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PROMOTING THE ADOPTION OF GREEN COOLING TECHNOLOGIES AND PRACTICES

INSIGHTS FROM INDUSTRIAL AND COMMERCIAL END USERS

IFC | International Finance Corporation
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Acronym List

ACRONYM	DEFINITION
°C	Degrees Celsius
APAC	Asia-Pacific
ASDA	Associated Dairies
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BASE	Basel Agency for Sustainable Energy
CaaS	cooling as a service
CAGR	Compound Annual Growth Rate
CEN	Comité Européen de Normalisation
CFCs	Chlorofluorocarbons
CLF	Cooling Load Factors
CLTD	Cooling Load Temperature Differential
CO2	Carbon Dioxide
EE	Energy Efficiency
EPB	Energy Performance of Buildings Directive
EU	European Union
F-gas	Fluorinated gases
FONERWA	Rwanda Green Fund
GDP	Growth Domestic Product
GTCO2e	Gigatons of Carbon Dioxide Equivalent
GWh	Gigawatt Hour
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbon
HFCs	Hydrofluorocarbons
HFOs	Hydrofluoroolefins
HVAC	Heating, Ventilation, and Cooling
ILO	International Labor Organization
IT	Information Technology
KG	Kilograms

KG	Kilograms
KPIs	Key Performance Indicators
kWh	Kilowatt Hour
MEPS	Minimum Energy Performance Standards
MMT	Million Metric Tons
NCPs	National Cooling Plans
NGO	Non-Governmental Organization
ODP	Ozone Depleting Potential
PPP	Purchasing Power Parity
RBDF	Rwanda's Business Development Fund
R-COOL	Rwanda Cooling Initiative
RE	Renewable Energy
ROI	Return on Investment
ROIC	Return on Invested Capital
TA	Time-Averaging
TETD	Total Equivalent Temperature Differential
TFA	Trifluoroacetic Acid
TFM	Transfer Function Method
TWh	Terawatt Hour
US	United States
USD	United States Dollar
WHO	World Health Organization

Glossary

- **Chiller:** A machine that cools air, typically in mid to large commercial and industrial settings. Chillers are either air or water-cooled. Generally, air conditioners are used for temperature and humidity control in smaller spaces.
- **Chloroflurocarbon (CFC):** Chemicals containing carbon, chlorine, and fluorine. They are ozone depleting substances. They were commonly used as propellants in consumer aerosol products until they were phased out by regulations and the Montreal Protocol.
- **Global Warming Potential:** A measure of the warming impact that a gas has in the atmosphere relative to the impact of CO2, which has a GWP of 1.
- **Halocarbon:** Industrial-produced chemical compounds containing carbon, hydrogen, and one or more halogen atoms (e.g., fluorine or chlorine). Their main application is as refrigerants.
- **Heat stress:** A medical condition in which a person or animal suffers due to excessive heat absorption. It can result in cramps, headaches, unconsciousness, heat stroke, and death.
- **Hydrocarbon (HC):** Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms. Hydrocarbons such as propane and isobutene can be used as refrigerants. They have no ozone-depleting potential and very low global warming potential.
- **Hydrochlorofluorocarbon (HCFC):** HCFCs are halocarbons containing only hydrogen, chlorine, fluorine, and carbon atoms. The chlorine in HCFCs are both ozone-depleting substances and greenhouse gases. HCFCs were used as intermediate replacements for CFCs, but they are being phased-out by the Montreal Protocol and will be entirely banned as of 2030.
- **Hydrofluorocarbons (HFC):** HFCs are halocarbons containing only carbon, hydrogen, and fluorine atoms. Because HFCs have no chlorine, bromine, or iodine, they are not ozone-depleting substances. However, like other halocarbons, they are potent greenhouse gases. Consumption of HFCs is growing worldwide, due to their function as replacements for CFCs and HCFCs.

- **Hydrofluoro-Olefins (HFO):** HFOs are composed of hydrogen, fluorine, and carbon. They low global warming potential and zero ODP.
- **Montreal Protocol**: An international agreement, finalized in 1987, to protect the ozone layer by phasing out ozone-depleting substances such as HCFCs. The Kigali Amendment to the Montreal Protocol brought together 197 countries in a commitment to cut the production and consumption of HFCs by over 80% over 30 years.
- **Ozone depletion potential (ODP):** A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by CFC-11. Specifically, the ODP of an ozone-depleting substance (ODS) is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of CFC-11.
- **Refrigerant:** A gas or fluid that provides room, industrial, or refrigeration cooling by absorbing heat from the surrounding environment.
- **Sustainable Cooling:** Cooling without climate impact, in line with the objectives of the Paris Agreement on Climate Change, even as demand for cooling increases. Measures that reduce the demand for artificial cooling (e.g. insulation, building design) are included in this definition.

1. Introduction

There are more than 1.1 billion people who face immediate risk related to a lack of access to cooling.[1,2] Sustainable cooling solutions must expand access to cooling while adhering to the climate goals established by the Paris Agreement.

By 2050, the world is projected to be 1.5°C warmer than in 2019, and the global population will have grown by 2.2 billion. The rising temperature and population will increase both the need and the demand for cooling.[3]

Cooling ensures food security and safety and the delivery of effective vaccines and medicines. It is critical for several industrial processes, and to provide decent working conditions and economic growth. Not only does a lack of cooling limit access to food, medicines, and vaccinations, but it puts a large percentage of the world's population at risk of heat stress, which has negative impacts on labor productivity and health.

Counterintuitively, the increased demand for cooling contributes to increased global temperatures due to higher energy demand (assuming that the electrical energy used is derived from fossil fuels) and refrigerant leakage with its associated greenhouse gas emissions.[4,5] In 2015, the Paris Agreement established the international goal to limit global temperature rise this century below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. Additionally, the 2016 Kigali Amendment to the Montreal Protocol calls for phasing down production and consumption of hydrofluorocarbons (HFCs) with high global warming potential (GWP) by more than 80% over the next 30 years.[6] These two agreements underscore the linkages between cooling, energy, and climate change.

Achieving the goals of the Paris Agreement and the Kigali Amendment will require industrial and commercial end-users to adopt green cooling technologies and practices. The total energy consumption associated with cooling equipment today is estimated to be 3,900 TWh, or 17%

[1] Sustainable Energy for All. 2018. "Chilling Prospects: Cooling for All".
[2] This is the most update to date figure available, however, Sustainable Energy for All will be releasing an update to this data later in 2019.
[3] United4Efficiency. 2018. "Efficient and Climate-Friendly Cooling".
[4] It should be noted that the increase in power that is required for cooling has been greatly underestimated. Should one consider additional losses not accounted for in the current LCCP analysis, this may lead to an extra 2% power plan efficiency decrease, 0.5% more transmission and distribution losses, 5% loss from voltage stabilizer and a total of 47% air conditioner co-efficient performance degradation, resulting in a 48% carbon emission increase.
[5] Andersen,S.,Wolf,J.Hwang,Y, and Ling,J. 2018. "Life-Cycle Climate Performance Metrics and Room AC Carbon Footprint"
[6] Sustainable Energy for All. 2018. "Chilling Prospects: Cooling for All".

of the global electricity demand.[7] Industrial and commercial cooling accounts for 19% of the total energy consumption associated with cooling.[8]

Figure 1: Cooling Energy Consumption, Source: UNEP

This paper will focus on commercial and industrial end-users of cooling[9] and proposes solutions to barriers to sustainable cooling that apply generally across sectors. It should be noted that cooling is an area of rapid technological development and that many of the potential solutions presented in this paper do not apply to all geographies and applications. The common barriers and associated solutions that are addressed in this paper are as follows:

a) Uncertainty in quantifying the cost to business of heat stress
b) Lack of awareness in the relevant time horizon for calculating ROI
c) Lack of training in how to structure tender documents and requests for proposals
d) Improperly sized equipment
e) Poor maintenance of equipment and systems
f) Misalignment in employee performance incentives

Lastly, the paper addresses regulatory policies that may help drive business decisions towards sustainable cooling solutions.

[7] UN Environment Programme, "Cooling in a warming world."
[8] Toby Peters "Cooling Block Chain" taken from GIZ Proklima Dataset.
[9] Cooling refers to any human activity, design or technology that dissipates or reduces temperatures and contributes to achieving: (i) reasonable thermal comfort for people, or (ii) preservation of products and produce (medicines, food), or (iii) effective and efficient processes (data centers, industrial or agricultural production). Sustainable cooling means cooling without climate impact in line with the objectives of the Paris Agreement on Climate Change. Measures that reduce the demand for artificial cooling (e.g. insulation, building design) are included in this definition. The paper focuses on cooling as a utility service (i.e. cold is delivered to a process through a medium such as cooled water) and not on applications where the generation of cold is an integral part of the core industrial process and/or chemistry such as cryogenic air separation or the cold end processing of olefins

2. Current State of Commercial and Industrial Cooling and Possible Pathways in Coming Decades

2.1. The Energy and Climate Impact of Commercial and Industrial Cooling

Across all uses of cooling, approximately 80% of the climate impact results from indirect emissions from the energy needed for cooling, while 20% is from direct HFC refrigerant emissions.[10] The total direct (refrigerant leakage) and indirect emissions (energy consumption) from cooling today is estimated to be 4.1GTCO2e, of which 20% is associated with industrial and commercial cooling equipment.[11] Therefore, the challenge of sustainably meeting the growing cooling demand is largely a question of energy efficiency gains in system design and equipment.

CFCs, HCFCs, and HFCs are synthetic substances used as refrigerants in the refrigeration cycle of air conditioning and refrigeration equipment. Under the Montreal Protocol, HCFCs and CFCs are being phased out due to their high global warming and ozone depletion potential (GWP and ODP).[12] HFCs are a replacement for HCFCs, and subsequently, HFC consumption has dramatically grown. However, the 2016 Kigali Amendment to the Montreal Protocol aims to phase down HFCs. Consequently, states and industries have been encouraged to choose alternatives that are both climate-friendly and do not deplete the ozone layer.

As a result, many alternative refrigerants have surfaced, such as HFOs and "non-synthetic substances" or " natural refrigerants" which both have lower GWP and no ODP.[13] There are varying views from industry players, civil society groups and practitioners on whether non-synthetic substances or HFO's are more sustainable. For example, civil society groups have raised that the decomposition of HFOs in the atmosphere can lead to the formation of TFA, a strong acid that may have negative environmental impacts. The exact nature and scale of TFA's environmental and health impacts are uncertain, but studies conducted in 2015 suggest that

[10] *Report of the Technology and Economic Assessment Panel*, Montreal Protocol on Substances that Deplete the Ozone Layer, May 2018, p10.
[11] Toby Peters "Cooling Block Chain" taken from GIZ Proklima Dataset.
[12] Green Cooling Initiative. "Refrigerants"
[13] Green Cooling Initiative. "Refrigerants"

the risks are negligible.[14] Moreover, not all HFOs breaks down completely into TFA.[15] Industrial and commercial chillers that are covered in this paper mainly use HFOs.[16]

Non-synthetic substances are often referred to as "natural refrigerants" since many of them can be found naturally occurring in the environment. "Natural refrigerants" are considered to be CO2, ammonia, water, air, and hydrocarbons such as propane, isobutene, and propene/propylene. However, referring to these as "natural refrigerants" is contested by industry players and academics both due to its 'volatility' and the inference that it is sustainable simply because it is naturally occurring. Regardless, these substances are considered to be climate-friendly since they have low or zero GWP and zero ODP and are part of the natural biogeochemical cycles that do not form persistent waste in the biosphere, atmosphere, or water. There are safety concerns, such as flammability, with "non-synthetic substances" or "natural refrigerants" .[17],[18] Many of the technologies using natural refrigerants are not yet commercially proven and available. The use of safe components, appropriate training, and materials may offset some or all of the unwanted characteristics of natural refrigerants. [19]

While the Kigali Amendment to the Montreal Protocol addresses the phasedown of refrigerants with high GWP, there has been no similar international agreement to address the indirect greenhouse gas emissions from cooling.

