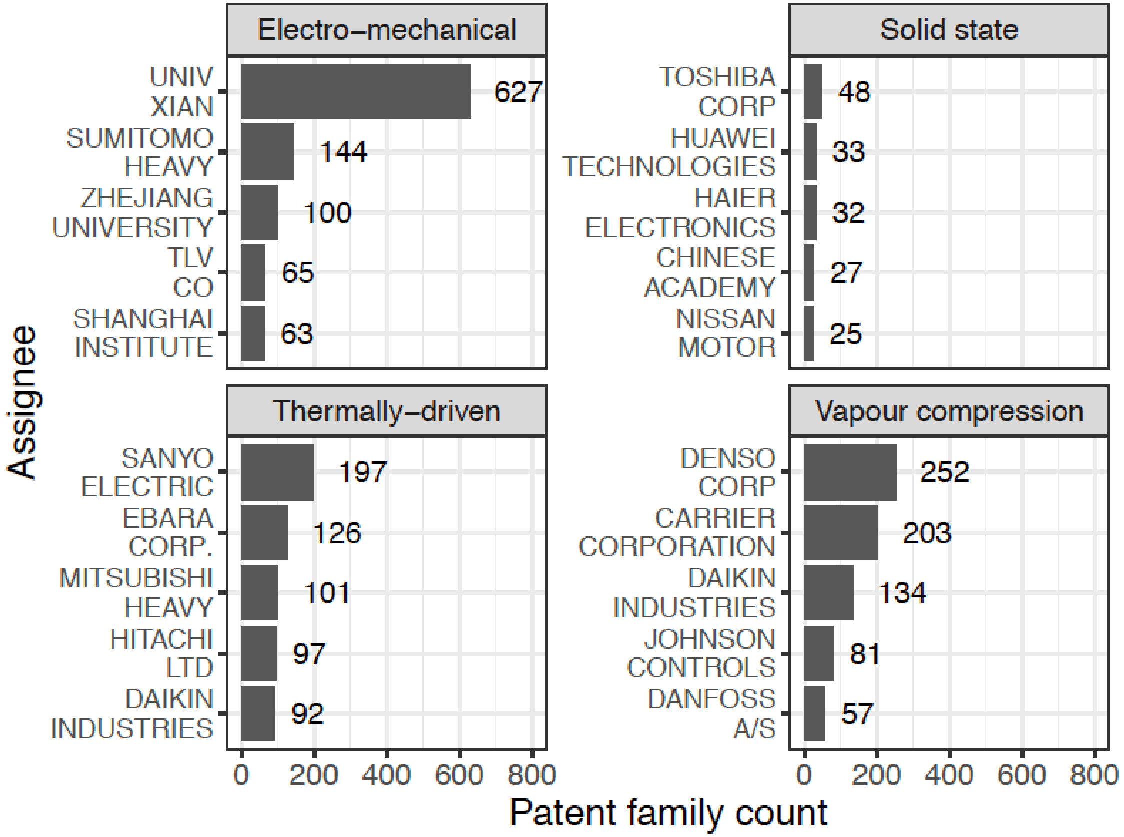
Patent landscape of alternative technologies

- Patent-based landscape of alternative cooling technologies.
- Top five countries: China, Japan, South Korea, US, and Germany.
- Promising alternatives: absorption, magnetocaloric, thermoelectric.





