BENDING THE CURVE

Cost-effective cooling emission reduction pathways for commercial real estate in China and the U.S.

Carbon Containment Lab

With support from:

Hang Lung Properties

LVMH

ACKNOWLEDGMENTS

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The Carbon Containment Lab is solely responsible for the findings and conclusions in this report, as well as any errors or omissions contained herein.

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All images courtesy of Hang Lung Properties unless otherwise noted.

Abbreviations

AC: Air conditioning

ACT: Alternative cooling technology

AEO: Annual Energy Outlook

AIM Act: American Innovation and Manufacturing Act

ANSI: American National Standards Institute

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BMS: Building management system

BREEAM: Building Research Establishment Environmental Assessment Method

CBECS: Commercial Buildings Energy Consumption Survey

CO_2e: Carbon dioxide equivalent

COP: Coefficient of performance

DAS: Data acquisition system

EIA: Energy Information Administration

EPA: Environmental Protection Agency

ERV: Energy recovery ventilator

GHG: Greenhouse gas

GWP: Global warming potential

HFC: Hydrofluorocarbon

HFO: Hydrofluoroolefin

HL: Hang Lung

HRV: Heat recovery ventilator

HVAC: Heating, ventilation, and air conditioning

IPCC: Intergovernmental Panel on Climate Change

IRR: Internal rate of return

kWh: Kilowatt-hour

LCCP: Lifecycle climate performance

LEED: Leadership in Energy and Environmental Design

LRM: Lifecycle refrigerant management

LVMH: Moët Hennessy Louis Vuitton

MT: Metric ton

$MTCO_2e$: Metric tons carbon dioxide equivalent (by GWP100)

MWh: Megawatt-hour

PDRC: Passive daytime radiative cooling

TCO: Total cost of ownership

TEWI: Total equivalent warming impact

VRF: Variable refrigerant flow

VSD: Variable speed drive

Executive Summary

Global cooling demand is expected to more than double by 2050, driven by climate change and economic development, leading to a dramatic increase in demand for refrigerants and electricity. At the same time, regulations are driving shifts to more climate-friendly refrigerants and cooling equipment. These realities will cause numerous challenges to building owners and operators, including refrigerant supply crunches and uncertain electricity prices.

Stakeholders need a better understanding of the size of the cooling sector's climate impact and of viable pathways to reduce the sector's emissions to navigate these coming challenges. The commercial real estate sector is a logical place to begin given its size, the climate commitments of many corporations, and its capability to affect significant emissions reductions.

This report represents a first-of-a-kind effort to quantify cooling-related emissions from commercial real estate and the economic viability of opportunities to abate them, providing a data-driven foundation for building owners, policymakers, and other stakeholders to develop effective mitigation pathways.

Commercial real estate cooling emissions are significant. Commercial real estate is a large and growing sector that includes offices, retail stores, food storage and sales, and various other types of properties. We estimate that commercial air conditioning and refrigeration in the U.S. and China are on track for **12.8 billion metric tons CO_2-equivalent (MTCO_2e) of greenhouse gas emissions between 2026 and 2060.** China represents 79% of these emissions, of which 77% are from electricity and 23% from refrigerants. The large volume of China's cooling emissions is due primarily to its population, growing cooling demand, and a coal-intensive electric grid. In the U.S., by contrast, emissions are roughly evenly split between direct refrigerant and indirect electricity emissions.

Economically attractive mitigation measures have the potential to reduce total cumulative commercial cooling emissions by 45%. We base this estimate on analyzing 18 measures and calculating the total impact achievable at a cost below 100 USD per MTCO_2e.

- This 45% represents 5.7 billion MTCO_2e of avoided emissions between 2026 and 2060, an amount just below the total 2022 emissions of the U.S.
- Of these avoided emissions, more than 65% are financially attractive, which we have defined as having an internal rate of return (IRR) above 8%.
- The two largest economically attractive measures are improving system controls and smarter maintenance and operations. Between the U.S. and China, implementing these measures could result in 1.4 billion MTCO_2e of avoided emissions and provide a present value of 178 billion USD in savings from 2026 to 2060.
- In China, energy efficiency measures comprise 57% of economically attractive abatement potential. Reducing emissions from air conditioning systems in small offices stands out as a large opportunity. However, policy and financial incentives will likely be needed to increase adoption.

- In the U.S., the reclamation of pure and mixed refrigerants is particularly impactful, with a potential impact of almost 500 million $MTCO_2e$, responsible for more than 45% of identified economically attractive abatement potential.

The implications of this study for building owners, policymakers, and other stakeholders are numerous.

1. **Size and location matter.** Local characteristics will ultimately determine which abatement opportunities among the 18 modeled will provide most impact for the stakeholders involved. Energy consumption patterns, in particular, are a major determinant for economic attractiveness.

2. **Savings require a system view.** Cooling happens in integrated systems where demand, loads, weather, building architecture, and equipment interact in complex ways. The largest and most financially attractive emission savings are achieved only from understanding and optimizing across this integrated system.

3. **Data and intelligence will point the way.** Operators need data to accurately respond to changing circumstances. Maintenance is most effective when responsive to measured performance and system conditions.

4. **We should consider heating and cooling together.** Cooling leads to waste heat, which is an often-overlooked resource for properties with simultaneous hot-water demands.

5. **Large properties can have outsized impact.** Emissions reduction opportunities are typically more financially attractive in large properties, and professionally managed properties tend to have better capabilities to implement these measures. These properties can show leadership by adopting new-generation equipment and using reclaimed gas in existing systems. Large properties can multiply their impact by engaging tenants and setting standards that incentivize them to do the same.

6. **The next ten years are critical—action now drives emissions for decades.** With large amounts of emissions-intensive equipment nearing the end of its life, a shift towards lifecycle refrigerant management (LRM) and new, cleaner equipment today could have a massive impact on emissions trajectories.

The commercial real estate sector has the potential to **nearly halve its cooling emissions through 2060**, meaningfully lessening global warming, cutting operational costs, and contributing to energy security. This report shows that the transition **can also be financially attractive.** Realizing this potential requires everyone—manufacturers, building owners, tenants, and regulators—to move decisively and work together. **The moment is ours to shape.**

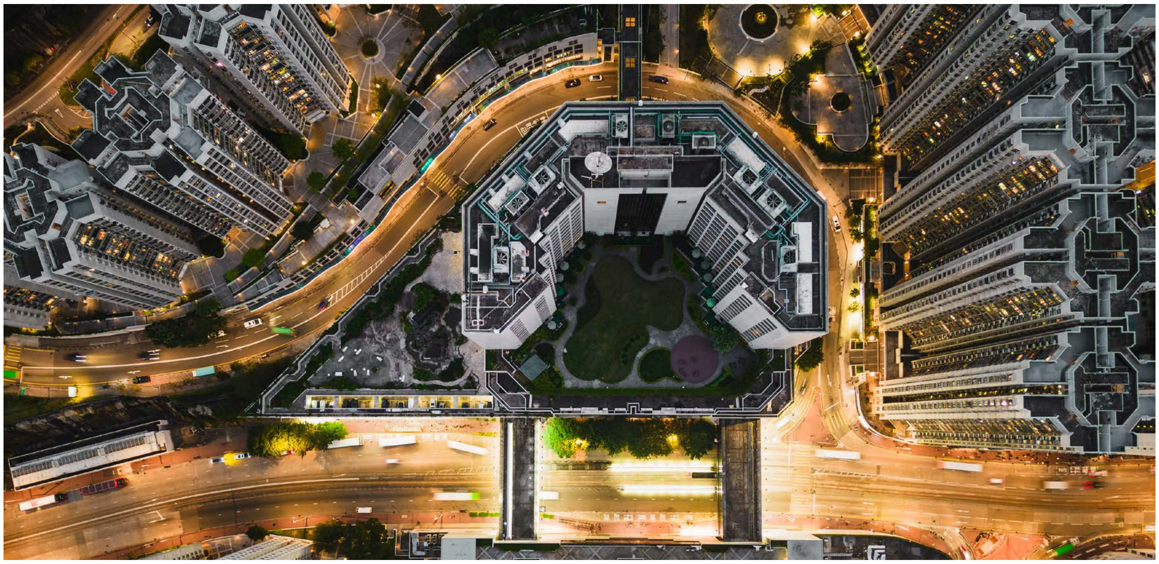
1. Introduction

Demand for cooling in residential, commercial, and industrial sectors is rising rapidly as global temperatures increase, heatwaves become more frequent, and cities trap additional heat. This growth has major implications for energy use, emissions, and building operational costs.

Cooling accounted for 15% of the increase in global energy demand from 2023 to 2024. The International Energy Agency projects that cooling electricity use could more than double from its 2025 level by mid-century.[1] This growth will have material effects on electricity and refrigerant prices, resulting in significant increases in cooling-related emissions and costs.

Direct emissions from refrigerant gases are also growing and poorly controlled. These gases, primarily hydrofluorocarbons (HFCs), have global warming potentials thousands of times higher than carbon dioxide (CO_2). Gases leak during equipment use, and people commonly vent them at the end of equipment life despite legal prohibitions. By some estimates, addressing these emissions through lifecycle refrigerant management (LRM) could help us avoid roughly 91 billion $MTCO_2e$ (metric tons of CO_2-equivalent) by 2100.[2] These reductions are possible in addition to what governments have already committed to under the Kigali Amendment to the Montreal Protocol, which mandates a phase down of the production and consumption of the highest-GWP gases and requires participating countries to develop national action plans for implementation.[3]

Despite strong existing policies, we still lack comprehensive data on refrigerant use, leakage rates, and lifecycle emissions. Cooling systems are decentralized, span many technologies and sectors, and operate under widely divergent geographies, climates, economic conditions, power systems, and regulatory regimes. The capacity to recover, reclaim, and destroy refrigerants is limited in many regions and virtually nonexistent in others, so we still do not understand the full financial and environmental footprints of these gases.



Regulators, manufacturers, building owners, investors, and consumers are increasingly motivated to take action, but uncertain as to where to start. For decision makers, translating environmental modeling into marginal abatement curves aligned with business decision-making is essential to show the economics and impacts of different options.

Commercial real estate is a large and dynamic part of the global energy and emissions profile. As of 2023, the building sector accounts for roughly 34% of global energy-related CO_2 emissions and more than 32% of global energy demand,[4] while cooling contributes about 2.7% of global energy-related CO_2 emissions and 3.2% of total greenhouse gas (GHG) emissions when direct emissions are included.[5]

This report develops a first-of-its-kind baseline model of cooling emissions in commercial real estate in the U.S. and China and provides a marginal abatement curve analysis of 18 mitigation measures. **It identifies no-regret actions, illustrates their implementation through case studies with differing payback periods, and discusses the implications of the results.** The report's aim is to help owners, tenants, policymakers, and investors integrate cost-effective cooling measures into investment and management decisions. This decision-making has the power to reduce emissions, stabilize costs, strengthen operational resilience, and secure energy and refrigerant supply.

Common Refrigerant Gases and their GWPs

The climate impact of different greenhouse gases is compared using their *global warming potential*, or GWP. GWP measures the total warming impact of a gas over a time period and compares it to the impact of CO_2, which by convention has a GWP of 1. Standard practice is to calculate GWP over a 100 year period. There are hundreds of refrigerant gases and blends in use; this table shows ten that are most used in commercial real estate.

Refrigerant	GWP Over 100 Years
R-717 (ammonia)	0
R-744 (CO_2)	1
R-454b	466
R-513a	573
R-32	677
R-134a	1,300
R-407c	1,624
R-22	1,760
R-410a	2,088
R-404a	3,922

2. Methodology and Scope

Methodology

This study builds on publicly available data on emissions associated with the commercial real estate sector. Given the holes in central data sources, we supplemented gaps or inconsistencies in data with interviews of experts and practitioners, and we continually validated model outputs to iteratively improve them.

Scope of the Study

This study covers electricity and refrigerant emissions from air conditioning and refrigeration in commercial real estate in the U.S. and China for the period between 2026 and 2060.

Commercial real estate encompasses a variety of activities, such as retail, offices, hotels, and mixed-use properties.

For air conditioning — commercial real estate includes all offices, buildings, retail outlets, restaurants, educational buildings, hospitals and other properties except for data centers.

For refrigeration — commercial real estate includes the cold chain and retail; but excludes transport cooling and industrial cooling.

We took a whole-building approach, and we did not use the categorization of scope 1, 2, and 3 emissions as stakeholders might do for GHG reporting purposes. We included electricity emissions, refrigerant leakage emissions (during both filling and maintenance), and vented emissions at equipment end-of-life.

Cooling-related GHG emissions arise through two channels:

Direct (refrigerants): refrigerant gases released during installation, servicing, operation, and end-of-life. Their warming potential makes them a significant share of total cooling emissions.

Indirect (energy): electricity used to move heat. Emissions depend on cooling demand, system efficiency, system operations, and the grid's carbon intensity.

The inclusion of all emissions sources enhances understanding of their relative importance. It also creates more accurate estimates of the economics for measures that affect both direct and indirect emissions and it allows for better understanding of trade-offs that sometimes occur between abatement measures.

Abatement Measures

We selected the abatement measures (Section 4) from literature and expert interviews with a focus on those that are plausible and quantifiable. Measures primarily focus on existing buildings, although many findings also apply to new buildings. Many measures collect more detailed specific actions—for example, integrated control improvements, or the multistep process of refrigerant reclamation.

Baseline Model Set-Up

Figure 1 shows a high level set-up of the baseline emissions model and its application to the abatement curves. Appendix I provides a more detailed list of the data sources and assumptions we used; with specific sources noted for the U.S. and China.

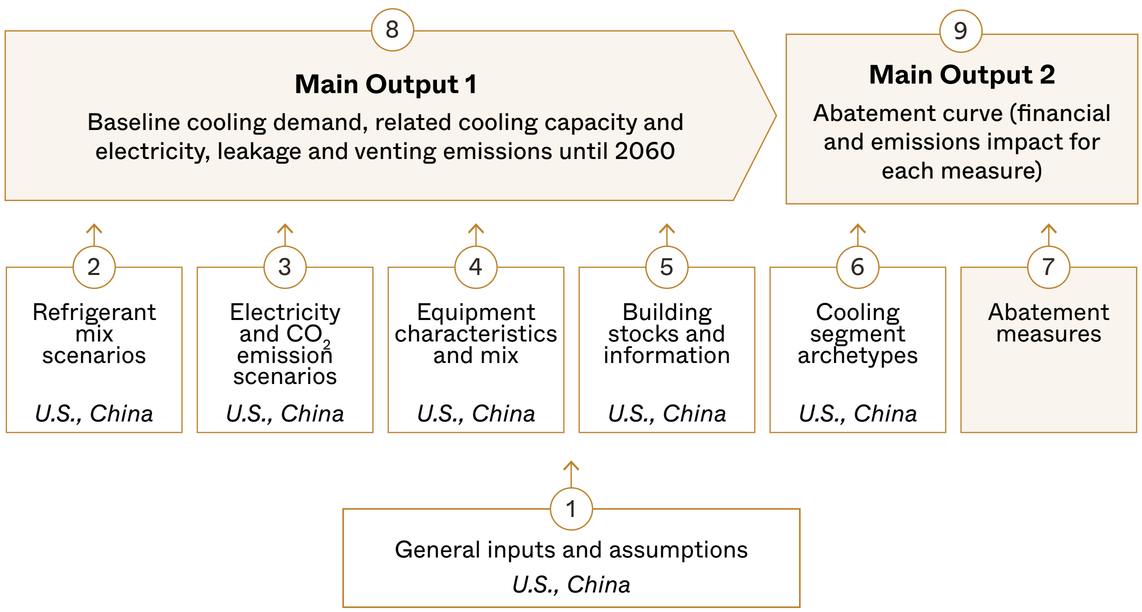


Figure 1: Overview of the model developed for this study. Numbering in the figure is for ease of reference with model specifics described in Appendix I, and does not imply sequentiality. Source: Carbon Containment Lab, 2026.

Marginal Abatement Curves

Combining the baseline model with cooling segment archetypes delineated by capacity, we then modeled the economic attractiveness of abatement measures and estimated the total impact the measures would have across the market. We present these in Section 5 of the report.