2.2. The Function and Types of Cooling for Industrial and Commercial Sectors

It is necessary to distinguish between comfort and process cooling. The former, much like residential air conditioning, cools spaces to a comfortable level for occupants. The latter is needed for several industrial and commercial processes. This paper does not address cooling that is an integral part of the core industrial process or chemistry, such as the cryogrenic separation of nitrogen. The paper does address non-core process cooling. Examples include removing heat from large spaces, such as data centers, or the use of chilled process water in cheesemaking. The cosntruction industry requires cooling processes to harden concrete, and

[14] Madronich,S.,Shao,M., Wilson,S., Solomon,K.,Longstreth,J.,Tang,X. 2015. "Changes in air quality and tropospheric composition due to depletion of stratospheric ozone and interactions with changing climate: implications for human and environmental health"
[15] EPEE.2018." EPEE Q&A ON HFOS AND HCFOS"
[16] Specifically, R-1234ze and R-1233zd and blends while R-1234yf is used in automotive cooling.
[17] Fricke,B., Schultz, K. and Wang,X.2017. "Refrigerants With Low Global Warming Potential"
[18] It should be noted that flammability is not a concern when CO2 is deployed as a refrigerant.
[19] Green Cooling Initiative. "Refrigerants"

the chemical and pharmaceutical industries must maintain humidity control of certain chemicals as well as store medications and vaccines at the correct temperatures. Without comfort cooling, heat stress is an occupational hazard with a significant impact on health, safety, productivity, and cost. Both comfort and process cooling are critical to the efficient functioning of industrial and commercial sectors.

Many technologies and equipment are used in industrial and commercial cooling.[20] Chillers are commonly used as part of air conditioning systems for buildings and to remove heat from industrial processes. The most common chillers for industrial and commercial use are centrifugal, rotary screw, reciprocating and absorption chillers.[21]

The three basic cooling systems used in industrial and commercial sectors in combination with chillers are the once-through cooling system, closed recirculating system, and open recirculating system. In industry, the most commonly used design is the open recirculating cooling systems or wet cooling, which dissipates heat through evaporation in an outdoor cooling tower. The cooling liquid then recirculates back into the system to absorb more heat.

Heat recovery systems may benefit several industrial processes that produce heat by recycling the heating for other uses. The exhaust air is used as a heat sink or heat source depending on the building requirements and climatic conditions. Heat recovery systems can recover anywhere between 60-95% of the heat in exhaust air which leads to energy efficiency improvements in buildings.[22] Similarly, district cooling is an important but underutilized option for efficiently supplying industrial and commercial real estate. The cooling plant pumps chilled water to buildings through the primary district cooling network and into heat exchangers in each building which cools water in the building's cooling system. The used water coming out of the heat exchanger and back into the primary district cooling network is returned to the cooling plant at a higher temperature to be chilled and distributed again in a closed-loop system. The district cooling market size is expected to grow significantly in the short-term, and this may be attributed to its energy efficiency potential.[23]

[20] See appendix for a long list of technologies and commercial and industrial applications.
[21] Sticker,D. "Warming Up to Chillers A Guide to Understanding Chilled Water Systems"
[22] Mardiana-Idayuab,A. and Riffata,S. 2012."Review on heat recovery technologies for building applications"
[23] See under chapter 2.5.2 for further insights

2.4. Recent Civil Society Efforts to Promote Alternative Cooling Technologies

2.4.1. The Global Cooling Prize

In 2018, Rocky Mountain Institute, the Government of India and Mission Innovation launched the Global Cooling Prize, which will award over $3 million in prizes over two years. The competition is designed to incentivize the development of a residential cooling solution that will have at least five times less climate impact than today's standard room air conditioner units at less than two times the manufacturing cost. This technology could prevent up to 100 gigatons (GT) of CO2-equivalent emissions by 2050, and put the world on a pathway to mitigate up to 0.5˚C of global warming by 2100, all while enhancing living standards for people in developing countries around the globe.[24] Although chillers and room air conditioners have very different applications, this contest is helpful in drawing attention to the challenge of sustainable cooling.

2.4.2. Kigali Cooling Efficiency Programme (K-CEP)

K-CEP is a $52 million program supported by a group of philanthropic foundations that aims to increase the efficiency of cooling in developing countries and assist with the HFC phase-down. Its work is split across four windows:

- Strengthening for Efficiency – support training for policymakers and provide information resources and funding to add energy efficiency into projects.
- Policies, Standards, and Programmes – work with policymakers to accelerate the adoption of energy efficiency standards for cooling equipment through advisory and information sharing practices.
- Finance – provide grants for cooling related initiatives to catalyze investment in the cooling sector, including the by the private sector.
- Access to Cooling – advocate internationally for cooling to be included in international development plans so that sustainable approaches that deliver universal access (to those that need it) can be delivered.[25]

[24] The Global Cooling Prize." About the Global Cooling Prize"
[25] K-CEP. "K-CEP Windows"

2.5. The Market For Cooling

Cooling represents a major investment opportunity. Currently, commercial and industrial cooling is a $15 billion market.[26] This is expected to grow in response to rising global temperatures, populations, and middle class purchasing power. Precise data is limited, but the following sections outline the best available market sizing information by location and sector.

2.5.1. GIZ Proklima Demand and Projections

Currently, the only comprehensive country-level cooling data that exists is the GIZ Proklima dataset.[27] However, no data exists which separates traditional cooling equipment from sustainable cooling equipment. Consequently, all projections are based on a mixture of traditional and sustainable cooling equipment. Using the GIZ Proklima dataset, a subset of 14 countries' data was analyzed to highlight the expected cooling demand by 2050 under a business as usual scenario.[28,29] These countries collectively represent about 55% of global population, 56% of global equipment stock and 61% of global energy consumption for cooling.[30]

These countries, which include India, China, and Bangladesh, are expected to see a stark rise in cooling demand over the coming decades with total stock increasing to 64% of the global total by 2050. At the moment, there are 90 million pieces of cooling equipment for the commercial and industrial sectors globally, which amounts to $15 billion in sales per annum.[31]

Business as Usual Scenario

Under the Green Cooling Initiative business as usual (BAU) equipment growth projection scenario (based on GIZ Proklima data), by 2050, equipment stock for industrial and commercial cooling is expected to increase 26% from 2018 figures. Consequently, energy use and associated emissions from industrial and commercial cooling are projected to increase by 13.6% and 13.7% respectively by 2050.[32]

[26] Toby Peters "Cooling Block Chain" taken from GIZ Proklima Dataset.
[27] The Green Cooling Initiative. "GIZ Proklima"
[28] Countries include Kenya, Ethiopia, Japan, China, Indonesia, Uzbekistan, Romania, Brazil, Jamaica, United Arab Emirates, Egypt, India, Bangladesh, United States. See Appendix for country data.
[29] This business as usual figures includes significant improvements in device efficiency and reductions indirect emissions, reflecting improvements incorporated in already enacted legislation and current technological progress. However, these improvements are still inadequate to mitigate the impact of market growth.
[30] Toby Peters "Cooling Block Chain" taken from GIZ Proklima Dataset.
[31] Toby Peters "Cooling Block Chain" taken from GIZ Proklima Dataset.
[32] It should be noted that other cooling applications are projected to grow much faster.

Universal Access Scenario

Under the theoretical universal access (UA) scenario, by 2050, industrial and commercial cooling equipment stock is expected to increase by 48% from 2018 figures. [33,34] Consequently, energy use is expected to increase by 134% and associated emissions are anticipated to increase by 155% from 2018 figures. In other words, emissions in 2050 would double under a universal access scenario when compared with the business as usual projections.

2.5.2. Additional Market Insights

Highlighted below are a few relevant and current market trends beyond the GIZ Proklima dataset. A comprehensive market overview does not exist, but the available data reveal that:

- Over the next few years, the chiller market will be greatest in the Asia-Pacific region, especially in the plastics and food & beverage industries.
- The digital economy will result in a surge in demand for data centers. The global data center cooling market is expected to nearly triple between 2017 and 2025.
- Evaporative cooling is considered an energy-efficient alternative to mechanical air conditioners. Growth in the Asia-Pacific region is largely driven by Japan, Australia, and India due to the growing data center market and e-commerce penetration in Japan.
- The rising demand for cooling towers is largely due to growing industrial and commercial activities globally. Advance cooling towers that are cost-effective and energy-efficient are projected to drive market growth.

Global Chiller Market

In 2015, the global chiller market generated revenues of $8.7 billion. At a compound annual growth rate (CAGR) of 4.1% from 2016 to 2022, it is expected to reach $11.5 billion.[35] . Asia-Pacific accounted for around 54.1% share of the global chiller market and is anticipated to show

[33] Under this scenario, for air conditioning, countries are categorized as high ambient or low ambient based on the number of cooling degree days (CDD) that they experience per year (2000 is taken as a boundary value and 21.1°C as the threshold value. This scenario includes a degree of improvement in terms of reductions in energy consumption and reductions of indirect emissions through refrigerant substitution and measures to reduce leakage.

[34] Figure includes traditional cooling equipment stock

[35] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"

further growth in the upcoming years due to the growth in manufacturing activity in countries such as China, Vietnam, Thailand, and India.[36]

Absorption chillers, mentioned in section 2.2 as a common industrial chiller, are expected to register the highest CAGR among all chiller types in the future due to demand from rubber, chemicals and petrochemicals and other industries. Absorption chillers can improve the energy efficiency of a system due to their ability to utilize waste heat. Furthermore, the growth in the industrial sector, consumption of frozen foods and demand from data centers are expected to supplement the market growth.[37]

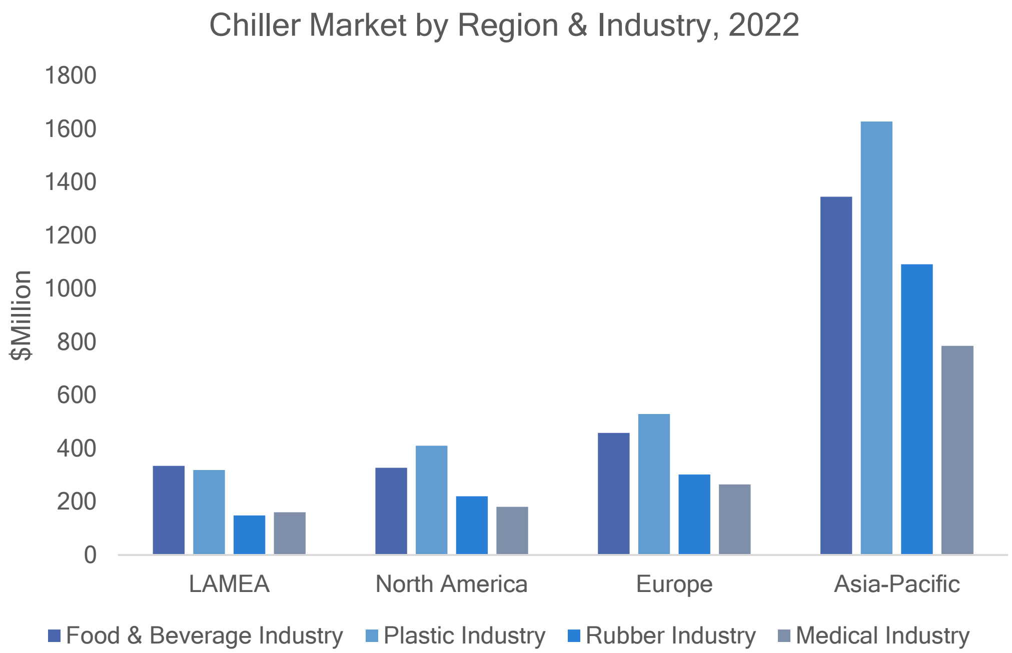

Figure 2:Chiller Market by Industry & Geography

In 2015, the global food & beverage industry chiller market was valued at $1.9 billion and is expected to reach $2.5 billion by 2022. The highest CAGR is estimated to be registered by Asia-Pacific at CAGR of 4.9%, generating $1.3 billion by 2022.[38] The plastics industry produces an enormous amount of heat during its manufacturing process, and chillers are used for cooling hot plastic and to cool plastic process equipment. In 2015, the global plastic industry chiller market was valued at $2.4 billion and is expected to reach $2.9 billion by 2022. The highest CAGR is estimated to be registered by Asia-Pacific at CAGR of 3.2%, generating $1.6 billion

[36] Refer to the Appendix for a full market overview.
[37] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"
[38] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"

by 2022.[39] In the rubber industry, chillers are used to cool the multimode water temperature control units of the rubber extruder barrel, rubber mill, and bambury mixers. Rapid growth in the automotive industry has increased the demand for rubber which is used to manufacture tires for vehicles. In 2015, the global rubber industry chiller market was valued at $1.3 billion and is expected to reach $1.8 billion by 2022. The highest CAGR is estimated to be registered by Asia-Pacific at CAGR of 4.7%, generating $1.1 billion by 2022.[40] In the medical industry, chillers are used to remove heat from MRI scanners. In 2015, the global medical industry chiller market was valued at $1.1 billion and is expected to reach $1.4 billion by 2022. The highest CAGR is estimated to be in Asia-Pacific at 4.4%, generating $786 million by 2022.[41]

Allied Market Research suggests that Daikin Industries Ltd. and Hitachi Appliances Inc. are the market leaders for these appliances, with eight other companies[42] rounding out the top ten.[43]