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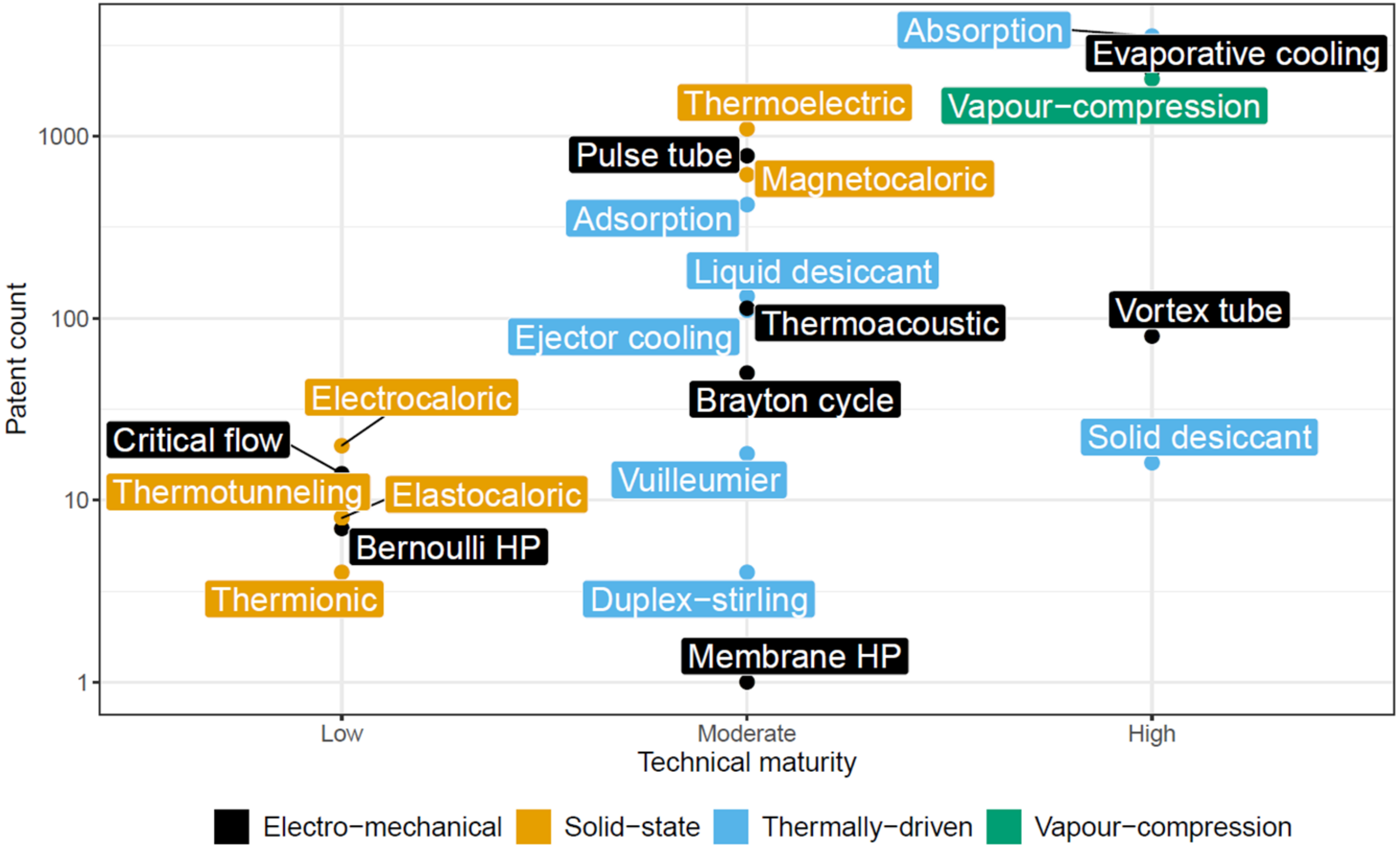
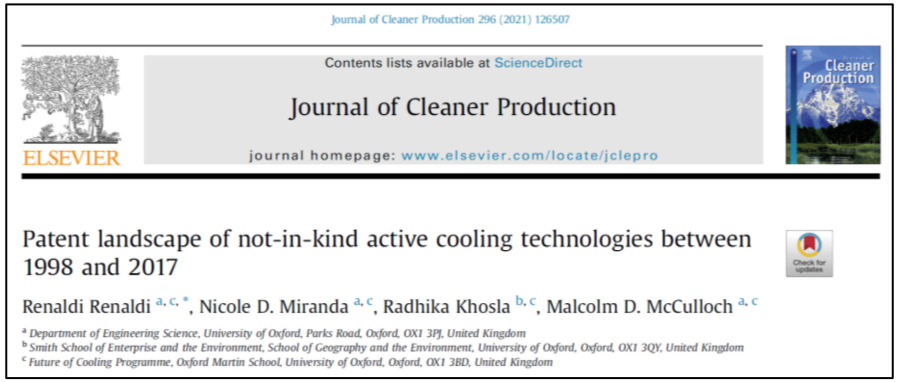
Patent landscape of alternative technologies

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Cleaner Production

Patent landscape of not-in-kind active cooling technologies between 1998 and 2017

