Ref #	Relevance (High, cited in Report)	Topic	Region	Title [Some publications are denoted 'Not Publicly available' (NPA)]	Key features of document	Link
1	High	Regulation or review	Australia	Expert Group 2020, Cold Hard Facts 2020	Industry stock and emissions for 2019	https://www.environment.gov.au/protection/ozone/publications/cold-hard-facts-2020
2	High	Regulation or review	Australia	DISER 2020, Quarterly Update of Australia's National Greenhouse Gas Inventory: December 2019, Department of Industry, Science, Energy and Resources, 2020.	Australian emissions 2019	https://www.industry.gov.au/data-and-publications/national-greenhouse-gas-inventory-december-2019
3	High	Best practice guide: RAC	Australia	TEWI 2012, Best Practice Guidelines: Methods of calculating Total Equivalent Warming Impact (TEWI) 2012	TEWI Method	https://www.airah.org.au/Content_Files/BestPracticeGuides/Best_Practice_Tewi_June2012.pdf
4	High	Regulation or review	Australia	Expert Group 2015, Assessment of environmental impacts from the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, prepared for the Department of the Environment, April 2015	Assess policy options for all RAC	https://www.environment.gov.au/system/files/consultations/fe81135c-a55e-45b6-ae4b-ef02f1616ba2/files/ozone-acts-review-environmental-impact-analysis.pdf
5	High	Maintenance	International	Optimization, monitoring, and maintenance of cooling technology	Global estimate of emissions possible from maintenance and optimisation	https://k-cep.org/wp-content/uploads/2018/03/Optimization-Monitoring-Maintenance-of-Cooling-Technology-v2-subhead....pdf

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6	High	commercial Air conditioning	North America	Sensitivity Analysis of Installation Faults on Heat Pump Performance	This study assessed the impacts that HVAC system installation faults had on equipment electricity consumption. The study found that duct leakage, refrigerant undercharge, oversized heat pump with nominal ductwork, low indoor airflow due to undersized ductwork, and refrigerant overcharge have the most potential for causing significant performance degradation and increased annual energy consumption. The effect of simultaneous faults was found to be additive. Includes meta summary of USA research/studies on installation faults in residential air conditioning/heat pumps. # The heat pump uses 10~16% more energy when overcharged by 30%. # If non-condensable gases are in the refrigerant, the overall results show a 1-2% energy use increase in heating and a 4% increase in cooling. # For 30% refrigerant undercharge the energy use increases by as much as 17-23%. # The percentage energy penalty of other faults was also modelled and the cumulative effect of 2 and 3 simultaneous faults assessed.	https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1848.pdf
7	High	Commercial air conditioning	North America	Generalized effects of faults on normalized performance variables of air conditioners and heat pumps	Meta-analysis of RACHP fault work. The effects of several types of faults on air conditioners and heat pumps have been studied in many laboratory experiments. All available data have been gathered, and the independent variable (fault intensity) and each of the dependent variables (fault impacts) are normalised to show the trends in a generalised fashion. Relationships are provided wherever there are sufficient results. Most of the significant fault types are included (except refrigerant charge variation, which was discussed in Mehrabi and Yuill (2017)): condenser heat transfer (CA), evaporator heat transfer (EA), liquid line restriction (LL), compressor leakage (VL), and non-condensables in the refrigerant (NC). Relationships are presented separately for fixed orifice and thermostatic expansion valve equipped systems. The variation level in the results indicates that in many cases, the generalised relationships provide reasonable predictors of fault effects on systems for which laboratory test results are unavailable. The similarity of results in many cases is remarkable considering that they come from different systems, both split and packaged, from different manufacturers, employing different refrigerants and compressor types. An informal examination has shown no clear trends with respect to rated efficiency of the systems, so it seems reasonable to use these models for new systems. However, it is likely that newer systems with microchannel condensers will respond differently to many faults. Among the faults presented in this paper, several can cause very significant reductions in performance. Typically, the cost associated with faults is larger for equipment wear than it is for increased energy consumption (particularly in the US), so these large impacts are quite serious. However, an important piece of information that is not currently well understood is how common faults are in field-deployed systems, as a function of FI.	https://experts.nebraska.edu/en/publications/generalized-effects-of-faults-on-normalized-performance-variables

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8	High	Maintenance	EU and UK	Maintenance an Opportunity for Energy Saving	Proposes a method to quantify the impact of maintenance and operating procedures, in terms of energy savings or cost effectiveness. Analysis has demonstrated the importance of optimising maintenance activities and operating procedures to increase the performance of the system. Using the developed efficiency analysis model, it's possible to quantify the impact of maintenance and operating procedures, in terms of energy savings or cost effectiveness, and can be calculate the cost of conserved energy CCE, also it is possible to estimate the potential reduction of greenhouse gas emissions (CO2).	https://www.aidic.it/cet/13/32/044.pdf
9	High	Maintenance	US	Common Faults and their Prioritization in Small Commercial Buildings	The top 20 faults are ranked by energy and financial impact (after infiltration through the building envelope). Air-duct leakage has the second-largest energy impact, and this was also identified as one of the major faults in the entire commercial-building sector	https://www.nrel.gov/docs/fy18osti/70136.pdf
10	High	Commercial air conditioning	North America	Residential HVAC Market Model Methodology	This report describes the Cadeo team's (the research team, or the team) methodology for estimating total residential HVAC electric consumption and Momentum Savings for the Seventh Power Plan Action Plan period (2016-2021; hereafter referred to as the Action Plan Period). BPA's modelling goals for this market are twofold: 1. Understand how total residential HVAC electric consumption is changing over the Action Plan period; and 2. Estimate draft electric Momentum Savings for the Action Plan period (2016-2021). Duct Sealing and Commissioning, Controls, and Sizing. The Northwest has ongoing incentive programs aimed at HVAC installers to improve the Commissioning, Controls, and Sizing (CC&S) installation practices for ASHPs. The research team believes these programs could have a meaningful impact on average, per-home HVAC energy consumption. Table 5. Other Factors that Impact HVAC Energy Consumption - Installation Practices (Commissioning, Controls and Sizing) Includes HVAC controls, airflow, refrigerant charge, and equipment sizing for ASHPs and CACs Table 9. Factors Impacting HVAC Consumption and Their UEC Development Approaches. Sources of Regional Program Savings. Utility program activity includes all incentives provided by utility-funded programs in the Northwest relevant to the residential HVAC market, including both HVAC equipment and envelope measures. These programs are run by several entities, which include BPA's public customer utilities, private investor-owned utilities (IOUs), Energy Trust of Oregon, and NEEA. Table 14. RCP Residential HVAC Savings Categories and Technologies (2016 & 2017).	https://www.bpa.gov/EE/Utility/Momentum-Savings/Documents/190601_Res_HVAC_Model_Methodology_Report.pdf
11	High	Maintenance	International	Optimal refrigerant charge and energy efficiency of an oil-free refrigeration system using R134a	Optimal refrigerant charge can effectively increase energy efficiency and capacity, and minimise refrigerant leakage	https://www.sciencedirect.com/science/article/pii/S1359431119330522

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12	High	Maintenance	Japan	Artificial Neural Networks for Fast Rooftop Unit Fault Impact Modelling and Simulation	Automated fault detection and diagnosis (AFDD) methods have been developed for these systems and much experimental effort has been undertaken for their evaluation. To reduce development costs required for AFDD technologies, additional research related to modelling DX equipment subject to faults has been undertaken.	https://docs.lib.purdue.edu/iracc/2059/
13	High	Commercial Air conditioning	Australia	NPA - CSIRO test data on EER vs refrigerant charge	Data from testing CSIRO did for Cresstec Pty Ltd (a company who specialise in refrigerant management). It shows the catastrophic loss of capacity and efficiency that occurs at low charge rates. 50% charge led to EER of 0.54 compared to 2.83 at 100% charge. 70% charge led to 2.12	NPA
14	High	Refrigeration	International	Experimental Analysis on Refrigerant Charge Optimization for Cold Storage Unit	Study of refrigerant charge affecting cool room performance	https://www.researchgate.net/publication/320762693_Experimental_Analysis_on_Refrigerant_Charge_Optimization_for_Cold_Storage_Unit
15	High	Refrigerant leaks	North America	Low Refrigerant Algorithm Detection for Cooling Systems Relying on Trending and Data Analysis	A hybrid algorithm of an enhanced version of Mann-Kendall trending and data analysis is proposed to solve the limitations of current technology in detecting and diagnosing cooling system refrigerant faults in general and refrigerant leakage specifically. In the early stages, leakage affects energy cost, whereby the system runs longer to satisfy the cooling load and the repair cost is constant. The repair and energy costs rise exponentially as the system persists in losing refrigerant. At a certain low refrigerant level, catastrophic system failures may occur. Figure 1: Financial impact of refrigerant leak over time, (David Cowan et al., 2010). A sample of 225 HVAC systems installed in real homes were used in this investigation. Of these systems, 118 were charged with R410A refrigerant and the rest were charged with R-22 refrigerant. In this study, only 44% of the valid alerts were fixed. This raise the difficult question on how to guarantee the right fix to be performed for systems with valid alerts. We believe understanding and accounting for the complex relationship between technician and homeowner, while designing the HVAC FDD algorithms is a key in answering this question.	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1165&context=ihpbc
16	High	Refrigerant leaks	Australia	Refrigerant Emissions in Australia 2010 - Sources, causes and remedies, 2010	Dirty dozen leaks	http://www.expertgroup.com.au/download/Refrigerant%20Emissions%20in%20Australia%202010%20final%20190510.pdf
17	High	Best practice guide: Leaks	North America	GreenChill Best Practices Guideline Commercial Refrigeration Leak Prevention & Repairs	Detailed information on where leaks occur, causes of leaks, getting started, preventative maintenance, leak detection, leak inspection, leak repair, reducing leak potential, and walk-through checklist.	https://www.epa.gov/sites/production/files/documents/leakpreventionrepairguidelines.pdf

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18	High	Refrigerant leaks	North America	Refrigerant Management at Giant Eagle	EPA GreenChill early adopter. Usage Sorted by Location. Usage Sorted by Cause. Identify Problem Areas - Poor design/installation. Develop Solutions	https://19january2017snapshot.epa.gov/sites/production/files/documents/RefrigerantManagementGiantEagle.pdf
19	High	Refrigerant leaks	EU and UK	An investigation of refrigerant leakage in commercial refrigeration	Long-term joint venture relationships between the equipment owners and their service organisations to undertake proactive maintenance is a reasonably effective leakage control strategy. One supermarket company in the UK, has demonstrated over a 14-year period that through employing best practices, refrigerant leakage rates were effectively reduced from 54% to 8%. In addition to good housekeeping practices in reducing refrigerant leakage, manufacturers of RACHP systems and equipment installers also have a role to play in leakage prevention. Analysis of this type, along with further investigation into the problematic components identified in the study as prone to leakage is recommended. It is considered that the findings can be used to influence and modify common practices in equipment design, installation and maintenance within the industry. The investigation showed that the most common faults are pipe or joint failure and leaking seal/gland/core, which agreed with the findings from previous studies. These faults were predominantly found within the compressor pack and HP liquid line. It is recommended that further research into developing leak tight design, installation and maintenance of refrigeration system components that frequently develop faults should be conducted.	https://www.sciencedirect.com/science/article/abs/pii/S0140700716303383
20	High	Best practice guide: Leaks	EU and UK	REAL Zero GN2-2015 (13 most common leaks).pdf	13 most common leak causes and solutions	https://ior.org.uk/careers/refrigerant-containment
21	High	Best practice guide: Leaks	EU and UK	REAL Zero GN3_2015 (Designing out leaks - Design standards and practices).pdf	Top ten tips for designers and specifiers	https://ior.org.uk/careers/refrigerant-containment
22	High	Maintenance	North America	Energy Savings from Maintenance	A summary of other studies - Centrifugal Chillers - Tube cleanliness - Water treatment program. Tube cleaning. 15% savings for eliminating microbes; 10-20% more if scale and iron deposits are present. 10% to 35% savings or more in extreme cases. Sub-optimal refrigerant levels. The efficiency of all chillers suffers if the system has either too little or too much refrigerant charge. Up to 20% savings. Oil contamination in refrigerant Chiller refrigerant charge reclamation to clean existing refrigerant in a one-time process, or the use of a purging system that cleans the refrigerant charge on an ongoing basis. 2% loss in chiller efficiency for every 1% of oil found in the refrigerant. It is not uncommon to find 10 percent oil in the refrigerant of older chillers. Rooftop Units - Suboptimal refrigerant charge - Check and adjust refrigerant charge as needed	https://buildingefficiencyinitiative.org/resources/fact-sheet-ibe-energy-savings-maintenance_and https://buildingefficiencyinitiative.org/articles/studies-show-hvac-system-maintenance-saves-energy

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					5-11% energy savings. The New Buildings Institute found that best practices in building maintenance and operations reduce energy use 10-20%. Industry practices: Reactive maintenance (55%) Preventative maintenance (31%) Predictive maintenance (12%). More studies are needed to accurately quantify the energy savings from varying maintenance strategies more quantification of the energy savings will lead more building owners to become interested in regular maintenance for their HVAC systems	
23	High	Commercial air conditioning	North America	Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States	A meta-analysis of commercial building faults (new and existing). From data on 122 buildings the study identified 6,652 deficiencies for existing buildings and 3,528 for new construction. Top faults causing energy inefficiencies in commercial buildings - Duct leakage. HVAC left on when space unoccupied. Lights left on when space unoccupied. Airflow not balanced. Improper refrigerant charge (0.7 billion $/year). Dampers not working properly. Insufficient evaporator airflow Improper controls setup/commissioning. Control component failure or degradation. Software programming errors Improper controls hardware installation Air-cooled condenser fouling Valve leakage. The initial benefit from commissioning is the unearthing of problems in a building that, remaining undetected, would burden the facility with higher operation and maintenance costs. For two buildings analysed in detail, one author found that 46% and 62% of the deficiencies identified during commissioning would in the future manifest as higher repair and maintenance costs	https://link.springer.com/article/10.1007/s12053-011-9116-8
24	High	Commercial air conditioning	North America	Review of recent commercial roof top unit field studies in the Pacific Northwest and California	Presents the aggregated results of four investigations into the efficiency and operational problems of packaged rooftop heating, ventilation and air conditioning units (RTU). Secondarily the report suggests recommendations for programmatic approaches to capture RTU savings potential and for further research and analysis. Total of 503 rooftop HVAC units, at 181 commercial buildings sites in 5 states were investigated. Refrigerant charge was found to be out of range on an average of 46% of the units tested. Economisers (64%), airflow (42%), thermostats (58%), sensors/controls (20%) were also identified problem areas. Many of the problems discovered by these studies are specification and installation problems. The initial specification of improper sensors and thermostats followed by inadequate and untested system installations have resulted in many systems not operating correctly from their initial start-up.	http://newbuildings.org/sites/default/files/NWPCC_SmallHVAC_Report_R3_.pdf

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25	High	Refrigeration	North America	Supermarket system characteristics and operating faults (RP-1615)	A study was conducted to investigate supermarket equipment characteristics, such as the prevalence of central vs. distributed systems, condenser types, control strategies, and common operating faults such as refrigerant leakage, failed evaporator or condenser fans, failed compressors, etc. The data come from four sources: expert surveys, facility management system messages, service calls, and service records. Some of the results of the study are that centralised direct expansion systems with on/off compressor capacity control strategy and air-cooled condensers are the most common system types and refrigerant charge problems are the most common source of equipment failure. Case-related problems, in aggregate, are the most frequently occurring faults in supermarkets. Fig. 3. Supermarket commonly occurring faults that lead to equipment failure - refrigerant charge problems are considered the most responsible fault for equipment failure. Oil problems are the second most common fault to cause equipment failure. Iced-up evaporator or evaporator fouling, and control system problems are the third and fourth causes of equipment failure, respectively Fig. 4. Supermarket most costly repairs. System charge problems and problems in the compressor racks are the other most frequent faults in stores.	https://www.tandfonline.com/doi/pdf/10.1080/23744731.2018.1479614?needAccess=true
26	High	Refrigerant leaks	International	Domestic Air Conditioner Test Standards and Harmonization Final Report	The length of refrigerant piping is not consistent between the countries. It varies from 5 meters to 7.5 meters, and the extra pressure drop in the piping could cause a change in EER of 1-3%. Alternatively, test methods could require verifying refrigerant charge prior to testing to alleviate the impact of varying piping length.	https://www.iea-4e.org/projects/air-conditioners