Global Data Center Cooling Market

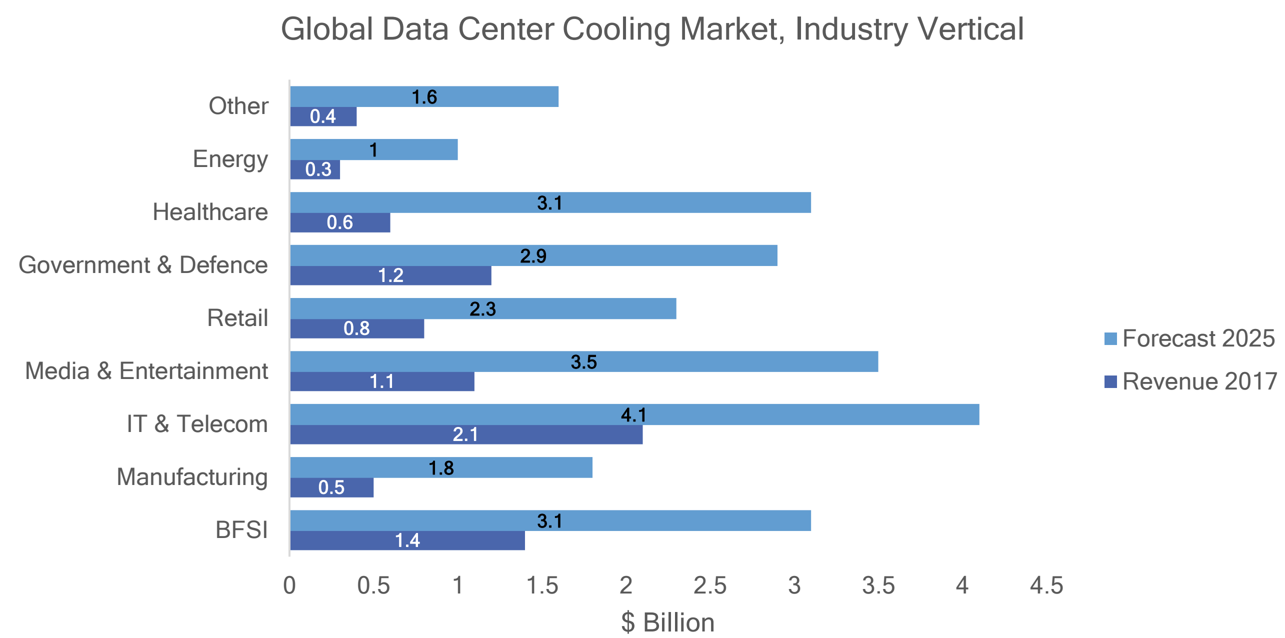

Figure 3: Global Industry Vertical Data Center Cooling Market

[39] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"
[40] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"
[41] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"
[42] Carrier Corporation, Johnson Controls, Trane, Dimplex Thermal Solutions, Climaveneta S.P.A., Thermax Ltd., Polyscience, and Smardt Chiller Group
[43] Allied Market Research. 2017. "Chiller Market: Global Opportunity Analysis and Industry Forecast, 2014-2022"

In 2017, the global data center cooling market was valued at $8.3 billion and is projected to reach $23.3 billion by 2025.[45] Preferences are shifting towards advanced cooling systems rather than traditional cooling systems in data centers. Unlike traditional cooling systems, advance cooling systems have a smaller carbon footprint, use less water, and prevent equipment damage which reduces maintenance cost.

The data center market is important to multiple industries as illustrated in Figure 3. [46] The IT & Telecom segment had the largest share of the market in 2017 at $2.1 billion and is expected to grow to $4.1 billion by 2025 at a CAGR of 9%. The growth in the IT & Telecom segment market domination is due to the penetration of big data, cloud, and other technologies as well as increasing digitalization. The healthcare sector is expected to register the highest CAGR between 2017 and 2025 at 21.2%, followed by energy and manufacturing respectively. In 2017, North America dominated the data center cooling market. However, Asia-Pacific is expected to register the highest CAGR (18.2%) between 2017 and 2025. This is attributed to the increase in internet penetration as well as the increase in the number of smartphones in the region.

Allied Market Research suggests that Schneider Electric is the top market player followed by Black Box Corporation, Nortek Air Solutions, LLC, Emerson Electric Co., Hitachi,Ltd., Ritall Gmbh & CO.KG., Fujitsu Ltd., STULZ Gmbh, Vertive Co. and Asetek respectively.[47]

Global Evaporative Cooling Market

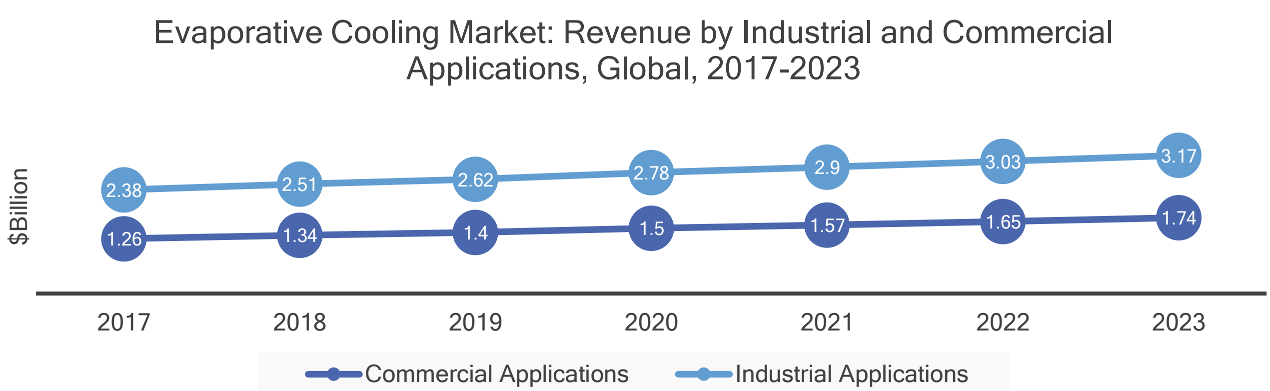

Figure 4: Evaporative Cooling Market Revenue by Industrial and Commercial Applications, 2017-2030

[44] Allied Market Global. 2019."Global Data Center Cooling Market"
[45] See annex for the full breakdown
[46] Allied Market Global. 2019."Global Data Center Cooling Market"
[47] Allied Market Global. 2019."Global Data Center Cooling Market"

Evaporative cooling, which can be used in data centers, is considered an energy-efficient alternative to mechanical air conditioners. A study conducted by the National Renewable Energy Laboratory found that in dry climates multi-staged indirect evaporative cooling systems have the potential to reduce energy use by 57-92%.[48] There is increased demand for multi-staged indirect evaporative cooling. In 2017, the global evaporative cooling market was valued at $5.47 billion and is expected to grow to $7.41 billion by 2023.[49] The Asia-Pacific market share value is expected to reach 2.91 billion by 2023. Growth in the region is largely driven by Japan, Australia, and India due to the growing data center and e-commerce market in Japan.[50]

According to Mordor Intelligence, the key market players are Delta Cooling Towers Inc., Condair Group AG, SPX Cooling Technologies, Baltimore Aircoil Company, Munters Corporation, Colt Group, Phoenix Manufacturing Inc., Bonaire Group (Celi Group), ENEXIO Water Technologies GmbH, CFW Evapcool, and Celsius Design Limited.

Global Cooling Tower Market

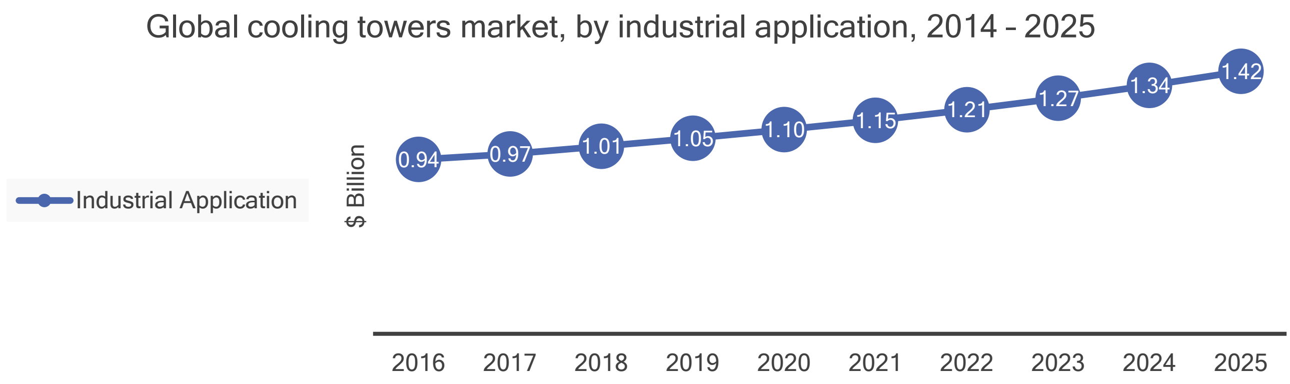

Figure 5: Cooling Tower Market, Industrial Application, 2014-2025

The rising demand for cooling towers is largely due to growing industrial and commercial activities globally. In 2016, the global cooling tower market was valued at about $3.3 billion and it is expected to increase to about $4.9 billion by 2025. [51] The industrial application segment is expected to grow from about $940 million to about $1.4 billion by 2025.[52] Asia-Pacific held the

[48] Mordor Intelligence. 2018. " Global Evaporative Cooling Market: Growth, Trends, and Forecast 2018 – 2023"
[49] Mordor Intelligence. 2018. " Global Evaporative Cooling Market: Growth, Trends, and Forecast 2018 – 2023"
[50] Mordor Intelligence. 2018. " Global Evaporative Cooling Market: Growth, Trends, and Forecast 2018 – 2023"
[51] Grand View Global Reports.2018. "Cooling Towers Market Analysis and Segment Forecasts to 2025"
[52] Grand View Global Reports.2018. "Cooling Towers Market Analysis and Segment Forecasts to 2025"

largest market share in 2016 and the region's growth is largely driven by the high rate of industrialization in China, India, Korea, and Singapore. The region's market value of cooling towers by industrial application was valued at $241 million in 2016 and is expected to reach about $433 million by 2025.

According to Grand View Global Reports, the key market players are SPX Corporation Baltimore Aircoil Company, Inc. Evapco Inc., Paharpur Cooling Towers, Liang Chi Industry Co. Ltd., B&W SPIG,Hamon & CIE International SA, Precision Cooling Towers, Composite Cooling Solutions, Johnson Controls Inc., Kelvion, Delta Cooling Towers, Inc., and Engie Refrigeration GmbH.

Global Waste Heat Recovery Market

Waste heat recovery systems have great potential for improving energy efficiency, reducing CO2 emissions, and reducing operational cost. The market is expected to reach over $80 billion by 2025. Stringent regulations on industrial gas emissions as well as the increasing number of countries implementing emission trading systems to meet global GHG and industrial emission targets are expected to drive market growth. The Asia-Pacific waste heat recovery market is expected to reach over $30 billion by 2025.[53]

According to Global Market Insights, the key players in the waste heat recovery system market include: AC Boilers, Aura GmbH, AMEC Foster Wheeler, Bosch Thermotechnology, Durr Group, General Electric, Forbes Marshall, Rentech Boiler Systems, Ormat Technologies, Exery SPA, Thermax, Viessman, Climeon AB, Boustead International, IHI Corporation, Cochran, Mitsubishi Hitachi Power Systems, Promec Engineering, HRS, Walchandnagar and Siemens.

Global District Cooling Market

The expected high growth rate of district cooling is largely driven by the changing preference of manufacturers for energy-efficient cooling technology. In 2015, the district cooling market

[53] Global Market Insights.2019. “Waste Heat Recovery System Market Size By Application, By, By End-Use, Industry Analysis Report, Regional Outlook, Application Potential, Competitive Market Share & Forecast, 2019 - 2025”

was estimated at $4.61 billion and is expected to increase to $9.53 billion by 2021, at a CAGR of 13.19%.[54] From 2016 to 2021, the Middle East and African markets are projected to grow at the highest rate due to increased temperatures and investment in infrastructure projects.[55]

Companies such as Emirates Central Cooling System Corporation (UAE), National Central Cooling Company PJSC (UAE), and Emirates District Cooling LLC (UAE) are key players in this region.