Renaldi Renaldi [a, c, *], Nicole D. Miranda [a, c], Radhika Khosla [b, c], Malcolm D. McCulloch [a, c]

[a] Department of Engineering Science, University of Oxford, Parks Road, Oxford, OX1 3PJ, United Kingdom
[b] Smith School of Enterprise and the Environment, School of Geography and the Environment, University of Oxford, Oxford, OX1 3QY, United Kingdom
[c] Future of Cooling Programme, Oxford Martin School, University of Oxford, Oxford, OX1 3BD, United Kingdom

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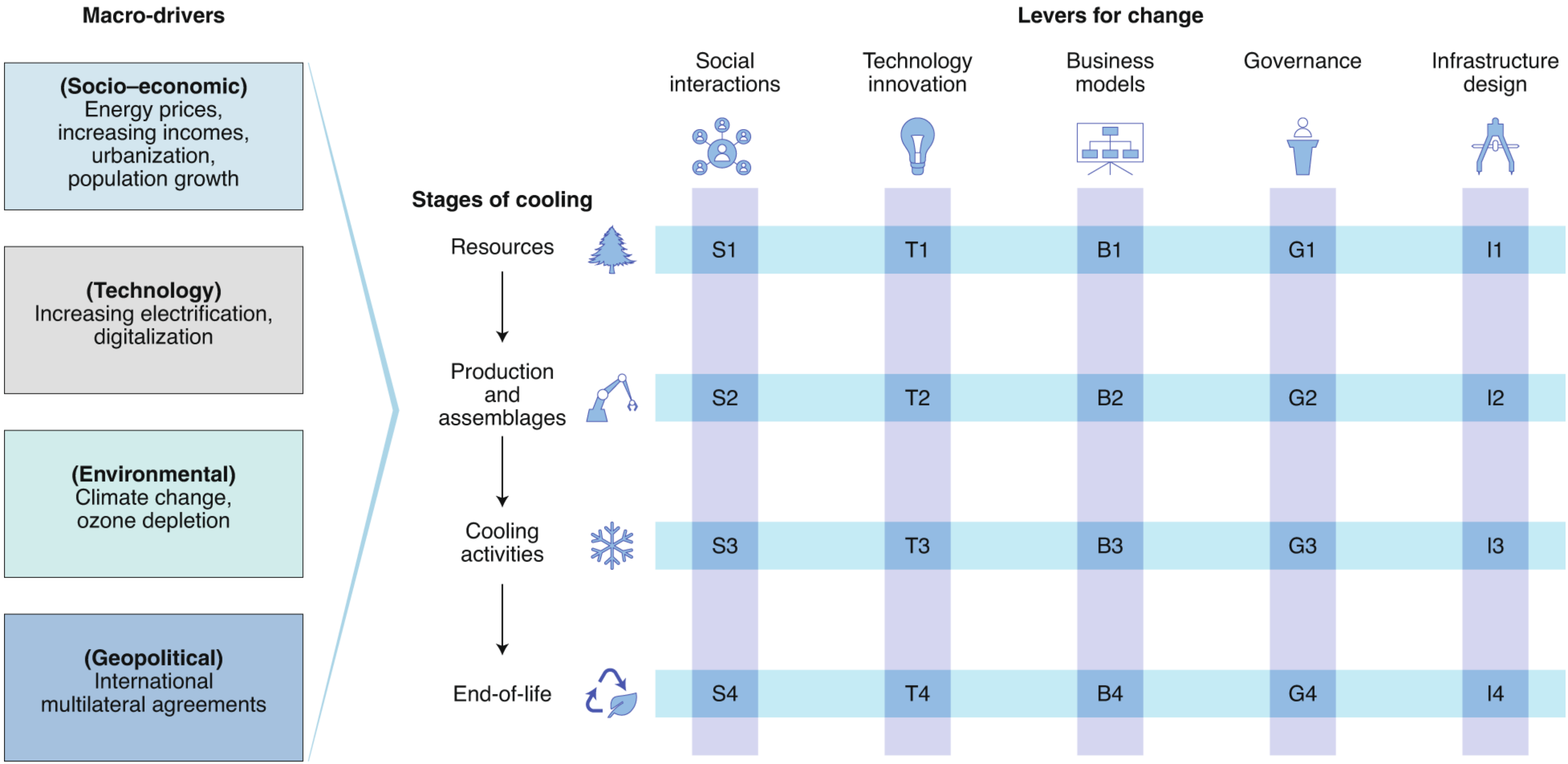
Sustainable cooling framework