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27	High	Commercial air conditioning	North America	Analysis of Heat Pump Installation Practices and Performance	2. Field Review: An extensive field review was conducted to examine the heat pump as installed, its set up and control strategy, and the characteristics of the ducts and house. This review included complete Duct Blaster® and blower door tests, as well as a check of the refrigerant charge. Overall Findings and Conclusions from the billing analysis is that heat pumps are performing at or near what might be considered the expected level, at least for the C&RD/ConAug program participants. Savings averaged approximately 4,149 kWh/yr., representing about 15% of total electricity use. The Purdue laboratory data, the EWEB billing data, and the field review all indicate that running the system with non-optimal refrigerant charge does not have a significant impact on heat pump performance in heating mode. The system had to be run at 20% or more undercharge before any reduction in efficiency was noted. In fact, the data points to a slightly undercharged system as the optimal condition in heating mode. The field study of base case installations found several important findings. First, only about 10% of systems were found with undercharged compressors. Only a few systems out of the approximately 140 evaluated were seriously undercharged, and these systems were overdue for service. Low airflow across the indoor coil was noted in about 25% of cases. Airflow is an important determinant of field performance and remains a central part of ongoing field verification efforts in the Northwest. Heat pump systems tend to be sized to about 70% of the required heating load. Despite the continued positive development of regional installation standards, there is still a need for field verification of system performance 4.1.1. Installation Practices: TXVs. One of the major items of interest in this study had to do with the availability of thermostatic expansion valves (TXVs) on the outdoor unit. The use of this technology was thought to be a technologically effective way to ensure unit capacity even if system charge was not optimal (and therefore could be used as a stand-in for a full charge check during installation). Table 22. Duct UA and Leakage Rates Generally, external static pressure of more than about 175 Pa indicates the ducts might be restricting airflow. Refrigerant charge was evaluated using a combination of tests (depending on season). Figure 40. Refrigerant Charge Distribution Only about 8% of systems were undercharged; they were so designated if the data suggested a major deviation from expected performance values. About 30% of systems were overcharged Other researchers have expressed the concern that this equipment tends to be oversized. At least in this study, it appears to have been undersized considerably.	https://library.cee1.org/system/files/library/1938/1123.pdf
28	High	Refrigeration	Australia	Refrigeration Masterclass webinar series - 6 of 6 - Maintain and operate for efficiency	Opportunities -refrigerant charge, maintain indoor and outdoor coils, superheat control, fans and door seals, blocked filter driers.	https://www.youtube.com/watch?v=Cz227Opm3Ic

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29	High	Maintenance	International	Press release	Partnership with Danfoss and $2M research for refrigeration applications	https://www.globenewswire.com/news-release/2019/01/14/1691168/0/en/Danfoss-and-Nelumbo-a-Surface-Modification-Technology-start-up-enter-Strategic-Partnership.html
30	High	Maintenance	North America	Envisioning the Kitchen of Tomorrow pp. 17-18	The PG&E Food Service Technology Center (FSTC) is an unbiased energy-efficiency research program funded by California utility customers standalone refrigeration. Cools saving project - from three restaurants: (1) Glass door merchandiser: $300/year savings; (2) Glass door merchandiser: $600/year savings; and (3) Solid door refrigerator: $590/year savings	https://www.pge.com/en_US/small-medium-business/business-resource-center/training-and-education/food-service-technology-center.page
31	High	Maintenance	North America	Preventative Maintenance Pays: Research from the Field, Online Tools and Best Practices pp. 14-22	Grey research showing 40-50% savings	https://fishnick.com
32	High	Commercial air conditioning	North America	A Literature Review on Heat Exchanger Air Side Fouling in Heating, Ventilation and Air conditioning (HVAC) Applications	This paper presented a literature review of fouling in heat exchangers focused on air conditioning applications. The review explains that fouling in heat exchangers depends on a number of factors on both the system as well as the airside. The overall impact of fouling is degradation of the performance of heat exchangers. This includes a degradation of the heat transfer by accumulating on the heat transfer surface as well as an increase in pressure drop. Numerous studies found that for a different type of fouling material, fouling is more severe on the front face as compared to the rear face. The impact of fouling in increasing pressure drop for constant air flowrate is greater than the decrease in heat transfer especially at the initial phase of the fouling process and if fibrous materials are involved. Using high efficiency filters before evaporators result in an increase in the fouling time but decreases the EER of the system due to the increased overall airside pressure drop. Increase in air velocity increases the COP of the system for both clean and fouled case, however, increase in COP with an increase in air velocity is not as significant in fouled case as in the clean case.	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2662&context=iracc

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33	High	Commercial air conditioning	North America	Experimental Comparison of the Impact of Air- Side Particulate Fouling on the Thermo-Hydraulic Performance of Microchannel and Plate-Fin Heat Exchangers	In this study, the air-side pressure drop and heat transfer performance of plate-fin and microchannel coils were tested under clean and fouled conditions. The ASHRAE dust was found to have a very significant impact on the pressure drop of the microchannel heat exchanger, increasing the air-side pressure drop of the microchannel heat exchanger by over 200% for a dust injection of 267g (1612.5 g/m2). Fouling of the microchannel heat exchanger with Arizona Road Test Dust was not found to increase the air-side pressure drop of the microchannel heat exchanger but was found to decrease the heat transfer rate by more than 10%. microchannel coils with louvered fins with fin pitch below 2.0 mm were significantly more prone to fouling than louvered heat exchangers with larger fin pitch. Particulate fouling of the wavy-plate-fin heat exchanger resulted in significantly lower reductions in heat transfer and increase in air-side pressure drop than for the microchannel heat exchanger Figure 5 Pressure drop of HXA with fouling Figure 6 Heat transfer of HXA with fouling Figure 7 Pressure drop of HXB with fouling Figure 8 Heat transfer of HXB with fouling 4.3 Fouling Evolution	https://docs.lib.purdue.edu/iracc/1024/
34	High	Maintenance	North America	Dirty Air Conditioners: Energy Implications of Coil Fouling	Applied experimental and simulation results describing particle deposition on evaporator coils as well as research about indoor particle and dust concentrations to determine the energy impacts of coil fouling. The results suggest that typical coils foul enough to double evaporator pressure drop (at constant flow) in about 7.5 years. This is considerably shorter than typical evaporator coil lifetimes of 15-30 years. The most important parameters in determining coil fouling times are the efficiency of the filter and indoor particle concentrations, with filter bypass and fin spacing as secondary effects. The reduced air flows that result from coil fouling cause flow reductions of 5 –7 % and typical efficiency and capacity degradations of less than 5%. However, these impacts can be much greater for marginal systems or extreme conditions. The importance of residential air conditioning energy use means that these degradations have a significant impact on peak electricity demand., residential commissioning procedures should include measurement of air flow, coil inspection for low flow situations, and verified cleaning to eliminate potential energy and indoor air quality effects.	https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel1_Paper23.pdf
35	High	Commercial air conditioning	North America	ACCA presentation - Federal Study Quantifies Efficiency Losses Due to Improper HVAC Quality Installation (ACCA 2014) - ACCA analysis of the NIST research referred to above	Commonly-noted field problems- Magnitude of energy increase. # Refrigerant charge - Up to 30% off OEM design. # Incorrect airflow over the coil - Up to 50% off design. # Equipment size - Routinely 100% too big. # Duct sizing - Routinely ½ the requirements. # Duct Leakage - Up to 50% of airflow. Refrigerant undercharge was identified as the 2nd most influential fault in terms of potential impact on energy efficiency. For double faults, 30% undercharge and 40% duct leakage combined to increase energy consumption to 172%. 20% energy penalty at 30% undercharge, 2 – 3% penalty at 10% undercharge, 10 to 15% energy penalty at 30% overcharge	https://www.achrnews.com/articles/127957-oct-29-2014-new-study-quantifies-efficiency-losses-due-to-improper-hvac-installation

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36	High	Maintenance	North America	2019 HVAC Market Characterization: Residential Building Stock Assessment	NYSERDA can influence the market adoption of higher efficiency unitary equipment in the replacement market through commercial HVAC maintenance programs. Most commercial customers in New York State (66%) have a reactive maintenance program, which indicates a substantial opportunity for enhanced maintenance programs. Maintenance programs can foster a partnership between engineering firms and contractors who then provide maintenance services and recommendations to install higher efficiency retrofits. One example of such a partnership is PG&E's Commercial HVAC Quality Maintenance Program, which offers incentives to customers who enrol in a three-year air conditioning quality maintenance service agreement and install optional unit retrofits. Installation Faults: Of the 70 surveyed contractors who installed HVAC systems, 84% reported that they perform maintenance on existing systems installed by other HVAC companies. These respondents often found issues with improperly designed ducts, oversized equipment, and duct leakage. As shown in Figure 34, 49% of contractors said they very frequently or frequently encountered ducts that were not properly designed, with 27% indicating this happens very frequently. Forty-six percent said they very frequently or frequently encountered equipment that was oversized, with 25% indicating this happens very frequently. Forty-four percent said they very frequently or frequently encountered duct leakage, with 19% indicating this happens very frequently. contractors also reported encountering issues with poor- or low-quality installation practices (49%), general equipment sizing (17%), and dirty parts (15%). Program implication. Opportunities remain for engaging this critical group of small contractors in training and certification to increase the installation of high-efficiency equipment and ensure quality maintenance and installation.	https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/rbsa-hvac-market-assessment.pdf
37	High	Commercial air conditioning	North America	The Business Case for Commissioning New and Existing Buildings	Earlier study than above (#99). 224 buildings (175 projects), of which 150 are existing buildings and 74 are new construction. Existing Buildings – Cx cost: $0.27/ft2 • Median NEBs: $0.18/ft2 – Deficiencies: 11 per building – Energy Savings: 15% – Payback time: 8.5 months • New Construction – Cx cost: $1.00/ft2 • Median NEBs: $1.24/ft2 – Deficiencies: 28 per building – Payback time: 4.8 years • Cost-effective over range of energy intensities, building types, sizes, locations. Types of deficiencies – Cooling. heating, air handling New 65% existing 90%. Observed non-energy impacts.	https://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf
38	High	Commercial air conditioning	Australia	Calculating Cool User Guide V4	Outlines the methodology for rating the HVAC systems of commercial office buildings	http://www.calculatingcool.com.au/Assets/UserGuide.pdf
39	High	Best practice guide: AC	North America	OSE Director's Rule 2016-01, Building Tune-Ups Requirement	Example - Outlines an approach to mandatory building/HVAC tuning - from Seattle	http://www.seattle.gov/Documents/Departments/OSE/OSE_DIRECTORS_RULE_2016-01.pdf

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40	High	Maintenance	North America	Sensitivity Analysis: Relative Impact of Design, Commissioning, Maintenance and Operational Variables on The Energy Performance of Office Buildings	The goal of this study is to compare the magnitude of energy impact that modifications to design, operation and tenant behaviour characteristics have on total building energy use. The selection of HVAC system type, distribution type, equipment and duct sizing, system efficiency, and ventilation damper settings and control strategies are all controlled by the HVAC system designer and have a huge impact on the energy use of the building. A significant percentage of building energy use is driven directly by operational and occupant habits that are completely independent of building design. Right-sizing HVAC equipment saved energy across all climates. When the effects of HVAC system selection are added, best design practices can lead to about a 50% savings, and worst practices can lead to a 60-210% increase in energy use The variables assumed by this study to be in this category include HVAC systems setpoints and schedules, economiser operation, ventilation controls and settings, and to some degree HVAC system efficiency and fan power (in that these variables can act as surrogates for adequate maintenance and balancing of the HVAC system). As shown in Figure 3, best practices in this area are shown to reduce energy use 10-20% across all climate zones. In contrast, bad practices in this area can increase energy use by 30- 60%.	https://newbuildings.org/wp-content/uploads/2015/11/SensitivityAnalysisReport1.pdf
41	High	Best practice guide: Refrigeration	Australia	DA12 Energy efficiency in cold rooms, AIRAH 2020	Extensive guide to best practice for WICs that mostly used remote condensing units	https://www.airah.org.au/DA_Manuals/Latest_releases/DA12_Energy_Efficiency_in_Cold_Rooms/DA_Manuals/2020_releases/DA12.aspx
42	High	Commercial air conditioning	EU and UK	ISERVCMB FINAL REPORT – JULY 2014	Summary of surveys discovering maintenance issues and energy conservation opportunities for a range of EU commercial buildings HVAC	https://www.researchgate.net/publication/265346322_ISERVCMB_FINAL_REPORT_-_JULY_2014_THE_INSPECTION_OF_BUILDING_SERVICES_THROUGH_CONTINUOUS_MONITORING_AND_BENCHMARKING_-_THE_ISERVCMB_PROJECT_Edited_by_Ian_Knight
43	High	Maintenance	International	Assessment of Climate and Development Benefits of Efficient and Climate-Friendly Cooling	Careful installation, maintenance, and servicing can improve energy efficiency over the product life. Improved installation and servicing practices to reduce refrigerant charge and leakage will also maintain energy performance of equipment and lower the cost of ownership through less frequent service. Skilled technicians are key to proper installation and servicing of equipment and to the rapid adoption of new technologies. Governments and industry have common interests in attracting, retaining, and upskilling technicians in the cooling sector to adapt to fast technological developments and maximise associated environmental and economic benefits. Degradation of equipment	https://eta-publications.lbl.gov/sites/default/files/ilovepdf_merged_11.01.02_am.pdf

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					energy performance can occur due to poor installation, such as stacking or clustering condensers to create mini "heat islands" or insufficient maintenance practices (contributing to reduced air flow and incorrect refrigerant charge) and environmental factors (depositions on heat exchangers). Momentum is growing on fast action on efficient cooling with the Biarritz Pledge	
44	High	Best practice guide: AC	Australia	Cooling Towers – Manufacture, design, installation and management	BPG for cooling towers	https://www.airah.org.au/ItemDetail?iProductCode=DA17&Category=DAMANUALS
45	High	Refrigeration	Australia	Refrigeration Efficiency, Sustainability Victoria	Benchmarking of 50 operational refrigeration systems in Victoria - using remote monitoring and AI. Minor problems with refrigerant leakage. Top issues - Ice build-up, low pump down pressure, short cycling. Reports included recommendations and paybacks	https://www.sustainability.vic.gov.au/Business/Energy-efficiency-for-business/Efficiency-by-system/Refrigeration/Improve-your-business-refrigeration-efficiency
46	High	Refrigeration	Australia	Refrigeration Masterclass webinar series - 5 of 6 - Design and install for efficiency - controls	-	https://www.youtube.com/watch?v=FVHwc53_klo
47	High	Refrigeration	Australia	AIRAH Walk-in cool room research project - Barriers to energy efficiency	Provides a range of findings about barriers (70 participants) - include Behaviour of user, Design, Education, Equipment, Installation, Operational, Structure (of cool room), Technology. It informed the development of DA12 - Energy Efficient Cool rooms	https://www.airah.org.au/Content_Files/Advocacy/2018/2018-AIRAH-WICF-findings-and-recommendations.pdf
48	High	Maintenance	North America	Residential Air Conditioning Fault Detection and Diagnostics (FDD) and Protocols to Support Efficient Operation	Faults, diagnostic algorithms and factors that impact energy efficiency. Common Degradation Faults. Refrigerant – Too little – Too much – Non-condensables – Low-side heat transfer problem • Dirty filter • Dirty indoor coil • Restricted ducts • Ineffective fan (e.g. slipping belt) – High-side heat transfer problem • Liquid line restriction – Low ET – High SH – High SC • Low refrigerant charge – Low ET – High SH – Low SC • Low-side heat transfer problem – Low ET – Low SH. Changes in rooftop operation due to refrigerant leakage. Changes in rooftop operation due to liquid line restriction. Changes in rooftop operation due to condenser fouling. Changes in rooftop operation due to evaporator fouling	https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/ns/b10_ac_fault_detection.pdf
49	High	Commercial Air conditioning	Australia	I am your optimisation guide - HVAC	This guide outlines 20 HVAC optimisation strategies and how they can be applied. These strategies can save up to 50 per cent of total HVAC energy use, or up to 80 per	https://www.environment.nsw.gov.au/resources/business/150317HVACGuide.pdf