Marginal abatement curves are a common method for ranking and assessing measures to reduce carbon emissions. The height of the bars shows the economic efficiency of a measure, or the cost per $MTCO_2e$ abated. We use a hurdle rate (or discount rate) of 8% for financial analysis. The width of the bars shows the total achievable abatement of a measure. When the cost is negative, the hurdle rate is exceeded without putting any price on carbon: the measure pays for itself.

When calculating the economic attractiveness of measures, we aimed to include all significant impacts on operational and upfront costs, including capital investments, technician costs, refrigerant and electricity costs, and other fixed and variable costs. We do not consider other indirect impacts such as impacts of comfort on productivity in offices or visitation to malls due to the difficulty of quantifying such effects. In our evaluation of measures, we define economically feasible opportunities as those achieving abatement at a cost of less than 100 USD per $MTCO_2e$.

The cost per $MTCO_2e$ abated is, of course, only one of the many possible measures for evaluation. Economic risks or practical considerations can easily be more decisive. Abatement curves are nevertheless an effective method to graphically combine multiple economic and impact considerations into a single visualization and provide a robust starting point for decision-making. Given the paucity of information and research in this area, we believe that a marginal abatement curve is a substantial addition to conversations about emissions abatement.

3. Emissions Baselines in the U.S. and China

To provide a starting point for modeling abatement opportunities, as well as to offer insights into emissions sources, we developed a baseline model of direct and indirect cooling emissions. Our model covers the emissions from air conditioning and refrigeration in the commercial real estate sector from 2026 to 2060 in the U.S. and China. These emissions stem both from indirect electricity emissions (i.e., Scope 2), as well as direct refrigerant emissions from leakage during the equipment's lifecycle and venting at end-of-life (i.e., Scope 1 and 3).

We built the U.S. and China model based on projections of exogenous factors such as population growth and grid intensity, relevant regulations governing the cooling sector, and industry reports and projections. For more detail on inputs and assumptions, see Appendices I and II. In both the U.S. and China, we assume that by 2060 the transition to low-GWP refrigerants (GWP <700) and a zero emissions electric grid is nearly complete.

U.S. Baseline Emissions Model

In the U.S., annual commercial AC and refrigeration emissions decline until 2060, from 153 to 43 million MTCO_2e. Cumulatively, U.S. cooling emissions from 2026 to 2060 reach 2.7 billion MTCO_2e.

This amount approximately equals 2024 emissions from transportation and heavy industry in the U.S.[6] Figure 2 shows projected emissions at five year intervals from 2026 to 2060, while Figure 3 shows cumulative emissions by source over the same period.

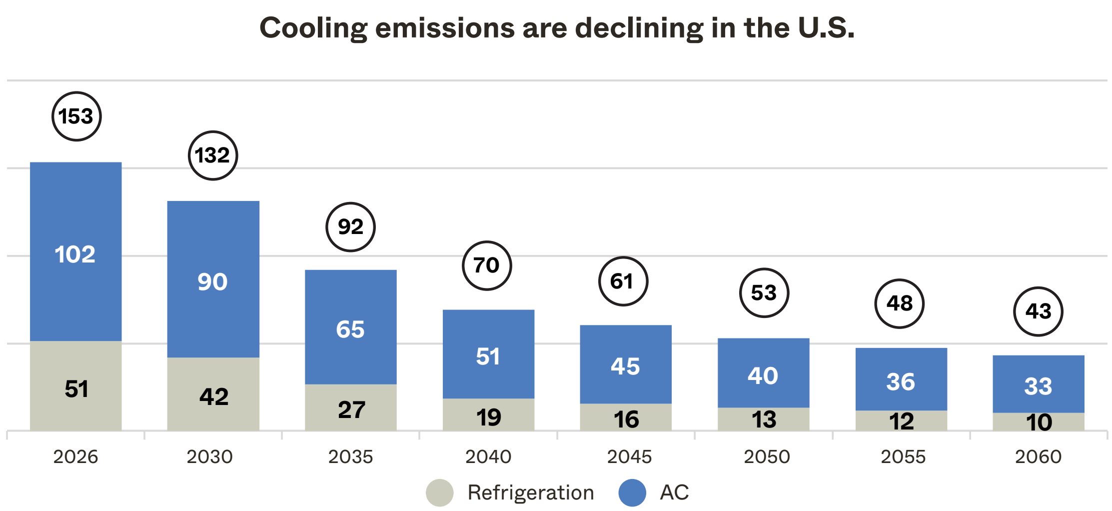


Figure 2: Annual projected U.S. cooling emissions in commercial real estate, from 2026 to 2060 (million MTCO_2e). Source: Carbon Containment Lab, 2026.

Refrigerant emissions are 53% of total cumulative emissions in the U.S.

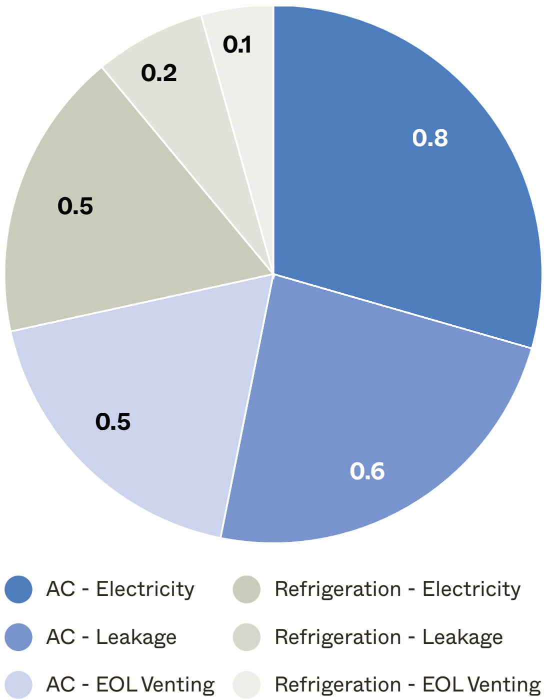


Figure 3: Cumulative cooling emissions by source in the U.S. commercial real estate sector, from 2026 to 2060 (billion $MTCO_2e$). Source: Carbon Containment Lab, 2026.

The U.S. baseline model indicates a rapid decline by 2040, driven by a grid that is decarbonizing and by the phase-out of high-GWP refrigerants under the AIM (American Innovation and Manufacturing) Act. This makes clear the importance of exogenous shifts to decision-making in this space.

Refrigeration represents 28% of cumulative total emissions, mostly due to indirect emissions (61%), while AC represents 72% of the total, with primarily direct emissions (59%). This difference, further discussed in sections 4 and 5, is a key to understanding abatement opportunities.

Direct emissions from leaks and end-of-life venting comprise a prominent part of the total emissions profile at 53%. Despite this important role, property owners, managers or tenants rarely consider these emissions. Leaks are also difficult to detect and measure, and although leakage means refrigerant needs to be replaced, this cost is typically small in comparison to electricity and other operating costs. However, this misses a significant financial effect: leakage lowers operating efficiency, increasing electricity costs. And with both refrigerant and electricity costs projected to rise in the coming decades, leaks will only increase in cost.

Avoiding end-of-life venting poses challenges as well, for a number of reasons. First, building owners have limited reporting responsibilities under the law, and they often consider these emissions to be out of their scope. Second, while venting is illegal under the Clean Air Act, enforcement poses difficulties. Third, a shortage of technicians trained to properly recover gases leads to difficulties even for savvy system owners.

We expect 74% of refrigerant emissions until 2060 to result from leakage from refrigerants (including blends) that have a total GWP of 700 or more, a cutoff chosen due to its presence as an upper bound for future technologies under the AIM Act. This occurs in spite of the fact that, measured by volume, refrigerants with GWP less than 700 comprise over 70% of cumulative stocks during the study period. As far as emissions are concerned, immediate shifts to lower GWP refrigerants may be more important than waiting until ultra-low (UL) GWP refrigerants and alternative cooling technologies (ACTs) become available.

Refrigerant emissions are dominated by medium to high-GWP HFCs in the U.S.

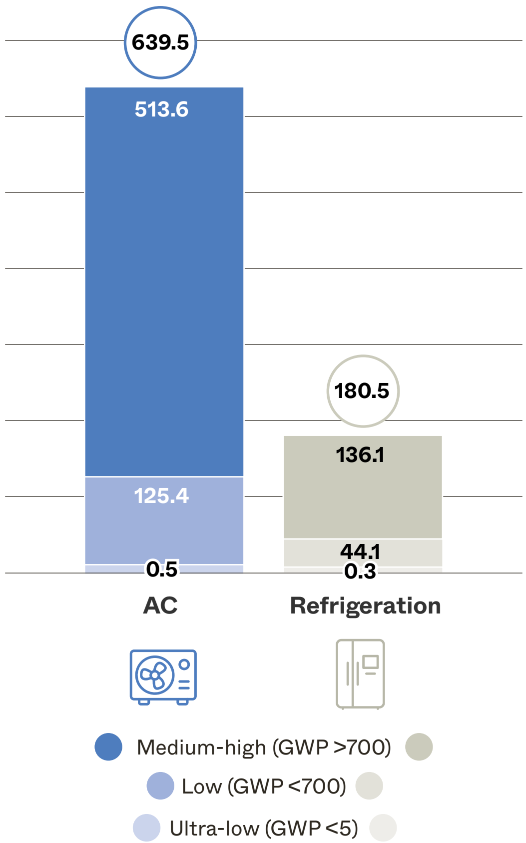


Figure 4: Cumulative emissions from refrigerant gases by GWP, in million MTCO$_2$e for refrigeration and air conditioning in the U.S. commercial real estate sector, from 2026 to 2060. Source: Carbon Containment Lab, 2026.

Small and medium offices comprise the bulk of AC emissions in the U.S.

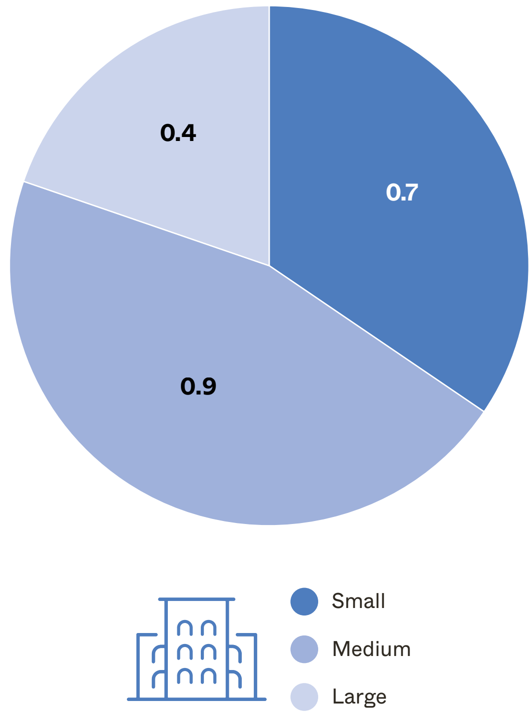


Figure 5: Cumulative air conditioning emissions by building size, in billion MTCO$_2$e, for the U.S. commercial real estate sector from 2026 to 2060. Source: Carbon Containment Lab, 2026.

We expect 80% of total U.S. AC emissions to come from small and medium offices with a surface area below 200,000 ft^2 (18,580 m^2) and a total cooling capacity below 1500 kW. This difference is partly driven by the largest properties tending to have higher-performing equipment and better energy management.

Emissions being weighted towards smaller properties poses several challenges for emissions reduction. Many abatement measures tend to be more economically attractive for large properties, and managers of large properties are also more likely to devote resources to improving energy and emissions performance. Smaller properties represent more decentralized decision-makers, requiring more action to achieve equivalent emissions reduction.

Supermarkets and small retail stores make up 72% of cumulative refrigeration emissions in the U.S.

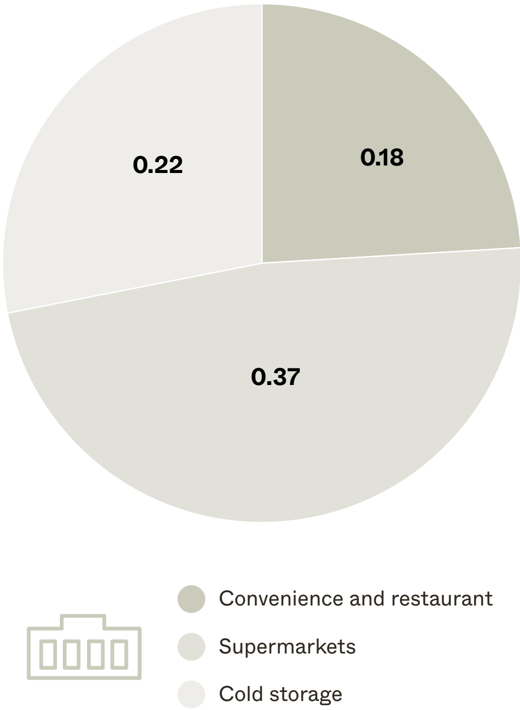


Figure 6: Cumulative refrigeration emissions by building type, in billion $MTCO_2e$, for the U.S. commercial real estate sector from 2026 to 2060. Source: Carbon Containment Lab, 2026.

In the U.S., supermarkets are responsible for 48% of refrigeration emissions, with convenience stores and restaurants accounting for another 24%. Food case leak rates are often estimated at around 25% a year, much higher than other sectors due to complex systems operating under pressurized conditions.[7] Moreover, due to the costly impacts of downtime on thin profit margins, many establishments find it challenging to perform large-scale maintenance which could improve efficiency or reduce leaks. The high emissions of food sales mean that for mixed malls and buildings that use relatively advanced AC systems, the supermarkets, restaurants, and convenience stores contained within them can have direct emissions from their refrigeration systems that exceed the total emissions of the rest of the building.

Image Credit: Shutterstock

China Baseline Emissions Model

In China, commercial cooling and refrigeration emissions peak in 2030 at 381 million $MTCO_2e$, then decline to 137 million $MTCO_2e$ in 2060. Cumulative emissions from 2026 to 2060 are 10.1 billion $MTCO_2e$, an amount slightly less than 2023 emissions from fossil fuel combustion in China.[8]

Emissions in China are much larger than in the U.S.: 241% as large in 2026 and 374% as large cumulatively from 2026 to 2060. Key factors driving this include a much larger population, a slower timeline under the Kigali amendment for phasedown of high-GWP refrigerants, and a more emissions-intensive electric grid.

Figure 7 shows baseline emissions until 2060 for all commercial real estate emissions in China, including electricity, leakage, and end-of-life emissions.

Cooling emissions are projected to peak around 2030 in China.

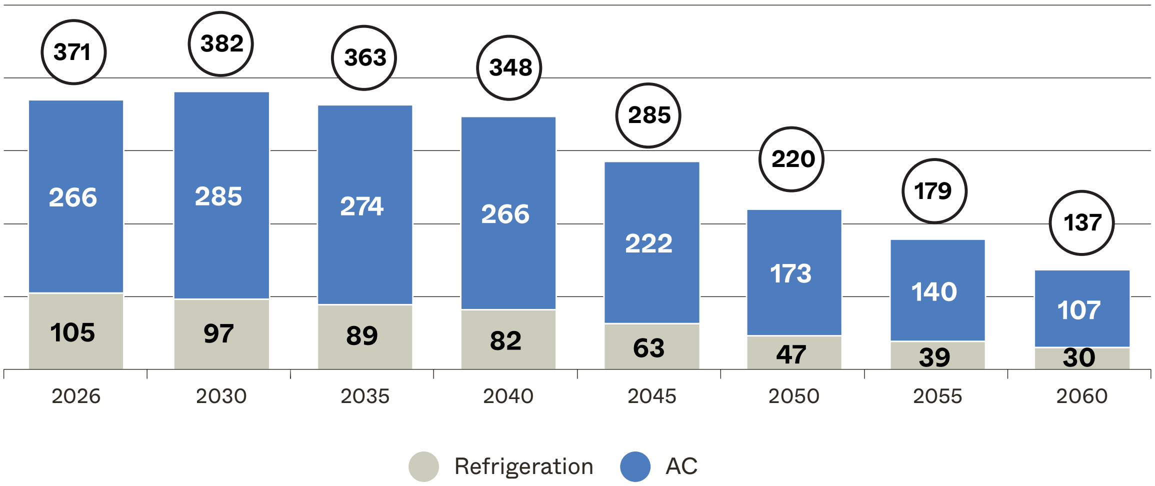


Figure 7: Projected cooling emissions in the Chinese commercial real estate sector, from 2026 to 2060 (million $MTCO_2e$). Source: Carbon Containment Lab, 2026.