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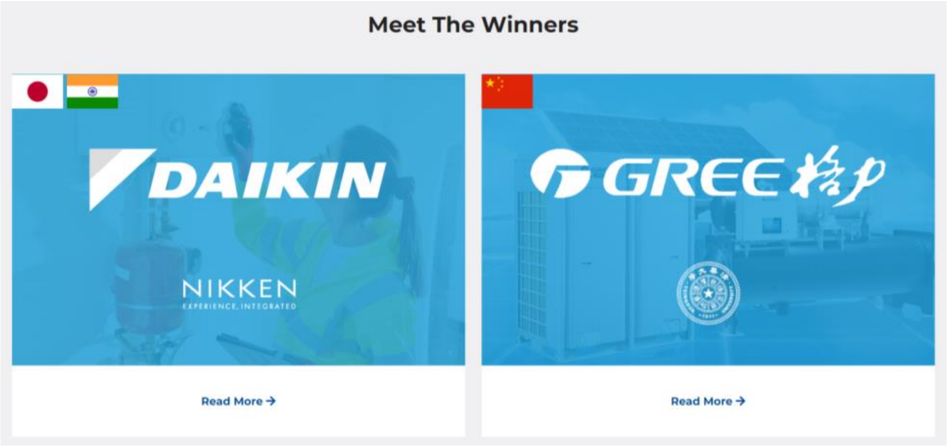
Technological innovation: Efficient air conditioners

- Global Cooling Prize (2018 – 2021)

1 The solution's climate impact had to be at least 5X lower than the standard AC units sold in the market today. Why 5X? This threshold was identified by considering both the need to neutralize the environmental impact of the inevitable growth in cooling over the next three to four decades and what science was indicating as the theoretical maximum efficiency of the cooling cycle.

2 The solution's installed cost to consumers could not be more than 2X that of the baseline AC unit when manufactured at a scale of 100,000 units per year.



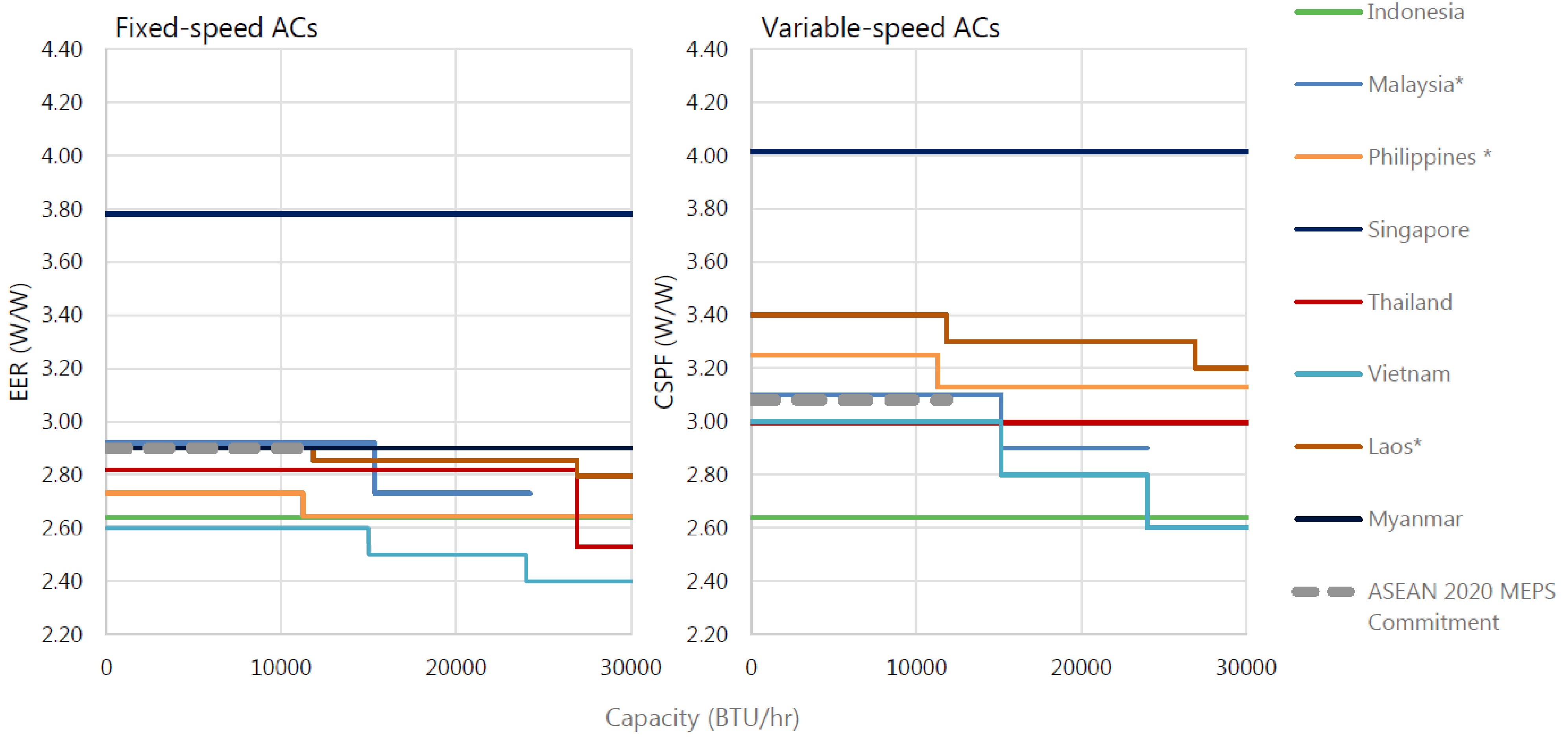
Key attributes of winning technologies:

- Variable-speed compressor that can modulate to very low cooling capacities.
- Improved evaporator design and advanced controls to enhance dehumidification capabilities.
- Direct evaporative cooling at condenser.
- Integrated solar PV and use of direct current components.
- Low-GWP refrigerant

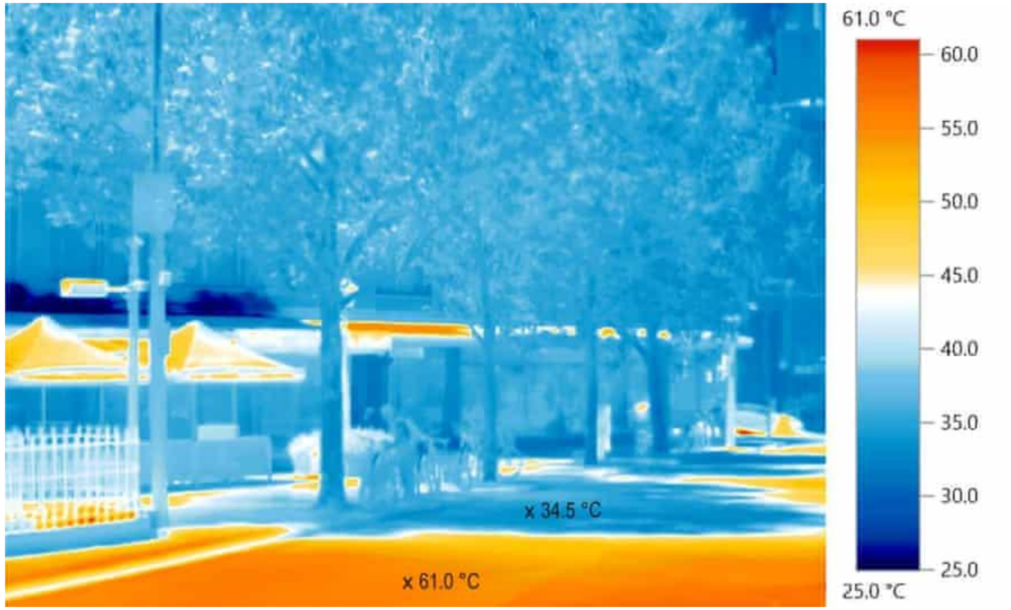
https://globalcoolingprize.org/

Governance: Efficient air conditioners

Levels of minimum energy performance standards in Southeast Asian countries for fixed-speed and variable-speed ACs based on cooling capacity (2019)