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					cent of energy use in individual HVAC components. Includes energy and financial calculations for each scenario	
50	High	Refrigerant	International	AHRI Standard 700, Specifications for Refrigerants, 2016	-	http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_700-2016.pdf
51	High	Commercial air conditioning	North America	Development of Fault Models for Hybrid Fault Detection and Diagnostics Algorithm, National Renewable Energy Laboratory, Purdue University, West Lafayette, Indiana 2015.	Fault detection and diagnostic algorithms	https://www.nrel.gov/docs/fy16osti/65030.pdf
52	High	Refrigerant leaks	North America	Residential Refrigerant Charge Testing and Related Issues	The research work consisted of a series of laboratory tests on two typical split system air conditioners to validate (refrigerant charge) test protocols and provide performance data under a range of refrigerant charge and environmental conditions. Some of the conclusions related to refrigerant charge included: 1. Air conditioner refrigerant charge can be successfully adjusted using a low temperature protocol. 2. Charging to a target liquid line temperature is a valid method of obtaining correct and uniform refrigerant charge levels and produces superior charging results on low volume coils. 3. Improper evacuation leaves non-condensables mixed with the refrigerant. Even a mild amount of non-condensables produce a 7.5% reduction in Sensible EER. 4. Charge Indicator Displays (CIDs) show promise in providing constant monitoring of air conditioners. The laboratory tests showed that two manufacturers are close to producing units that can meet the Title 24 specifications. Testing for the study showed the relative independence of efficiency from refrigerant charge differences of up to ±10% but variations beyond that (>10% under/over charge) started to have a significant variation on efficiency.	http://www.energy.ca.gov/title24/2008standards/special_case_appliance/refrigerant/2013_CASE_R_Refrigerant_Charge_Testing_Dec_2011.pdf
53	High	Refrigeration	Australia	AIRAH DA19 HVAC&R Maintenance, 4th Edition, 2019	Industry best practice guide about maintenance and maintenance management. Assists in the development of routine and preventative maintenance. Sections focus on range of stakeholders in the value chain (e.g. owners, FMs, tenants, technical service providers). Topics included - overview - Design, install, and commissioning - in operation - strategies - smart maintenance - continuous improvement: tuning and optimisation. Widely referred to in govt, private sector and institutions (hospitals, universities).	https://www.airah.org.au/da_manuals/da19
54	High	Refrigerant	Australia	Refrigerant Health Check by A-Gas	Refrigerant test provides: purity, composition, non-volatile residue, acidity, moisture, chloride, particulates, particularly relevant with large systems including supermarket, industrial refrigeration and chillers.	https://www.agas.com/media/2542/refrig-healthcheck_information-sheet.pdf

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55	High	Best practice guide: RAC	North America	ACCA Quality Standards	ACCA have produced a range of quality standards covering HVAC&R installation and maintenance. ACCA/ANSI Quality Standards: 1. Quality Maintenance of Commercial Refrigeration Systems, 2. HVAC Quality Installation Specification (English). 3. Home Evaluation & Performance Improvement 4. HVAC Quality Installation Verification Protocols. 5 Quality Maintenance of Residential HVAC Systems. and, HVAC System Cleanliness & Restoration. ACCA claim (based on the NIST Technical Note 1848 report) that not following the requirements in the 5 ACCA Quality Standards can increase annual energy consumption by 30% or more due to design/installation and maintenance deficiencies. The ACCA use the standards to underpin their QA accreditation program which offers contractors two tracks: New Homes - Started in 2011 - More than 700 contractors have qualified for the QA New Homes Program nationwide. Residential Service and Installation - Started in 2013 - 150+ (and growing) contractors nationwide in 2015.	https://www.acca.org/standards/quality and https://hvac-contractors.acca.org/qa-contractors?_ga=2.244109509.1752956523.1594857922-1525041152.1594857922
56	High	Commercial air conditioning	Australia	Residential heating and cooling systems — Minimum applications and requirements for energy efficiency, performance and comfort criteria	Best practice standard for small to medium AC	https://www.standards.org.au/standards-catalogue/sa-snz/electrotechnology/ee-001/as-slash-nzs--5141-colon-2018
57	High	Commercial air conditioning	Australia	Routine service of fire protection systems and equipment	Specifies minimum requirements for maintenance for fire protection	https://infostore.saiglobal.com/en-au/Standards/AS-1851-2012-120190_SAIG_AS_AS_251902/?source=predictive
58	High	Best practice guide: AC	Australia	Building commissioning	BPG for commissioning and retro-commissioning	https://www.airah.org.au/ItemDetail?iProductCode=DA27
59	High	Best practice guide: AC	Australia	The Soft Landings Framework Australia and New Zealand - For better briefing, handover and building performance in-use	BPG for extended commissioning process	https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I76SAAS
60	High	Maintenance	North America	PG&E's Commercial HVAC Quality Maintenance Program	PG&E's Commercial HVAC Quality Maintenance Program ("the Program") offers generous incentives for enrolling in a three-year air conditioning quality maintenance service agreement and installing optional unit retrofits. The Program is designed for commercial rooftop units powered by electricity from PG&E. Customers who switch	https://www.pge.com/mybusiness/energysavingsrebates/rebatesincentives/rethinkhvac/fs_HVAC_QM.pdf

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					from a "service only when needed" plan to the Program can save up to $500/year/unit* in operating, servicing and repair costs. Even customers who operate with a regular "checkbased" plan could save up to $260/year/unit. *	
61	High	Commercial air conditioning	Australia	Application Manual DA15 Air filters and cleaning devices	Complete best practice approach to filter over entire lifecycle.	https://www.airah.org.au/ItemDetail?iProductCode=DA15
62	High	Best practice guide: AC	New Zealand	Good practice guide Heat pump installation	Specifies requirements for design, installation, commissioning and service	https://www.eeca.govt.nz/our-work/research/research-papers-and-guides/good-practice-guide-heat-pump-installation/
63	High	Commercial air conditioning	Australia	Air-handling and water systems of buildings - Microbial control Part 2: Operation and maintenance	Specifies minimum requirements for maintenance of HVAC for microbial control	https://infostore.saiglobal.com/en-au/Standards/AS-NZS-3666-2-2011-116883_SAIG_AS_AS_267808/
64	High	Best practice guide: AC	Australia	Fire safety – Kitchen hood exhaust systems - Understanding and addressing the special fire risks inherent in commercial kitchen ventilation systems	-	https://www.airah.org.au/Content_Files/Resources/Technical-Bulletin-Kitchen-Exhaust.pdf
65	High	Commercial air conditioning	Australia	AIRAH presentation AS 4254.2- 2012 Duct Leakage Testing	Discussion of duct leakage testing	https://www.airah.org.au/Content_Files/Divisionmeetingpresentations/ACTNSW/Owen-Ryan.pdf
66	High	Commercial air conditioning	Australia	A Survey of Thermal Performance of Flexible Duct	Survey and test of nine products all of which failed to produce the declared R value.	http://www.insulationaustralasia.org/wp-content/uploads/2014/05/Report-ACA-131108-INSULATION-AUSTRALASIA-Flexible-Duct-Tests-140507.pdf
67	High	Commercial air conditioning	Australia	AIRAH Ecolibrium FORUM Duct leakage and leakage testing	Discussion of duct leakage in Australia	https://www.airah.org.au/Content_Files/EcoLibrium/2013/M%20ay13/05-13-Eco-Forum.pdf

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68	High	Commercial air conditioning	North America	Duct Leakage Impacts on VAV System Performance in California Large Commercial Buildings	Study of VAV systems in large commercial buildings in California calculated that, compared to "tight" duct systems (2.5% leakage), systems with 10% leakage had annual HVAC system operating costs 9 to 18% higher, while those with 5% leakage used 2 to 5% more energy	https://www.osti.gov/biblio/819481-duct-leakage-impacts-vav-system-performance-california-large-commercial-buildings
69	High	Refrigeration	Australia	Insulated Panel Council Australasia Ltd (IPCA) CODE OF PRACTICE	Best practice guide for insulated panels.	http://www.insulatedpanelcouncil.org/code-of-practice-v2/
70	High	Maintenance	North America	Evaluation of Air Conditioning Performance Degradation: Opportunities from Diagnostic Methods	First ever long-term empirical measurement of the degradation of residential air conditioner/heat pump (AC/HP) performance. 2012 - 2016, FSEC monitored 56 homes in Florida Within the analysis, cooling system performance at many sites was found to worsen over the baseline period, typically degrading 5%, and ranging from -8% to 40%, per year. The reason for the progressive decline of cooling performance is not determined in the study although earlier research suggests coil fouling and refrigerant charge problems likely play roles in the phenomenon. Filter maintenance could be another important factor. Some systems experienced sudden, severe declines in performance often associated with need for system replacement. The only previously available estimates on AC degradation came from an LBNL study by Matson et al. (2002) Equation [1] was adopted by the Building America benchmark methods for analysing existing buildings (Hendron, 2006): SEERdegrade = SEERnominal * (1- M) Age. Where M is the Maintenance factor, 0.01 for expertly maintained equipment and 0.03 for unmaintained; and Age is equipment age in years Refrigerant charge. Improper refrigerant charge is a very common problem with residential air conditioning systems. Deficiencies lead to low cooling and heating capacity for heat pump systems. Low coil air flow and coil fouling. Low evaporator coil air flow is another common problem with residential air conditioning systems Unfortunately, within the project, no data were available on how the cooling systems were maintained or how filter were changed etc., either professionally or by homeowners. Beyond equipment age, degradation was also found to be more influenced by system size and the seasonal energy efficiency ratio (SEER).	http://publications.energyresearch.ucf.edu/wp-content/uploads/2018/09/FSEC-PF-474-18.pdf
71	High	Refrigeration	New Zealand	Trial Retrofit of Doors on Open Refrigerated Display Cabinets, NZ ECCA 2015	Study commissioned by ECCA to demonstrate savings from doors on refrigerators and understand impact on sales.	https://www.airah.org.au/Content_Files/Resources/Trial-Retrofit-of-Doors-on-Open-Refrigerated-Display-Cabinets.pdf
72	High	Refrigeration	Australia	Retrofit doors for Open Cabinets, Advanced	Testimony of savings from retrofitting best in class doors to open display cases.	http://www.artmaslen.com.au/product-guide

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				Refrigeration Technologies		
73	High	Maintenance	North America	O&M Best Practices Guide, Release 3.0 Chapter 5 Types of Maintenance Programs	The predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance program as follows: • >55% Reactive • 31% Preventive • 12% Predictive • 2% Other. Depending on the facility's current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities purely reliant on reactive maintenance could save much more than 18% by instituting a proper preventive maintenance program. Past studies have estimated that a properly functioning predictive maintenance program can provide a savings of 8% to 12% over a program utilising preventive maintenance alone. The following maintenance program breakdowns of continually top-performing facilities would echo the RCM approach to utilise all available maintenance approaches with the predominant methodology being predictive. • <10% Reactive • 25% to 35% Preventive • 45% to 55% Predictive.	https://www.energy.gov/sites/prod/files/2013/10/f3/omguide_complete.pdf
74	High	Maintenance	International	BRIEFING NOTE A the Importance of Energy Efficiency in the Refrigeration, Air-conditioning and Heat Pump Sectors	Outlines potential for the cost-effective improvement of the energy efficiency of RACHP equipment and application of good installation, operating and maintenance practices to support high efficiency operation throughout the life of the equipment.	https://ozone.unep.org/sites/default/files/2019-08/briefingnote-a_importance-of-energy-efficiency-in-the-refrigeration-air-conditioning-and-heat-pump-sectors.pdf
75	High	Maintenance	International	BRIEFING NOTE B the Potential to Improve the Energy Efficiency of Refrigeration, Air-conditioning and Heat Pumps	Efficiency factor 6: Check operating performance and correct any faults of existing RACHP systems. This efficiency factor is the only one that specifically applies to existing equipment. Many RACHP systems operate for years with control or maintenance related problems that go undetected. Performance should be regularly measured. If energy use is creeping up there could be a maintenance issue that can quickly be resolved. It is common to find that savings of 10% to 20% can be achieved by monitoring the performance of an existing system and correcting any faults identified.	https://ozone.unep.org/sites/default/files/2019-08/briefingnote-b_potential-to-improve-the-energy-efficiency-of-refrigeration-air-conditioning-and-heat-pumps.pdf
76	High	Maintenance	Australia	NPA - Advice provided by AIRAH on maintenance for low emission HVACR	Clause 4.1 Reactive (60%) - Preventative (30%) - Predictive (10%) and Clause 5.1.2 - Maintenance for energy efficiency is anecdotally reported to be able to generate energy savings in the range of 10 – 60% in the first intervention and then savings in the range of 10 – 20% for annual interventions thereafter.	NPA
78	High	Maintenance	North America	Keeping refrigeration running right is a lot easier and cheaper than fixing it	80% of operators do no maintenance. 20% of operators do some maintenance. Operators that do quarterly maintenance rarely experience system failure. Clean condensers quarterly or more often, check seals and door hinges. Preventative maintenance = equipment will operate better, last longer and have less down-time.	https://www.refrigeration-magazine.com/

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79	High	Maintenance		NPA - Advice provided by AMCA regarding their service group survey	recent AMCA Service Survey, which highlights the fact that preventative (proactive) maintenance only makes up around 21% of company revenue on average. To AMCA, this seems like any area that could be incentivised further.	NPA
80	High	Best practice guide: AC	North America	Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems	Scheduled maintenance recommendations from ASHRAE	https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/previews_2016639_pre.pdf
81	High	Maintenance	Asia (excl. Japan)	Maintenance for Energy efficiency: A Review	Energy saving can be obtained by application of energy-efficient technologies, operational improvement, and effective maintenance. The purpose of this paper is to investigate the role of maintenance in energy saving and available maintenance approaches for energy consumption reduction. There are eight common faults occur on the chiller system [57]: reduced condenser water flow, reduced evaporator water flow, refrigerant leak, refrigerant overcharge, excess oil, condenser fouling, non-condensables in the refrigerant, and defective expansion valve. Each of the common faults contributes to reduced chiller performance, in other words, it increases chiller energy consumption. maintenance had a major role to make sure refrigeration system operates at maximum. Good maintenance practice could improve energy efficiency, increase the reliability of refrigeration system and reduce the leakage of greenhouse gasses. The heart of maintenance for energy efficiency is predictive maintenance. such as ultrasonic leak detector. Predictive maintenance – condition-based maintenance – Fault detection and diagnosis. The trend of maintenance strategy for energy efficiency is condition-based maintenance. First is by combining energy monitoring with IoT technologies. Second is by introducing an energy-related performance indicator for condition-based maintenance. Next is the use of advanced condition monitoring method such as fault detection and diagnosis (FDD), and thermoeconomic diagnosis. However, maintenance for energy efficiency cannot be separated from operational improvement. During an inspection or condition monitoring, energy can be saved by both proper maintenance and operational improvement.	https://iopscience.iop.org/article/10.1088/1757-899X/530/1/012047/pdf
82	High	Maintenance	north America	Commercial Baseline Study HVAC Market Assessment	HVAC Market Assessment (New York) plus breakdown of maintenance application	https://www.nyserda.ny.gov/-/media/Statewide-Commercial-Baseline-Study-Report/NYSERDA-CBS-Vol-3-HVAC-Market-Assessment.pdf

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83	High	Refrigerant leaks	North America	Generalized effects of refrigerant charge on normalized performance variables of air conditioners and heat pumps	Meta-analysis of refrigerant charge fault work. Among the faults, refrigerant charge variation is believed to be very common, and has been the focus of experiments by many researchers. In the current paper, using all available results in the literature, the effect of refrigerant charge faults on single-speed air-cooled air-conditioners and heat pumps is summarised. Results are presented separately for fixed orifice (FXO) and thermostatic expansion valves (TXV), for both cooling and heating modes. The variation level of the results indicates that for many applications, it is reasonable to use these generalised relationships to estimate the effect of refrigerant charge variation on systems that have not been tested in a laboratory. Figs. 3 and 4 show the effect of FICH on system normalised variables in FXO and TXV-equipped units in A and B test conditions, respectively. Table 6 demonstrates the mean value and standard deviation of normalised variables for several discrete values of FICH. For example, at 20% undercharge (FICH = −0.2) in the A test condition, FXO systems produce 80.7% of their nominal cooling capacity, with a standard deviation of 3.6%.	https://experts.nebraska.edu/en/publications/generalized-effects-of-refrigerant-charge-on-normalized-performan
84	High	Refrigerant leaks	Australia	Management guideline for the phase-out of refrigerant R22 - Impacts and strategies for building owners, operators and maintainers	Covers fractionation explanation for HFC blends	https://www.airah.org.au/Content_Files/Resources/R22-phase-out-management-guideline.pdf
85	High	commercial air conditioning	Australia	AS4524.1 2012 Ductwork for air-handling systems in buildings Part 1: Flexible duct	Australian standard for flexible ductwork; including requirements for R-values and air sealing	AS 4254.1-2012 Ductwork for air-handling systems in buildings Fle (saiglobal.com)
86	High	Commercial air conditioning	Australia	AS4524.2 2012 Ductwork for air-handling systems in buildings Part 2: Rigid duct	Australian standard for rigid ductwork; including requirements for air sealing	AS 4254.2-2012 Ductwork for air-handling systems in buildings Rig (saiglobal.com)
87	High	Maintenance	Australia	AS/NZS 5149.4. Refrigerating systems and heat pumps - Safety and environmental requirements, Part 1:	Compliance standard for refrigeration safety and environmental aspects of refrigeration maintenance	https://www.standards.org.au/standards-catalogue/sa-snz/manufacturing/me-006/as-slash-nzs--5149-dot-4-colon-2016