Our modeling suggests that China's cooling emissions will peak around 2030. The near-term increase in emissions stems mostly from high growth in total cooling demand, associated with economic growth and increased AC penetration into the commercial sector. However, the declining emissions intensity of China's power grid soon begins to drive emissions down. In the refrigeration sector, emissions are already declining, with legacy refrigerants being replaced with lower GWP alternatives including natural refrigerants, and slow growth in the sector.

In contrast to the U.S., emissions are dominated by electricity. China's electricity grid continues to heavily rely on coal despite a rapidly growing renewables sector, leading to an emissions intensity almost 50% higher than that of the U.S.[9] Another reason for this is the relatively late growth of cooling access in China, leading to prevalence of newer refrigerants with lower GWPs, reducing the emissions impact of leaks.

Unlike the U.S., China does not have large databases around building sizes that we could easily link to equipment data. What is clear, however, is that smaller individual cooling systems with capacities below 70 kW dominate the market (>55% of capacity). This implies that larger office buildings often have many individual AC systems each serving smaller sections, instead of one large central chiller system with centralized management, something expert interviews confirmed. In such situations, the efficiency and economics of cooling system operations resemble that of small offices.

For refrigeration, the situation bifurcates even more strongly between smaller-scale retail and large-scale cold chain assets than in the U.S. Supermarkets, the largest sector by emissions in the U.S., account for only 5 to 10% of total emissions in China due to much smaller cooled and fresh sections. Fresh markets without cooling remain prevalent in less-wealthy cities, where it is common for goods to be sold at room temperature.

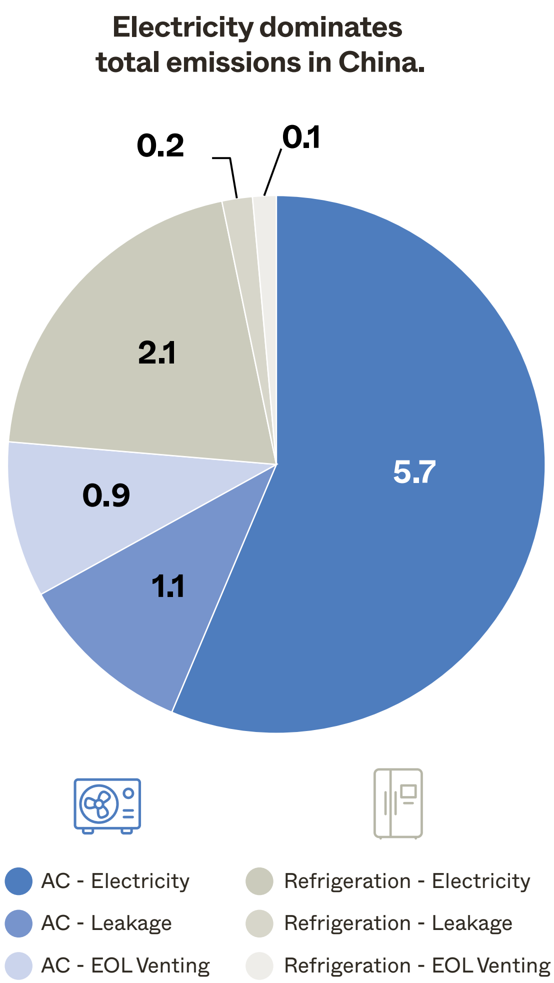


Figure 8: Cumulative cooling emissions by source in billion $MTCO_2e$ in the Chinese commercial real estate sector, from 2026 to 2060. Source: Carbon Containment Lab, 2026.

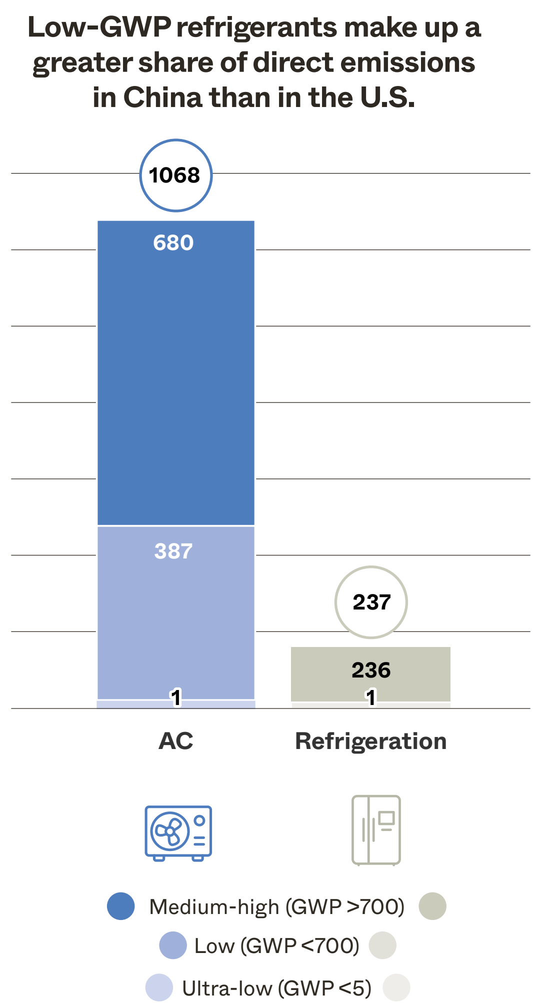


Figure 9: Cumulative cooling emissions from refrigerant gases by GWP, in million $MTCO_2e$ in the Chinese commercial real estate sector, from 2026 to 2060. Source: Carbon Containment Lab, 2026.

CASE STUDY 1:

Improving efficiency and air quality in City Center Mall, Central China

Chiller pump room in City Center Mall, Central China.

Overall Context

The City Center Mall* is a large (approximately 1,600,000 ft^2 or 150,000 m^2) enclosed retail complex opened in the 2010s in a hot-summer, cold-winter climate. Despite having well-designed mechanical systems, incomplete commissioning led to unstable controls, and all operations are fully manual, leading to high operating costs and electricity intensity. Building Analytics & Applied Research for Climate and Humans (BAARCH), an energy efficiency consultancy based in Shanghai, supported the building management in improvements.

The Challenge

The mall used multiple centrifugal chillers with cooling towers and constant-flow water pumps. Chillers were started manually based on return water temperature, pumps and fans ran at constant speed, and tower fans cycled based on simple thermostats. Air conditioning was provided by hundreds of air handling and terminal units, many designed for variable speed but operated at fixed output. The mall operated in full recirculation mode, reducing cooling costs at the expense of air quality.

Improvements and Impact

Improvements spanned four categories. First, **controls**: a restoration of the building management system, modulation of chilled-water flow for variable speed operation, and sensors to monitor chiller performance. Second, **maintenance**: replacing worn filters and cleaning coils, and adding differential-pressure taps. Third, **variable-speed retrofits**: installing variable-frequency drives on water pumps and cooling tower fans, and converting selected air handling units to variable speed. Fourth, **ventilation restoration**: restoring the existing heat-exchanger loop to provide free cooling during mild outdoor conditions and reopening fresh air dampers with outdoor pretreatment units.

Lessons

The mall's cooling inefficiencies stemmed not from a lack of equipment capacity but from the absence of control systems. Many advanced design features, such as the BMS and condition-based maintenance functions, were never used because of faulty installation and commissioning. The upgrades described provided total energy savings of 20 to 30% and have individual payback periods of 3 to 8 years. Additionally, noticeable improvements to indoor conditions came from more consistent temperatures, improved humidity control, and fresher air.

* The name of the mall and certain identifying characteristics have been altered for confidentiality.

4. Mitigation Measures

There are many ways in which emissions from cooling commercial real estate can be mitigated. This section describes each of our abatement measures and the scope under which it was considered. For more information, including context and discussions on each of these measures, see Appendix III.

We group these measures into the following four categories:

- **A. Lifecycle Refrigerant Management** (this is akin to the "fuel")
- **B. Cooling Equipment Upgrades** (this is akin to the "engine")
- **C. Reduced Primary Cooling Load** (ways to reduce overall "demand" for cooling)
- **D. Cooling System Management** (improvements that affect the "system" as a whole)

We developed the list of measures by reviewing literature of relevance to the sector, including standards such as LEED, BREEAM, and LVMH's LIFE in Architecture, then refined these measures with the help of cooling and commercial real estate experts. We excluded several plausible measures from the marginal abatement curve analysis due to lack of information published on their performance and capabilities or commercial availability: for example, alternative cooling technology (ACT) opportunities, desiccant wheels, and secondary glycol loops for supermarket / large convenience store refrigeration. *See the "Watch This Space: Innovative Alternative Cooling Technologies" box on page 38 for a discussion of this new and upcoming class of cooling technologies.*

CATEGORY A.

Lifecycle Refrigerant Management

This category includes mitigation measures related to the existing stock of refrigerants utilized in AC and refrigeration systems, which serve as the "fuel" for cooling equipment. Broadly, they relate to Lifecycle Refrigerant Management (LRM), a comprehensive approach to mitigating downstream refrigerant emissions by recovering refrigerant during servicing and at end-of-life and subsequently recycling, reclaiming, or destroying it.[10]

Measure Name	Definition and Scope
1. Recover & recycle refrigerants on-site	In most cases, refrigerant gas recovered during calibration or at the end-of-life can be cleaned and stored on-site. Through the recycling process, used refrigerant gases undergo a basic, on-site cleaning process and can be stored to be reused later in the same or similar equipment.
2,3. Recover & reclaim pure and mixed refrigerants	Reclaiming refrigerant is distinct from both recovered and recycled gas. Refrigerant recovered from equipment can be sent to a licensed reclamation facility, where it is reprocessed to meet similar purity standards of new refrigerants. Used refrigerant gas is cleaned and, in the case of mixed refrigerants, separated into original components before being recombined and sold to be reused later as "certified reclaimed" gas. Note that since reclaiming *mixed* refrigerants is more expensive and involves more potential losses than pure gases, the two are treated as separate measures on the marginal abatement curves.
4. Recover & destroy refrigerants	In some cases, mixed refrigerant gases recovered during servicing or at end-of-life cannot be recycled or reclaimed due to excessive contamination or a lack of reclamation facilities. In such cases, the recovered refrigerants should be sent to certified destruction facilities rather than released. Destruction involves breaking the chemical bonds of the refrigerant, leading to decomposition or conversion into stable compounds.
5. Use "drop-in" lower GWP refrigerants	In certain cases, existing systems can be retrofitted to substitute high-GWP refrigerants with lower-GWP "drop-in" refrigerants (e.g., substituting R-410A with R470A) along with necessary equipment upgrades or modifications.[11] (See Appendix II.)

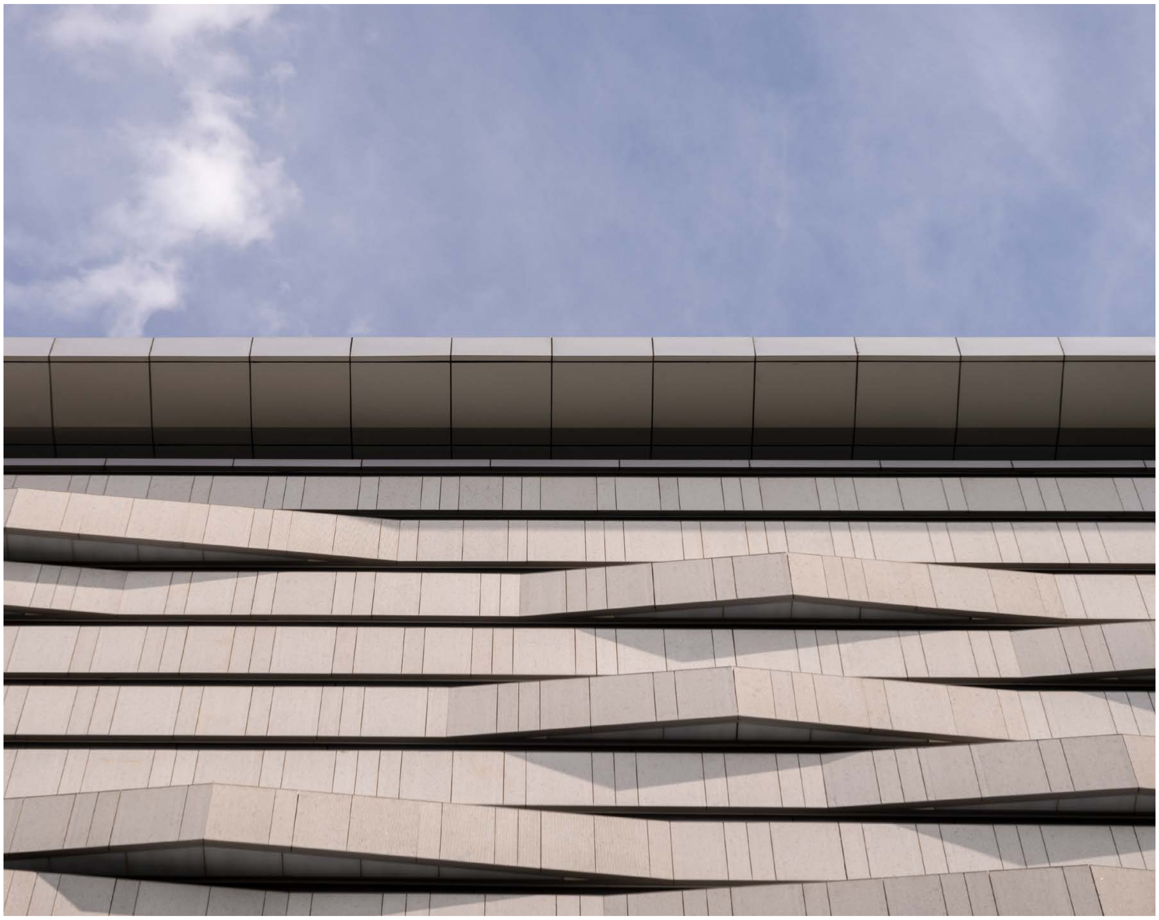
CATEGORY B.

Cooling Equipment Upgrades

This category encompasses mitigation measures targeting the equipment package, specifically the compressor, which functions as the "engine" performing the cooling process. The measures upgrade or enhance certain aspects of equipment to increase efficiency and performance and/or to decrease reliance on high-GWP refrigerants.

Measure Name	Definition and Scope
6. Upgrade to lower GWP refrigerant equipment	Cooling equipment can be directly upgraded to use low-GWP alternatives like hydrofluoroolefins (HFOs), R-717 (ammonia), R-744 (CO_2), R-290 (propane), and R-600a (isobutane); leapfrogging the intermediate step of using medium-GWP refrigerants such as R-32, R-454B, and R-466A. Generally, the path to ultra-low-GWP equipment appears to be harder for AC than for refrigeration where it is being adopted more quickly.
7. Conduct smart equipment maintenance and calibration	This measure covers a wide range of maintenance activities, including leak detection and testing (e.g., using nitrogen pressure testing or electronic detectors), system recommissioning, recalibration, minor equipment repairs, integration with building management systems (BMS), and data acquisition systems (DAS). Equipment efficiency declines over time due to refrigerant losses, mechanical degradation, and thermal fouling. Seasonal load changes further require continuous adjustment of control parameters. While operators can perform basic adjustments, technicians can carry out deeper diagnostics and more precise calibration during service visits. Proper calibration can improve system efficiency by double-digit percentages and, for larger systems, quickly pay for itself. In addition, regular inspections and early fault detection help prevent breakdowns, refrigerant leakage, and costly repairs following more severe failures.
8. Install sensors to detect leaks in compressors	Additional instruments for detecting leaks can be installed either directly within the compressor or externally in the compressor room housing the unit, or near refrigerant lines. These systems provide immediate monitoring of refrigerant loss.