2.6. Market for Cooling – Key Takeaways

- Industrial and commercial cooling is expected to grow under both BAU and UA scenarios, resulting in increased energy use and associated emissions.
- Asia-Pacific accounted for around 54% of the global chiller market due to growth in manufacturing activity in the region.
- The Asia-Pacific region dominated the evaporative cooling market in 2017 due to the growing data center market and e-commerce penetration in Japan.
- North America dominated the data center cooling market in 2017 but Asia-Pacific is expected to grow the fastest due to the increase in internet penetration as well as the increase in the number of smartphones in the region.
- The rising demand for cooling towers is largely due to growing industrial and commercial activities globally.
- Stringent regulations on industrial gas emissions as well as the increasing number of countries implementing emission trading systems to meet global GHG and industrial emission targets are expected to drive the waste heat recovery systems market growth.
- The increasing consumer awareness on climate change and the respective governments in Asia-Pacific sustainable development plans are anticipated to supplement waste heat recovery system product deployment.
- The Middle East and African district cooling markets are projected to grow at the highest rate due to increased temperatures and investment in infrastructure projects.

[54] Markets and Markets. 2017. “District Cooling Market by Production Technique (Free Cooling, Absorption Cooling, Electric Chillers), Application (Commercial, Residential & Institutional), Region - Global Forecast to 2021”
[55] Markets and Markets. 2017. “District Cooling Market by Production Technique (Free Cooling, Absorption Cooling, Electric Chillers), Application (Commercial, Residential & Institutional), Region - Global Forecast to 2021”

3. Barriers, Risks, and Solutions

Despite the importance of cooling for industrial and commercial applications and the benefits of adopting green cooling technologies, several barriers hinder the uptake of green cooling technologies and practices. This paper considers barriers and solutions common across multiple commercial and industrial sectors. These include, but are not limited to: quantifying the cost to business of employee heat stress; maintenance for cooling equipment; and calculating return on investment. Moreover, there is a lack of training on how to properly size equipment and how to structure tender documents and requests for proposals in a manner that promotes the adoption of green cooling technologies and practices.

3.1. Quantifying the Cost of Heat Stress and Savings of Cooling to Business

3.1.1 Barrier: Uncertainty and lack of calculator tools

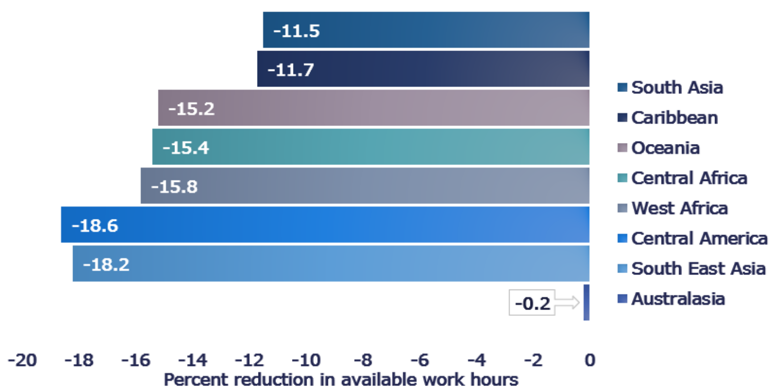

Figure 6: Reduction in Available Work Hours Due to Heat

Heat stress is a significant and growing business risk. In the buildings sector, practitioners use the term “overheating hours” to express the portion of time a building is maintained above a certain temperature threshold. This metric can be used for occupied hours or for the entire year. According to a 2006 study from Lawrence Berkely National Laboratory and the Helsinki University of Technology, the highest productivity levels for office work were observed at 22 ºC and starts to decline above 23-24 ºC.[56]

[56] Seppänen, Olli, Fisk, William, and Lei, QH. “Effect of Temperature on Task Performance in Office Environment.” 2006. Lawrence Berkeley National Laboratory.

Among the more severe results of overheat is heat stress, which is a labor risk in many industrial applications. Heat stress is one of the most ignored occupational hazards in tropical and subtropical countries, despite having a significant impact on employee health and accident rates. Excessive heat stress can result in heat edema, rashes, cramps, and other ailments. There is potentially a link between occupational heat stress and chronic kidney disease.[57] Furthermore, it is a common issue in many industries, including metal refining, glassmaking, mining, commercial baking and catering, and other sectors that require workers to interact with sources of heat. Based on climate change trends projected to 2050, the available work hours in all regions will be reduced due to extreme heat (see Figure 6). In 2014, the World Health Organization projected that by 2030, there would be a loss of 1-1.7% of global annual productive daylight work hours and 1.7-2.4% by 2050.[58] In July 2019, the International Labor Organization similarly reported that a rise in temperature could result in a 2.2% drop in global work hours, which roughly equates to 80 million full-time jobs and global economic losses of $2.4 trillion.[59,60] Although many of the losses are in agriculture and construction, the International Labor Organization estimates that, in 1995, industry accounted for 9% and the service sector accounted for 3% of the total global working hours lost to heat stress. It is projected that the industry and service sector share of global working hours lost to heat stress will increase to 12% and 10% by 2030 respectively. This upward trend is based both on the increasing number of workers in the service industry globally as well as increased work heat exposure. [61]

Effective Temperature ⁰F/⁰C	75/24	80/27	85/29	90/32	95/35	100/38	105/41
Loss of Work Output	3%	8%	18%	29%	45%	62%	79%
Loss in Accuracy	0%	5%	40%	300%	700%	>700%	>700%

Figure 7: The Effect of Temperatures Over 24 °C on Productivity and Accuracy

Temperatures in the 18-30 °C range can have been found to affect employee performance. It is suggested that 21-25 °C is the optimal range for office productivity, whereas productivity is

[57] Nerbass, F., et al. 2017. "Occupational Heat Stress and Kidney Health: From Farms to Factories."
[58] Kjellstrom, T., Briggs, D., Freyberg, C. Lemke, B., Otto, M., Hyat, O. and Dear, K. 2014.Occupational Heat Stress Contribution to WHO project on "Global assessment of the health impacts of climate change"
[59] Taylor, L. 2019. " Rising heat stress could cost 80 million jobs by 2030–U.N."
[60] International Labor Organization. 2019. "Increase in heat stress predicted to bring productivity loss equivalent to 80 million jobs"
[61] ILO. 2019." Working on a Warmer Planet"

decreased by 2% per 1 °C increase in the range of 25-30 °C.[62] In summer months, industrial warehouses, manufacturing facilities, and sheds experience temperatures above 24 °C, going as high as 40-45 °C, which may be further exacerbated by machinery usage.[63] This results in a slowdown of production due to employee sicknesses, absenteeism, and inefficient or slow work due to the hot working environment.

Although the risk and cost associated with heat stress are high, studies conducted by Better Work, in collaboration with IFC and the International Labor Organization, reveal that across Bangladesh, Indonesia, Cambodia, and Nicaragua there were significant rates of non-compliance relating to work environment conditions, including temperature and ventilation [64] Similarly, a study conducted on heat stress in a glass factory in Central India discovered that 77 out of 263 workers experienced 212 episodes of heat stress. About 40% of affected workers were in the manufacturing section and 38% in the furnace section. In addition, 28% of workers experienced burns as a direct result of heat exposure.[65] Despite the vulnerability of industrial workers to heat stress, many industrial and commercial players are not aware of the monetary cost of heat stress. Stakeholders also need to understand the cost per worker to provide increased thermal comfort to view it as a low-cost benefit and/or risk avoided.

3.1.2 Solution: Better record-keeping and development of heat stress calculators

A potential solution to assist commercial and industrial end-users with quantifying the cost to a business may be a calculator tool, which allows users to input data such as the number of employees, the age of employees, geographic area of operation, data relating to manufacturing equipment and cooling equipment, etc. Think tanks, industrial associations, and international development organizations are well-placed to develop such a tool. Accurate record-keeping of empiral heat exposure and absenteeism is recommended as best practice for commercial and industrial actors in order to refine models. The tool could then draw statistics from relevant institutions on the average cost of workers' claims for excessive heat exposure injuries, disability, and fatalities by country. For example, the U.S. Bureau of Labor Statistics 2008 data reveals that the average U.S.-based workers' compensation claim for injuries related to excessive heat exposure is $9,000, a disabling injury costs a company $43,000 per occurrence,

[62] Symphony. n.d. "Industrial air cooling: The optimum solution to increase workplace productivity".
[63] Symphony. n.d. "Industrial air cooling: The optimum solution to increase workplace productivity".
[64] Better Work. "Compliance Synthesis Reports" [Available]: https://betterwork.org
[65] Brahmapurkar, K. et al. 2012. "Heat Stress and its Effect on Glass Factory Workers of Central India"

and a fatal accident costs a company an average of $1.3 million per occurrence.[66] Additional data on labor productivity losses and gains due to heat exposure and thermal comfort respectively may give further insights to allow industrial and commercial users to quantify the cost to business of heat stress. For example, a 2% dehydration factor equates to a 20% loss of worker productivity. Calculating losses based on worker hourly rates is fairly straightforward.[67] Conversely, a research study conducted by IIM-Ahmedabad has revealed that workers' productivity can be enhanced by up to 12% by increasing the level of thermal comfort through cooling solutions.[68] Overall, the calculator could provide industrial and commercial end-users with cost-benefit productivity estimates for providing workers with access to adequate cooling.

3.2. Calculating the Return on Energy Efficiency Investments

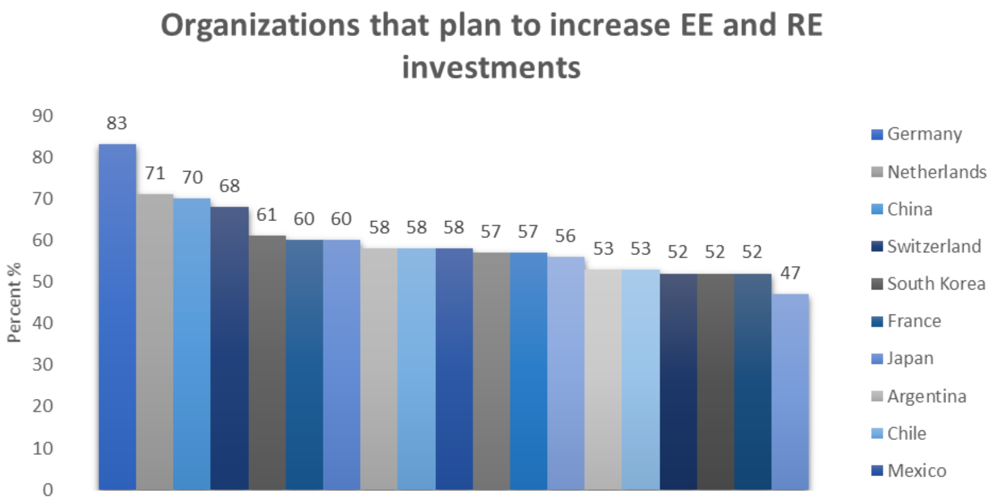

Figure 8: 2018 EE Indicator Survey: Organizations' Plans to Increase EE and RE Investments

3.2.1. Barrier: Inappropriate time horizons for payback periods

As illustrated in Figure 17, organizations surveyed in all countries planned to increase investments in renewables and energy efficiency.[69,70] In most instances, more than half the organizations surveyed planned to increase these investments. However, companies that are unfamiliar with energy-efficient cooling may seek a shorter payback period or a higher return on investment compared to other capital investment alternatives because they may perceive

[66] Lawson Products. 2014. "Product Information Report: Heat Stress"
[67] Lawson Products. 2014. "Product Information Report: Heat Stress"
[68] Economic Times. 2016. "Cooling comfort at the workplace can up productivity by 12%: IIMA"
[69] Johnson Controls. 2018. "Energy Efficiency Indicator Survey"
[70] The 2018 report marked the 12th edition of the survey with more than 1,900 respondents represented from 20 countries, including Argentina, Brazil, Canada, Chile, China, Colombia, France, Germany, India, Ireland, Italy, Japan, Mexico, Netherlands, South Africa, South Korea, Spain, Switzerland, the United Kingdom and the United States.

the investment as riskier. This issue is broadly applicable to any energy efficiency investment but is worth exploring in the context of sustainable cooling.