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				Definitions, classification and selection criteria (ISO 5149-1:2014, MOD)		
88	High	Maintenance	Australia	AS 1851 Routine service of fire protection systems and equipment	Compliance standard for HVAC Maintenance	https://www.standards.org.au/standards-catalogue/sa-snz/building/fp-001/as--1851-2012
89	High	Maintenance	Australia	AS/NZS 3666.3 Air-handling and water systems of buildings - Microbial control, Part 3: Performance-based maintenance of cooling water systems	Compliance standard for HVAC Maintenance	https://www.standards.org.au/standards-catalogue/sa-snz/manufacturing/me-062/as-slash-nzs--3666-dot-3-colon-2011
	Medium	Refrigerant leaks	North America	Peel and Stick Sensor for Refrigerant Leak Detection	Future possibilities	-
	Medium	Refrigeration	Australia	NPA - AIRAH Future of refrigeration 2017 - survey raw data	Raw results from survey at 2017 national conference (unpublished)- Three questions asked 1) What will refrigeration and the industry look like in a net-zero world? - people, systems, technology etc? 2) What will the refrigeration regulatory framework look like in a net-zero world? 3) 3) What needs to change to get there? Responses included a range of big picture (disruption of supply chain and integrated design) to specific details (new ways of pipe joining) - recurring themes included big push to natural refrigerants - this supports the findings in the PRIME work, and the findings in the Latest Drawdown reports. A range of new technology is also mentioned - non-vapour compression systems, smaller plug and play systems etc.	NPA
	Medium	Refrigeration	Australia	NPA - Raw Data for AIRAH Walk in cool room Research report	Extensive raw data	NPA
	Medium	Commercial Air conditioning	Australia	NPA - Energy Productivity: A Scoping for ARENA	Unpublished report - HVAC is identified as one of the top priority areas to focus on. The core of this project is the "Energy Productivity Opportunity Identification and Implementation Framework" (EP Framework). The framework is intended to provide a coherent analytical framework for identifying, prioritising and implementing energy productivity opportunities by ARENA. Notes on HVAC findings - Strong market transformation potential through knowledge and technology demonstration projects, key	NPA

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					stakeholders exist to drive change and strong alignment with other ARENA investment priorities. There is good fit between innovation barriers and ARENA instruments, program gaps and opportunities exist to complement existing programs and supportive local and global trends	
	Medium	Commercial Air conditioning	Australia	NPA - Study for ARENA Appendix 7.4: Heating Ventilation and Air-Conditioning in Buildings Case Study	Appendix to ARENA scoping study – focus on HVAC. - Focus on new and existing residential and commercial buildings. New HVAC installations will encompass design and commissioning of systems, selection of equipment, new technologies, and design of building envelopes. Existing installations will be concerned with upgrading building envelopes and retrofitting improved equipment based on audits and performance evaluations. Residential applications are often smaller in scale, and less likely to involve expert advice or regular monitoring and maintenance. Case study includes recommendations for two streams of projects – HVAC focused and a net zero energy buildings program.	NPA
	Medium	Commercial air conditioning	Australia	NPA - Grosvenor Engineering Group, Problem Source Library Codes	This is fault code for largest mechanical services contractor in Australia that has been collecting data on Asset Resource Management System since 2000	NPA
	medium	Refrigeration	Australia	Refrigeration Masterclass webinar series - 4 of 6 - Design and install for efficiency - hardware	Condenser location, water assisted cooling for condensers, Low TD condensers, Electronic Expansion Valves, LEDs for cool/freezer rooms, Solenoid valve location, insulation, infiltration management, heat recovery	https://www.youtube.com/watch?v=aBUcn5zBWAY
	Medium	Maintenance	International	The Montreal Protocol Evolves to Fight Climate Change (UNIDO)	The amendment emphasises the importance of energy efficiency in refrigeration and air conditioning. HFCs can contribute to global warming through direct and indirect emissions. Improving the energy efficiency of refrigeration systems therefore plays a key role in climate change mitigation and represents an essential goal for future projects. UNIDO will assist developing countries and countries with economy in to improve energy efficiency. UNIDO are experienced in promoting energy efficiency and introducing low-carbon and low-emission technologies and practices.	https://www.unido.org/sites/default/files/201707/UNIDO_leaflet_07_MontrealProtocolEvolves_170126_0.pdf
	Medium	Refrigerant	International	The Kigali Amendment to the Montreal Protocol (UNEP)	The capacity of National Ozone Officers (NOOs) in Article 5 countries will be strengthened by UNEP so they can adjust their national Montreal Protocol compliance programmes to respond to the Kigali Amendment and incorporate energy efficiency considerations into their countries' work with the refrigeration and air conditioning sector. Since this cannot happen in isolation, a variety of national stakeholders need to	https://www.unenvironment.org/ozonaction/kigali-cooling-efficiency-programme

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					come together to develop or revise policies and programmes for integrated, holistic refrigerant management approaches to this next refrigerant transition.	
	Medium	Maintenance	International	The Kigali Cooling Efficiency Program (K-CEP)	Launched in 2017, K-CEP is deploying US$ 52 million of philanthropic funds to strengthen institutions, support adoption of model policies, scale-up technology deployment, leverage finance and help make cooling more affordable and sustainable and to achieve energy efficiency objectives related to the Kigali Amendment. The UNEP and the IEA are co-leads.	https://www.unenvironment.org/ozonaction/kigali-cooling-efficiency-programme https://www.iea.org/areas-of-work/promoting-energy-efficiency/kigali-cooling-efficiency-programme
	Medium	Maintenance	International	Series of webinars on the IEA website - including IOT for Appliances.	The IEA has launched a cross-agency initiative to explore the potential impacts of digitalisation on energy efficiency and implications for policy makers. Looking at how digital technologies enable greater control, optimisation and analytics, and how this in turn enables greater end-use and systems efficiency, especially when combined with the right policy frameworks and innovative business models.	https://www.iea.org/areas-of-work/promoting-energy-efficiency/energy-efficiency-and-digitalisation
	Medium	Commercial air conditioning	International	The Future of Cooling	This special IEA report aims to raise awareness globally about one of the most critical energy issues of our time, outlining a sustainable path to the future of cooling. There is an enormous opportunity to quickly influence the growth of cooling-related energy demand through policies to improve equipment efficiency. "There are several areas where efficiency of existing AC technologies could be improved". "Better sizing, installation and maintenance can ensure that air-conditioning equipment and controls work as intended, by making sure that the right amount of refrigerant is circulating, by cleaning the fans and filters, and by optimising control settings." Recommendations: "Introduce or strengthen codes and standards for existing buildings, including requirements for maintenance and operation that improve demand-side management. Support information and capacity-building efforts on issues such as AC maintenance, behaviour and building management that can enhance the efficiency of equipment use."	https://www.iea.org/reports/the-future-of-cooling
	Medium	Refrigerant leaks	North America	Benefits of Energy Efficient and Low-Global Warming Potential Refrigerant Cooling Equipment	This paper estimates 'system total refrigerant leakage factors' when calculating benefits of switching to Low GWP refrigerant. This includes installation emission factor, plus average annual operating emissions and plus End-of-life (EOL) charge loss for a range of RAC system architectures – mini-split AC, Variable Refrigerant Flow/Ducted AC systems, Air-Cooled Chillers, Water-Cooled Chillers, Packaged Air Conditioners, Large Centralised Refrigeration Systems, Remote Condensing Units, Self-Contained	https://eta.lbl.gov/publications/benefits-energy-efficient-low-global

Ref #	Relevance (High, cited in Report)	Topic	Region	Title [Some publications are denoted 'Not Publicly available' (NPA)]	Key features of document	Link
					Commercial Refrigeration Units and Domestic Refrigerators. Operating emissions are the loss in refrigerant charge from leakage during equipment operation relative to the charge at the beginning of each year	
	Medium	Refrigerant leaks	North America	Benefits of Leapfrogging to Super efficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning	This paper estimates 'system total refrigerant leakage factors' when calculating benefits of switching to Super efficiency and Low Global Warming Potential Refrigerants for room air conditioners. Like other LBNL paper (#7). The study adopted a total lifetime refrigerant loss of 170% of initial charge for new equipment. An installation emission factor of 1% and average annual operating emissions of 10% is assumed and the system is recharged at 35% initial charge loss.	https://ies.lbl.gov/sites/default/files/lbnl-1003671.pdf
	Medium	Refrigeration	Australia	Carnegie Fruit Markets - SV case Study	Fruit produce - Case study of SV project (1 or 50) - identifies efficiency problems with two cool rooms, makes recommendations with paybacks. Water sprays, door seals, ice up	https://www.sustainability.vic.gov.au/About-us/Case-studies/Food-processing-and-storage
	Medium	Refrigeration	Australia	Schnitz Bendigo - SV case study	Fast food store - Case study of SV project - no equipment problems found but general behavioural recommendations that are common in these projects - Don't keep doors open too long, keep coils dust and dirt free, ensure good air flow in the space.	https://www.sustainability.vic.gov.au/About-us/Case-studies/Food-processing-and-storage
	Medium	Refrigeration	Australia	Mirfak mills SV Case Study	Produce storage (e.g. ground floor) - Case study of SV project - severe air recirculation problem on outdoor unit (install problem), defrost issues at peak periods	https://www.sustainability.vic.gov.au/About-us/Case-studies/Food-processing-and-storage
	medium	Refrigeration	Australia	Refrigeration Masterclass webinar series - 1 of 6 Understanding refrigeration basics	YouTube - Context setting for master class	https://www.youtube.com/watch?v=zJnkb1EIuJY
	medium	Refrigeration	Australia	Refrigeration Masterclass webinar series - 2 of 6 - Refrigeration compressors and system types	-	https://www.youtube.com/watch?v=mGxCUvtXArg
	medium	Refrigeration	Australia	Refrigeration Masterclass webinar series - 3 or 6 - Remote monitoring and benchmarking	-	https://www.youtube.com/watch?v=aBnq8lPzaic

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	Medium	Refrigeration	Australia	Reduce refrigeration costs in your business	Webpage guidance for small, medium and large business owners. Includes upgrade, temp setpoints, maintenance, LED lights, using the space, keep door closed, loading policies	https://www.sustainability.vic.gov.au/Business/Energy-efficiency-for-business/Efficiency-by-system/Refrigeration
	Medium	Best practice guide: RAC	Australia	AIRAH Guide to Model WHS Law in Australia for the HVAC&R industry final	Big picture overview of the law for work place health and safety - refrigerant obligations as a toxic substance	https://www.airah.org.au/AIRAH/Navigation/AboutAIRAH/PressReleases/2017/2017_Press_Releases/Changing_the_culture_of_safety_in_the_HVACR_industry.aspx
	Medium	Refrigeration	Australia	Australian Refrigeration and Air-conditioning Volume 1, 5th Ed, 2013	Together, Australian Refrigeration and Air-conditioning, Volumes 1 and 2, form the primary resource for training in the refrigeration and air-conditioning industry in Australia. The completely revised fifth edition combines coverage of both new trends and industry fundamentals with a new full-colour format and updated images that make for easier reading and understanding. This latest edition of Volume 1 reflects the industry's increased focus on efficiency and sustainability, as well as updates in technologies, while maintaining comprehensive coverage of industry basics in terms of principles and equipment. The underlying principles and basic hardware needs of refrigeration and air-conditioning have not changed. But the requirement for the technician and the designer to apply those principles, and to make system decisions, to achieve a more efficient and sustainable outcome has never been greater.	https://www.airah.org.au/AIRAH/Navigation/Resources/Australian_Refrigeration_and_Air-conditioning_Volumes_1_and_2/Australian_Refrigeration_and_Air-conditioning_Volumes_1_and_2.aspx
	Medium	Refrigeration	Australia	Australian Refrigeration and Air-conditioning Volume 2, 5th Ed, 2014	Australian Refrigeration and Air-conditioning Volume 2 investigates the factors that affect the efficient operation of refrigeration and air-conditioning plant and equipment, including explaining use of the pressure–enthalpy diagram and psychrometric chart as key diagnostic tools to help maintain peak efficiency. It also explains service and maintenance techniques, as well as heat load calculations and the selection of equipment based on those calculations. Also included are an overview of air-conditioning systems, large and small, and a detailed look at piping design.	https://www.airah.org.au/AIRAH/Navigation/Resources/Australian_Refrigeration_and_Air-conditioning_Volumes_1_and_2/Australian_Refrigeration_and_Air-conditioning_Volumes_1_and_2.aspx
	Medium	Refrigeration	Australia	AIRAH Report - HVACR Safety Survey May 2017 Final	FOCUS ON THE HVACR MECHANIC - Industry survey of safety in HVACR sector - 79 respondents. 77% say there are safety issues. 37% say quality and training is main issues. 29% access for maintenance issues. 21% working fluids issues. Report identifies problems, solutions and next steps including a broader collaborative strategy - govt, industry and research.	www.airah.org.au/safety
	Medium	Refrigeration	Australia	DISER Technology Investment Roadmap Discussion Paper - A framework to accelerate	Discussion paper from May 2020 - Covers residential, commercial buildings - including commercial refrigeration - natural and new refrigerants gets a lot of coverage. Includes non-mechanical solutions to address cooling - e.g. phase change material, heat pumps too.	https://consult.industry.gov.au/climate-change/technology-investment-roadmap/supporting_documents/techn

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				low emissions technology		ologyinvestmentroadmapdiscussionpaper.pdf
	Medium	Commercial air conditioning	Australia	DISER Technology Investment Roadmap Discussion Paper - A framework to accelerate low emissions technology	Discussion paper from May 2020 - Covers residential, commercial buildings - including commercial refrigeration - natural and new refrigerants gets a lot of coverage. Includes non-mechanical solutions to address cooling - e.g. phase change material, heat pumps too.	https://consult.industry.gov.au/climate-change/technology-investment-roadmap/supporting_documents/technologyinvestmentroadmapdiscussionpaper.pdf
	Medium	Refrigeration	Australia	Cool Room Efficiency Fact Sheet - Cool room Hero - tips for owners and operators	Fact sheet covering small and medium sized small/medium cool and freezer rooms. Includes behavioural, technical and maintenance and monitoring solutions.	https://www.airah.org.au/Content_Files/Special-Technical-Groups/Cool-rooms-SME-owners-and-operators.pdf
	Medium	Refrigeration	Australia	Cool Room Efficiency Fact Sheet - Cool room Hero - tips for service providers	Focus is on upselling the benefits of energy efficiency to clients. Topics include Behaviour change, maintenance for Energy Efficiency, Upgrades (e.g. leak detection), Best Practice (e.g. siting of equipment, New systems. (and things not to do - e.g. Water sprays).	https://www.airah.org.au/Content_Files/Special-Technical-Groups/Cool-rooms-SME-service-providers.pdf
	Medium	Refrigeration	Australia	The HFC Refrigerant Levy Fact Sheet 1 - The Clean Energy Future Plan and HFCs	Context setting for the refrigerant levy in 2013?	https://iifiir.org/en/fridoc/the-hfc-refrigerant-levy-the-clean-energy-future-plan-and-hfcs-low-135064
	Medium	Refrigeration	Australia	The HFC Refrigerant Levy Fact Sheet 2 - Managing the financial and associated risks	Risks with refrigerant levy - risks for owners - financial, security, quality of refrigerant, energy efficiency, compliance, perverse outcomes. Risks for tech service providers - Financial, Skill and tech capacity, theft of refrigerant, quality and supply of refrigeration, risks for low GWP refrigeration, Energy efficiency, Compliance. How risks can be managed.	https://iifiir.org/en/fridoc/the-hfc-refrigerant-levy-managing-the-financial-and-associated-risks-135065
	Medium	Refrigeration	Australia	The HFC Refrigerant Levy Fact Sheet 3 - Leak prevention strategies	Why important, common causes, what should owners do, detecting leaks, cost to prevent leaks, industry strategies that need to change and what will be the impact	https://iifiir.org/en/fridoc/the-hfc-refrigerant-levy-leak-prevention-strategies-low-emission-135066
	Medium	Refrigeration	Australia	The HFC Refrigerant Levy Fact Sheet 4 - Opportunities in a low emission future	For owners and service providers - • Improved design and installation standards to prevent refrigerant leakage. • Improved maintenance and refrigerant management/handling standards to reduce emissions. • A move in design to low GWP refrigerants and refrigeration systems that are more energy efficient. • Increased reclamation, recycling and destruction of HFC refrigerants	https://iifiir.org/en/fridoc/the-hfc-refrigerant-levy-opportunities-in-a-low-emission-future-low-135067