Measure Name	Definition and Scope
9. Use best practice equipment installation and calibration	Best-practice installation measures reduce later leaks and inefficiencies. Measures include using low-permeability hoses and fittings, ensuring proper pipe installation and insulation, performing high-quality leak and commissioning tests (including pressure and duration checks), accurately and fully charging equipment with refrigerant, and testing the system under normal operating conditions.
10. Upgrade to higher coefficient of performance (COP) cooling equipment	Options for equipment upgrades to increase COP include: incorporating Variable Speed Drives (VSDs), optimizing heat exchanger size, incorporating additional heat recovery methods, and implementing advanced instrumentation and controls to improve energy efficiency.



CATEGORY C.
Reduced Primary Cooling Load

This category focuses on the mitigation measures that reduce primary cooling load or "demand" before the cooling process takes place. Reducing the primary cooling load has the dual benefit of improving energy efficiency and lowering the demand for refrigerants.

Measure Name	Definition and Scope
11. Establish higher cooling set-points	Raising indoor cooling setpoints by even a small amount—such as 2 to 3 °C above current standards—can significantly reduce energy consumption and associated emissions. For instance, increasing setpoints from 72 °F (22 °C) to 77 °F (25 °C) can, in some cases, lower cooling energy demand by almost 30%. When supported by proper ventilation and humidity control, occupant comfort is not compromised.[12]
12. Increase isolation, shading, reflection	Measures to reduce heat gain and improve the thermal performance of buildings include: installing additional window panels or shades, applying reflective foils or low emissivity films, adding shading devices, and passive daytime radiative cooling (PDRC) coatings that emit heat to the sky[13] and improving overall insulation. These upgrades to the building envelope help block or reflect solar radiation, thereby lowering indoor cooling loads.
13. Install heat exchanger between incoming and outgoing air	Installing a heat exchanger between incoming and outgoing air—typically through a Heat Recovery Ventilator (HRV) or Energy Recovery Ventilator (ERV)—allows buildings to capture thermal energy from exhaust air and transfer it to the fresh air supply. This process reduces heating and cooling loads by pre-conditioning the incoming ventilation air.[14]
14. Install occupancy sensors for lighting systems	Occupancy sensors automatically control lighting based on the presence or absence of people in a space. By turning off or dimming lights when areas are unoccupied, these systems reduce electricity consumption and lower internal heat gains, which in turn reduces the load on cooling systems.[15]
15. Transition from open to closed refrigerated displays	Open refrigerated display cabinets—commonly multi-deck "reach-in" coolers—can be retrofitted into closed cases by adding transparent glass doors or lids. This modification significantly reduces the exchange of cold air with the surrounding space, improving energy efficiency by lowering compressor load and decreasing overall cooling load.

CATEGORY D.
Cooling System Management

This category encompasses mitigation measures related to the entire air conditioning and refrigeration system—including the ducts, pipes, fans, cooling towers, and heat exchangers distributed throughout the property—as well as the data-enabled control and management of the overall system including behavioral changes and management measures.

Measure Name	Definition and Scope
16. Implement intelligent, data-driven controls	With the help of advanced instrumentation, software, and analytics, inefficiencies can be detected, demand predicted, and cooling supply optimized via flow control in valves and pumps. These instruments provide high-resolution data across the system, including temperatures in conditioned spaces and refrigerated enclosures, as well as outdoor temperatures for energy-efficient evaporator control or smart ventilation. Example sub-measures include: leak prognostics (forecasting potential refrigerant leaks), enhanced refrigerant inventory management, and deployment of Internet of Things (IoT)-enabled sensors. These elements are typically integrated into BMS for centralized control and optimization, reducing refrigerant losses and improving system performance.
17. Enhance management & operator skills	The skills of building operators and managers for managing complex cooling systems in commercial buildings are key to ensuring that short-term and long-term system needs and maintenance actions are performed.
18. Upgrade system hardware	System hardware upgrades include better insulation and optimization of pipes and ducts, installing larger and more efficient evaporators and fan units, adding coatings to reduce fouling, installing air curtains where none exist, and adding doors in place of air curtains to improve thermal insulation of exits and entrances.

Measure Name	Definition and Scope
19. Combine cooling with hot water/heat delivery* *Note that this measure is excluded from marginal abatement curve analysis, as impact is extremely site-specific.	This measure focuses on replacing existing fossil-fuel boilers with Air Source Heat Pumps (ASHP) that cool the air and provide hot water or Water Source Heat Pumps (WSHP) that provide chilled water and hot water. These technologies share the ability to deliver useful energy on both sides of the heat pump—the source and the sink—simultaneously. Through this measure, waste heat from the cooling system is captured and reused to meet building or facility hot water and heating demands, reducing reliance on natural gas or other conventional heat sources.

CASE STUDY 2:

Supermarket refrigeration system upgrade in Ohio, U.S.

A refrigeration display in Baltimore, Ohio. Image Source: Clarence Cardwell, Inc.

Overall Context

A 25,000 ft^2 (2,323 m^2) IGA supermarket in Baltimore, Ohio, had open displays for its fresh food, including produce, baked goods, and deli products. For supermarkets, prepared fresh foods are important contributors to profitability, commanding margins of 30 to 50%, compared to average supermarket margins of 2 to 5%. Spillage and product expiration, however, remain major challenges in this category.

The Challenge

This supermarket used open display cabinets for its fresh products. Open displays, used in 70 to 80% of supermarkets in the U.S., provide easier access but also accelerate spoilage. The owner, supported by consultancy J. Vidal Associates, decided to upgrade the system by placing fresh products behind closed glass doors and modernizing the central compressor. Placing fresh products behind doors is already common in Europe, and some American chains are moving in this direction.

Improvements and Impact

Replacing the refrigeration system and display cabinets reduced energy consumption by about 80% and the emissions footprint by more than 90%. The largest contributor to these savings came from the display cabinets, whose energy use declined by almost 90%, some of which was offset by additional air-conditioning demand. A second major source of improvement was the upgrade of the compressor system and refrigeration rack, featuring more responsive controls, higher system stability, and reduced leakage. Emissions savings also came from replacing R-404a (GWP ≈ 3,900) with R-448a (GWP ≈ 1,300) and reducing leak rates from 25% to 10%. The total investments required for these upgrades was around 800,000 USD. Preliminary financial results, based on the first year of operation with the new system, indicate a payback period of seven years from future energy savings. When reduced spoilage, increased sales, and a government grant which covered 50% of the initial investment are included, the return improves from near break-even to an ROI of 11%.

Lessons

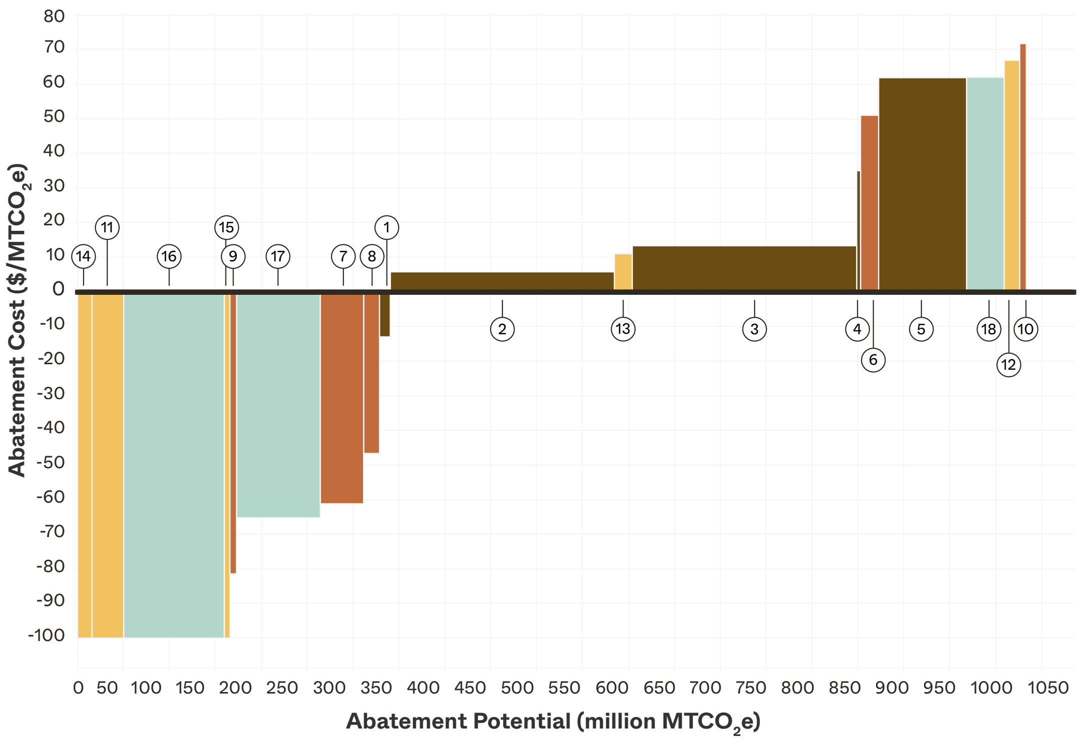
Investments in energy-efficiency upgrades can have enormous impact and be financially attractive. However, they often require substantial initial outlays, which can be difficult to justify for small stores. Incentive programs, government grants, or favorable loans can play a decisive role in these decisions.

5. Key Results

U.S. Abatement Opportunities

How to read this chart: This marginal abatement curve shows the potential for abatement and cost per $MTCO_2e$ abated of each abatement opportunity. The width of each bar corresponds to potential abatement. The height corresponds to cost, with bars below the x-axis providing cost savings and those above the x-axis requiring positive investment.

U.S. Marginal Abatement Cost Curve



Category A:
Lifecycle Refrigerant Management ("fuel")

1. Recover & recycle refrigerants on-site
2. Recover & reclaim pure refrigerants
3. Recover & reclaim mixed refrigerants
4. Recover & destroy refrigerants
5. Use 'drop-in' lower GWP refrigerants

Category B:
Cooling Equipment Upgrades ("engine")

6. Upgrade to lower GWP refrigerant equipment
7. Conduct smart equipment maintenance and calibration
8. Install sensors to detect leaks in compressors
9. Use best practice equipment installation and calibration
10. Upgrade to higher COP cooling equipment

Category C:
Reduced Primary Cooling Load ("demand")

11. Establish higher cooling set-points
12. Increase isolation, shading, reflection
13. Install heat exchanger between incoming and outgoing air
14. Install occupancy sensors for lighting systems
15. Transition from open to closed refrigerated displays

Category D:
Cooling System Management ("system-wide")

16. Implement intelligent, data-driven control
17. Enhance management & operator skills
18. Upgrade system hardware

Figure 10: Marginal abatement curve for measures that reduce cooling-related emissions in the U.S. commercial real estate sector, from 2026 to 2060 (million $MTCO_2e$). Source: Carbon Containment Lab, 2026.

The two largest opportunities that show a negative abatement cost in the U.S. are intelligent controls (measure 16) and better behavior and maintenance (measure 17). These two opportunities combine many steps properties can take to manage their operation and maintenance in response to the needs and demands of the system. This can lower total energy consumption and improve compressor performance, indirectly improving system quality and reducing leakage. The other two large opportunities that stand out by size are the reclamation opportunities for pure (measure 2) and mixed (measure 3) refrigerants. These opportunities have a positive cost, but due to the high climate impact of refrigerants, would have an estimated cost per $MTCO_2e$ abated of only 10 USD.

Another notable finding is how many opportunities have a small estimated total impact (i.e., the bars are relatively narrow). One reason for this is that some measures resulting in greater abatement require upfront investments that pay back over very long periods, making the IRR too low to be considered by the small properties that constitute a major share of total emissions. This is the case for opportunities such as system upgrades, higher COP equipment (measure 10), additional shading (measure 12), and the addition of a heat exchanger (measure 13).

LRM measures comprise 58% of economic emissions reduction potential in the U.S.

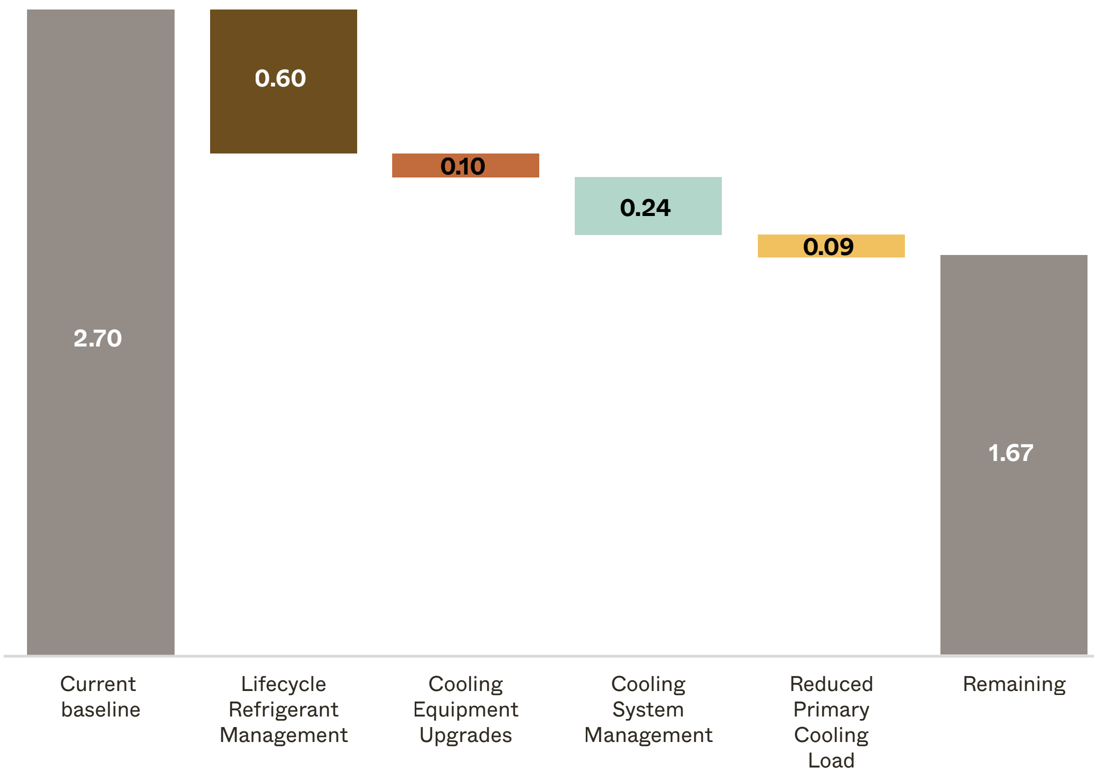


Figure 11: Cumulative 2026 to 2060 emissions (billion $MTCO_2e$) reduction potential from economically feasible abatement opportunities, by category, for cooling in the U.S. commercial real estate sector. Source: Carbon Containment Lab, 2026.

We define measures as *economical* when they provide abatement at a cost of less than 100 USD/$MTCO_2e$. The total identified economical reduction potential in the U.S. is 1.03 billion $MTCO_2e$, roughly 38% of the total cumulative emissions until 2060, a significant number given that we focused only on abatement achievable through retrofits. Figure 11 shows the impact by category of measure.

In the U.S., electricity emissions account for 41% of emissions reduction potential, with the rest due to refrigerant emissions. This stems in part from the fact that refrigerant emissions can, in principle, be reduced by 80 to 90%. Electricity emissions, by contrast, link to operations, creating physical limitations to the maximum efficiency systems can achieve. The second major category of economical abatement involves improvements at the system level through smarter and more data-driven operations and maintenance (measure 17). Meanwhile, demand as a category delivers less total improvement opportunity because a building's demand for cooling is difficult to change after construction: improvements via retrofit are typically very costly. New buildings can make greater use of these measures to reduce their cooling demand.

One central challenge for assessing the economic attractiveness of opportunities is dependence on the specific type and size of property. In Figure 12, we show abatement potential by small, medium and large property categories for both AC and refrigeration. This analysis indicates that the economics of upgrades typically worsen for smaller properties. With relatively low utility costs and high labor costs for smaller facilities in the U.S., the number of possible interventions that have a positive IRR is somewhat limited.

Some of evaluated abatement measures are uneconomic in smaller properties.