Out of the 10 countries surveyed in the 2018 Energy Efficiency Indicator Survey, organizations in eight identified insufficient return on investment (ROI) and payback as a barrier to investment.[71] The payback period for energy-efficient upgrades needs to be approximately 3.1 years in most markets.[72] In the replacement/upgrade market for energy-efficient technologies, ROI periods are longer than three years for commercial markets, making it a difficult sell.[73] Companies that are unfamiliar with energy-efficient cooling may seek a shorter payback period or a higher return on investment compared to other capital investment alternatives because they may perceive the investment as riskier or they are uncertain about the savings and performance of EE technologies such as sustainable cooling[74,75] Furthermore, many companies find return on invested capital (ROIC) more important than ROI and the capital nature of the equipment, financed or not, will form part of the capital base. In other instances, companies are interested in increasing their energy efficiency investments, but they lack the technical expertise to evaluate projects and the appropriate ROI period.[76]

3.2.2. Solution: Selecting the relevant time horizon for calculating return on investment

Commercial and industrial should reassess the time horizons used for calculating ROI for efficiency investments, with the understanding that the relevant time horizons for ROI in energy-efficient cooling upgrades may vary by technology, country, and markets. For example, a 2011 study[77] evaluated the cost of improvements in a data center[78] and found energy savings of 300 kW, equating to $300,000 in savings over one year. The payback period for the upgrades was only 15 months. Similarly, upgrades to cooling towers such as upgrading constant-speed pump to variable-speed, tower constant-speed fan to variable-speed and conductivity controller retrofitting may yield energy savings and a payback period of fewer than 3 years.[79] Guidance notes or calculation tools that draw together relevant research and data on appropriate time

[71] Johnson Controls. 2018. “Energy Efficiency Indicator Survey”
[72] Johnson Controls. 2018. “Energy Efficiency Indicator Survey”
[73] Johnson Controls. 2018. “Energy Efficiency Indicator Survey”
[74] U.S. Dept. of Energy. 2015. “Barriers to Industrial Energy Efficiency”
[75] Johnson Controls. 2018. “Energy Efficiency Indicator Survey”
[76] Johnson Controls. 2018. “Energy Efficiency Indicator Survey”
[77] Green Grid. 2011. “ Case Study: The ROI of cooling system energy efficiency upgrades.”
[78] Original Equipment Manufacturer Variable Speed Drives in all Computer Room Air Handler (CRAH) units to save energy if the airflow demand was less than 100%, replacing older CRAHs with more efficient models, improving rack airflow, repositioning temperature/humidity settings, and adjusting temperature set points.
[79] Johnson Controls. 2014. “Improvement Measures and Investment Analysis Framework”

horizons for various energy-efficient cooling upgrades, alongside energy savings and disaggregated by geography and end-use, would be useful. For example, Daikin developed a tool for chillers in which users may enter the building type, cooling load, energy rate amongst other indicators to determine the payback period and savings associated with different chillers.[80] A collective guidance from the industry, such as a trade association, would provide insights into the relevant risk and/or mitigation options for energy-efficient cooling upgrades.

3.2.3. Solution: Financing replacement costs

Replacement costs for traditional cooling equipment are often not includend in calculating the cost of energy efficient upgrades. Financial incentives from policymakers or capital providers, many of whom have their own sustainability targets, can encourage deployment of more efficient equipment. For example, the World Bank Philippines - GEF Chiller Energy Efficiency Project replaced inefficient chillers with energy-efficient units by providing either: (i) an up-front grant subsidy of 15% of the cost of new, non-Chlorofluorocarbon (CFC) based energy-efficient chillers to replace their stock of aging, inefficient chillers: or, (ii) carbon finance reflows option, i.e., an annual subsidy of 80% via the Kyoto Protocol's Clean Development Mechanism.[81]

3.3. Energy Efficient Procurement Practices

3.3.1. Barrier: Procurement practices often lack defined and measurable energy/cooling targets

Deloitte reports that corporate procurement rivals public policy as a driver for growth in the renewable energy sector.[82] However, traditional procurement methods often lack defined and measurable energy-efficiency and/or sustainable-cooling targets as well as accountability to meet the targets. This is especially important at the building design phase. There is a general need for simplified methods and tools that can provide timely feedback on performance implications and help compare and rank design variations.[83]

[80] Daikin. "Chiller payback". [Available]: https://chillerpayback.daikinapplied.com/chiller
[81] World Bank.2017." Philippines - GEF Chiller Energy Efficiency Project".
[82] Deloitte. 2017. "Serious business: Corporate procurement rivals policy in driving growth of renewable energy".
[83] Vullo. P., et al. 2018. "Implementation of a multi-criteria and performance-based procurement procedure for energy retrofitting of facades during early design"

Green Leasing

"Green leasing, also known as energy-aligned, energy-efficient, or high-performance leasing, is the practice of realigning the financial incentives of sustainability or energy measures in lease documents…A green lease is essentially a standard lease that has "rehabilitated" certain clauses to better align financial incentives and sustainability goals between a landlord and a tenant…Realigning cost structures through a green lease allows both building owners and tenants to save money, conserve resources, and ensure the efficient operation of buildings…By addressing the split incentive and other energy issues, green leases can remove significant impediments to sustainable cooling improvements."

-Andrew Feierman, Institute for Market Transformation

Case Study 1: Green Leasing [84]

3.3.2. Solutions: Provide real-world-based training, leveraging existing partnerships such as utilities

Case studies – Showing by example is invaluable. Real examples of innovative procurement demonstrate what is possible.

Technical guidance and criteria - Access to technical support on issues such as total cost of ownership, measuring energy efficiency, and alternative financing models would give confidence to procurers.

Capacity building - Commercial and industrial end-users can better train procurement staff in whole-life costing of buildings and dialogue-based procurement approaches.

Absolute energy targets - In an assessment of success factors for performance-based procurement, the Institute for Sustainable Energy and the U.S. National Renewable Energy Lab found that absolute energy targets were critical. Optimally, such targets should be set early in the pre-design phase, and enforced through contractual mechanisms.[85] Procurement

[84] "What's in a Green Lease?" Andrew Feierman, Institute for Market Transformation, May 2015
[85] "Accelerate Performance: Final Technical Report," Institute for Sustainable Energy, National Renewable Energy Lab, May 2019

documents should include performance goals to encourage designers and contractors to include performance goals when they sell the project to owners.

Design considerations – Designer can reduce the cooling load of buildings by including passive measures, such as shading, insulation, green roofing, natural ventilation, and even coating building exteriors with light colored, reflective coatings. Employing such passive measures can result in a 23.6% reduction in total energy consumption.[86]

Post-design considerations - Procurement documents should stipulate that the building and associated cooling systems should be easy to operate. This helps set building operators succeed in meeting energy efficiency and cooling targets even if they have not received specialized training.

Leverage electric utility relationships - Utilities are likely to want to engage owners early in the building procurement process. By reducing the energy needs of end-users, utilities can reduce their own capital needs. Furthermore, early engagement allows utilities to understand the consumption patterns of end-users, which allows them to adjust their operations in a way that serves the market and optimizes revenue. Utilities can assist owners in establishing energy goals and selecting appropriate design teams and contractors to meet energy goals, particularly when there is a lack of skill or understanding of energy-efficient cooling and building design.[87] Large commercial and industrial users often have large energy demands and are considered key accounts; they are well placed to negotiate support for energy efficiency with their utiltiies. Such support can include time-of-use rate structures, which allow electricity providers to alleviate demand during peak periods, and demand response and storage to enhance power system flexibility. Utility engagement can occur during design, operation, and retrofitting of the building asset.

3.3.3. Solution: Switch to a Cooling-as-a-Service (CaaS) Provider

A more radical approach to cooling procurement is to switch to the CaaS model. In this model, customers do not own their own cooling infrastructure but instead pay a technology provider by ton of refrigeration or cubic meter of cooled air. As with the Energy Service Company (ESCO)

[86] Taleb, Hanan. "Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings," June 2014, *Frontiers of Architectural Research, Volume 3, Issue 2,* pp154-165.
[87] NREL. 2018. "Establishing Building-Level Energy Goals in Procurement Documents: Lessons Learned from Pilot Utility and Portfolio Projects"

model, rates are agreed upon in advance. The technology providers have a strong profit incentive to reduce their cooling systems' operating costs.[88]

3.4. Improperly Sized Cooling Equipment

3.4.1. Barrier: Vendors often oversell cooling capacity

One of the main issues with sizing cooling equipment is that customers depend on the expertise of contractors in selecting cooling systems.[89] In order to successfully operate at outlier meterological events (i.e., conditions which occur 1-2% of the year), HVAC cooling systems are intentionally oversized and rarely operate at full design load.[90] However, many contractors oversize by more than 25%. For example, a study in California concluded that more than 40% of the units studied were more than 25% oversized and about 10% were considerably greater than 50% oversized.[91] A Florida study reported a 9% increase in electricty usage for units oversized by 50% or more.[92] The correct sizing of cooling systems is critical for optimal energy efficiency and comfort.[93] When equipment is oversized, initial costs are higher, efficiency is reduced, energy costs increase, and comfort may be compromised.[94]

In humid climates, it is especially important to correctly size equipment because short-cycling of air conditioning equipment can lead to poor humidity control and excessive cycling reduces the overall efficiency of cooling equipment. Excessive cycling can lead to premature equipment failure. Oversized systems also use more fan power for the blower and often exhibit more duct leakage due to higher operating duct pressures.[95] Finally, oversized air conditioners and heat pumps aggravate the summer utility peak demand on hot days. In the same Florida study cited above, a 13% higher summer peak electrical demand was correlated to oversized units.[96] The general sizing method is 1 ton of cooling capacity for every 500 square feet of floor area, but

[88] Kigali-Cooling Efficiency Program, "Cooling as a Service (CaaS)." This brief includes several case studies.
[89] Energy Star. n.d. "A Guide to Energy-Efficient Heating and Cooling".
[90] Davis, G. 2016. "HVAC codes and standards: cooling and energy efficiency". Consulting-Specifying Engineer,
[91] Djunaedy, E., Van Den Wymelenberg, K., Acker, B. and Thimmana, H. 2010. "Oversizing of HVAC system signatures and penalties"
[92] NREL. n.d. "Right-Size Heating and Cooling Equipment: The correct size improves comfort and reduces costs, maintenance, and energy use".
[93] Energy Star. n.d. "A Guide to Energy-Efficient Heating and Cooling".
[94] NREL. n.d. "Right-Size Heating and Cooling Equipment: The correct size improves comfort and reduces costs, maintenance, and energy use".
[95] NREL. n.d. "Right-Size Heating and Cooling Equipment: The correct size improves comfort and reduces costs, maintenance, and energy use".
[96] NREL. n.d. "Right-Size Heating and Cooling Equipment: The correct size improves comfort and reduces costs, maintenance, and energy use".

this ratio does not take building design into account.[97] Without training on sizing equipment methods, both contractors and industrial and commercial buyers are more prone to fitting or buying oversized cooling equipment.

3.4.2. Solution: Provide training on calculating the cooling load

Accurate HVAC load calculations is necessary for right-sizing equipment. Designers can use computer-aided load analysis to remove uncertainties such as shading and weather.[98] Geographic location is a critical input into these calculations, and designers can benefit from training provided by professional organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). ASHRAE's members come from over 132 nations, and trainings are provided in international locations.[99]

3.5. Employee Incentives: Insights from Data Centers

3.5.1. Barrier: Employee performance incentives are often misaligned with corporate sustainability targets

Employees are more likely to adhere to energy-efficient practices if following these practices is seen as a key aim of their job.[100] In certain instances, performance measures can contradict or undermine energy-efficient measures. Data centers are used here as an illustrative example. Data centers not only cut across various industries but are anticipated to grow rapidly and drive global cooling demand[101].

In data centers, the key performance indicators for site managers typically focus on metrics that describe how often data centers fail to keep servers running.[102] Generally, they are not evaluated on site energy usage. Computer servers require cooling to remain operational, so site managers are incentivized to overcool data centers to "play it safe" and prevent system failure. Accountability is fragmented in that the departments responsible for paying energy bills and those responsible for system performance are often siloed.

[97] Bhatia, A. "Cooling Load Calculations and Principles," CEDengineering.com
[98] Davis, G. 2016. "HVAC codes and standards: cooling and energy efficiency". Consulting-Specifying Engineer,
[99] https://www.ashrae.org/professional-development/all-instructor-led-training/global-training-center
[100] Rioux, S. M., & Penner, L. A. 2001. The causes of organizational citizenship behavior: A motivational analysis.
[101] This is illustrated by the Asia-Pacific market domination in evaporative coolers which is driven by Japan, India and Australia's growing data center market.
[102] Bigelow, J. 2018. "Which data center KPIs are the most useful?"

Multi-tenant data centers, which are shared locations where customers lease space rather than operate their own data centers, face unique challenges in this regard. It is also a segment that is growing rapidly, with annual rates of 18-20%.[103] For multi-tenant data centers, the units responsible for system performance and for paying the energy bills are more than distinct departments – they are typically in different companies.

3.5.2. Solution: Aligning energy performance and employee performance

Industrial and commercial users should review the internal organizational structure and external contractual arrangements, as well as ensure that incentives are aligned to provide financial rewards for efficiency best practices. Incentives between those who make decisions affecting efficiency and those who pay the energy bills should be aligned.