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	Medium	Refrigeration	Australia	The HFC Refrigerant Levy Fact Sheet 5 - Energy Saving Strategies - Existing Systems	Key steps to efficiency, - Refrigerants, heat load, energy saving options, how to improve systems	https://iifiir.org/en/fridoc/the-hfc-refrigerant-levy-energy-saving-strategies-existing-systems-135068
	Medium	Commercial Air conditioning	Australia	Specifying a Maintenance Package with DA19	Online 7 step guide to assist building owners and managers in better understanding the steps they need to take to use DA19 to specify their maintenance needs	https://da19fmuserguide.com/
	Medium	Commercial Air conditioning	Australia	Specifying a Maintenance Package with DA19	YouTube summary of guide	https://www.youtube.com/watch?v=6kZ5pEZ-zMg
	Medium	Commercial Air conditioning	Australia	Specifying a Maintenance Package with DA19	PDF of online version	https://da19fmuserguide.com/da19fmuserguide/wp-content/uploads/2019/10/AIRAH-DA19-Manual_Printable-Version_LR.pdf
	Medium	Refrigeration	Australia	PRIME Roadmap - Issues and solutions on maintenance	Summary of maintenance issues and solutions from PRIME. - ISSUES - Monitoring, Skills, Leakage, Tuning, recommissioning, retro commissioning, fault detection and diagnosis, maintenance by sector, (commercial, residential, vehicles, supermarkets, refrigerated warehouses. SOLUTIONS - Industry data, Trade Training, Mandatory energy efficiency schemes, Documentation standards, Facilities for maintenance, best practice HVACR install, building tuning and recommissioning, Commercial refrigeration, maintenance for energy efficiency, Residential AC, HVAC system rating, Technical comparison tool, Maintenance records, Government procurement, Incentives, opportunities, demand - supply and demand.	https://www.airah.org.au/Content_Files/UsefulDocuments/AIRAH_Transition_to_low_emission_HVACR_Issues_and_solutions.pdf
	Medium	Refrigeration	Australia	Australia and New Zealand Refrigerant handling code of practice 2007 - Part 2 - Systems other than self-contained low charge systems	Code of practice called up in legislation for the ODPSGG. Main focus is refrigerant containment.	-
	Medium	Refrigeration	Australia	HVAC&R Nation - Skills workshops (various - relevant to leaks)	Refrigeration safety standards - AS/NZS 5149 parts 1-4, Silver Brazing, Refrigerant leaks caused by corrosion. Residential Air Con standard (a quality process for good outcomes) AS/NZS 5141	-

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	Medium	Commercial Air conditioning	Australia	Future of HVAC in a Net Zero World – 2017	Report based on a fore sighting workshop. Key findings Building regulations must assess true performance and target net-zero energy over time; A renewed focus on existing buildings is required, including mandatory energy disclosure, incentives for energy efficiency maintenance, and upgrade assistance and support; Training and education initiatives should help all stakeholders understand the risks and opportunities of a net-zero building, including the development of a Net-Zero Building Retrofit Toolkit and behaviour change programs for building users; Increased research into low-emission HVAC and better support for innovative technology and approaches are needed, including an HVAC research roadmap and improved research/industry communications pathways; Increased investment in Australian research for Australian innovations in HVAC is required to counteract the conservatism of the industry. Government and industry should support innovation and commercialisation of low-emission HVAC technologies by supporting demonstration projects.	-
	Medium	Commercial Air conditioning	Australia	AS/NZS 5141:2018 - Residential heating and cooling systems - Minimum applications and requirements for energy efficiency, performance and comfort criteria	Describes a quality process that is relevant to small commercial AC too.	https://infostore.saiglobal.com/en-au/standards/as-nzs-5141-2018-1136625_saig_as_as_2688871/
	Medium	Commercial Air conditioning	Australia	Trajectory Addendum - EY-Achieving Low Energy Existing Commercial Buildings in Australia	HVAC is identified as one of the proposed policy drivers to reduce energy use in existing buildings. Mandatory HVAC inspection and certification is proposed. Suggested measures include - Installing modern temperature sensors to ensure that heating and cooling is responsive to real ambient and indoor temperatures - Fixing jammed dampers to enable fresh air to be brought into the building - Clearing blocked coils and ducts to reduce the amount of energy needed to pump air through buildings - Installing modern building management systems to optimise how plant and equipment work together, and to detect and rectify problems quickly - Balancing air to measure air flow rates and recommissioning dampers and controls to distribute air flow more effectively - Recommissioning timers to make sure equipment is only operating when necessary - Installing variable speed drives for fans and pumps so that they can throttle in response to demand - Installing sub-metering to give facility managers better visibility as to where energy is being used in buildings - Installing carbon monoxide sensors in car parks, so that exhaust fans run only when a build-up of exhaust gases is present - Complete replacement of HVAC system. Commissioning is also referenced as a problem.	-

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	Medium	Commercial Air conditioning	Australia	Achieving Low Energy Commercial Buildings in Australia - COAG – Energy Action 2019 -	Building Commissioning is recommended the future in the National Construction Code.	-
	Medium	Refrigeration	Australia	Using IoT solutions for remote monitoring of small commercial refrigeration systems - Dr Michael Bellstedt	Sustainability funded benchmarking project – From Conclusions - Nearly 80% of the units have faults - 23% can be identified by the operator or owner of the unit. Another 18% of the faults detectable by technician without instrumentation or extensive examination. Remaining 59% of the faults require measurement of operational variables over time to diagnose. Diagnosing faults = the most important part of preventive maintenance and the cost can be very high without having an assurance of success. The list of defects has been categorised as housekeeping, installation, maintenance and faults - Poor housekeeping-dirty evaporator and condenser coil and non-refrigerated goods in the refrigerated space is the major defect. The installation problems including phased-out or incorrect refrigerant, incorrect installation of condensing unit leading to hot air recirculation, non-standard insulation and unsafe electrical installation is the second major defect. Poor maintenance practices such as non-operational fans, damaged door seals and evaporator coils, and non-standard fixes carried out are observed in one-fourth of the units. A few units have been found with complex faults such as bubbles on liquid line sight glass and excessive ice on the evaporator coil.	-
	Medium	Best practice guide: Leaks	EU and UK	REAL Zero GN1-2015 (Guide to good leak testing).pdf	Leak testing, leak reduction and charging procedures	https://ior.org.uk/careers/refrigerant-containment
	Medium	Best practice guide: RAC	International	Cooling Emissions and Policy Synthesis Report: Benefits of cooling efficiency and the Kigali Amendment	Broad policy, including identifying the need to Improve installation of new equipment and monitoring and maintenance of existing equipment	https://www.iea.org/reports/cooling-emissions-and-policy-synthesis-report
	Medium	Refrigerant leaks	North America	California Building Energy Efficiency Standards	Mandatory building standards that address energy efficiency of new buildings and refurbishments (like NCC Section J in Australia). Mandatory Requirements for residential buildings include "Correct refrigerant charge must be confirmed/verified by the system installer (using prescribed field test methods)." Historically, many of the new air conditioners in California failed to achieve their rated efficiency due to improper amounts of refrigerant, improper evacuation, metering device malfunctions, and other problems. To address this situation, the California Building Energy Efficiency Standards define methods of verifying correct charge and proper air conditioner system operation. These methods were developed from the major manufacturers' specifications and	https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency

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					verification protocols. The California Building Energy Efficiency Standards also contains Mandatory Requirements for energy efficiency of Refrigerated Warehouses, Commercial Refrigeration and Heat Rejection Systems.	
	Medium	Refrigerant leaks	North America	Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants	A roadmap prepared to identify and highlight high-priority R&D activities that DOE could support to help accelerate the transition to next-generation low-GWP refrigerants in HVAC&R equipment. This R&D roadmap covers the following equipment types: Residential refrigeration; Self-contained commercial refrigeration; Supermarket refrigeration; Residential and commercial direct-expansion air conditioning; Chillers. High-Priority Initiative with Direct Impacts on Energy Efficiency - 10 Develop techniques for detecting and dramatically reducing refrigerant leakage in currently installed systems. High-Priority Initiative with Indirect Impacts on Energy Efficiency – 6 Develop prototype systems that demonstrate leak detection with high-reliability, inexpensive sensors. Although identifying the source of leaks is difficult, leakage rates need to be addressed, particularly in supermarket systems. LCCP modelling tools should incorporate more reliable estimates of equipment leakage rates. High-Priority Initiatives with Direct Impacts on Energy Efficiency. Summary of Technical and Market Barriers. #10: Develop techniques for detecting and dramatically reducing refrigerant leakage in currently installed systems. 6: Develop prototype systems that demonstrate leak detection with high-reliability, inexpensive sensors. Finally, while most refrigeration applications exhibit small amounts of refrigerant leakage, supermarket systems typically have the highest leakage rates among all HVAC&R equipment. Thus, these systems consume large amounts of refrigerant and should be considered one of the high-priority sectors to address	https://www.energy.gov/sites/prod/files/2014/12/f19/Refrigerants%20Roadmap%20Final%20Report%202014.pdf
	Medium	Refrigerant leaks	North America	Greenhill - Prioritizing Leak Tightness During Commercial Refrigeration Equipment Installation	The typical food retail store refrigeration system leaks an estimated 25% — or approximately 1,000 pounds — of refrigerant annually. GreenChill Best Practices for Ensuring Leak-Tight Installations. Outlines the process for testing a refrigeration system for leaks immediately after installation, which includes the following steps: • Pre-check and preparation procedures • Pressure testing procedures and standards • Stair-step evacuation procedures and standards • Charging the system with refrigerant • Final check procedures	https://www.epa.gov/sites/production/files/2015-09/documents/gc_leaktightnesscommercialequipinstall_fact_sheet_20130912.pdf
	Medium	Refrigerant leaks	North America	Understanding Refrigerant Leak Detection and	Good visual on EPA Greenhill data - Major Causes of Leaks •Vibration •Corrosion •Flare Nuts •Valve Fittings •Thermal Stress •Installation Techniques. Major locations Racks (39%), Cases (21%), condensers (12%), Piping (10%), walk ins (8%), AC units	https://climate.emerson.com/documents/webinar-15-understanding-refrigerant-leak-detection-

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				Implementing Effective Leak Detection Programs	(4%), condensing units (4%), remote headers (2%). Key Elements of a Leak Detection Program. The Benefits of Detecting a Leak Early. Types of Leak Detection Technologies.	implementing-effective-programs-en-us-2884878.pdf
	Medium	Refrigerant leaks	International	BEYOND THE DIRTY DOZEN: Is your local supermarket still destroying the global climate?	In the USA, each supermarket on average leaks 25% of its refrigerant charge. Globally, 32% of HFC consumption is in commercial refrigeration, and when associated loss of energy efficiency is accounted for, almost 50% of a supermarket's total greenhouse gas emissions come from the refrigeration equipment. In the United States there are more than 37,000 supermarkets, with each emitting on average 1,556 metric tons of CO2e of HFCs a year, just from leaks in their refrigeration units. Proper maintenance and leak detection programs are vital for controlling emissions from older installed refrigeration systems The document reports on the performance of a number of large supermarket chains/owners and includes assessment against the following criteria (among many); membership of EPA's GreenChill Partnership,; has a company-wide maintenance program designed to reduce refrigerant leakage or has increased maintenance to reduce leakage rates; has a policy to improve refrigeration energy efficiency and/or is implementing improved efficiency programs. Some supermarkets report good emission reduction from leak reduction and refrigerant management programs. Results and approaches vary.	https://eia-global.org/reports/beyond-the-dirty-dozen
	Medium	Maintenance	North America	Keep it Cool: Greenhill Guide to Refrigeration Management for Small and Independent Grocers	Provides store owners and managers with the background and resources to effectively manage their store's commercial refrigeration system. Provide Questions for the technician (on refrigerant usage, routine maintenance and leak events.), The sources and cause of Refrigerant leaks, system design options, Refrigerant options, Servicing and Maintenance including leak detection, repair and repair verification. Appendix C Leak Prevention Maintenance Checklist. A variety of practices can be used to reduce the energy consumption of display cases, including the use of LED lights, electronically commutated motors (ECMs), and no-heat glass doors. Reducing the energy consumption of cases reduces the required refrigerant load, which in turn reduces the amount of refrigerant charge required of the system. Your installation contractor should complete and sign the Installation Leak Tightness Testing: Verification Form to verify that……	https://www.epa.gov/sites/production/files/2017-03/documents/greenchill_guide_refrigeration_management_jan2017_final.pdf

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	Medium	Refrigerant leaks	North America	Containment of refrigerants within RACHP	Refrigerant leakage is, however, not just about emissions and global warming because it also increases costs through: 1. reduction in reliability, 2. increased down-time, 3. reduced efficiency; 4. reduced system capacity. 5 additional costs for replacement refrigerant, service and repairs. It should be recognised that even a relatively small leak may significantly increase the annual energy costs for the system. TEWI for typical R404A system (in UK supermarket) - Refrigerant leakage predominates TEWI for leak rates greater than 11%/17%. Leakage rates in the range 10% - 20% can double the TEWI of a refrigeration system when using high GWP refrigerants. Actions required to minimise leaks depend on the type of equipment concerned and can be divided into broad categories including: #integrated systems: small commercial and household appliances (refrigerators, freezers, small air conditioners, etc.). Most of these appliances are fully brazed and tightness depends on the quality of brazing: generally, less than 1 or 2 out of 10,000 appliances present defects. #chillers: all components of these systems are normally located in machine rooms, thus facilitating indication of leakage though detection of emissions. #direct-expansion systems with long refrigerant circuits: these systems are used in commercial and industrial refrigeration (particularly in the food industry) and residential space conditioning and tend to be leak-prone. #Recommendation 5 is to implement financial and regulatory incentives to promote recovery, refrigerant emissions reduction and use of low-GWP replacement refrigerants;	https://iifir.org/en/fridoc/137288#:~:text=The%2024th%20IIR%20Informatory%20Note%20%22Containment%20of%20Refrigerants,to%20aid%20containment%2C%20reference%20sources%20providing%20additional%20information.
	Medium	Refrigerant leaks	International	Refrigerant charge in refrigerating systems and strategies of charge reduction	This paper evaluates the influence of the refrigerant charge on the coefficient of performance (COP) and on the cooling capacity. Optimal refrigerant charge - The appropriate refrigerant mass charge into the system is linked to the system performance. For instance, it is possible to determine a charge which maximises the refrigerating system performance (COP); it is called 'optimal charge'. Too little charge causes draining of the condenser in the evaporator which initially has as a consequence of a reduction of the condenser super cooling, then a two-phase feeding of the expansion valve, i.e. a bad evaporator feeding. Too high charge only influences the condenser, by reducing the area for condensation. Goswani (2001) shows that, a 10% total charge reduction generates a cooling capacity reduction of 3.5% and a 2% COP increase compared to the charge giving a maximum COP. Colasson et al. (2001) observed that, on a 10 kW-liquid-chiller with corrugated plate heat exchangers, a charge range wherein the COP does not significantly vary (less than 10%); However, when the charge variation exceeds 25% around the optimal charge, a significant degradation of the COP is noticed.	https://www.academia.edu/1449540/Refrigerant_charge_in_refrigerating_systems_and_strategies_of_charge_reduction
	Medium	Maintenance	Asia (excl. Japan)	Electrical Energy Equipment: Refrigeration and Air Conditioning	Maintenance of Heat Exchanger Surfaces - Fouled condenser tubes force the compressor to work harder to attain the desired capacity. For example, a 0.8 mm scale build-up in condenser tubes can increase energy consumption by as much as 35 %. Table 8. Similarly, fouled evaporators (due to residual lubricating oil or infiltration of air) result	https://www.academia.edu/15327264/Electrical_Energy_Equipment_Refrigeration_and_Air_Conditioning_Energy_Efficiency_Guide_for_Industry_in_