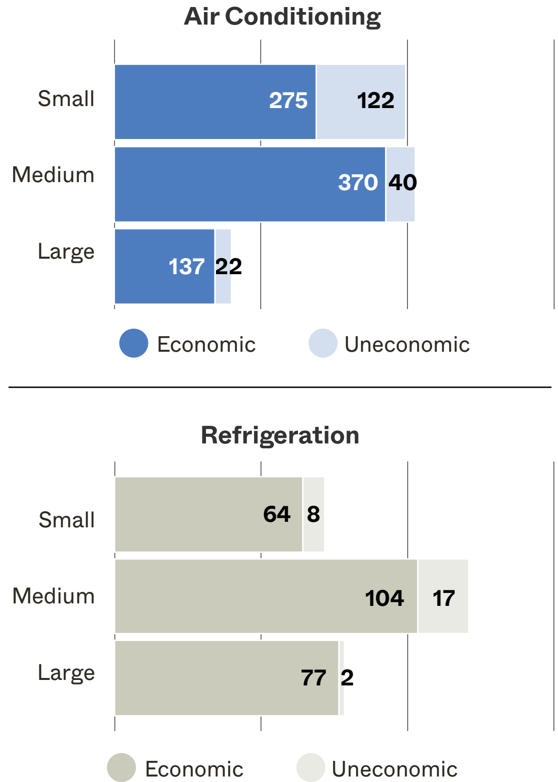


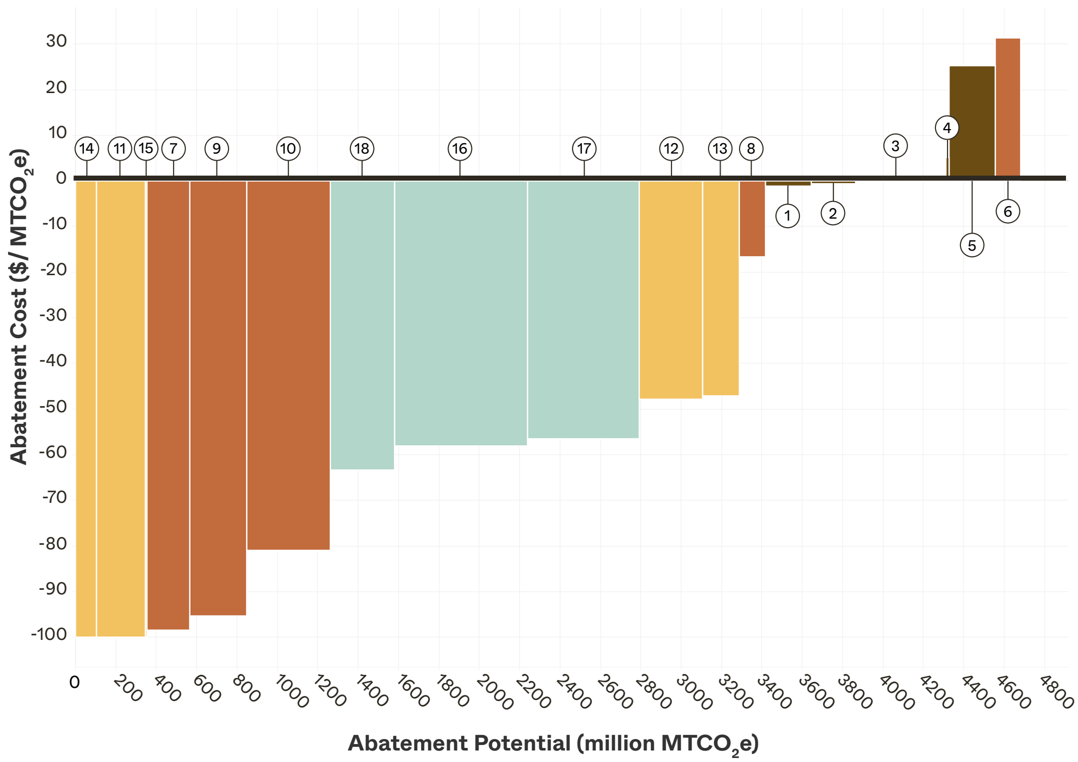
Figure 12: Cumulative (2026 to 2060) potential abatement in million $MTCO_2e$ that falls under economic (positive IRR) and uneconomic opportunities, by category and facility size. Source: Carbon Containment Lab, 2026.

5. Key Results

China Abatement Opportunities

How to read this chart: This marginal abatement curve shows the potential for abatement and cost per $MTCO_2e$ abated of each abatement opportunity. The width of each bar corresponds to potential abatement. The height corresponds to cost, with bars below the x-axis providing cost savings and those above the x-axis requiring positive investment.

China Marginal Abatement Cost Curve



Category A:
Lifecycle Refrigerant Management ("fuel")

1. Recover & recycle refrigerants on-site
2. Recover & reclaim pure refrigerants
3. Recover & reclaim mixed refrigerants
4. Recover & destroy refrigerants
5. Use 'drop-in' lower GWP refrigerants

Category C:
Reduced Primary Cooling Load ("demand")

11. Establish higher cooling set-points
12. Increase isolation, shading, reflection
13. Install heat exchanger between incoming and outgoing air
14. Install occupancy sensors for lighting systems
15. Transition from open to closed refrigerated displays

Category B:
Cooling Equipment Upgrades ("engine")

6. Upgrade to lower GWP refrigerant equipment
7. Conduct smart equipment maintenance and calibration
8. Install sensors to detect leaks in compressors
9. Use best practice equipment installation and calibration
10. Upgrade to higher COP cooling equipment

Category D:
Cooling System Management ("system-wide")

16. Implement intelligent, data-driven control
17. Enhance management & operator skills
18. Upgrade system hardware

Figure 13: Cumulative (2026 to 2060) emissions reduction potential from economically feasible abatement opportunities, by category, for cooling in the Chinese commercial real estate sector. Source: Carbon Containment Lab, 2026.

A few key findings emerge from this curve. First, 47% of emissions can be abated at below 100 USD/$MTCO_2e$, compared to 38% in the U.S. Second, as in the U.S., the two largest negative-cost opportunities are intelligent controls and smart maintenance—system measures that can have an impact across the cooling system by improving load management and increasing operational efficiency. Third, given China's relatively low refrigerant emissions, LRM is less prominent as a measure, although still attractive. One key policy difference from the U.S. is that recovered gas can be resold without reclamation and recertification in China.

More abatement opportunities appear on the left side of this curve than the U.S. curve, delivering positive financial returns. The main driver for this is that the cost of implementation of opportunities in China is far lower than in the U.S. Labor and equipment typically costs 50 to 80% less in China than in the U.S., in contrast to electricity cost which is only 30% lower. This renders the payoff from energy savings much larger in relative terms, making energy-saving opportunities that are financially unattractive in the U.S. compelling in China. Although we did not include subsidy and incentive programs in our modeling, cooling retrofit projects can qualify for support under China's Special Fund for Ecological Civilization Construction,[16] making them even more attractive.

As we show in Figure 14, cooling system measures have the highest potential impact, with all other categories also representing significant potential.

All categories show significant potential for economic emissions reduction in China.

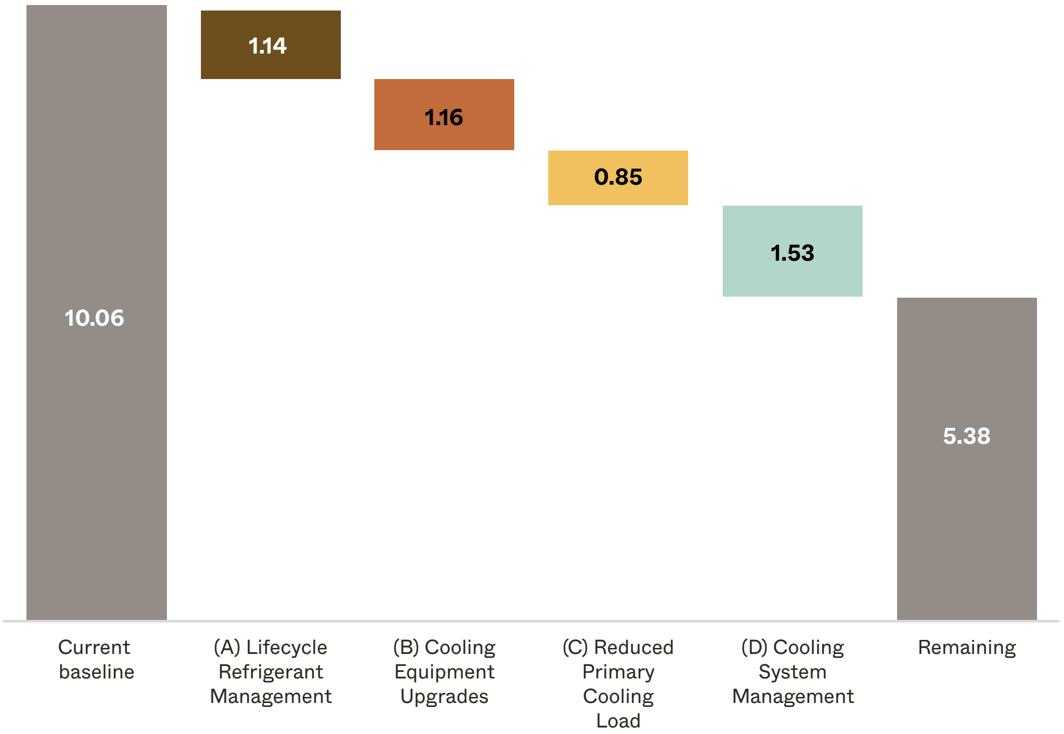


Figure 14: Cumulative 2026 to 2060 emissions (billion $MTCO_2e$) reduction potential from economically feasible abatement opportunities, by category, for cooling in the Chinese commercial real estate sector. Source: Carbon Containment Lab, 2026.

Avoided leakage emissions account for a majority of potential abatement in China.

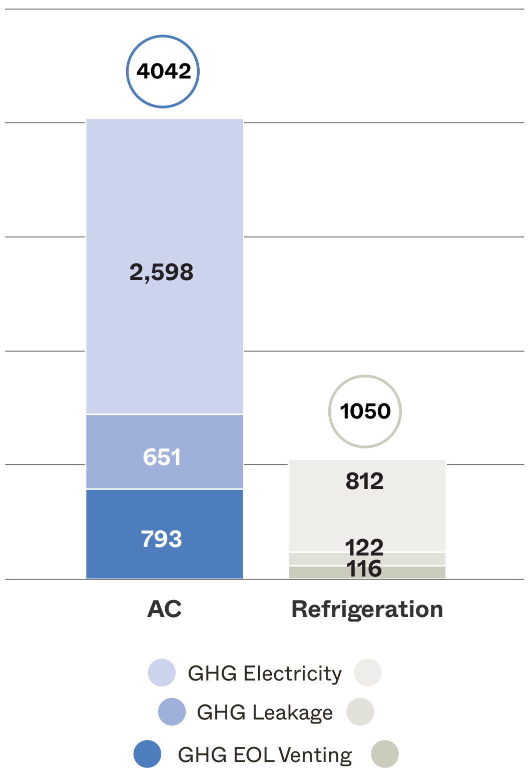


Figure 15: Cumulative 2026 to 2060 emissions reduction potential from modeled abatement measures. Source: Carbon Containment Lab, 2026.

While 57% of total economical abatement potential is due to measures focused on improving energy efficiency, other measures also reduce electricity demand, leading to indirect emissions representing 77% of total economical abatement potential, a much higher value than in the U.S.

Implementation of these measures will inevitably face familiar obstacles in the real estate sector, particularly for smaller buildings. Misaligned incentives between owners and tenants, demands for short payback periods, and limited cash availability all pose challenges. China's struggling property market, where high vacancy rates and falling prices make owners even more reluctant to invest, further compound these factors.

China's Opportunity in Smaller Offices

China's small-scale commercial building sector offers a significant opportunity to reduce cooling-related energy use and emissions. This segment uses many inefficient split units with poor controls, often in buildings with limited insulation and poor air-tightness. The measures we describe in this report could abate 1.5 billion $MTCO_2e$ in this sector over the study period—an amount that exceeds all opportunities for AC and refrigeration in the U.S. The necessary technical and operational solutions are widely available. However, barriers such as misaligned incentives between owners and tenants, short payback expectations, and limited capital access need to be addressed. Green finance facilities, government and utility incentives, and retrofit subsidy programs could accelerate adoption.

CASE STUDY 3:
Integrating cooling and heating

Overall Context

The Conrad Shenyang is a five-star, 315-room hotel located in the city center of Shenyang, one of northeast China's largest metropolitan areas which is in a cold-winter, hot-summer climate. The high-end hotel is part of a mixed-use high-rise complex opened in 2019.

The Challenge

The hotel faces high operational energy costs from space cooling, domestic hot water, and swimming pool heating. A centralized chiller provided cold water for summer air conditioning, and gas-fired boilers provided hot water, with no heat recovery between them despite usage often occurring simultaneously.

Improvements and Impact

In 2022, consulting company NECreat retrofitted the system, completing work within 120 days. Measures included: installing heat recovery between the hot water delivery and hotel air conditioning, decentralizing systems to reduce transmission losses and pumping costs, and installing new control systems. Separate air source cooling was added for the machine room and this system connected to hot water delivery as well. The result is a seamless year-round system that simultaneously produces hot water and cooling, eliminating the need for gas boilers during the nine-month cooling season.

Between July 2022 and February 2023, the system produced 1.14 GWh of heating and 0.59 GWh of cooling using 0.305 GWh of electricity, achieving an overall combined system COP of 5.67. Compared to a 2019 baseline, energy costs were reduced by 72%, even as occupancy rates and electricity prices increased. This saved the hotel RMB 1.68 million (236,000 USD) and avoided an average of 40 $MTCO_2e$ per month. The payback period for the retrofit was less than three years.

Lessons

Heat recovery and system integration can deliver substantial energy and emissions savings in large commercial buildings, especially those with concurrent heating and cooling demands in mixed climates. For hotels, leveraging internal synergies is often the largest opportunity to reduce both costs and emissions. Even in newer buildings, refining commissioning and system design can yield returns comparable to investing in new equipment.

Image Source: Harald Kumpfert

6. Implications of the Study

This analysis highlights several strategic opportunities for stakeholders to reduce direct and indirect emissions, reducing energy consumption, improving building resilience, and saving money in commercial properties.

Implication 1

Size and location matter.

The marginal abatement curves rank the most economically attractive opportunities, but the economic attractiveness of any emission reduction measure depends on a property's type, use, location, and size. Total energy consumption is a major determinant for financial attractiveness, and this varies by region and projected trajectories of electricity costs.

- **Large properties'** challenges stem less from pure economics and more from management attention, data availability, and practicalities such as the availability of service providers.
- **Small properties** face similar challenges as large ones, but with far less attractive economics. Government programs, regulation, and standards must remain the primary drivers of change. In addition, private sector initiatives, such as aggregated refrigerant purchasing, maintenance programs, or end-of-life gas collection, could lower costs.

Implication 2

Savings require a system view.

Cooling happens in an integrated system where demand, usage, building architecture, and equipment interact in complex ways. Numerous external factors also influence what is possible, including spatial and temporal demand variations, external temperatures, seasonality, and humidity. Currently, many commercial building operational settings are managed as individual components under worst-case conditions, and operators do not adjust them to changing conditions and demand.

The largest and most attractive emission savings are achieved only from understanding and optimizing across this integrated system. Once managers handle cooling in this way, operations become flexible and operators more easily identify improvement opportunities. Actions include:

- Integration, such as linking Building Management Systems (BMS) with real-time occupancy and weather data to enable dynamic responses.
- Optimization, such as implementing pre-cooling before peak hours.
- Coordination, such as aligning systems like shading, lighting, and ventilation to reduce the overall cooling load.

Knowing which part of the system offers the largest potential savings requires skill, and can bring significant rewards.

Implication 3

Data and intelligence will point the way.

Data and intelligence emerged as powerful levers for performance improvement in this study. Operators need data to properly respond to changing circumstances. Maintenance is most effective when responsive to measured performance and issues.