3.5.3. Solution: Restructure pricing models for multi-tenant data centers

Rather than have customers pay by space, e.g., square footage, multi-tenant providers whould charge customers on the basis of actual energy consumption, as recommended by the Natural Resources Defense Council.[104] In this structure, the customer is incentivized to find ways to reduce their energy usage, and providers that are energy efficient can attract customers through lower prices.

3.6. Maintenance

3.6.1. Barrier: Companies tend to under-invest in maintenance

According to the Building Efficiency Initiative, appropriate maintenance may decrease energy bills by 15-20% in commercial buildings.[105] Conversely, the New Buildings Institute found that poor maintenance of HVAC systems can increase energy use by 30-60%.[106] The Indoor Air Quality Association estimates that regular HVAC maintenance can reduce the risk of breakdowns by as much as 95%.[107] The Buildings for Efficiency Initiative notes that fewer than half of companies perform preventive or predictive maintenance on their building HVAC systems. Reactive maintenance, i.e., running HVAC systems to the point of failure, remains the

[103] Natural Resources Defense Council. 2014."Data Center Efficiency Assessment. Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers"
[104] Natural Resources Defense Council. 2014."Data Center Efficiency Assessment. Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers"
[105] Building Efficiency Initiative. 2011. "Studies Show: HVAC System Maintenance Saves Energy"
[106] New Buildings Institute. 2011. "Sensitivity Analysis: Comparing the Impact of Design, Operation, and Tenant Behavior on Building Energy Performance".
[107] https://iaqa.org/consumer-resources/hvac-preventive-maintenance-is-essential/

dominant management practice by companies. This may be attributed to managers lacking awareness of the benefits of early maintenance.[108]

3.6.2. Solutions: Follow preventative or predictive rather than reactive maintenance

Managers need to be made aware of the benefits of preventative and predictive maintenance, such as cutting energy costs, reducing operating costs, and avoiding breakdowns.[109] Commercial and industrial property managers should carry out schedule-based preventative maintenance at a minimum and, if possible, predictive maintenance. Predictive maintenance uses machine learning to monitor realtime performance provide tailored, unit or system-level repair and replacement schedules.[110]

ASDA's best practice on setting KPIs

ASDA, a British supermarket retailer, integrates performance ratings of refrigeration systems and engineers by setting key performance indicator (KPI) targets and monitoring certain data for response time, repair time and first fix. ASDA's KPI approach is summarized below:

1. Refrigeration equipment uptime has KPIs for all stores, which are calculated using the in-house operating systems that log when service calls are placed and when they are completed. The system then calculates the uptime in proportion to the number of assets on-site and available trading hours.
2. Each store is assigned an annual refrigerant leakage in Kgs, calculated using the historical usage data for each site and the annual leakage target set for the following year. Stores with higher leakage rates are assigned more stringent reductions for the following year.
3. All data collected under the F Gas regulations are used to produce a leak coding database. By reviewing and using this additional data, ASDA can ensure engineers' tasks, in terms of planned leak testing, are focused on the areas where the greatest risk of leaks is currently being found.
4. Refrigeration monitoring and alarm systems are set up to use all available software within the refrigeration alarm panel. One of the tools that can be used is

[108] Building Efficiency Initiative. 2011. "Studies Show: HVAC System Maintenance Saves Energy"
[109] See Appendix for the full list of HVAC maintenance issues, solutions, and estimated energy savings.
[110] Yoskovitz,Saar. "Predictive Maintenance Considerations for Property Managers," FacilitiesNet.com, October 2016

the temperature performance indicators function. This function is used by onsite engineers to pre-warn of any issues that will affect the refrigeration system's performance and encourages an initiative-taking approach to service and maintenance delivery. The system may be set up to generate TPI alarms, but caution must be taken when using this, as parameters must be discussed and agreed upon between both the operator and the service provider. This approach will increase alarm traffic and service call volumes.

Case Study 2: ASDA's Best Practice on Setting KPIs

3.7. Barriers, Risks, and Solutions – Key Takeaways

- A potential way to assist industrial and commercial end-users with quantifying the cost of heat stress to a business may be a calculator tool that allows users to calculate the potential risk and cost of heat stress as well as the potential savings with providing thermal comfort.
- Guidance notes or calculation tools that draw together relevant research and data on appropriate time horizons for various energy-efficient cooling upgrades, alongside energy savings and disaggregated by geography and end-use may be useful.
- Financial incentives may persuade industrial and commercial end-users to replace traditional cooling equipment with more sustainable equipment.
- Building and system designers should accurately calculate HVAC load in order to right-size equipment.
- Managers need to be made aware of the benefits of preventative and predictive maintenance, such as cutting energy costs, reducing operating costs, and avoiding breakdowns.

4. Enabling Regulatory Environment

To date, the literature around the regulatory environment for the adoption of sustainable cooling technologies and practices has been largely dispersed, untargeted, or not focused on the end-user experience. However, a few building blocks for an enabling regulatory environment are highlighted in various studies, including policy instruments for refrigerants, incentives and mandates, financing mechanisms, mini, energy efficiency labeling, and building codes.

Policy instruments on the use of refrigerants	Bans	
	Quotas	
	Leakage control & certification	
	Destruction regulations	
	Reporting	
Incentives & mandates for industrial and commercial users	Mandates	Sustainable cooling targets
		Progress/tracking reports
		Mandatory audits
		M & V program
	Incentives	Performance recognition
		Partial risk guarantees
		Preferential loans
		Discounts on green cooling technologies
		Tax incentives
EE MEPs	MEPs adopted for industrial refrigerators and HVAC	Verification program for refrigerators & HVAC
		Update to reflect cooling technological advances and changes in best practices
EE labelling	Labelling schemes adopted for industrial refrigerators & HVAC	Update to reflect cooling technological advances and changes in best practices
EE building codes	EE codes for new commercial buildings adopted	Updated on a regular basis to reflect cooling technological advances and changes in best practices

Table 1: Enabling Regulatory Environment for Sustainable Cooling[111]

[111] RISE indicators & Green Cooling Initiative

4.1. Policy Instruments Aimed at Controlling the Use of Refrigerants

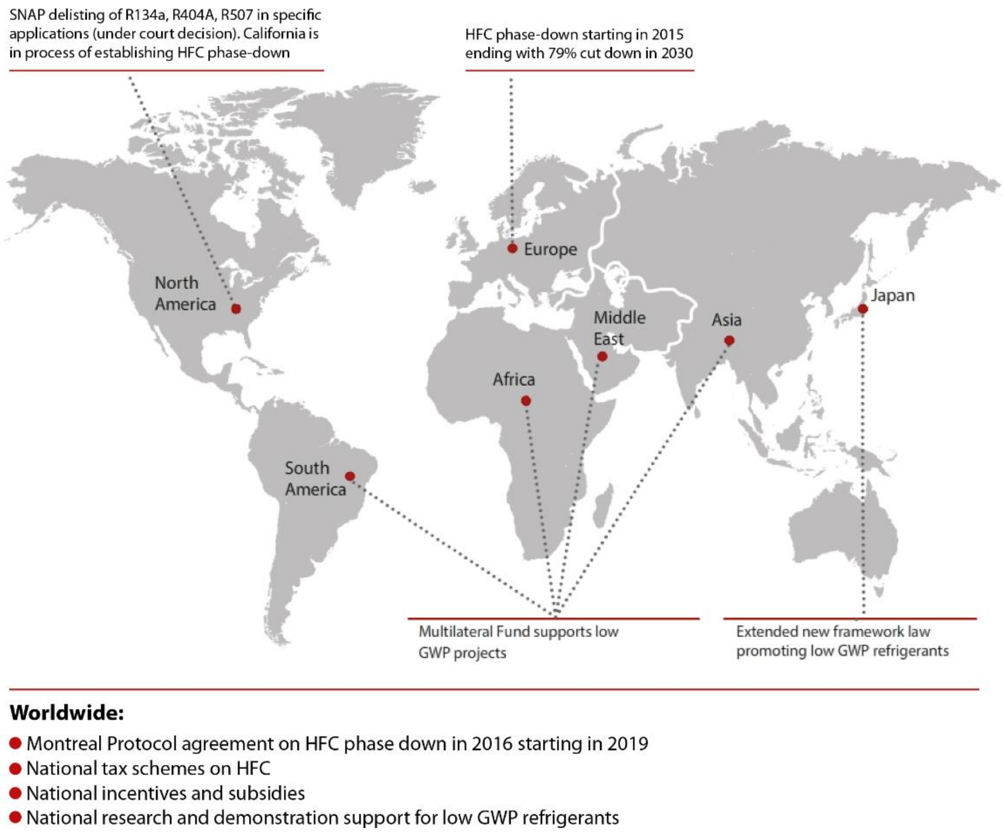

Figure 9: Policy Instruments Controlling the Use of Refrigerants [112]

Policy instruments controlling the use of high ODP and GWP refrigerants are found throughout the world. These instruments include bans that restrict the use of certain refrigerants, such as the HCFC ban in the European Union. Additionally, quotas such as the HCFC phase-out under the Montreal Protocol limit the number of certain refrigerants within certain countries or sectors. Moreover, some countries have introduced leakage controls and obligatory certification programs, which aim to monitor and limit the leakage of refrigerants. Destruction regulations, such as the takeback schemes in Belgium and the Netherlands, may be used to extract toxic refrigerants or those with high ODPs and GWPs at the end of life of the equipment. Many countries have introduced mandatory reporting on the use of refrigerants in order to determine whether to impose further restrictions. For example, in line with the Kigali Amendment phasedown of HFCs, HFC refrigerant manufacturers and suppliers in Canada must report all HFCs exported, imported, or manufactured over 100 kg during the years 2008-2012.[113]

[112] Green Cooling Initiative. “Policy instruments: refrigerants”
[113] Green Cooling Initiative. “Policy instruments: refrigerants”

4.2. Incentives and Mandates

Financial incentives for efficient cooling can take the same form as financial incentives for standard energy efficiency: rebates, grants, or loans for energy-efficiency improvements, direct income tax deductions for individuals and businesses, and exemptions or reduced sales tax on eligible products..[114]

Rwanda's Coolease Scheme

Rwanda's Business Development Fund partnered with the Rwanda Green Fund, the UN Environment's United for Efficiency initiative and the Basel Agency for Sustainable Energy to launched the 'Coolease' financial mechanism to promote adoption of energy-efficient and climate-friendly cooling solutions in Rwanda. The Coolease scheme is one of the first of its kind in Africa. Interested commercial and industrial clients receive financing for upfront installation costs for efficient cooling equipment that uses low GWP refrigerants. The user makes monthly payments and the technology provider commits to provide maintenance.

Case Study 3: Rwanda's Coolease Scheme

4.3. Energy Efficiency Labeling and Minimum Energy Performance Standards (MEPS)

Energy performance labeling of industrial refrigerators and HVAC units prominently displays the energy consumption of a unit and its efficiency ranking amongst other products, which allows commercial and industrial users to make informed purchasing decisions. This, in turn, incentivizes industrial refrigerator and HVAC manufacturers to produce more efficient cooling solutions to industrial and commercial end-users. MEPs set floors that ban equipment that fails to achieve a specified efficiency. It should be noted that with regards to refrigeration and air conditioning systems, existing standards dealing with safety are relevant. Safety standards may present a barrier to the introduction of alternative, climate-friendly technologies due to concerns over flammability for hydrocarbons or toxicity for ammonia.[115]

[114] American Council for an Energy-Efficient Economy, "Financial Incentives for Energy Efficiency"
[115] Green Cooling Initiative. "Policy instruments: reducing emissions"

In addition to labeling equipment, green building labels that aim to reduce overall energy use often incorporate options for energy efficiency in cooling systems. IFC's own green building certification program, EDGE ("Excellence in Design for Greater Efficiencies"), requires at least 20% reduced resource intensity in energy, water, and embodied energy in materials and provides users with information and recommendations for low GWP refrigerant selection.[116] Other green buildings certification systems also include guidance and even requirements for refrigerants. Under the LEED ("Leadership in Energy and Environmental Design") system, users can get credit for enhanced refrigerant management that complies with the Montreal Protocol and also reduces greenhouse gas emissions.[117] BREEAM ("the Building Research Establishment Environmental Assessment Methodology") includes credits based on limiting the GHG impact of refrigerants.[118] Estidama, which means "sustainability" in Arabic, is Abu Dhabi's sustainable urbanization initiative that includes the Pearl Rating System for buildings.[119] In order to receive credit, buildings must adhere to standards for fans, air conditioning systems, and refrigerants. The certification system also awards credit for use of low GWP refrigerants that meet a minimum standard.[120]

4.4. Building Codes

IFC has done extensive work in reforming building codes, many of which include cooling system efficiency requirements in residential and commercial buildings. IFC has engaged in building code activity in Vietnam, Indonesia, Colombia, and the Philippines.