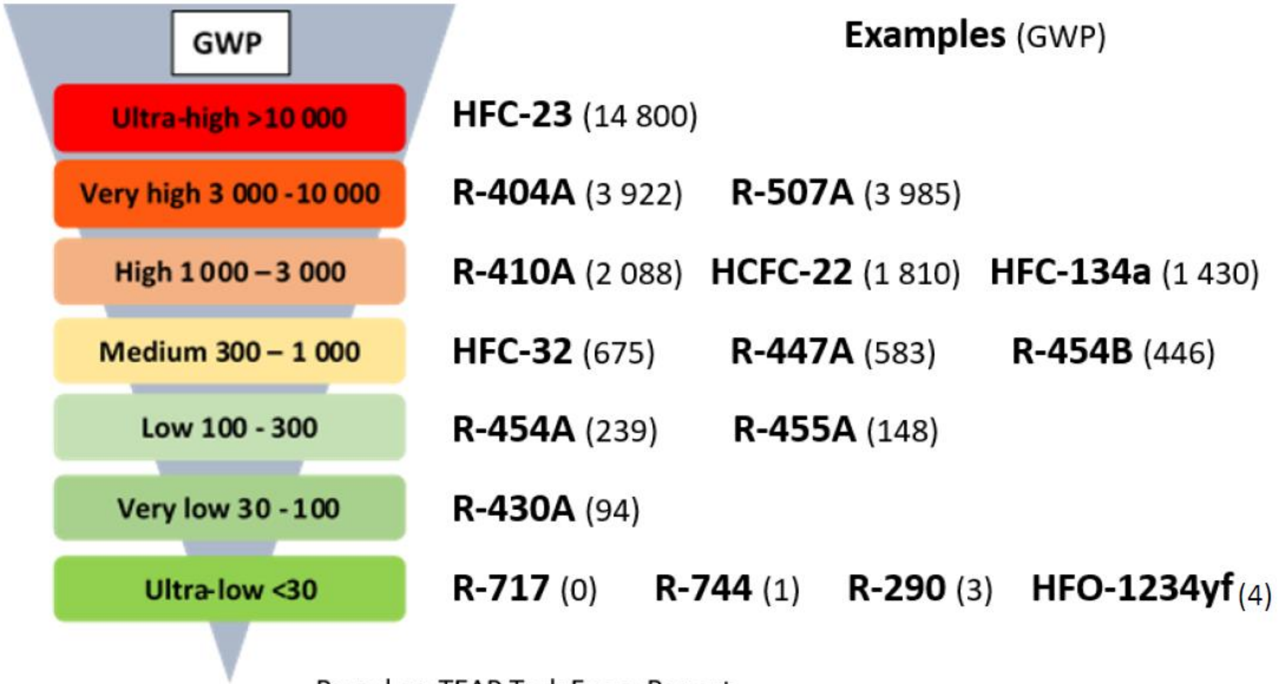
Infrastructure design: Passive cooling



Governance: Low-GWP refrigerants

- Montreal Protocol (1987)
  - → Phasing out substances with high Ozone Depletion Potential (ODP)
  - → Chlorofluorocarbons (CFC)
  - → Hydrochlorofluorocarbons (HCFC)

- Kigali Amendment (2016)
  - → Phasing out substances with high Global Warming Potential (GWP)
  - → Hydrofluorocarbons (HFC)



Based on TEAP Task Force Report

Summary

- Global cooling demand is rapidly increasing & could impede climate change mitigation.
- Electric-driven vapour compression AC will still dominate the market in the near future.
- Reduce demand by implementing passive cooling measures.
- Minimise direct emissions by using low-GWP refrigerants.
- Reduce indirect emissions through power sector decarbonisation.
- Reduce direct & indirect emissions by using high efficiency AC.

Contents

Cranfield
Energy and Power

Renaldi Renaldi
Lecturer in Thermal Engineering
renaldi@cranfield.ac.uk

DTMI & DTKI

International Guest Lecture

Sustainable Thermal Engineering (Cooling and Heating)

Friday, June 10, 2022
3.00 PM

DR. RENALDI

- Centre for Thermal Energy Systems and Materials
- Cranfield University, UK

Moderator
M. Lukman Hakim, MT
Industrial Mechanical Eng. Department

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