Intelligent operations systems improve occupant comfort and stabilize temperatures while reducing cooling demand. Actions include:

- Running motors, pumps, and compressors at optimal points.
- Utilizing simple controls (e.g., occupancy/outdoor sensors) or advanced systems that anticipate peak demand, carbon intensity, and/or grid power prices.
- Integrating with demand response programs, allowing users to be paid for reducing load at key times.

Intelligent maintenance is most effective when it responds to actual system conditions. Actions include:

- Measuring pressure drop or performance across evaporators and condensers quickly identifies cleaning needs, leakage, or general poor performance.
- Creating simple temperature profiles of piping systems or equipment using inexpensive contact sensors or handheld infrared thermometers.
- Assessing building envelope heat maps, for example with drones and/or AI-assisted assessments, before major maintenance.

Implication 4

Heating and cooling should be considered together.

Cooling creates waste heat, which is an underused resource, particularly for large properties with year-round hot water demand (e.g. hotels, universities, and restaurants). Cooling towers or condensing units consume energy and dump excess heat to the surroundings. Managers can reuse this heat, for example for other building zones or for hot water. Because the heat is essentially free, it presents an opportunity category with substantial energy and cost savings.

Implication 5

Large properties' leadership can have an outsized impact.

Emission reduction opportunities typically become more attractive as a property increases in size. For instance, a few percent increase in COP from regular maintenance of a compressor becomes highly compelling when monthly electricity bills grow to tens of thousands of dollars. While many large, well-managed properties have already adopted measures, three additional avenues for impact remain:

- **Refrigerant Guidance for Tenants:** Building owners should expand tenant specifications beyond energy use to include requirements for refrigerant type (e.g., natural refrigerants), minimum energy performance, and/or options to address high-leakage rack systems. This is critical for complexes with many highly-emitting tenants like supermarkets.
- **Proactive Lifecycle Refrigerant Management (LRM):** This remains a partial blind spot even for large properties, despite regulatory reporting requirements in both the U.S. and China. Properties should track refrigerant use by combining data from procurement and maintenance providers. They should purchase reclaimed refrigerants to recharge equipment, correct for leaks, and ensure that end-of-life emissions are monitored and that workers collect refrigerants for reclamation or destruction. Tenant cooperation can magnify the impact of such initiatives and help meet economic and climate goals.
- **Drive Adoption of Ultra-Low-GWP Refrigerants and Equipment:** Large customers purchasing high-value systems can accelerate market adoption by proactively demanding equipment that uses low and ultra-low-GWP refrigerants, along with systems-level optimization strategies. This accelerates adoption of the next generation of sustainable cooling systems.

Implication 6

The next ten years are critical.

Building investment decisions today have emissions impacts for decades. We project 44% of the total leakage and end-of-life venting emissions projected until 2060 will occur in the next ten years alone. Phase-down schedules for high-GWP refrigerants under the Kigali Amendment stretch all the way out to 2036 (U.S.) and 2045 (China). Even once governments phase out older high-GWP gases will remain in equipment and eventually escape to the atmosphere for decades without intervention.

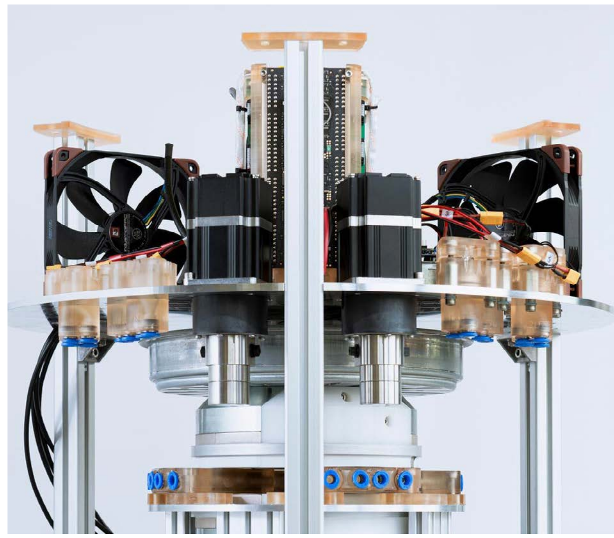
To avert these emissions, stakeholders must take urgent action. Commercial real estate has the opportunity to lead this essential transition, cutting cumulative cooling emissions nearly in half by 2060.

WATCH THIS SPACE:

Alternative Cooling Technologies

There is a new generation of technologies that offer alternatives to traditional vapor-compression cooling. These can help owners and operators address the full suite of cooling-related emissions and reduce cooling loads.

These dual benefits make ACTs a powerful complement to the other cooling emissions mitigation measures identified in this report. Many ACTs are at an early stage, which is why they are not modeled as mitigation measures in our study. However, some are rapidly moving from concept to reality, already demonstrating application across residential, commercial, and industrial settings. With targeted policy and financial support, these next-generation solutions are poised to become an important part of the toolkit for commercial real estate to cut both emissions and operating costs. More details on example technologies and companies supplying them can be found in the Carbon Containment Lab's online ACTs database.[17] The Carbon Containment Lab categorizes ACTs into three general categories based on their operational principles:[18]



Magnetocaloric refrigerator. Image Source: Magnotherm

Active Cooling	Passive Cooling	Hybrid Cooling
Technologies use electrically or mechanically driven processes involving advanced materials. These technologies eliminate the traditional need for refrigerants. This category encompasses prominent **solid-state cooling technologies**, such as **elastocaloric, barocaloric, magnetocaloric, and thermoelectric systems.**	Technologies operate without external power, harnessing environmental conditions and the inherent properties of materials. These technologies reduce the demand for active cooling. A notable example here is **radiative cooling**, which emits infrared radiation to the sky to dissipate heat.	Technologies combine active and passive cooling methods to enhance efficiency or broaden application potential. For example, **desiccant-based systems** use solid or liquid moisture-absorbing materials to remove humidity from the air, reducing cooling load and allowing the system to work alongside evaporative or solid-state cooling methods.

7. Next Steps

Our current analysis suggests several avenues for future development.

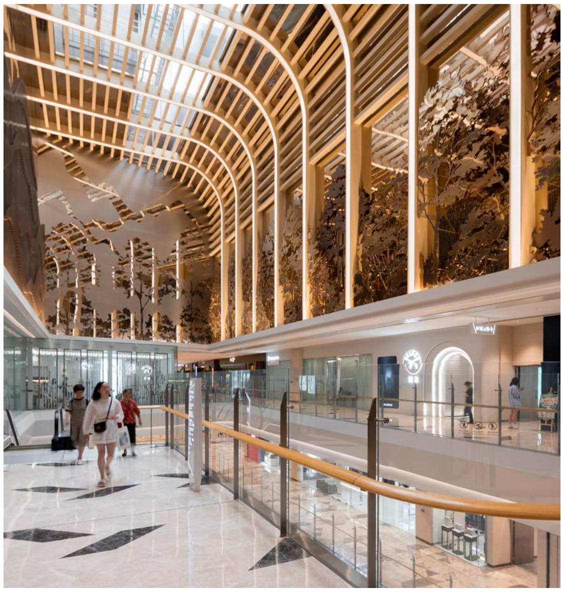
Conducting Sector- or Client- Specific Engagement: The aggregated nature of the model means its underlying logic may not apply to individual stakeholders. Engaging directly with property owners, tenants, and/or managers allows for the use of specific property or portfolio data to create tailored baselines and generate customized roadmaps for improvement. Adapting the model's logic for specific property types such as hospitals, data centers, or warehouses, could lead to valuable insights for property managers.

Refining Technology Deep Dives: We could deepen the analysis by moving beyond high-level assumptions to explore variations within the current technology stack including, for example, evaporation towers, fans, heat exchangers and energy recovery options. We can also expand the analysis to include ACTs. Beyond equipment innovations, we could also consider demand response programs, which offer financial incentive for load shifting, or integrating heating and cooling into a single model to offer a more comprehensive tool for property owners managing costs and emissions. In addition, analyzing trade-offs between measures, such as the impacts of ultra-low-GWP refrigerants on system efficiency, would be helpful.

Expanding Scope to New Sectors and Regions: Opportunities exist to broaden the analysis. While this report focused on commercial real estate, the residential sector also presents a major opportunity. Applying a similar marginal abatement curve analysis to homeowners' decisions could yield valuable insights, reaching beyond traditional top-down policy approaches. Expanding the model to other countries with different HFC phase-down timelines under the Kigali Amendment and with different climate conditions would reveal different abatement priorities.

Engaging Green Building Standards: The treatment of refrigerants is uneven among major green building certifications and recognition programs. Ensuring that standards consistently incentivize LRM, leak detection, selection of lower-GWP refrigerants, and efficient equipment would help reinforce better norms and practices.

Updating and Refining the Model: Despite our best efforts, the current model has areas where hard data was scarce, necessitating assumptions that will inevitably be superseded by evolving conditions. We can update and refine the existing model as more empirical data becomes available, ensuring the analysis remains current and accurate.



8. Conclusion

This report represents a first effort to create a framework for studying the cost and climate impacts of different actions in commercial real estate in the U.S. and China. It provides a list of potential measures to consider and data that can help guide discussions and decisions by different stakeholders. We hope that commercial real estate owners, tenants, and managers can use the measures we identified and analysis we provided to look for opportunities to reduce cost, increase performance, and reduce climate impact in their own properties.

Commercial real estate is a large and growing sector with a significant role to play in meeting corporate and national climate goals. Cooling-related emissions have been, to date, overlooked by the industry and by policymakers, but will only grow in importance over time. With this report, we aim to shed light on the many cost-effective ways stakeholders can reduce these emissions and the economic co-benefits of those reductions.

We hope that this report inspires and guides decision-makers to take action, and we look forward to the ongoing dialogue on the best ways to reach ambitious financial, energy, and climate goals.

Appendix I: Data Sources and Assumptions

This appendix outlines the key data sources and assumptions our model is built on. Wherever possible, we compared multiple data points, checked our bottom-up calculations with top-down estimates, and compared findings with inputs from industry experts. When data were inconsistent or missing, we relied on team expertise.

Many of the data sources listed below required adjustment to fit our model structure. The forecasts we rely on are themselves modeled and will not perfectly match reality. Our results should therefore be considered in the context of this project, which aims to provide pathways to reduce emissions in commercial buildings and compare the general attractiveness of measures. We do not claim to offer final property-specific answers on individual measures, which will always be highly context dependent.

The structure of this appendix follows the overall model structure introduced in Section 2.

General

Commercial Building Scope

We considered the commercial AC and refrigeration sectors in the U.S. and China, excluding residential, industrial, and transport sectors. We also excluded data centers from our scope due to their specific technical requirements and rapid recent growth. All other buildings, including public buildings and distribution centers, are in scope.

We focused the abatement measures on existing buildings rather than new building design, restricting measures to viable retrofits.

Refrigerant and Electricity Emissions

The GWPs of refrigerant gases, which compare their warming impact to CO_2 over a 100-year period, are taken from the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report.[19] The mix of refrigerants modeled varied by country, and is described in more detail below.

We included both indirect power emissions from cooling equipment and direct refrigerant emissions, and do not attempt to attribute these emissions to specific responsible parties. This allowed us to understand the economic tradeoffs between various choices. When certain measures to reduce cooling demand also reduce heating emissions or costs we include those in our economic assessments, but do not count them towards total abatement potential.

While a transition is also underway in the heating sector, primarily driven by a shift from combustion furnaces to heat pump technologies, we maintain a focus on cooling in this report. As such, heating emissions were excluded from baselines, but they were included in the economic analysis when a measure aimed at reducing cooling emissions had a co-benefit of reducing heating emissions.

Time Period

We assess the impact of abatement measures cumulatively over the time period from 2026 to 2060. This differs somewhat from the common method of assessing impact in a single future year. This decision is rooted in the transition currently underway due to the Kigali Amendment to the Montreal Protocol, which will fundamentally change the landscape of the cooling industry in the coming decades.

Because of this transformation, the cumulative view provides greater insight than a single future time period. Additionally, this view allows our recommendations to better align with total impact on global warming. The end year of 2060 is chosen because of expectations for a nearly complete shift away from HFCs in cooling equipment and fossil fuels in electric grids by that point.

Discount Rate

We adopt a discount rate of 8%, based on average costs of capital to businesses in 2025.[20] The use of this rate instead of the lower discount rates typical of research on the economics of climate reflects our focus on commercial decision-making.

The structure of this appendix follows the overall model structure introduced in Section 2.

United States

1. General Inputs

A key general input is an initial electricity price of 127.50 USD/MWh, the 2024 average cost for commercial users.[21] Additionally, baseline gas collection rates came from IPCC research,[22] and leak rates were an informed average from ANSI/ASHRAE standards[23] and IPCC estimates.[24]

2. Refrigerant Mix Scenarios

Current refrigerant stocks across segments were assessed by combining sources that provided estimates of total stocks, data on stocks in new sales in past years, and from equipment information. Projections of their evolution over time were constrained by the U.S. *Technology Transitions Rule*,[25] an Environmental Protection Agency (EPA) regulation under the AIM Act that creates deadlines for partial and full phaseout of certain categories of refrigerant by sector.

Calculated new sales were combined with data on equipment lifetimes and demand growth rates to create our model of stocks over time. Growth rates in sectors were sourced from market projections.[26] [27] [28]

3. Electricity Usage and Grid Emissions

The electricity module is built on the 2025 *Annual Energy Outlook* (AEO)[29] published by the Energy Information Administration (EIA). The AEO predicts sectoral electricity consumption, grid CO_2 emissions, and demand by end use out to 2050; we extended the projections to 2060 to align with our time horizon. Grid emissions intensity is a key input to the abatement potential of any opportunity that affects energy use. The AEO's projected electricity use in commercial cooling and refrigeration was used as a check on our modeling outputs.

The 2025 AEO is based on policies in place at the end of 2024, which were expected to rapidly bring deep renewable penetration to the U.S. This means that our assumptions of potential energy-related emissions reductions and cost savings are likely conservative, as the policies implemented in the U.S. over the course of 2025 are widely expected to create a more emissions-intensive and expensive electricity supply than previously projected.[30]

4. Equipment Stocks and Characteristics

Our baseline modeling and opportunity assessments depend in part on specifications that correlate with equipment type. Metrics such as coefficient of performance, leak rate, and cost per kW of cooling differ widely by size and type of equipment. Data on distribution of various types of equipment thus provides information for estimation of those parameters.

The installed equipment base for air conditioning was modeled primarily from the National Renewable Energy Laboratory's *ComStock,*[31] a comprehensive model of the commercial building stock in the U.S., its characteristics, and equipment installed in it including for cooling. *ComStock* provided a breakdown of the representation of different types of AC equipment in the U.S. Further calculations about equipment stocks and equipment characteristics were based on industry materials.[32] [33]

Installed equipment base for refrigeration was primarily drawn from the 2012 *CBECS,*[34] which included a detailed breakdown of existing equipment and was scaled to 2025. Further data came from market reports.[35] [36]

5. Market Segments

Buildings are categorized as small, medium and large: small are less than 25,000 ft^2 (2,323 m^2), medium buildings are 25,000 to 200,000 ft^2 (2,323 and 18,581 m^2), and large buildings 200,000 ft^2 (18,581 m^2) and above.[37]

The characteristics of the current stock of commercial buildings in the U.S. were drawn from the EIA's 2018 *Commercial Buildings Energy Consumption Survey* (CBECS).[38] 2018 was the most recent CBECS; we interpolated data to our base year of 2025 by analyzing the growth between 2018 and the previous CBECS in 2012. The survey provided robust data on building size and type. Additional sectoral data came from various industry reports.

Equipment utilization numbers for AC were sourced from a report conducted by the California Public Utilities Commission[39] and normalized by comparing national cooling degree days to those in California. For refrigeration, utilization numbers came from assorted industry publications.

6. Cooling Segment Archetypes

Cooling and refrigeration systems vary widely in their characteristics. The challenge for an integrated economic assessment such as this one is that this variation can easily be buried in averages, losing important insight into opportunities that apply only to certain areas of a market.

To address this for AC, we use archetypes that relate to building sizes outlined in *ComStock*. We define a building with a floor area less than 25,000 ft^2 (2,323 m^2) as small, greater than 25,000 ft^2 and less than 200,000 ft^2 (18,581 m^2) as medium, and greater than 200,000 ft^2 as large. These archetypes, built on the building data described above, allow us to derive system characteristics that form the basis of economic assessments.