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				Energy Efficiency Guide for Industry in Asia	in increased power consumption. Equally important is proper selection, sizing, and maintenance of cooling towers. A reduction of 0.55oC in temperature of the water returning from the cooling tower reduces compressor power consumption by 3%.	Asia_www.energyefficiencyasia.org_UNEP_1_REFRIGERATION_and_AIR_CONDITIONING_SYSTEM
	Medium	Refrigerant leaks	North America	Effect of Refrigerant Charge, Compressor Speed and Air Flow through the Evaporator on the Performance of an Automotive Air Conditioning System	(Note Automotive AC – But VC) The steady state performance of the system has been investigated for three independent variables, namely the refrigerant charge level, the compressor speed and the speed of the evaporator fan. While the refrigerant flow rate is influenced primarily by refrigerant charge level and compressor speed, the COP and cooling capacity depends on all the three operating variables. an increase in the suction and discharge pressure accordingly as the refrigerant charge increases suction and discharge temperature decreases with the increase of refrigerant charge. The cooling capacity of an air conditioning system will increase with the increase of refrigerant charge up to certain level. Further increment of refrigerant charging deteriorates the cooling capacity of the system. The COP increases with the refrigerant charge, but after the optimal charge level it decreases. With the increase of refrigerant charge cooling capacity and COP of the system increases up to a certain range then, it decreases whereas, the compression work continuously increases with the refrigerant charge. The optimal performance of the system is not only dependent on the system COP; rather it is also dependent on its suction temperature. The refrigerant overcharge decreases the suction pressure and temperature which will significantly increase the degree of superheat and eventually decrease the cooling capacity by more than 15%.	https://www.researchgate.net/publication/283894641_Effect_of_Refrigerant_Charge_Compressor_Speed_and_Air_Flow_Through_the_Evaporator_on_the_Performance_of_an_Automotive_Air_Conditioning_System_Effect_of_Refrigerant_Charge_Compressor_Speed_and_Air_Flow
	Medium	Refrigerant leaks	International	Refrigerant charge reduction: On a new design optimization criterion for compact heat exchangers	It has been shown (Farzad and O'Neal, 1991) that the cooling capacity increases up with the refrigerant charge related mainly with better HEXs filling. At the same time, the volumetric efficiency of the compressor decreases with increasing charge as consequence of condenser's pressure and temperature rise. Hence the compressor entropy generation rate can also be seen as function of the total charge. It is well known that for machines, the charge is distributed mainly in condenser, compressor, evaporator, and pipes (Corberan et al., 2008), and that it exists an optimum COP versus the refrigerant charge but not versus the heating capacity.	https://www.academia.edu/20244983/Refrigerant_charge_reduction_On_a_new_design_optimization_criterion_for_compact_heat_exchangers
	Medium	Refrigerant leaks	International	Charge optimisation study of a reversible water-to-water propane heat pump	This paper presents the results and conclusions regarding the optimisation of the charge obtained throughout a thorough development study performed with a reversible water-to-water heat pump using propane as refrigerant. The paper first describes the influence of the charge on the capacity and COP of the unit at given operating conditions and then analyses the causes of such influence. Then, the theoretical study carried out with a detailed mathematical model to estimate the amount of refrigerant in each part of the unit	https://www.researchgate.net/publication/229277781_Charge_optimisation_study_of_a_reversible_water-to-water_propane_heat_pump

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					is discussed. employing a POE or a mineral oil for lubrication on both performance and optimal charge is discussed.	
	Medium	Refrigerant leaks	International	Effect of refrigerant charge on the performance of air conditioning systems	Based on this experimental study, it can be concluded that the level of charge greatly affects the performance of air conditioning systems. For charge levels down to 90 per cent the effect is negligible. However, for charge levels of 80 per cent or below the steady-state cooling capacity and the COP may be zero or even negative. For a brief transitional period, a system with a lower charge level will provide cooling when it is first turned on. After that an ice layer forms on the evaporator coil resulting in drastic reductions in the cooling capacity and COP. The refrigeration used up in forming the ice layer represents wasted energy. The consumer may not realise that the system is not working until the charge level goes below 80 per cent, especially where the system cycles on and o! frequently. Routine maintenance may avoid the problem and prevent the wastage of energy. An economic analysis shows that the cost of charging an 85 per cent undercharged system can pay for itself in savings over a period of 3-4 months	https://www.researchgate.net/publication/229803147_Effect_of_refrigerant_charge_on_the_performance_of_air_conditioning_systems
	Medium	Refrigerant leaks	Asia (excl. Japan)	Energy and exergy analysis of an R410A small vapor compression system retrofitted with R290	The energy analysis consisted of the refrigerating capacity, electric power of the compressor, and COP. Figure 4 shows the refrigerating capacity function as the refrigerant charge variation.	https://www.researchgate.net/publication/341784201_Energy_and_exergy_analysis_of_an_R410A_small_vapor_compression_system_retrofitted_with_R290
	Medium	Refrigerant leaks	International	Optimal refrigerant charge and energy efficiency of an oil-free refrigeration system using R134a	Referenced - Kim and Braun [3] evaluated the impacts of refrigerant charge on air conditioner and heat pump performance. The results show that refrigerant undercharging in the range of 25% can lead to an average reduction of 20% in cooling capacity and 15% in energy efficiency. Fig. 12. EER against refrigerant charge for the oil-free refrigeration system	https://www.researchgate.net/publication/336247085_Optimal_Refrigerant_Charge_and_Energy_Efficiency_of_an_Oil-free_Refrigeration_System_using_R134a
	Medium	Refrigerant leaks	North America	Refrigerant Charge Reduction in Small Commercial Refrigeration Systems	Figure 2 Optimal charge is between 280 - 360 g, corresponding to the highest COP. (note quite a broad range) Small leaks if charge stored in receiver is inadequate may result in insufficient charge and reduced performance; lower refrigerant charge may lead to lower leakage,	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2502&context=iracc
	Medium	Refrigerant leaks	North America	Influence of Refrigerant Charge Variation on the Performance of an Automotive Refrigeration System	Figure 6: Simulation results of the Coefficient of Performance indicate an optimum refrigerant charge and dependence on receiver position	https://docs.lib.purdue.edu/iracc/843/

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	Medium	Best practice guide: Leaks	North America	ANSI/ASHRAE Standard 147-2019 Reducing the release of halogenated Refrigerants from refrigerating systems	This standard establishes practices and procedures that will help air-conditioning equipment designers, installers and operators reduce the inadvertent release of halogenated refrigerants. The standard helps reduce refrigerant release during equipment manufacture, testing, installation, operation, maintenance, repair and disposal. Leak threshold limits in Table 6.2.1 are expressed with "oz/year". (latest proposed amendments July 2020) additions to Section 9.2, Refrigerant Transfer, Transport, and Storage. These changes address the safe storage of flammable refrigerants and adds NFPA 55 and IFC-ICC Chapter 58 to the normative references. additions to Section 7.1.2, Major Considerations, and 8.1.6, Repairs. The purpose of the changes is to address the proper means and methods for repairing refrigeration systems. Highlights; Single flare fittings not allowed • 4.3.3 Tubing in a case must be supported • Tethered caps • 4.11 Systems over 500 Lbs need to "alert" owner of refrigerant release • 6.1 Factory Leak testing & Leak rate spec • Section 7 – Installation • Section 8 – Service and Operation • Annex – Not part of the Standard, but an FYI	https://webstore.ansi.org/Standards/ASHRAE/ANSIASHRAE1472019
	Medium	Refrigerant leaks	North America	Protection of Stratospheric Ozone: Revisions to the Refrigerant Management Program's Extension to Substitutes A Rule by the Environmental Protection Agency on 03/11/2020	In 2018 the EPA proposed to withdraw the extension of the provisions at § 82.157 to appliances using only non-exempt substitute refrigerants. These provisions include requirements related to appliance maintenance and leak repair. This action finalises that proposed withdrawal and will relieve businesses from having to repair leaks, conduct leak inspections, and keep records for appliances containing only substitute refrigerant. (i.e. HFC refrigerants with zero ODP are no longer covered by the rule) The EPA estimates that this action will result in forgone annual greenhouse gas (GHG) emissions reductions benefits of about 3 million metric tons of carbon dioxide equivalent (MMTCO2 e). The leak rate thresholds that trigger the duty to repair refrigeration and air-conditioning equipment containing 50 or more pounds of refrigerant. Lowered from 35% to 30% for industrial process refrigeration (IPR), Lowered from 35% to 20% for commercial refrigeration equipment. Lowered from 15% to 10% for comfort cooling equipment	https://www.federalregister.gov/documents/2020/03/11/2020-04773/protection-of-stratospheric-ozone-revisions-to-the-refrigerant-management-programs-extension-to
	Medium	Refrigerant leaks	North America	EPA Section 608 2019 Refrigerant Compliance checklist & guidelines	A summary the 2019 regulation and associated compliance requirements for RAC, Records, calculate leak rate, equipment leak thresholds, leak repair times, leak inspection requirements, retrofit and retirement, chronically leaking appliances, - Spruiking Bacharach refrigerant detection, refrigerant tracking and compliance software. (Note Section 608 amended to no longer require compliance for HFCs)	https://www.rsd.net/fx/pdf/suite/legislation/us_epa/EPA_Section_608_Refrigerant_Compliance_2019.pdf

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	Medium	Refrigerant leaks	International	A vapour compression chiller fault detection technique based on adaptative algorithms. Application to on-line refrigerant leakage detection	The existence of faults in vapour compression chillers plays a significant role in terms of energy efficiency loss, performance degradations, and even environmental implications. In this paper, a dynamic model-based fault detection technique suitable for real-time implementation is proposed. The technique is successfully applied for on-line refrigerant leakage detection with experimental tests involving the artificial introduction of the fault in a laboratory vapour compression plant, showing the results its capability of detecting incipient leakage failure conditions avoiding false alarms. The experimental results have shown a high reaction speed, noting that there is no significant time delay between the fault and its detection and the proposed technique can detect a refrigerant leakage in steady-state or transient operation. First, the tests involving gradual refrigerant leakages reveal that the chiller can operate during a certain period without significant impact on its performance. These results are coincident with other authors findings [23,24], who concluded that for a charge level of 90% of normal, the effect on COP and cooling capacity is found to be negligible.	https://www.sciencedirect.com/science/article/pii/S0140700705002665
	Medium	Refrigerant leaks	International	Sensitivity of refrigeration system performance to charge levels and parameters for on-line leak detection	The environmental impact of refrigeration systems can be reduced by improving their efficiency and reducing refrigerant leakage. This paper presents results of experimental investigations on the effect of refrigerant charge on steady-state system performance and identifies parameters sensitive to charge level for on-line leak detection in vapour compression refrigeration systems. The investigations were performed on a small 4 kW nominal cooling capacity vapour compression water-to-water chiller equipped with plate type heat exchangers. The results indicate that the chiller could operate over a wide range of charge levels, 25% below to 25% above the design value without significant impact on its performance. Outside this range, the performance of the chiller was found to be strongly dependent upon the charge level. The degree of superheat at the evaporator outlet and sub-cooling at the condenser outlet were shown to be significantly dependent on the level of refrigerant charge. Overcharging was found to lead to excessive discharge pressures, but suction pressure was found to be relatively insensitive to charge level. It can be concluded that the parameters of superheating and sub-cooling together with discharge pressure can form the basis of a reasonably inexpensive on-line leak detection system. – (VA) Perhaps an indication that older systems were not optimised for refrigerant charge?	https://www.sciencedirect.com/science/article/abs/pii/S1359431104001863
	Medium	Maintenance	North America	MEASURE 2.7.2 Maintain the proper refrigerant charge. (referenced in 97)	The efficiency of all chillers suffers if the system has either too little or too much refrigerant charge. Also, the compressor may suffer damage if the system is overcharged. Some systems have only minimal reservoir capacity, making it important to charge the system precisely. Such systems are more vulnerable to loss of efficiency from small leaks. Other systems have a large amount of reservoir capacity. In these	http://www.energybooks.com/wp-content/uploads/2015/07/342346.pdf and http://energybooks.com/energy-efficiency-manual/

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					systems, a small leak may persist for a long time before being noticed. SAVINGS POTENTIAL: Up to 20 percent of chiller operating cost	
	Medium	Maintenance	International	Cooling for All: Needs based assessment	Global cooling needs assessment. Local maintenance infrastructure is crucial to sustainable cold-chain, i.e. an adequate skilled workforce to design, install and maintain plant and equipment. Clean cooling requires regular preventative and predictive maintenance to ensure optimal operating performance. Defining the right maintenance regimes is part of the mix. In the absence of correct installation and maintenance of cooling units, inefficient energy use and refrigerant leakage rates above 25% are possible.	https://www.sustainablecooling.org/wp-content/uploads/2020/06/Needs-Assessment-June-2020.pdf
	High	Refrigerant leaks	Africa	Environmentally Harmful Dumping of Inefficient and Obsolete Air Conditioners in Africa	CLASP conducted an impacts evaluation for four African regions covered by this study. The impacts evaluations focus on two sources of GHG emissions: direct emissions from leakage and servicing over the life of the equipment and the end-of-life disposal of the refrigerants used in RACs; and indirect emissions from generating the electricity consumed by RACs. Table 2: Leakage rate, operating life, and recycling factor assumptions. the Indian RAC market, the operational leakage rates for split RAC units was estimated at between 5-15%.	https://clasp.ngo/updates/2020/new-report-identifies-sources-of-environmental-dumping-of-air-conditioners-in-ten-african-countries
	Medium	Refrigerant leaks	Asia (excl. Japan)	India's Long-Term Hydrofluorocarbon Emissions	Figure 3: Operation leakages of key HFC applications - Room AC 10%, chiller 15%, supermarket 30%. Operational leakages are estimated from average information on developing countries from various sources (IPCC/TEAP, 2006; IPCC, 2006; RTOC/UNEP, 2010; TEAP/UNEP, 2014), manufacturers' brochures and interaction with different stakeholders. Table 4: Operation leakage for all sectors under low, medium and high leakage scenario Table 11: Summary of BAU assumptions for commercial AC. Table 12: Assumptions under BAU for commercial refrigeration Supermarkets use centralised refrigeration systems where compressors racks are installed in a machine room. As a result, length of piping, containing liquid refrigerant from the machinery room and vapour phase refrigerant back from the sales area, increases significantly and could be up to several kilometres (RTOC/UNEP, 2010). This explains the high leakages that are prevalent in the supermarket systems the four big sectors contributing to emissions are residential cooling, commercial cooling, mobile air-conditioning in cars, and commercial refrigeration. In 2050, these sectors respectively are responsible for 35%, 28%, 15% and 14% of overall HFC emissions for India. For the first three sectors, the key driver of increasing emissions is undoubtedly increase in economic activity that leads to higher penetration of household and commercial	https://www.researchgate.net/publication/277506995_India's_Long_Term_Hydrofluorocarbon_Emissions

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					appliances and vehicles. For the fourth sector however, it is the high leakage rate that results in a significant share of the emissions from this sector	
	Medium	Commercial air conditioning	Asia (excl. Japan)	Fault Detection and Diagnosis Process for Oversizing Design on Multiple Packaged Air-conditioning Units	Heating, ventilation, air-conditioning and Refrigeration (HVAC&R) systems are seldom designed or commissioned properly. The situation leads to abrupt or degradation faults resulting in inefficient energy uses, excessive energy consumption and high service costs. To solve these problems, fault detection and diagnosis (FDD) is utilised to firstly detect any abnormal conditions of a system and then diagnoses and determines their causes. Soft faults are caused by non-optimal design and fault operations; they are not cost effective to be repaired immediately if the severity level is not high enough resulting in degraded system performance but allow continued operation of the system. For example, there are oversizing, faulty control and typical hardware faults (e.g. incorrect refrigerant charges, drifted sensors, non-condensable, liquid-line restriction, evaporator fouling and condenser fouling). The impact of non-optimal design and faulty operations can be minimised or mitigated by adaptive controls called "soft-repair" before they are physically repaired. Most AFDD in HVAC is mainly used to improve productivity in terms of equipment efficiency and better thermal comfort and to reduce operating costs and potentially schedule maintenances.	https://www.researchgate.net/publication/289263736_Fault_Detection_and_Diagnosis_Process_for_Oversizing_Design_on_Multiple_Packaged_Air-conditioning_Units

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	Medium	Maintenance	North America	Comparing Maintenance Strategies for Rooftop Units having Multiple Faults through Simulation	Three types of maintenance strategies are compared using a commercial building simulation model utilising a fault impact equipment model. Along with comparing different strategies under the same fault scenario, ambient conditions, and loads, optimal maintenance schedules are generated using dynamic programming. Benefits of a condition-based maintenance approach utilising a suite of AFDD methodologies are highlighted with respect to reducing operating costs. One of the variables that was selected at the start of each simulation was the fault evolution rate, e.g. the refrigerant leakage rate. Because choosing combinations of fault rates is somewhat arbitrary due to the lack of reliable fault prevalence data, rates for refrigerant charge leakage, condenser fouling, and evaporator fouling were sampled from random distributions (Yuill & Braun, 2017). To consider a relatively wide range of fault rate combinations, uniformly distributed random samples were chosen for each. For refrigerant leakage fault rates, a uniformly distributed random sample between 0% to 20% leakage per year was selected for each trial. Likewise, condenser fouling fault rates were sampled uniformly between 0% to 20% per 5000 hours of condenser fan runtime for each trial. For evaporator fouling fault rates, a uniformly distributed random sample between 0% to 20% per 5000 hours of evaporator fan runtime was selected. In all, a distribution of 200 random combinations of refrigerant charge leakage, evaporator fouling, and condenser fouling faults were simulated in this study. Emergency service policies may contribute to large operating costs for oversized systems since capacity violations may not occur until faults have degraded performance significantly. preventative maintenance more cost effective since larger energy consumption savings are possible.	https://docs.lib.purdue.edu/iracc/2060/
	Medium	Refrigeration	North America	Design and Optimization of a Walk in Refrigeration System	The purpose of this paper is to discuss the design of an optimised refrigerant systems using R404A in a walk-in refrigeration unit. Different parameters setting will affect system performance therefore there is the need to investigate the effect of such behaviour. The parameters used in investigating the optimised performance were airflow, superheat setting and refrigerant charge. Figure 5: Relation Between Refrigerant Charge and Power Consumption	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1857&context=iracc
	Medium	Maintenance	Asia (excl. Japan)	A Survey of Predictive Maintenance: Systems, Purposes and Approaches	Provides a comprehensive survey of PdM system architectures, purposes and approaches.	https://www.researchgate.net/publication/337971929_A_Survey_of_Predictive_Maintenance_Systems_Purposes_and_Approaches
	Medium	Maintenance	North America	Proactive maintenance Checklists for Facility Manager	Maintenance checklists - like AIRAH DA19 and UK	https://www.althoffind.com/facility-manager-proactive-maintenance-checklists?hsCtaTracking=8e996fb0-8096-4f11-98c0-