Jakarta Building Codes

Excerpt from Vol. 2 Air Conditioning & Ventilation System from the Government of the Province of Jakarta Capital Special Territory, in cooperation with IFC:

"Code Requirement 1: Mechanical system for occupied spaces should be designed to maintain a minimum 25ºC (twenty-five) and relative humidity 60% ± 10% (i.e. between 54% and 66%). This requirement applies to occupied and air-conditioned spaces only."[121]

Case Study 4: Jakarta's Building Codes

[116] "EDGE Guidance Document for Refrigeration Selection to Reduce Climate Impact Based on the Montreal Protocol, Version 1"; April 3, 2017; International Finance Corporation.
[117] Ibid.
[118] Ibid.
[119] "The Pearl Rating System for *Estidama*: Public Realm Rating System Design & Construction," Version 1.0.
[120] "The Pearls Design System, New Buildings Rating Method," May 2009.
[121] Jakarta Green Building User Guide, "Vol. 2 Air Conditioning & Ventilation System."

4.5. Benchmarking and Voluntary Agreements

According to an Energy Star study of U.S. commercial buildings, the buildings that benchmark energy use tend to reduce energy consumption by 2.4% per year on average.[122] Voluntary agreements may go beyond regulatory requirements and may, under certain conditions, drive collective commitment to improved energy performance for all building systems, including cooling.

Japan's Top Runner Programme

Introduced in 1999, this is a set of efficiency standards for energy intensive products, from home appliances to motor vehicles. The efficiency standards are forward-looking targets based on the most efficient model in the market (the "Top Runner"). The program was introduced partly to achieve the 1997 Kyoto Protocol targets, and to improve on the lackluster results of the mandatory energy efficiency standards that Japan had implemented for refrigerators, air conditioners, and cars in 1980. The companies that receive the "Top Runner" label tend to be large, well-known domestic companies. The Minister of Environment is empowered to disclose the names of companies that fail to meet the targets, which drives companies to avoid negative publicity. Manufacturers support the program. They are directly involved in setting the targets and view efficiency as a competitive advantage.[123]

Case Study 5: Japan's Top Runner Programme

4.6. National Cooling Strategies

National cooling strategies, plans, and roadmaps integrate consideration of HCFC phase-out and HFC phasedown, energy efficiency and access to cooling. China, India, and Rwanda have released cooling plans and several countries are in the process of developing their own.[124] At the September 2019 U.N. Climate Action Summit, 26 countries, including Bangladesh and Lebanon, announced their intention to adopt comprehensive national cooling plans.[125]

[122] Energy Star. "Data Trends: Benchmarking and Energy Savings"
[123] Future Policy. "Japan's Top Runner Programme"
[124] Madan, P. "Momentum Towards Cooling with Less Warming - Part I," NRDC blog, October 2019
[125] Press release: "Climate Action Summit to provide solutions for increasing energy efficiency and for sustaining cooling in a warming world." 23 September 2019.

India's National Cooling Plan

India was the first country in the world to launch an national cooling plan. It laid out actionable pathways and goals to achieve:

- 20-25% reduction in cooling demand by 2037-2038
- 25-30% reduction in refrigerant demand by 2037-2038
- 25-40% reduction in cooling energy requirements by 2037-2038
- Training and certification of 100,000 sector technicians by 2022-2023
- 25-40% reduction in cooling energy requirements and 25-30% reduction in refrigerant demand across sectors—as compared to business as usual—over the next 20 years.[126]

Case Study 6: India's National Cooling Plan

4.7. Regulatory Environment - Key Takeaways

- Policy instruments controlling the use of high ODP and GWP refrigerants are found throughout the world.
- Financial incentives for efficient cooling can take the same form as financial incentives for standard energy efficiency: rebates, grants, loans, tax incentives, etc.
- Minimum Energy Performance Standards (MEPS) set floors that ban equipment that fails to achieve a specified efficiency.
- Building codes are effective tools to drive efficiency and can also reduce operating costs. Between 2010-2040, U.S. building model codes are expected to save $126 billion in energy costs.
- Buildings that benchmark energy use tend to reduce energy consumption by 2.4% per year on average
- National cooling strategies, plans, and roadmaps integrate consideration of HCFC phase-out and HFC phasedown, energy efficiency and access to cooling. Three countries have introduced national cooling plans; in September 2019, 26 countries announced their intention to launch such plans.

[126] Ministry of Environment, Forest & Climate Change, Government of India. 2019. "India cooling action plan"

Appendices

BAU GROWTH FOCUS GROUP COUNTRIES

	Equipment Stock		
Country	2018	2050	Change
Kenya	4,789,720	40,523,320	746%
Ethiopia	7,238,140	49,173,100	579%
Japan	167,941,300	168,214,400	0%
China	808,133,000	3,424,566,000	324%
Indonesia	62,159,450	242,416,700	290%
Uzbekistan	6,233,107	14,458,930	132%
Romania	13,957,740	20,403,440	46%
Brazil	103,202,140	237,806,980	130%
Jamaica	1,109,199	2,088,743	88%
United Arab Emirates	10,191,990	22,778,501	123%
Egypt	24,213,370	73,636,920	204%
India	216,155,000	906,223,100	319%
Bangladesh	19,671,370	88,810,920	351%
United States	584,962,100	830,926,600	42%
Group Total	2,029,957,626	6,122,027,654	202%

INDUSTRIAL AND COMMERCIAL COOLING GROWTH FOR FOCUS COUNTRIES BAU

Country	Equipment Stock			Energy		Emissions	
	2018	2050	Change	2018	2050	2018	2050
Kenya	586,763	1,264,587	116%	3,822	7,850	3	6
Ethiopia	1,234,273	2,448,200	98%	5,693	10,707	4	8
Japan	2,286,300	2,190,067	-4%	35,283	30,133	31	22
China	16,539,333	17,939,333	8%	130,233	129,433	208	213
Indonesia	3,075,417	4,188,367	36%	21,097	27,430	22	31
Uzbekistan	359,134	474,453	32%	1,556	1,959	2	2
Romania	387,440	360,073	-7%	5,870	4,856	8	5
Brazil	2,427,940	3,014,747	24%	13,863	16,427	8	10
Jamaica	33,183	36,622	10%	231	243	0	0
United Arab Emirates	118,367	202,324	71%	831	1,361	1	2
Egypt	1,031,870	1,588,320	54%	5,303	7,780	5	8
India	10,824,333	14,770,433	36%	78,333	102,300	132	179
Bangladesh	1,932,270	2,630,353	36%	10,593	13,763	12	16
United States	5,023,767	6,726,600	34%	51,933	59,867	46	45
Group Total	45,860,390	57,834,480	26%	364,643	414,109	482	548

INDUSTRIAL AND COMMERCIAL GROWTH UA

Country	Equipment Stock			Energy		Emissions	
	2018	2050	Change	2018	2050	2018	2050
Kenya	586,763	1,353,728	131%	3,822	18,784	3	15
Ethiopia	1,234,273	2,613,104	112%	5,693	24,370	4	20
Japan	2,286,300	2,190,067	-4%	35,283	30,133	31	22
China	16,539,333	19,294,333	17%	130,233	198,845	208	332
Indonesia	3,075,417	4,477,155	46%	21,097	65,807	22	75
Uzbekistan	359,134	497,042	38%	1,556	4,210	2	6
Romania	387,440	360,073	-7%	5,870	4,856	8	5
Brazil	2,427,940	3,219,770	33%	13,863	38,731	8	25
Jamaica	33,183	39,122	18%	231	585	0	1
United Arab Emirates	118,367	215,640	82%	831	3,286	1	5
Egypt	1,031,870	1,696,784	64%	5,303	18,033	5	20
India	10,824,333	22,569,185	109%	78,333	353,658	132	622
Bangladesh	1,932,270	2,813,366	46%	10,593	32,377	12	39
United States	5,023,767	6,726,600	34%	51,933	59,867	46	45
Group Total	45,860,390	68,065,970	48%	364,643	853,542	482	1,231

OTHER MARKET INSIGHTS

Global Chiller Market	2015	2022	CAGR (2016-2022)
	$8,784 million	$11,542 million	4.1%

Key Players

- Daikin Industries Ltd.
- Johnson Controls
- Trane Inc.
- Carrier Corporation
- Smartd Chiller Group Inc.
- Thermax Ltd.
- Hitachi Appliances Inc.
- Climaveneta S.P.A.
- Polyscience
- Dimplex Thermal Solutions

Segments	Subsegments	Revenue (2015)	Forecast (2022)	CAGR (2016-2022)
Type	Scroll chiller	$5,242 million	$6,730 million	3.7%
	Screw chiller	$2,501 million	$3,320 million	4.3%
	Centrifugal chiller	$250 million	$347 million	5.0%
	Reciprocating chiller	$278 million	$379 million	4.6%
	Absorption chiller	$513 million	$767 million	6.0%
End User	Chemicals & petrochemicals	$2,122 million	$3,032 million	5.4%
	Food & beverages	$1,856 million	$2,466 million	4.3%
	Rubber	$1,345 million	$1,764 million	4.1%
	Plastics	$2,382 million	$2,887 million	2.9%
	Medical	$1,078 million	$1,393 million	3.9%

Growth Rate *High* *Medium* *Low*

Data Centers

SEGMENTS	SUB-SEGMENTS	REVENUE-2017 ($Million)	FORECAST-2025 ($Million)	CAGR (2018-2025)
By Component	Solutions	5,269.36	13,358.83	12.5%
	Services	3,114.64	9,856.17	15.6%
By Type of Cooling	Room based Cooling	4,150.60	10,156.49	12.0%
	Rack based Cooling	1,841.07	6,182.91	16.5%
	Row based Cooling	2,392.32	6,875.59	14.2%
By Type of Data Center	Enterprise Data Center	4,071.41	9,231.40	10.9%
	Colocation Data Center	2,228.63	7,371.96	16.2%
	Wholesale Data Center	1,104.90	3,246.90	14.6%
	Hyperscale Data Center	613.5	2,411.83	18.7%
	Others	365.56	952.91	12.9%
By Industry Vertical	BFSI	1,382.03	3,093.03	10.7%
	Manufacturing	516.72	1,775.92	16.8%
	IT & Telecom	2,063.01	4,086.62	9.0%
	Media & Entertainment	1,100.19	3,465.72	15.6%
	Retail	836.90	2,277.86	13.5%
	Government & Defence	1,199.35	2,877.98	11.7%
	Healthcare	648.91	3,050.16	21.2%
	Energy	269.66	1,033.58	18.3%
	Others	367.23	1,554.12	19.7%

Source: Primary Research, Public Sector Publications, Company Releases, and AMR Analysis

Global Refrigerant Market

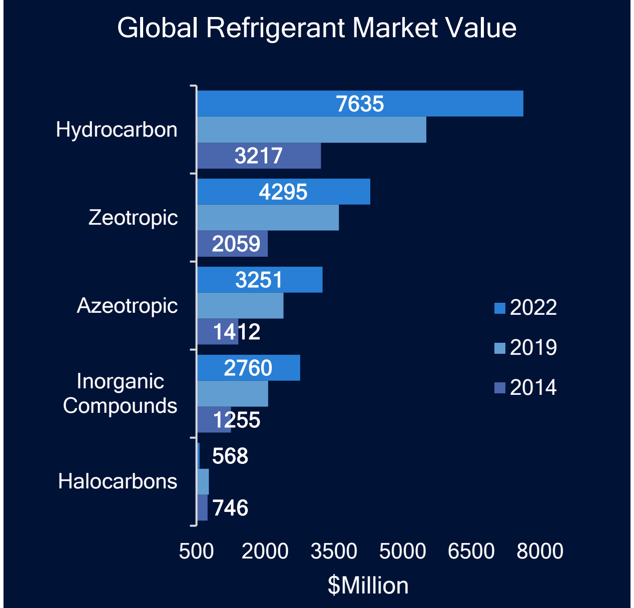

Figure 10: Global Refrigerant Market Value, by Type, 2014-2022 ($ Million)

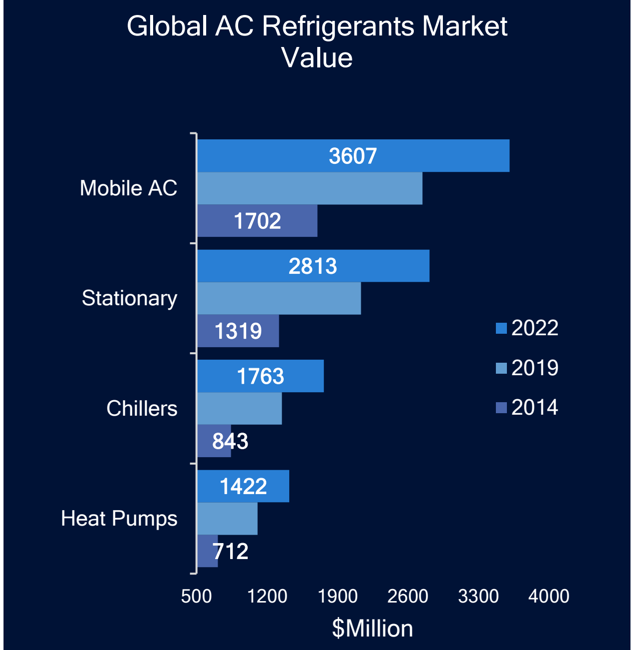

Figure 11: Global AC Refrigerants Market Value by Type, 2014-2022 ($ Million)

In 2015, the Global Refrigerants Market Value was $9,552 million and is expected to reach $18,509 million by 2022.[127] Halocarbons are expected to decline as its market share drops from about $746 million in 2015 to $568 million in 2022. Hydrocarbon and Zeotropic together accounted for about 61% of the total Global Refrigerants Market Value in 2014.