For refrigeration, we use as archetypes convenience stores and restaurants, supermarkets, and cold storage facilities. While this division is somewhat more subjective than the AC division, each facility type has clear characteristics that allow for emissions and abatement opportunity modeling.

7. Abatement Measures

The measures, which are described in detail in Section 4 and were drawn from interviews and Carbon Containment Lab internal sources. We have aimed to include measures that are broadly impactful and relevant, but make no claim to be exhaustive. Some measures are by necessity broad and encompass multiple steps.

8. Baseline Outputs

From the input modules, we derive the baseline emissions consisting of emissions from leakage, end-of-life venting, and electricity. The leakage and venting emissions are a function of refrigerant GWP, which is expected to decline over time.

9. Abatement Curves

Our ultimate economic assessment of abatement measures relies on all of the above modules. The economic attractiveness of each measure, in dollars per $MTCO_2e$ abated, is calculated for each system archetype. The total potential impact of each measure is then calculated by adding the abatement potential in each archetype with a cost per $MTCO_2e$ abated of less than 100 USD. These aggregated numbers form the abatement curves shown in Section 5.

China

1. General Inputs

General inputs for China include an average commercial power price of 97 USD/MWh,[40] calculated as the 2025 mean of rates charged to commercial users across 33 provinces and cities. Commercial cooling electricity demand is derived from Energy Foundation China (2019)[41] research, which we scale to 2024 using historical annual growth rates in electricity consumption. Leak rates were derived by comparing refrigerant stocks with energy usage totals.

2. Refrigerant Mix Scenarios

Current refrigerant banks in China are estimated using a combination of academic literature[42] [43] [44] [45] and industry research[46] on installed refrigerant stocks. For future refrigerant use, we rely on China's 2025 to 2030 National Plan for the Implementation of the Montreal Protocol[47] and the obligations under the Kigali Amendments to set up key milestones for phasing out high-GWP refrigerants. These policy milestones are combined with projections of new equipment sales and retirements, assumed equipment lifetimes, servicing practices, and leakage/end-of-life loss rates to derive evolution of refrigerant mix, and thus the average GWP over time. Where available, we cross-check these bottom-up estimates against published forecasts of refrigerant emissions and banks in China.

3. Electricity Usage and Grid Emissions

Commercial electricity consumption is sourced from the International Energy Agency[48] and from China's National Energy Administration.[49] Current electricity-related emissions are calculated using the most recent grid emission factors published by China's Ministry of Ecology and Environment.[50] For future years, we construct a trajectory for grid emissions intensity that is the average between China's announced climate targets, which achieve carbon neutrality by 2060 and China's stated policies which will have remaining emissions by 2060 (in both scenarios emissions intensity peaks before 2030).

4. Equipment Stocks and Characteristics

The equipment mix is used for deriving technical and economic characteristics of equipment such as seasonal coefficient of performance, investment cost, refrigerant efficiency, and investment cost per kW of cooling. For commercial air conditioning, the equipment types included are unitary air conditioners, variable refrigerant flow (VRF) systems, scroll chillers, screw chillers, and centrifugal chillers. For commercial refrigeration, we consider light commercial equipment (refrigerated retail) and cold stores.

Market size, equipment sales, and installed capacity (cooling banks) are primarily drawn from a publication[51] of the China Association of Refrigeration, which compiles survey results, research articles, and manufacturer sales data. Additional data on domestic sales, installed cooling capacity, and stock evolution come from industry data platforms and trade sources.[52] [53] [54] Equipment characteristics are derived from product manuals and technical datasheets from leading Chinese air-conditioning and refrigeration manufacturers. Short- to medium-term growth rates for equipment sales and stocks are based on recent market research reports and industry outlooks.

5. Market Segments

To size the segments within the Chinese commercial cooling market, we used domestic sales of commercial air-conditioning equipment and their typical size to estimate the relative size of the small, medium and large-scale cooling segments, which fall within roughly the same boundaries used in the U.S.

For the Chinese commercial refrigeration market, we used an academic report[55] to understand the current market size and characteristics of the two main sectors, retail and cold chain distribution, using historic sales numbers and growth.

6. Cooling Segment Archetypes

For China, as with the U.S., we use cooling characteristics typical for each segment as inputs for estimating the economics of the abatement measure. We base these archetypes on total installed cooling capacity per property. Small AC includes all unitary AC, plus approximately half of VRF systems and a subset of small scroll chillers, with total cooling capacity below 150 kW per property. Large AC includes all centrifugal chillers, plus a share of large VRF and screw chillers, with total cooling capacity above 1250 kW per property. Medium AC covers the remaining VRF, scroll, and screw chiller installations with total cooling capacity between 150 and 1250 kW per property.

For commercial refrigeration, we define three archetypes. Small retail refrigeration includes light commercial equipment, such as remote and self-contained refrigerated display cabinets and all other systems used in convenience stores, restaurants, supermarkets, and hotels. China's retail refrigeration has a far smaller share of large-scale supermarket rack systems, and this segment was thus included in the small retail segment. The medium refrigeration segment was defined as cold storage facilities with a total cooling capacity below 500 kW, while large refrigeration consists of cold storage facilities with total cooling capacity of 500 kW or more.

Steps 7–9 process the inputs into final outputs and are consistent between the U.S. and China.

Appendix II: Achievable "Drop-In" Substitutions

Some drop-in replacements are available for older and higher GWP refrigerants. Any such conversion is dependent on system characteristics, requiring modifications and component upgrades (see Section 4, Measure 5 for additional information). Further, flammability concerns are not yet addressed for some newer refrigerants. The table below, based on research from the Heating, Refrigeration, and Air Conditioning Institute of Canada,[56] shows some of the potential conversions available today.

Additionally, commercial development of new drop-in substitute gases is taking place as users anticipate reduced supply of high-GWP gases. Selected examples include R-442a, a replacement for R-404a with less than half the GWP that has been field-tested in various supermarkets and shown higher energy efficiencies, and R-453a, a low-GWP replacement for R-22. Further innovation is likely as regulation is expected to reduce the supply of traditional HFCs.

Refrigerant to Be Replaced	GWP	Primary Application	Replacement Refrigerant	GWP
R-12	10,200	Refrigeration	R-134a R-426a	1,300 1,508
R-123	79	Central chillers	R-1233zd	1
R-134a	1,300	Refrigeration	R-1234yf R-1234ze	573 6
R-404a	3,922	Refrigeration	R-407a R-448a R-449a R-454c R-464a	2,110 1,273 1,282 148 1,288
R-507a	3,985	Refrigeration	R-442a R-449a R-464a	1,888 1,282 1,288

Appendix III: Additional Context and Discussion of Mitigation Measures

For definitions and scope of measures, see Section 4.

● CATEGORY A.

Lifecycle Refrigerant Management

Measure Name	Context and Discussion
1. Recover & recycle refrigerants on-site	In the U.S., recycled refrigerants must be used on the same site/property, as they are considered uncertified products. This limits the total potential of the measure because few properties have the interest or capability to store and manage larger stocks of refrigerants. China does not have an explicit regulation restricting the sale of recycled refrigerants for use at other sites. While this presents a potential opportunity, there is currently little indication that such a market is developing. Successful implementation of this measure requires widespread availability of certified recovery and recycling equipment, improved recovery methods and efficiency, and adequate training for technicians to ensure they follow best recycling practices.
2,3. Recover & reclaim pure and mixed refrigerants	Unlike a simple recycling process, reclamation relies on specialized machinery and procedures only available at designated and certified reprocessing facilities. Commercial real estate owners and operators can help implement this measure by ensuring that refrigerants on their properties are properly collected and sent to certified facilities. They can also champion the broader availability of certified recovery equipment, advancements in recovery methods and efficiency, and comprehensive technician training to ensure the safe handling of recovered refrigerants at end-of-life.
4. Recover & destroy refrigerants	Main HFC destruction technologies include incineration (e.g., rotary kilns, cement kilns, and municipal solid waste incinerators), plasma, and chemical conversion into other stable chemical forms under high heat conditions.[57] According to industry standards, destruction efficiencies must reach at least 99.99% for concentrated sources of HFCs and 95% for dilute sources of HFCs.[58] Commercial real estate owners and operators can help promote this measure by making sure gas is recovered and destroyed in a certified facility; and that technicians are trained and certified to properly handle refrigerant gases. In some regions, carbon credits may help finance destruction.[59]
5. Use "drop-in" lower GWP refrigerants	This upgrade enables the transition away from high-GWP refrigerants without replacing the entire system, making it a cost-effective mitigation measure. However, substitute refrigerants often require system modifications and component updates (such as new valves, seals, or lubricant changes) to maintain pressure compatibility and prevent issues like freeze-ups, reduced efficiency, or increased safety risks.[60] Component upgrades can reduce leaks, but the change in refrigerant, especially when the new refrigerant operates at higher pressures, can also induce a slight increase in leakage. For a list of drop-in refrigerant options for high-GWP refrigerants, see Appendix II.

CATEGORY B.

Cooling Equipment Upgrades

Measure Name	Context and Discussion
6. Upgrade to lower GWP refrigerant equipment	Limits on the production and import of HFCs, established under the Kigali Amendment to the Montreal Protocol, will gradually reduce the supply of HFC refrigerants, on a CO_2-equivalent basis, in both the U.S. and China.[61] The baseline used in the marginal abatement curves already reflects this ongoing HFC phase-down mandated under the Kigali Amendment. This measure captures the additional potential that can be unlocked by pursuing an accelerated HFC transition schedule. By upgrading now to equipment that uses ultra-low (<5 GWP) refrigerants, commercial real estate owners and operators can leapfrog the medium-GWP refrigerant phase and further reduce total emissions over the equipment's lifetime, possibly unlocking financial savings from avoiding refrigerant supply crunches. Specific applications of this measure vary by sector and building type.
7. Conduct smart equipment maintenance and calibration	Effective leak management goes beyond testing to require integration with BAS and DAS to enable continuous monitoring and early fault detection. Maintenance should also include proactive responses to create a more comprehensive leak prevention strategy (*See Measure 16*) and recommissioning and calibration for efficiency gains.
8. Install sensors to detect leaks in compressors	Leak detection in AC systems is highly dependent on system design and the length of the refrigerant line sets. For example, systems with longer or more intricate piping configurations, such as VRF systems, generally present a greater risk of leaks and can be challenging to monitor effectively. Large-scale compressors can indirectly indicate leaks through reduced performance, though this may take time to become detectable. Direct leak detection technologies allow for early detection and faster response to refrigerant loss. In the United States, under the AIM Act, new and existing commercial refrigeration appliances that meet specified criteria must be equipped with automatic leak detection systems beginning January 2026.[62]
9. Use best practice equipment installation and calibration	Executing best-practice equipment installation requires highly trained technicians familiar with the specific refrigerant used–a skill set currently in short supply. Commercial real estate owners and operators can lead by example here by choosing to work exclusively with certified technicians. Time constraints often pressure technicians to rush calibration, which can compromise long-term system effectiveness. Ensuring an accurate refrigerant charge at installation is critical. Undercharging reduces system performance and increases the need for subsequent refrigerant top-ups.[63]
10. Upgrade to higher COP cooling equipment	COP remains an important measure for performance where the most efficient option can often be more than 30% better than the average. Of course, this improvement in efficiency needs to be understood and evaluated across the seasons and the performance envelope within the operating envelope it will be used. Other sustainability metrics such as Lifecycle Climate Performance (LCP) and Total Equivalent Warming Impact (TEWI), can also be considered when purchasing new equipment along with financial metrics like Total Cost of Ownership (TCO). System-wide upgrades are discussed in measure 18.

CATEGORY C.
Reduced Primary Cooling Load

Measure Name	Context and Discussion
11. Establish higher cooling set-points	Cultural and regional expectations strongly influence acceptable indoor temperatures. In the US, building occupants often are accustomed to cooler indoor environments whereas in many Asian countries comfort standards typically allow higher setpoints. For example, in China, the Ministry of Ecology and Environment has set a guideline for its eco-friendly campaign that indoor air-conditioner set-points should be no less than 79 °F (26 °C) during the summer.[64] Similarly Japan encourages a set-point around 82.4 °F (28 °C) as part of national energy-saving initiatives such as Cool Biz.[65] Commercial real estate owners and operators can contribute to adjusting expectations and standards to encourage slightly higher cooling setpoints on their properties. Additionally, businesses can adopt a more casual, lighter summer dress code to ensure occupant comfort.
12. Increase isolation, shading, reflection	While many of these measures are best incorporated during new construction for maximum performance, several technologies (e.g., reflective window and roof films, internal shading systems) can be readily implemented as retrofits, offering immediate reductions in cooling energy demand and improved occupant comfort. These measures can be combined with others cost-effectively.
13. Install heat exchanger between incoming and outgoing air	Legal requirements for building ventilation can be a major source of energy demand during winter and summer, which can be addressed with heat exchangers. In addition to energy savings of up to 80%, these systems can enhance indoor air quality by providing continuous ventilation, stabilize humidity levels, and extend the lifespan of AC equipment by reducing system strain.[66]
14. Install occupancy sensors for lighting systems	Lighting can be a significant contributor to internal heat gains in commercial properties. Occupancy sensors offer a reliable strategy to mitigate this additional cooling demand. Modern occupancy sensors use infrared, ultrasonic, or dual-technology detection to ensure reliable performance.[67] These sensors can also be integrated into BMS for coordinated control of lighting, ventilation, and cooling.
15. Transition from open to closed refrigerated displays	Beyond reducing cooling load, closed displays also reduce product spoilage and food safety concerns, as items are better protected from temperature fluctuations. In many cases, the reduction in product spoilage can lead to cost savings that exceed the energy savings, making this a highly cost-effective measure for commercial refrigeration in supermarkets, convenience stores, and other retailers. Some countries in Europe are sponsoring initiatives to promote the use of closed refrigerated display cabinets to reduce energy consumption in stores. For example, in France, the Federation of Commerce and Distribution has committed to equipping 75% of positive temperature refrigerated display cases with doors by 2020, with a target of total closure by 2030.[68] In October 2023, approximately 60% of the stock of refrigerated display cases were already equipped with doors.[69] *(See Case Study 2 for the environmental and economic benefits of implementing this measure in supermarkets.)*

CATEGORY D.
Cooling System Management

Measure Name	Context and Discussion
16. Implement intelligent, data-driven controls	The range of costs for this measure can vary significantly. However, industry feedback suggests that data-driven system controls offer numerous opportunities for performance improvements—often significant enough to justify the upfront investment. Better controls also enable participation in demand response programs, unlocking further financial savings. Additionally, implementing a refrigerant inventory and tracking system also supports cost-benefit analyses that can guide early replacement of equipment with new equipment that uses lower GWP refrigerants. *(See Measure 6.)*
17. Enhance management & operator skills	The performance of a building's cooling system can be complex, making it challenging to pinpoint the causes of deterioration or identify opportunities for improvement. Improved system management, which is a behavioral measure, is particularly critical for large systems and is most effective when combined with complementary measures such as enhanced data analytics. (*See Measure 16.*) Although most systems have technical support and maintenance schedules, these are often ineffective when the key levers for performance improvement are not well understood.
18. Upgrade system hardware	System hardware improvements complement data-driven controls and behavioral measures to enhance overall cooling system performance. (*See Measures 16–17.*). However, while strategies under this measure can be highly effective for new buildings, they can often be expensive to implement in retrofit projects.
19. Combine cooling with hot water/heat delivery*	Heat-recovery capable ASHPs can supply cool air in spaces with year-round cooling needs, such as kitchens or dishwashing areas, while delivering hot water. This approach has been successfully implemented in commercial settings, achieving significant energy savings and greenhouse gas reductions. By integrating cooling and heat delivery, buildings can improve overall energy efficiency, reduce operational costs, and lower emissions. *(See Case Study 3 for the environmental and economic benefits of implementing this measure in commercial buildings.)*

References

1. International Energy Agency, *The Future of Cooling: Opportunities for Energy Efficient Air Conditioning* (Organisation for Economic Co-Operation and Development, 2018), 62, https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf.