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						0e80ba39b30b%7C74ce4386-f8a9-4c3f-9b97-bdae13ca17f5
	Medium	Refrigerant leaks	Asia (excl. Japan)	Fault Detection in Compression Refrigeration System with a Fixed Orifice and Rotary compressor	Incorrect superheat can indicate improper refrigerant charge and a dirty condenser coil. A low charge will give a high superheat. An overcharge will give a low superheat along with a higher compression ratio. conducted tests in different modes; with 40%, 30%, 20% and 10% decrease in refrigerant charge; 50%, 40%, 30 %, 20% and 10% increase in refrigerant charge, dirty condenser and reduced evaporator flow. Table 4. Change in any of parameters in the faults. Shows that the superheat value increases in undercharge fault and decreases in dirty condenser and reduced evaporator airflow fault. Also, sub-cooling value decreases in undercharge fault, dirty condenser and reduced evaporator airflow fault and increasing in RO fault. Increased charge has a negative effect on the coefficient of performance. Electricity consumption increases due to an increase charge and reduced due to undercharge.	https://ajme.aut.ac.ir/article_3569.html
	Medium	Refrigerant leaks	North America	Experimental study on electrical signatures of common faults for packaged DX rooftop units	The types of faults that a typical RTU may have include a dirty filter, evaporator coil fouling/blockage, condenser coil fouling/blockage, an undercharge, overcharge, and refrigerant leakage. All such faults are associated with air-side or refrigerant-side parameter changes such as: •Thermodynamic changes in the vapor or liquid phase. •Heat exchange between the air and refrigerant at the evaporator and condenser coils. •Air and refrigerant transportation. •Fan and compressor motors power consumption. refrigerant leakage is a special case of undercharge. the expansion device used in this experiment is a fixed orifice. The compressor power increased along with a charge level increase of 70–130%. This means that the compressor power increased when the system was overcharged but decreased when it was undercharged. the supply air temperature increased when undercharged but tended to decrease when over-charged. An overcharge led to a greater mass flow rate while an undercharge resulted in a reduced flow rate. The refrigerant overcharge fault can be detected by an increase in the compressor power and a reduction in the supply air temperature. The undercharge or refrigerant leakage fault can be detected by a compressor power reduction and an increase in the supply air temperature. fouling the system performance for the condenser coil fouling conditions is shown in Fig. 2(a–c). This group of experiments demonstrated that evaporator coil blockage can be identified by a reduction in the fan power. Compared with the minute change in the compressor power, the reduction in fan power was large.	https://www.researchgate.net/publication/261918313_Experimental_study_on_electrical_signatures_of_common_faults_for_packaged_DX_rooftop_units

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	Medium	Refrigerant leaks	North America	Literature review for application of fault detection and diagnostic methods to vapor compression cooling equipment. ASHRAE Research Project 1043-RP	A literature survey of FDD for HVAC (Pre-2000). Many/Most reports acknowledge refrigerant charge and condenser/evaporator fouling as common faults that affect system performance and efficiency. The most comprehensive experimental study of the effect of fault levels on performance was reported by Breuker and Braun (1998a). They quantified the impact of five faults on a variety of refrigerant and air states for a rooftop air conditioner during both transient and steady state operation at a range of fault levels and operating conditions. They also evaluated changes in cooling capacity, COP, superheat at the compressor inlet, and the compressor discharge temperature due to the five faults. Capacity and COP provide a means of comparing the impact of different faults and quantifying the level at which faults become important	https://pdfs.semanticscholar.org/a035/2e97b4e709ff8df50f7d9d8212b3e0246493.pdf
	Medium	Maintenance	North America	Impact of air filter condition on HVAC	Although the energy cost savings were slight, filter replacement is an important part of any preventative maintenance program. An operating condition that can lead to a premature compressor failure was identified: clogged filter combined with a high outdoor temperature, beginning at 40 degrees Celsius, for units having capillary tube as the expansion device. Regular filter replacement can contribute to a longer life for compressors and motors and can be very cost-effective, if early failure is prevented. Filters should be replaced before they become clogged and dirt begins to accumulate on the evaporator coils. Replacing the filter is quick and easy; cleaning the evaporator coil is time consuming and tedious	https://info.ornl.gov/sites/publications/Files/Pub57073.pdf
	Medium	Maintenance	North America	The impact of filter loading on residential HVAC performance	Based on a relatively strong linear regression of system airflow versus induced filter pressure drop, airflow rates were reduced 10% from no filter airflow at around 90 Pa and reduced 20% from no filter airflow at around 150 Pa. This data can inform decisions about filter replacement and be used to educate builders, contractors, and homeowners about the importance of routine HVAC maintenance. Once a maximum acceptable reduction in sensible capacity is established, this data can be used to identify the airflow and filter pressure drop thresholds. For example, a 10% reduction in sensible capacity would result in approximately a 10% increase in AC run time, all is being equal. If a 10% reduction in sensible capacity is selected as the threshold for filter replacement, 63 then the data indicates filters should be replaced at around 80-85% of no filter airflow, which is around a filter pressure drop of 150 Pa.	https://smartech.gatech.edu/bitstream/handle/1853/50344/KRUGER-THESIS-2013.pdf

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	Medium	Maintenance	International	Experiences and Case Studies on Energy Efficiency in the Refrigeration and Air Conditioning Sector	Past successes and future opportunities case studies from the UNDP portfolio and innovative approaches to cooling without warming. Canada/MLF supporting the replacement to Energy Efficient CFC-free Chillers in CUBA. The project included training of maintenance technicians of the beneficiary institutions on the new equipment operation. Canadian and MLF funds were used for the acquisition of equipment and Smart provided all the training as its in-kind contribution, conducting 7 training workshops which trained 65 technicians. Training of staff was a key component to ensure maximum benefits (efficiency, energy savings) of the new equipment as different operational and maintenance approaches were required. GEF supporting the deployment of efficient A/C in TAJIKISTAN: Additionally, servicing costs decreased 55-65% and the A/C equipment lifespan increased by over 40%, while HCFC leakage was significantly reduced (up to 60%).	http://conf.montreal-protocol.org/meeting/workshops/energy-efficiency/presession/casestudies/UNDP-case-studies.docx
	Medium	Refrigerant leaks	EU and UK	Field measurements of supermarket refrigeration systems. Part II:	The amount of refrigerant charge in medium and large-size supermarkets is in the range of hundreds to few thousands of kilograms and due to the long pipe runs and numerous piping connections, the leakage rate is reported to be 3–22% by different researches [1].	https://www.sciencedirect.com/science/article/pii/S1359431116316775
	Medium	Refrigerant leaks	North America	Measured Effect of Air Flow and Refrigerant Charge on a High-Performance	At charges of 100 and 125% there is a loss of COP of about 5% at a flow of 800 SCFM. At the lower outdoor temperatures, increasing the charge to 125% has very little effect and reducing the charge lowers the COP by about 7%. At an outdoor temperature of 125 F, the effects of charge are larger: 75% charge reduces COP by about 12% and 125% charge reduces COP by 5%.....notes the importance of the suction-line accumulator on these results, "This insensitivity is in contrast to the behaviour of the low-first-cost unit previously tested, which has no suction-line accumulator and showed an almost linear reduction of heating capacity and COP with reduction of refrigerant charge."	https://www.aceee.org/files/proceedings/2008/data/papers/1_734.pdf
	Medium	Refrigerant leaks	North America	Automated fault detection and diagnosis methods for supermarket equipment (RP-1615)	Supermarkets could be a very beneficial setting to deploy automated fault detection and diagnostics, particularly in the refrigeration systems, which are major energy users and are known to commonly suffer from significant refrigerant leakage problems. The current article provides an overview of the common mechanical systems deployed in supermarkets, and then describes a comprehensive review of the literature on automated fault detection and diagnostics methods from other systems that could potentially be applied in supermarket settings. A typical supermarket refrigeration system contains 3000 to 5000 lb (1361 to 2268 kg) of refrigerant in a closed circuit (Walker and Awarded 2001). It is estimated that an average 15%–20% of the refrigerant in each store is lost annually due to leakage (Assawamartbunlue and Brandemuehl 2006). Table 1. Fault characteristics of two AFDD protocols for unitary air-conditioning systems with TEV and EEV. There is a need for additional data such as faulty data at known fault severity levels from refrigeration equipment to facilitate the development of	https://www.tandfonline.com/doi/pdf/10.1080/23744731.2017.1333352

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					supermarket-specific AFDD approaches. Without such data, it is very difficult for developers of AFDD to develop or test new methods for supermarket equipment.	
	Medium	Refrigerant leaks	Asia (excl. Japan)	Refrigerant Leakage Detection and Diagnosis for a Distributed Refrigeration System	A new technique to detect and diagnose leakage in a distributed refrigeration system is proposed in this paper. Unlike a simple refrigeration system of an HVAC system, a distributed refrigeration system, such as the refrigeration system in a supermarket, consists of several racks of compressors and evaporators, large condenser systems on the roof, meters of refrigerant piping systems, and liquid receivers. There are several potential leak points all over the system, and the presence of liquid receivers alters the equilibrium of the system. Therefore, existing leakage instruments or existing thermodynamic-based measuring techniques for HVAC applications do not guarantee correct detection and diagnosis. The proposed technique is not only based on simple and inexpensive measurements of refrigerant thermodynamic states but also accounts for the complexity of the system and the presence of the liquid receiver. Key disciplines to develop the leakage detection and diagnosis include the belief network technique and the decision theory. The probabilistic approach embedded in these two principles makes the detection and diagnosis more effective and precise. Additionally, a neural network model is constructed to make the technique faster and more practical for field implementation with small microcomputers. By implementing the technique in a real supermarket store in Longmont, Colorado, it is shown that the technique can distinguish between leak and no-leak systems. The developed technique detected a leakage if the refrigeration system lost more than 1.0%, or 5.3 kg, of the initial charge and misclassified one data set from ten data sets.	https://www.tandfonline.com/doi/abs/10.1080/10789669.2006.10391186

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	Medium	Commercial Air conditioning	North America	Oversizing of HVAC system - signatures and penalties	All studies found various problems with RTU installation, maintenance, and operations, and all of them recommend action programs to mitigate these problems. Based on the cycling rates identified during the measurements, the previous studies concluded that many RTUs are oversized. Prior research [2] shows that over 60% of rooftop units surveyed had a cycling rate of at least 3 cycles/hour. The same study further concluded that more than 40% of the units studied were more than 25% oversized and about 10% are considerably greater than 50% oversized. This paper outlines the measurement protocol to quantify the oversizing and the associated penalties. Given the methods outlined in this paper, it is reasonable that professional maintenance engineer or HVAC contractor to conduct the measurement and process the measurement results to facilitate rightsizing of new equipment and to support utility incentive program requirements. We caution anyone engaging in a RTU replacement to avoid simply replacing the unit with a new unit of the same capacity.	https://www.academia.edu/8681477/Oversizing_of_HVAC_system_Signatures_and_penalties
	Medium	Commercial Air conditioning	EU and UK	Innovative thermoeconomic diagnosis of multiple faults in air conditioning units: Methodological improvements and increased reliability of results	Thermoeconomic faults diagnosis of air conditioning units are a pioneeristic approach to detect single or multiple faults and quantify their impact in terms of additional energy consumption. The poor reliability of conventional thermoeconomic approaches has been limiting the interest for practical applications of this technique. In this paper an improved thermoeconomic diagnosis is proposed and applied to a reference 120 kWc air-cooled air conditioning system; a simulator is used to evaluate thermodynamic data under normal and faulty conditions. Four faults are individually or simultaneously imposed: fouling at condenser and evaporator, refrigerant undercharge and compressor valve leakage. For setting up the diagnostic tool only a few numerical or experimental tests are required; the results testify the procedure to be sufficiently reliable both when heavy or light faults are considered. Also, the performance of the diagnostic procedure slightly improves when the effects of "system level" faults like refrigerant undercharge are preliminarily filtered. Highlights •An improved thermoeconomic diagnosis of refrigeration systems is proposed. •Condenser and expansion valve are both modelled as dissipative units. •Filtering the effects of refrigerant undercharge improves the performance of diagnosis. •Appropriate distribution ratios must be accurately fixed to increase diagnostic performance. •The method was tested for several multiple faults scenarios, resulting sufficiently reliable	https://www.sciencedirect.com/science/article/abs/pii/S0140700713001813

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	Medium	Maintenance	North America	Fouling and Its Effects on Air-cooled Condensers in Split System Air Conditioners (RP-1705)	The generalised results showed that for the systems equipped with fixed orifice expansion valves, a 10% reduction in condenser airflow caused a 0.8% reduction in capacity and a 2% reduction in efficiency, whereas a 50% reduction in condenser airflow caused an 11% reduction capacity and a 25% reduction in efficiency. The test results of the field-fouled condenser coils show that the effect of fouling on the total system performance is usually not very significant. The results show that, on average, the COP for the tested coils if they were used in FXO equipped systems would decrease by about 0.2% (Table 3) due to fouling, which is within the limits of measurement uncertainty. Unexpectedly, in some cases fouling can enhance the performance of the condenser and, therefore, the whole air conditioning system. Another surprising result from this research is that washing with detergent had no meaningful advantage when compared to washing with water only. a negligible performance reduction of 0.7% compared to washing with water alone. Based on the results, in most of the cases, fouling does not have a significant effect on coil's heat transfer capacity, hence system efficiency, even though it significantly decreases the coil's airside pressure drop. NOTE that these results contradict much of the earlier research and would need to be replicated to be validated. Significant questions on method and conclusions??	https://www.tandfonline.com/doi/pdf/10.1080/23744731.2019.1605197?needAccess=true
	Medium	Maintenance	North America	The impact of evaporator fouling and filtration on the performance of packaged air conditioners	The goal of the study presented in this paper was to evaluate the impact of different filter types on the performance of three typical packaged air conditioners under both clean and fouled conditions. In a companion paper, combinations of six different levels of filtration and four different coils were tested under clean and fouled conditions. From the tests, it was found that fouling has a relatively small impact on air-side effective heat transfer coefficient but can have a large impact on coil pressure drop. Data from the experimental study were used in developing simulation models for the three packaged air conditioners. Simulations show that the equipment cooling capacity is reduced with fouling primarily because of a decrease in air flow due to the increased pressure drop. In most cases, EER (energy efficiency ratio) was reduced with fouling primarily due to increased fan power. However, the changes in EER were relatively small, in the range of 1–10%. Equipment having low efficiency filters had higher EER after fouling than equipment with high efficiency filters, because high efficiency filters result in significantly higher pressure drops than low efficiency filters. The impact of the evaporator side fan efficiency was found to be significant. The energy penalty associated with high efficiency filters was reduced greatly when fan efficiency increased. Although high efficiency filters cause higher energy penalties they provide considerably better air quality. The quantity of dust passing through the coil with an MERV14 filter was approximately 30 times less than the dust passing the coil with an MERV4 filter. This difference was doubled when the MERV14 filter was compared to a case with no filter in place.	https://www.researchgate.net/publication/245052694_The_impact_of_evaporator_fouling_and_filtration_on_the_performance_of_packaged_air_conditioners