In 2015, the Global AC Refrigerants Market Value was $5,021 million is anticipated to reach $9,605 million by 2022. [128] Mobile AC and Stationary, together accounted for 66.1% of the total Global AC Refrigerants Market Value in 2015 and is anticipated to reach 66.8% by 2022.

[127] Allied Market Research. 2017. “Refrigerants Market: Global Opportunity Analysis and Industry Forecast, 2014-2022”.

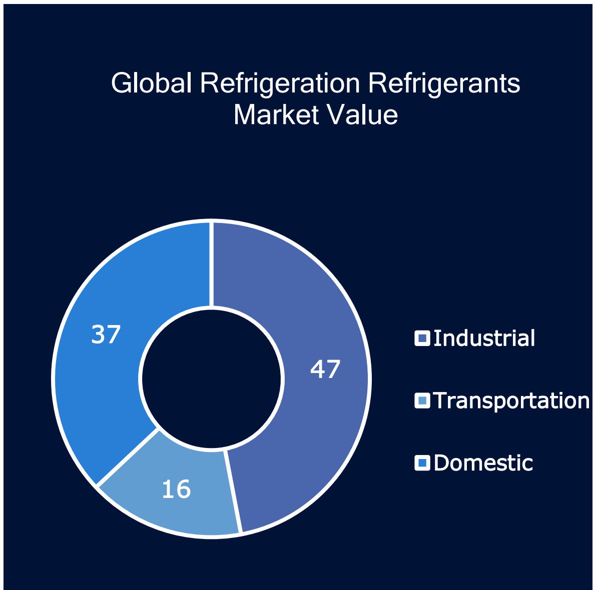

Figure 12: Global Refrigeration Refrigerants Market Value by Type, 2014-2022 ($Million)

In 2015, the Global Refrigeration Refrigerants Market Value was $4,531 million and is expected to reach $8,905 million by 2022.[129] Industrial was the highest contributor to the Global Refrigeration Refrigerants Market Value, constituting 46.9%. In 2015, industrial was at $2,129 million and is estimated to reach $4,347 million by 2022 growing at a CAGR of 10.7% from 2016 to 2022. [130]

The key market players include Arkema S.A. (France), Dongyue Group Co. Ltd. (China), Honeywell International Inc. (US), The Chemours Company (US), The Linde Group (Ireland), Air Liquide (France), Sinochem Lantian Co. Ltd. (China), Daikin Industries (Japan), Mexichem (Mexico), and Asahi Glass Corporation (Japan).

[128128] Allied Market Research. 2017. “Refrigerants Market: Global Opportunity Analysis and Industry Forecast, 2014-2022”.
[129] Allied Market Research. 2017. “Refrigerants Market: Global Opportunity Analysis and Industry Forecast, 2014-2022”.
[130] Allied Market Research. 2017. “Refrigerants Market: Global Opportunity Analysis and Industry Forecast, 2014-2022”.

PREVENTATIVE AND PREDICTIVE MAINTENANCE SOLUTIONS

Causes of Degraded Energy Performance in HVAC Equipment	HVAC Maintenance Solution	Estimated Impact on Chiller Energy Consumption
Centrifugal Chillers		
Tube cleanliness. Microbes in the chiller tube bundle reduce heat transfer. Reduction in heat transfer can be compounded by the formation of scale or iron deposits on the microbe site. The increase in temperature difference needed to overcome the heat transfer losses increases energy consumed.	Water treatment program. Tube cleaning.	15% savings for eliminating microbes; 10-20% more if scale and iron deposits are present. 10% to 35% savings or more in extreme cases.[1]
Reduced condenser flow rate from partially closed or damaged valves, clogged hot-deck nozzles in the cooling tower, clogged line strainers, sediment in the condenser tubes, and air in the system piping. Common causes of reduced flow are partially closed or damaged valves, clogged hot-deck nozzles in the cooling tower, clogged line strainers, sediment in the condenser tubes, and air in the system.	Monitor condenser flow at least annually and repair the cause of the reduced flow.	A 20% reduction in the condenser flow rate will increase full-load energy consumption by 3% in mechanical and absorption chillers used in chemical process cooling.[2]
Sub-optimal refrigerant levels. The efficiency of all chillers suffers if the system has either too little or too much refrigerant charge.	Maintain refrigerant levels according to the manufacturer's instructions.	Up to 20% savings.[3]

<table>
<tr><th>Causes of Degraded Energy Performance in HVAC Equipment</th><th>HVAC Maintenance Solution</th><th>Estimated Impact on Chiller Energy Consumption</th></tr>
<tr><td colspan="3">Centrifugal Chillers (continued)</td></tr>
<tr><td>Oil contamination in refrigerant</td><td>Chiller refrigerant charge reclamation to clean existing refrigerant in a one-time process, or the use of a purging system that cleans the refrigerant charge on an ongoing basis.</td><td><table><tr><th>Oil in Evaporator</th><th>Performance Loss</th></tr><tr><td>1–2%</td><td>2–4%</td></tr><tr><td>3–4%</td><td>5–8%</td></tr><tr><td>5–6%</td><td>9–11%</td></tr><tr><td>7–8%</td><td>13–15%</td></tr></table>[4]

2% loss in chiller efficiency for every 1% of oil found in the refrigerant. It is not uncommon to find 10 percent oil in the refrigerant of older chillers.[5]</td></tr>
<tr><td>Leaks in the compressor in a low-pressure chiller. Any leak in the machine reduces airflow into the unit. Air collects in the condenser, blanketing tubes and displacing refrigerant vapor, resulting in higher condenser pressure and temperature.</td><td>Test compressors for leaks.</td><td>About 1 psi of air in a condenser equates to a 3 percent loss in chiller efficiency.[6]

6 to 8% efficiency loss at 60% load and 8 to 14% at full load.[7]

For every 1°F increase in condenser leaving temperature, energy consumption increases about 1.5%.[8]</td></tr>
</table>

Causes of Degraded Energy Performance in HVAC Equipment	HVAC Maintenance Solution	Estimated Impact on Chiller Energy Consumption
Rooftop Units[9]		
Economizer failure	Adjust a functioning economizer; repair a broken economizer actuator or a frozen damper.	14 to 40% energy savings.
Airflow problems	Measure airflow and compare to standards; correct as needed.	10% savings (much higher in laboratories, cleanrooms, vivariums and other environments with significant outdoor ventilation air requirements.)
Thermostat control problems, including improper thermostat settings, cycling fans during occupied periods, fans running continuously during unoccupied periods, improperly installed resistors, no nighttime setup or setback.	Check thermostat settings.	Up to 40% savings.
Sensor problems: Failed sensors, snap discs that cannot be calibrated or adjusted, broken wires.	Repair failed sensors.	Savings on the order of 40% percent if it enables a nonfunctioning economizer.
Suboptimal refrigerant charge	Check and adjust refrigerant charge as needed.	5-11% energy savings.[10]

BASIC COOLING SYSTEMS

Cooling System	Description
Once-Through Cooling System	In once-through cooling, water is pumped from a nearby source and passes only once through the system to absorb process heat. It is then discharged back into the original source.
Closed Recirculating System / Dry Cooling Tower	In closed recirculating systems or dry cooling towers, heat absorbed by the cooling water is either transferred to a second coolant or released into the atmosphere. Evaporation is not used in closed recirculating cooling towers. Instead, cool air rushes over a series of small tubes containing circulating coolant. Heat is transferred from the hot liquid inside the tubes to the cool air, resulting in cooling.
Open Recirculating System / Wet Cooling Tower / Evaporative Cooling Tower	Open recirculating cooling systems or wet cooling towers are the most widely used designs in industry. Just as in closed recirculating systems, the open system uses the same water repeatedly. Its most visible feature is the large, outdoor cooling tower that uses evaporation to release heat from the cooling water. Due to the mechanism, this type of cooling tower is also called an evaporative cooling tower. This system consists of three main pieces of equipment: the recirculating water pump(s), the heat exchanger(s), and the cooling tower.
District cooling	District cooling delivers chilled water to offices, shopping malls, apartments and other kinds of buildings that need indoor cooling. Through the district cooling network, the cooling plant pumps chilled supply water to buildings. The chilled water is fed into the individual buildings' cooling systems through a heat exchanger. When the water has

	cooled the building, it returns to the cooling plant at a higher temperature where it is chilled again and redistributed in a closed loop. The cold water used in a district cooling system can come from free sources such as seawater, or it can be produced from sources like waste heat with the use of steam turbine-driven or absorption chillers or electric chillers.

	Heat Pumps	Unitary Air Conditioners	A/C Chillers	Mobile Air Conditioning Equipment
Description	Reversible heat pumps capable of providing heating and cooling to buildings. Most commonly these use air source techniques though versions using other heat sinks are also available.	Air conditioning installations typically aimed at the market for smaller units, incorporates direct expansion (DX), ducted, packaged, and split systems.	Air conditioners aimed at large installations. The typical mode of operation is to cool water and then circulate it through a pipe network over which air blows to achieve cooling in the environment external to the chiller.	Car, train, and plane air conditioning systems. These systems are most often configured as direct expansion (DX) systems.
Cooling Temperatures	16-25°C	16-25°C	16-25°C	16-25°C
Cooling Power Range	Up to ~30kW	Up to ~30kW	Up to MWs	5kW
Typical End Users	Hotels, retail spaces, larger offices, and mixed-use buildings	Single-split systems: small offices, shops, cafés, and server rooms. Multi-Split System: restaurants, offices, doctor's surgeries, and shops.	Office buildings, retail sector, but also the health sector (e.g. hospitals), leisure and hotel sector	Car manufacturers (OEM, original equipment manufacturers)

INDUSTRIAL AND COMMERCIAL COOLING TECHNOLOGIES, APPLICATIONS AND END USERS

	Commercial Refrigeration	Industrial Refrigeration	Transport Refrigeration
Description	This category covers the type of equipment installed in restaurants and retail premises, including display cabinets and cold rooms.	Industrial refrigeration is most commonly used on farms, in food processing and pharmaceutical factories, and product distribution centers. The distinction from commercial refrigeration is its use for reducing, rather than maintaining, the temperature of products.	Trucks and vans carry small onboard refrigeration units so that they can maintain the temperature of goods they are transporting.
Cooling Temperatures	-1 to 5°C <-15°C	Product-specific 2-12°C Chilled -35 to -45°C for freezing <-18°C frozen storage	0°C & -20°C
Cooling Power Range	2-5kW	Up to hundreds kW	0.5 to 25kW
Typical End Users	Supermarkets, restaurants, retailers	Food processing, pharmaceutical factories, product distribution centers.	Retailers, logistics companies

DIFFERENT GROUPS OF REFRIGERANTS AND THEIR OZONE DEPLETION AND GLOBAL WARMING POTENTIALS (IPCC, 2007)

Substance group	Abbreviation	ODP	GWP	Example (refrigerant/foam blowing agent)
Saturated chlorofluorocarbons	CFC	0.6-1	4750-14,400	R11, R12
Saturated hydrochlorofluorocarbons	HCFC	0.02-0.11	77-2310	R22, R141b
Saturated hydrofluorocarbons	HFC	-	124-14,800	R32, R134a
Unsaturated hydrochlorofluorocarbons	u-HCFC	<0.001	0-10	R1233zd
Unsaturated hydrofluorocarbons	u-HFC	-	<1-12	R1234yf, R1234ze, R1234yz
Natural refrigerants		-	0-3	R744 (carbon dioxide) R717 (ammonia) R290 (propane)