2. Christina Theodoridi et al., *Lifecycle Refrigerant Management: How minimizing leaks and maximizing reclaim can avoid up to 91 billion metric tons CO_2-eq emissions* (Natural Resources Defense Council; Environmental Investigation Agency; Institute for Governance & Sustainable Development, 2022), 4, https://www.nrdc.org/sites/default/files/lrm-90-billion-ton-opportunity-report-20221020.pdf.

3. United Nations Environment Programme, *HFC Baselines and Phase-down Timetable* (United Nations, 2025). https://www.unep.org/ozonaction/resources/factsheet/ozonaction-kigali-fact-sheet-no-5-hfc-baselines-and-phase-down-timetable.

4. Global Alliance for Buildings and Construction, *Global Status Report for Buildings and Construction 2024/25* (UN Environmental Programme, 2024), 13, https://globalabc.org/sites/default/files/2025-03/Global-Status-Report-2024_2025.pdf.

5. Hannah Ritchie, “Air conditioning causes around 3% of greenhouse gas emissions. How will this change in the future?” *Our World in Data*, July 29, 2024, https://ourworldindata.org/air-conditioning-causes-around-greenhouse-gas-emissions-will-change-future.

6. Energy Information Administration, *U.S. Energy-Related Carbon Dioxide Emissions, 2024* (U.S. Department of Energy, 2025) https://www.eia.gov/environment/emissions/carbon.

7. Environmental Protection Agency, *Refrigerant Leak Prevention through Regular Maintenance* (U.S. Environmental Protection Agency, 2013). https://www.epa.gov/sites/default/files/2013-12/documents/gc_preventativemaintenance_20130913.pdf.

8. International Energy Agency, China. (International Energy Agency, 2025). https://www.iea.org/countries/china/emissions.

9. Our World in Data, *Carbon intensity of electricity generation, 2024* (Our World in Data, 2025). https://ourworldindata.org/grapher/carbon-intensity-electricity.

10. Technological and Economic Assessment Panel, *TEAP Task Force Report on Lifecycle Refrigerant Management* (United Nations Environmental Program, 2024), https://ozone.unep.org/system/files/documents/TEAP-May2024-DecXXXV-11-TF-Report.pdf; Carbon Containment Lab, “Lifecycle Refrigerant Management,” *Carbon Containment Lab, 2025*, November 11, 2024, https://carboncontainmentlab.org/projects/refrigerants.

11. “Nonflammable Alternatives to R-410A,” ACHR News, October 14, 2020, https://www.achrnews.com/articles/143923-nonflammable-alternatives-to-r-410a.

12. Tyler Hoyt, Hui Zhang, and Edward Arens, “Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings,” *ResearchGate* Building and Environment 88, no. 1 (2015): 89–96, https://doi.org/10.1016/j.buildenv.2014.09.010; Allyson Mann, “Turn up the thermostat: lower energy costs, no complaints,” University of Georgia (UGA) Research, September 15, 2020, https://research.uga.edu/news/turn-up-the-thermostat-lower-energy-costs-no-complaints/#:~:text=By%20Allyson%20Mann,as%20much%20as%20$110%2C675%20annually.

13. Lindsay Rasmussen, Colm Quinn, and Rushad Nanavatty, “Clean Energy 101: Passive Daytime Radiative Cooling—or Really Cool Roofs,” *RMI*, November 21, 2023, https://rmi.org/clean-energy-101-passive-daytime-radiative-cooling-really-cool-roofs.

14. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI), “Energy Recovery Ventilators,” *AHRI*, accessed November 7, 2025, https://www.ahrinet.org/scholarships-education/education/homeowners/how-things-work/energy-recovery-ventilators.

15. Commercial Buildings Energy Consumption Survey (CBECS), “Trends in Lighting in Commercial Buildings,” *U.S. Energy Information Administration*, May 17, 2017, https://www.eia.gov/consumption/commercial/reports/2012/lighting.

16. Sustainable Energy for All, *Chilling Prospects 2022: China’s progress towards sustainable cooling*. https://www.seforall.org/data-stories/chinas-progress-towards-sustainable-cooling.

17. Selin Gören, Kyra Hall, and Anastasia O’Rourke, “CC Lab’s Alternative Cooling Technologies Database,” Carbon Containment Lab, accessed November 23, 2025, https://carboncontainmentlab.org/publications/cc-lab-s-alternative-cooling-technologies-database.

18. Selin Gören, Anastasia O’Rourke, and Scott Stone, Beyond Refrigerants: Alternative Cooling Technologies – Issue Brief for the 47th Open-Ended Working Group of the Montreal Protocol and Side-Event, (Carbon Containment Lab, July 2025), https://carboncontainmentlab.org/documents/oewg47-issue-brief---alternative-cooling-technologies.pdf.

19. G.D. Myher et. al., *Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2013). https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf.

20. Johannes Post, *KPMG Cost of Capital Study 2025* (KPMG, 2025). https://kpmg.com/ch/en/insights/deals/cost-capital-study.html.

21. Energy Information Administration, *Electric Power Monthly, Table 5.3: Average Price of Electricity to Ultimate Customers* (U.S. Department of Energy, 2025). https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_5_03.

22. Sukumar Devotta and Stephen Sicars et. al., *IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate, Chapter 4: Refrigeration* (Intergovernmental Panel on Climate Change, 2005). https://archive.ipcc.ch/pdf/special-reports/sroc/sroc04.pdf.

23. American National Standards Institute and American Society of Heating, Refrigerating and Air-Conditioning Engineers, *ANSI/ASHRAE Standard 228-2023: Standard Method of Evaluating Zero Net Energy and Zero Net Carbon Building Performance* (American National Standards Institute and American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2023). https://www.scribd.com/document/658378785/Ansi-Ashrae-Standard-228-2023.

24. Sukumar Devotta and Stephen Sicars et. al., *IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate, Chapter 4: Refrigeration* (Intergovernmental Panel on Climate Change, 2005). https://archive.ipcc.ch/pdf/special-reports/sroc/sroc04.pdf.

25. Environmental Protection Agency, *Technology Transitions HFC Restrictions by Sector* (U.S. Environmental Protection Agency, 2025). https://www.epa.gov/climate-hfcs-reduction/technology-transitions-hfc-restrictions-sector.

26. Grand View Research, *U.S. HVAC Systems Market (2025-2033)* (Grand View Research, 2025). https://www.grandviewresearch.com/industry-analysis/us-hvac-systems-market.

27. TechSciResearch, *Commercial Refrigeration Marker 2019-2029* (TechSciResearch, 2024). https://www.techsciresearch.com/report/commercial-refrigeration-market/22540.html.

28. Market Data Forecast, *North America Refrigerants Market* (Market Data Forecast, 2025). https://www.marketdataforecast.com/market-reports/na-refrigerant-market.

29. Energy Information Administration, *Annual Energy Outlook 2025* (U.S. Department of Energy, 2025). https://www.eia.gov/outlooks/aeo.

30. Nicholas Roy and Dallas Burtraw, *Promoting Energy Efficiency Using State Climate Policy* (Resources for the Future, 2025). https://www.rff.org/publications/issue-briefs/promoting-energy-affordability-using-state-climate-policy.

31. National Renewable Energy Laboratory, *ComStock: Highly granular modeling of the U.S. commercial building stock* (U.S. Department of Energy, 2025). https://comstock.nrel.gov.

32. HVAC Hess, *Factsheet: Chiller Efficiency* (HVAC Hess, 2025). https://www.energy.gov.au/sites/default/files/hvac-factsheet-chiller-efficiency.pdf.

33. Facilities Net, *How Variable Refrigerant Flow (VRF) Improves HVAC Efficiency* (Facilities Net, 2025). https://www.facilitiesnet.com/hvac/article/How-Variable-Refrigerant-Flow-VRF-Improve-HVAC-Energy-Efficiency--18425.

34. Energy Information Administration, *Commercial Buildings Energy Consumption Survey (CBECS)* (U.S. Department of Energy, 2012). https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b45.php.

35. Carrier, *Air Conditioning Solutions* (Carrier, 2025). https://ahi-carrier.gr/wp-content/uploads/2021/12/50UCUPV_Commercial-Brochure.pdf.

36. Northeast Energy Efficiency Partnerships, *Variable Refrigerant Flow (VRF) Market Strategies Report* (Northeast Energy Efficiency Partnerships, 2025). https://neep.org/variable-refrigerant-flow-vrf-market-strategies-report.

37. National Renewable Energy Laboratory, *ComStock* (U.S. Department of Energy) https://comstock.nrel.gov.

38. Energy Information Administration, *Commercial Buildings Energy Consumption Survey (CBECS)* (U.S. Department of Energy, 2018). https://www.eia.gov/consumption/commercial/data/2018/index.php?view=characteristics.

39. California Public Utilities Commission, *California Statewide Commercial Sector Natural Gas and Electricity Efficiency Potential Study* (California Public Utilities Commission). https://docs.cpuc.ca.gov/published/Report/30172.htm.

40. Based on tariff data collected from the official websites of China's State Grid subsidiaries (33 sources in total, e.g., Shanghai State Grid Shanghai Municipal Electric Power Company – Power Purchase Tariff Table for Industrial and Commercial Users); individual sources are not listed here for brevity.

41. Energy Foundation, *Scoping Study on Mitigation Potential of Refrigeration and Air Conditioning Products in China* (Energy Foundation, 2019). https://www.efchina.org/Attachments/Report/report-cip-20210119/SCOPING_STUDY_FINAL_VERSION.pdf/view.

42. Bai et. al., *Pathway and Cost-Benefit Analysis to Achieve China's Zero Hydrofluorocarbon Emissions* (Environmental Science & Technology, 2023). https://pubs.acs.org/doi/10.1021/acs.est.3c00166.

43. Wu et. al., *Banks, emissions, and environmental impacts of China's ozone depletion substances and hydrofluorocarbon substitutes during 1980–2020* (Science of the Total Environment, 2023). https://doi.org/10.1016/j.scitotenv.2023.163586.

44. Chen et. al., *Sustainable Management of Banked Fluorocarbons as a Cost-Effective Climate Action* (Environmental Science & Technology, 2025). https://pubs.acs.org/doi/10.1021/acs.est.5c02575.

45. Liu et. al., *Rethinking time-lagged emissions and abatement potential of fluorocarbons in the post-Kigali Amendment era* (Nature Communications, 2024). https://doi.org/10.1038/s41467-024-51113-2.

46. China Association of Refrigeration, *Current Status of Refrigerant Use and Pathways for Substitution in China* (China Science and Technology Press, 2025).

47. Ministry of Ecology and Environment, *National Implementation Plan on Fulfilling the Montreal Protocol on Substances that Deplete the Ozone Layer During the 2025-2030 Period* (Ministry of Ecology and Environment of the People's Republic of China, 2025). https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202504/t20250423_1117396.html.

48. International Energy Agency, *China* (International Energy Agency, 2025). https://www.iea.org/countries/china/electricity.

49. National Energy Administration of China, *2021 National Power Industry Statistics* (National Energy Administration of China, 2022). https://www.nea.gov.cn/2022-01/26/c_1310441589.htm.

50. Ministry of Ecology and Environment of the People's Republic of China & National Bureau of Statistics of the People's Republic of China, *Announcement on the issuance of the 2022 power sector carbon dioxide emission factor (Announcement No. 33 of 2024)* (Ministry of Ecology and Environment of the People's Republic of China & National Bureau of Statistics of the People's Republic of China, 2024). https://www.mee.gov.cn/xxgk2018/xxgk/xxgk01/202412/t20241226_1099413.html.

51. Wu et. al., *Banks, emissions, and environmental impacts of China's ozone depletion substances and hydrofluorocarbon substitutes during 1980–2020* (Science of the Total Environment, 2023). https://doi.org/10.1016/j.scitotenv.2023.163586.

52. China Industry Online, *AC* (China Industry Online, 2025). https://data.chinaiol.com/ecdata/index.

53. HVAC Home, 2025. https://hvacrhome.com.

54. Japan Air Conditioning, Heating, and Refrigeration News, 2025. https://www.ejarn.com.

55. Changqing et. al., *Carbon Emission and Emission Reduction with Low-Carbon Technologies in Chinese Cold Chain Industry*, (Journal of Refrigeration, 2023). https://www.zhilengxuebao.com/previewFile?id=62521830&type=pdf&lang=zh.

56. Heating, Refrigeration, and Air Conditioning Institute of Canada, *Refrigerant Table* (Heating, Refrigeration, and Air Conditioning Institute of Canada, 2019). https://www.hrai.ca/uploads/userfiles/files/refrigerant_table_June2019.pdf.

57. "Destruction of Regulated Substances." Code of Federal Regulations, title 40 (2021): 116-260, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-84/subpart-A/section-84.29.

58. Irene Papst & Manuel Prieto Garcia, *ODS/HFC Reclamation and Destruction Technologies: A review for Article 5 Countries* (Climate and Ozone Protection Alliance, 2023), 26, https://www.copalliance.org/imglib/publications/COPA_Publication_ODS_HFC_%20Destruction_Reclamation.pdf.

59. Tilden Chao et al., Recovery and Destruction of Hydrofluorocarbon (Carbon Containment Lab, 2023), https://carboncontainmentlab.org/documents/yale-cc-lab-hfc-methodology-white-paper-may-2023-draft.pdf; Technological and Economic Assessment Panel, *TEAP Task Force Report on Lifecycle Refrigerant Management* (United Nations Environmental Program, 2024).

60. Niyas Yousuf, "Drop-in Refrigerant," *Goodwind*, November 16, 2024, https://goodwindco.in/blog/drop-in-refrigerant.

61. Montreal Protocol on Substances that Deplete the Ozone Layer, opened for signature Sept. 16, 1987, 1522 U.N.T.S. 3, "Annex F: Hydrofluorocarbons," (entered into force Jan. 1, 1989), https://ozone.unep.org/treaties/montreal-protocol/annex-f-hydrofluorocarbons.

62. U.S. EPA, "Regulatory Actions for Managing HFC Use and Reuse," Overviews and Factsheets, October 3, 2022, https://www.epa.gov/climate-hfcs-reduction/regulatory-actions-managing-hfc-use-and-reuse.

63. Lekhya Vennamaneni, Raghav Muralidharan, and Ankit Kalanki, “Why Refrigerant Matters More Than You Think for AC (or Heat Pump) Efficiency,” *RMI*, September 25, 2025, https://rmi.org/why-refrigerant-matters-more-than-you-think/?utm_campaign=organic&utm_source=LinkedIn&utm_medium=social&utm_content=RMIBrand.

64. “Room Temperature Should Be No Less than 26 C in Summer as China Sets Norms for Eco-Friendly Behavior,” Ministry of Ecology and Environment the People’s Republic of China, accessed November 13, 2025, https://english.mee.gov.cn/News_service/media_news/201806/t20180607_442700.shtml.

65. Kana Takagi, “The Japanese Cool Biz Campaign: Increasing Comfort in the Workplace,” *Environmental and Energy Study Institute (EESI)*, September 30, 2025, https://www.eesi.org/articles/view/the-japanese-cool-biz-campaign-increasing-comfort-in-the-workplace.

66. AHRI, Air-to-Air Energy Recovery Ventilators (ERVs), *AHRI*, accessed November 7, 2025, https://www.ahrinet.org/scholarships-education/education/contractors-and-specifiers/hvacr-equipmentcomponents/air-air-energy-recovery-ventilators-ervs.

67. Federal Energy Management Program, “Wireless Occupancy Sensors for Lighting Controls: An Applications Guide for Federal Facility Managers,” *U.S. Department of Energy*, https://www.energy.gov/femp/articles/wireless-occupancy-sensors-lighting-controls-applications-guide-federal-facility.

68. “Fermeture Des Meubles Frigorifiques Pour 2020,” Fédération du Commerce et de la Distribution, January 16, 2012, https://www.fcd.fr/qui-sommes-nous/actualites-de-la-fcd/detail/fermeture-des-meubles-frigorifiques-pour-2020.

69. “Petit à petit, les supermarchés installent des portes à leurs rayons réfrigérés,” La Dépêche, accessed December 3, 2025, https://www.ladepeche.fr/2023/10/15/petit-a-petit-les-supermarches-installent-des-portes-a-leurs-rayons-refrigeres-11520403.php.