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	Medium	Refrigerant leaks	North America	Effect of Common Faults on the Performance of Different Types of Vapor Compression Systems	Since operational faults such as refrigerant undercharge, low airflow, or presence of non-condensable gases in the system may decrease the system capacity, increase energy consumption, and shorten the service life, early and correct fault detection and diagnosis (FDD) can provide economic and indoor comfort benefits. The effect of faults on the cooling capacity, coefficient of performance, and sensible heat ratio, was analysed and compared for five split and rooftop systems, which use different types of expansion devices, compressors and refrigerants. The systems differed by the design type (split and single-package rooftop), compressor (scroll and reciprocating), expansion device (TXV and FXO) and refrigerant (R410A and R407C). We noted different fault effects on the systems' capacity, COP, and SHR. The expansion device type had the strongest impact on performance characteristics under different faults. The impact of the compressor type was the smallest. The analysis indicated differences in responses and trends between the studied systems, which underscores the challenge to devise a universal FDD algorithm for all vapor compression systems and the difficulty to develop a methodology for rating the performance of different FDD algorithms.	https://www.nist.gov/publications/effect-common-faults-performance-different-vapor-compression-systems
	Medium	Refrigerant leaks	International	UNEP Fact Sheets - Background Material for HFC Workshop, 2015	UNEP Fact Sheets - Background Material for UNEP Ozone Secretariat Workshop on HFC management: technical issues Bangkok, 20 and 21 April 2015. Contain description of sectors, alternative technology, changes and discussion of issues. Nominates typical refrigerant leakage rates for each technology. FACT SHEET 2 Overview of HFC Market Sectors FACT SHEET 3 Domestic Refrigeration FACT SHEET 4 Commercial Refrigeration FACT SHEET 5 Industrial Refrigeration FACT SHEET 7 Small self-contained air conditioning FACT SHEET 8 Small split air conditioning FACT SHEET 9 Large Air Conditioning (air to air) FACT SHEET 10 Water chillers for air conditioning	-
	Medium	Maintenance	International	Fixing Fridges Helps Save The Planet	Leakage also leads not only to poor performance of refrigeration or air conditioning equipment, but also high energy costs. Service technicians have an important role to play, both in ensuring the equipment's efficient and safe operation, and protecting the environment. While installing, maintaining and repairing equipment, service technicians follow guidelines provided by the Montreal Protocol and several international and national standards, which ensure that the procedures are carried out in the safest and most environmentally friendly manner What? Periodic routine inspections and maintenance of refrigeration appliances, such as refrigerators, freezers, and air conditioners Who? Service and maintenance technicians, trained and certified by an approved programme in both theory and practice, in different categories, and with different responsibilities Why? Because inefficient equipment and breakdowns are expensive, potentially dangerous, and damaging to the environment	-

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	Medium	Maintenance	International	(Brochure on) Good refrigeration practices	According to a survey carried out on 200 mini stores within Kampala, most end-users only service their refrigeration systems when need arises. A recent study at a local refrigerator manufacturer showed that for a system, if the refrigerant charge is reduced by 20% compared with the design charge, the energy consumption would be almost 70% higher compared with fully charged system.	https://www.k-cep.org/wp-content/uploads/2020/03/Brochure-on-good-refrigeration-practices_UNIDO.pdf
	Medium	Best practice guide: AC	International	Biarritz Pledge for Fast Action on Efficient Cooling (22 August 2019)	The Biarritz Pledge for Fast Action on Efficient Cooling aims to transform the global cooling sector and lower emissions by coordinating efforts to improve the energy efficiency of air conditioners and other cooling equipment, in parallel to the phase down of HFCs, ▪Identifying and mobilising additional resources to assist developing countries enhance the energy efficiency of cooling equipment while phasing down HFCs. (in part). Recognising the importance of good servicing practices in maintaining the rated energy efficiency of cooling equipment and in reducing refrigerant leakage from the equipment, that also contribute to the reduction of both direct and indirect emissions of the cooling equipment throughout their life cycle 1. To undertake ambitious measures to improve energy efficiency in the cooling sector while phasing out HCFC and phasing down HFC refrigerants, such as developing national cooling plans based on domestic circumstances, using energy performance standards (MEPS) and labelling, and promoting use of good servicing practices; and to undertake efforts that the related GHG emissions reductions are reflected in the Nationally Determined Contributions to the Paris Agreement as per country priorities;	https://www.ccacoalition.org/en/resources/biarritz-pledge-fast-action-efficient-cooling
	Medium	Best practice guide: AC	North America	Heating and cooling strategies in the clean energy transition *Outlooks and lessons from Canada's provinces and territories*	Energy use for needs such as heating and cooling, which together represent around 65% of the sector's energy consumption. The Canadian government can work with industry and international partners to identify and deploy innovative technology solutions that meet rapidly growing cooling demand in different climate contexts. This includes support of research collaboration programmes, such as work being led by the IEA Technology Collaboration Programmes (TCPs) on Heat Pumping Technologies (HPT TCP) and Energy Storage (ECES TCP) to deliver an affordable, energy-efficient and low-carbon "Comfort and Climate Box".	https://www.iea.org/reports/heating-and-cooling-strategies-in-the-clean-energy-transition
	Medium	Refrigerant leaks	International	Cold chain technology brief - cold storage and refrigerated warehouse	Reduction of energy consumption by cold stores should focus on three principal areas: □ Reducing heat loads on the store. □ Improved maintenance and usage operations. □ Improved operation/efficiency of the refrigeration system. The scale of refrigerant leakage varies considerably between different refrigeration equipment types and from country to country. The leakage rates shown in Table 2, which are believed to be typical for the EU-15 region, are based on the UK Greenhouse Gas Inventory for 2007 (Defra, 20108). Table 2: Typical refrigerant emissions by RAC sector	https://www.unenvironment.org/ozonaction/resources/publication/cold-chain-technology-brief-cold-storage-and-refrigerated-warehouse

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	Medium	Commercial Air conditioning	International	Perspectives for the clean energy transition – The critical role of buildings	There was a 17% increase in spending on energy efficiency in heating, ventilation and air conditioning (HVAC) systems in 2017. Heat pumps cut typical energy use for heating by a factor of four or more. Electrification plays a major role in the transition, combined with clean power generation. Electricity's share in final energy reaches about 35% by 2050, compared to less than 20% today. That growth is mainly due to adoption of heat pumps in buildings and industry, as well as a swift evolution in transport. Efficiency improvements keep electricity demand for other end uses, such as lighting and cooling, relatively stable, while access to electricity improves worldwide. Immediate action is needed to expand and strengthen mandatory energy policies everywhere, and governments can work together to transfer knowledge and share best practices.	https://www.iea.org/reports/the-critical-role-of-buildings
	Medium	Refrigerant leaks	North America	Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners	To increase the heat transfer area by increasing the frontal area of the coils and/or the number of rows of tubing in the coil. This, in turn, tends to increase the amount of copper used in the tubes and the amount of aluminium used in the fins, as well as usually raising the amount of refrigerant charge. An increase of the heat exchange area by 80% (by increasing the number of tubes while maintaining a constant horizontal tube spacing as well as other physical coil parameters), achieves a 35% increase in the efficiency of the unit. Heat transfer rates increase when cooling fin patterns evolve from smooth to louvered and variegated surfaces. It is thought there is a potential to improve AC efficiency by a further 10% by optimised slit fins in place of plain fins. These measures also enable the refrigerant charge to be decreased. Micro-channel heat exchangers enable the units to increase their equivalent heat exchange areas at a constant cabinet size. have the potential to reduce the refrigerant charge as much as 20 to 40% for a comparable efficiency to air conditioner devices that do not use this technology (EuP, 2009). Figure 2-23: Relationship between efficiency and refrigerant charge per kW of cooling capacity. illustrates the importance of refrigerant charge (mass) and energy efficiency for air conditioner devices using R410A.	https://ies.lbl.gov/publications/cooling-planet-opportunities
	Medium	Best practice guide: Refrigeration	International	Building back better: How climate-friendly cooling can support a clean, resilient Covid-19 recovery	Cold chain investment and standards offer training opportunities on use and maintenance, and new job opportunities while also improving access to cooling. - and the monitoring, maintenance, and servicing of newly improved cold chains will enhance vaccine distribution and efficacy, as well as reduce climate impact and operating costs.	https://www.climateworks.org/report/building-back-better-climate-friendly-cooling/

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	Medium	Refrigerant leaks	North America	Beyond Control: Enabling Smart Thermostats for Leakage Detection	Early detection of such leaks can benefit the retail enterprises in - (1) increasing their profits by reducing the energy wastage, (2) avoiding leakage of hazardous refrigerant in the open environment, and (3) maintaining the product quality. In this paper, we reinforce smart thermostats with Greina1 - a framework that observes deviations in the measured temperature from the estimated temperature to detect refrigerant leakage. The performance evaluation of Greina on data from 74 stores (from a city in India) testifies that the simple yet powerful framework can reduce the reporting delay by a week with best of around 20-30 days in few instances. During these days, the retail enterprise could have saved twice the energy RU consumes on a typical day. Moreover, by timely repairing the refrigeration unit, they could have kept the rooms 5◦C-10◦C colder every day when refrigerant was leaking.	https://dl.acm.org/doi/10.1145/3314401
	Medium	Refrigerant leaks	EU and UK	Low charge transport refrigerator (I). Refrigerant charge and strategies of charge reduction	2. Sensitivity of refrigerating system performance to charge levels and optimal charge. The sensitivity to refrigerant charge levels is a function of the system considered and liquid-to-liquid systems are less sensitive to refrigerant charge than air-to-air systems. 3. The charge distribution and refrigerant mass measurement 5. Superheat in evaporator and subcooling in condenser Superheat in evaporator for TXV and EEV controlled systems does not depend on refrigerant charge, except of the cases of significant undercharge (below 25% of optimal charge [2, 3]). At 50% undercharge [2] the superheat rises to approximately 10 K. The high superheat at low charge levels is a result of insufficient refrigerant in the evaporator which leaded to larger evaporator area devoted to superheating. Summarising the available works considering refrigerant charge we can see that the refrigerant mass charge in the system is linked to the system performance. Independently on the system, too little charge will cause draining of the condenser into the evaporator, two-phase feeding of expansion valve (incomplete condensation) and inadequate filling of evaporator. As long as the charge is sufficient to ensure the complete condensation, the effect of further charge increase depends on refrigerating system used. If the system allows liquid subcooling in condenser (no high-pressure liquid receiver present in the system), the unit performance depends on the charge. Significant performance degradation is observed when the charge reduction exceeds 25% from the optimal charge. However, charge reduction up to 20% is possible without significant deterioration of performance, and at 10-15% of charge reduction the effect on performance is negligible for systems with TXV or EEV. It is safe to suggest, that incomplete condensation occurs only when charge reduction is 20 - 25% from optimal and all (rather insignificant) efficiency increase is the effect of liquid subcooling in condenser.	https://www.researchgate.net/publication/267411264_Low_charge_transport_refrigerator_I_Refrigerant_charge_and_strategies_of_charge_reduction

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	Medium	Maintenance	Australia	Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency HVAC HESS	The aim of the Guide is to be a change accelerator and encourage those working with maintenance & operation of HVAC Systems to have a sharper focus on improving energy and water efficiency. Focused on commercial HVAC systems in commercial buildings. Also considers topics to consider for new buildings. Includes sections on HVAC maintenance and implementation process, Building operation, Documentation, Financial and environmental evaluation, HVAC equipment and efficiency	http://energycut.com.au/business/wp-content/uploads/2015/02/HVAC-Best-Practice-Guide.pdf
	Medium	Maintenance	Australia	Factsheet Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency	Fact sheet on Best practice guide	https://www.energy.gov.au/sites/default/files/hvac-factsheet-guide-best-practice-operation-energy-efficiency.pdf
	Medium	Maintenance	Australia	Energy Saver Website - maintaining your air conditioner	Consumer focused information on residential AC maintenance – filters, coils, fins, refrigerant leakage,	https://www.energy.gov/energysaver/maintaining-your-air-conditioner
	Medium	Commercial air conditioning	Australia	Mid-tier commercial office buildings in Australia - A national pathway to improving energy productivity November 2015	Report from workshop focusing on the barriers to energy efficiency and opportunities in the mid-tier building sector. HVAC is mentioned several times. Deeming method for HVAC is suggested to support financing mechanism. The uptake of energy efficiency improvements has been slow in the mid-tier sector due to barriers such as lack of awareness, difficulty in accessing capital and information, lack of networking among mid-tier owners and tenants, split incentives, lack of skills and expertise amongst industry professionals.	https://www.gbca.org.au/uploads/97/36449/Mid-Tier%20Commercial%20Office%20Buildings%20Pathway%20report.pdf
	Medium	Commercial air conditioning	Australia	CBD 2019 Program Review	Website only	http://cbd.gov.au/overview-of-the-program/cbd-review/cbd-2019-program-review
	Medium	Commercial air conditioning	Australia	CBD 2019 Program Review - CIE draft report	One major property group also provided aggregated information from more than 500 individual energy efficiency projects across the group's portfolio. Average implementation costs, annual energy (and water) cost savings and payback periods for different types of projects are shown in table 4.13. From 4.13 Average payback in years - Metering and Analytics 3.3, Commissioning 3.5, HVAC 17.5	http://cbd.gov.au/files/CBD%20Review%20CIE%20report%20draft.pdf
	Medium	Refrigeration	Australia	Australian Refrigeration Council - Cool Change news letter	Information on the Refrigerant Handling code of practice. (see #46)	https://www.arctick.org/media/1165/coolchange-issue-38-september-2015.pdf
	Medium	Commercial air conditioning	Australia	Blowing hot and cold - how to retrofit and	Presentation from City of Melbourne's 1200 Buildings program - includes HVAC – What it does and how it works, Regulatory Issues, Ownership issues, Installation and	https://www.melbourne.vic.gov.au/SiteCollectionDocuments/hvac-management-improvement-opps.pdf

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				manage HVAC in commercial buildings	Commissioning, Management, operation and Maintenance, Tuning and Improvement, Replacement and Retrofit	
	Medium	Refrigeration	Australia	Woolworths Group - 2019 Sustainability Report	Our refrigerant technology is currently susceptible to leaking gases of high global warming potential, at a rate of around 11 per cent below 2015 levels.	https://www.woolworthsgroup.com.au/icms_docs/195583_2019-sustainability-report.pdf
	Medium	Refrigeration	Australia	GREENHOUSE GAS REDUCTION SCHEME	Part of The Energy Savings Scheme (ESS) reduces energy consumption in NSW by creating financial incentives for organisations to invest in energy savings projects. - Energy savings are achieved by installing, improving or replacing energy savings equipment.	https://www.ipart.nsw.gov.au/Home/Industries/Energy/Energy-Savings-Scheme/Greenhouse-Gas-Reduction-Scheme
	Medium	Best practice guide: Refrigeration	EU and UK	Sustainable Retail Refrigeration	Good list of "Current and Future Carbon-saving Options for Retail Refrigeration"	https://onlinelibrary.wiley.com/doi/book/10.1002/9781118927410
	Medium	Best practice guide: Leaks	EU and UK	REAL Zero-GN4-2015 (Leakage Matters for service and maintenance contractors).pdf	Tips for service and maintenance contractors: (couched as obligations) - a) Regular leak testing; b) Maintaining records; c) Refrigerant recovery; d) Use of certified staff; e) Label clearly stating the type and quantity of HFC refrigerant used. Free e-learning is available for technicians	https://ior.org.uk/careers/refrigerant-containment
	Medium	Best practice guide: Leaks	EU and UK	IOR REAL Zero – Reducing refrigerant emissions & leakage-feedback from the IOR Project	Analysis of current use in installed systems and leakage record data and notes that for existing RAC systems the opportunities to reduce refrigerant emissions are most likely to be associated with improvements to service and maintenance regimes and procedures. System upgrades will also offer improvements that will achieve financial and environmental benefits relative to the capital cost.	https://openresearch.lsbu.ac.uk/item/879xq
	Medium	Maintenance	International	A Study of Optimal Refrigerant Charge Amount Determination for Air-Conditioning Heat Pump System in Electric Vehicles	Cooling and heating performance; optimum refrigerant charge; charge determination modelling	https://www.mdpi.com/1996-1073/13/3/657
	Medium	Refrigerant leaks	UK	An investigation of refrigerant leakage in commercial refrigeration	82% of the recorded leaks were from R404A refrigeration systems, and mainly consisted of pipe or joint failures or a leaking seal/gland/core. Physical damage caused by a third party and fracture/rupture/crack were responsible for the highest addition of refrigerant mass - catastrophic losses accounted for a very large proportion of the total refrigerant losses	https://doi.org/10.1016/j.ijrefrig.2016.10.009

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	Medium	Commercial air conditioning	North America	HVAC TOTAL SYSTEM PERFORMANCE RATIO	The HVAC Total System Performance Ratio (TSPR) goes into effect in the 2018 Washington State Energy Code (WSEC). This code update will save energy by requiring building designers to use more efficient HVAC systems evaluated on whole-system performance. TSPR is a performance-based compliance path for HVAC systems. It is defined as the ratio of the sum of a building's annual heating and cooling load compared to the sum of the annual carbon emissions from energy consumption of the building's HVAC systems. See TSPR Appendix D—Calculation of HVAC total system performance ratio.	https://www.waenergycodes.com/pdf/TSPR-Flyer_Final.pdf
	Medium	Refrigerant leaks	Asia (excl. Japan)	Advanced Monitoring of R-22 Refrigerant Leakage	Proposed a low cost, portable and wireless detection system using android application and automated responses to cease the leakage of refrigerant. Figure 4 shows the block diagram of the refrigeration system and the sensors used to detect any leakage of refrigerant. Figure 7 shows the 3D model of a refrigerant leakage detection sensor. Figure 8 shows the pressure sensors equipped within the pipes as shown in figure 4.	-
	Medium	Refrigerant leaks	North America	GreenChill Store Certification Program	Food retail stores can achieve platinum certification. The store must achieve an average HFC refrigerant charge of no more than 0.5 pounds of refrigerant per 1,000 BTU per hour total evaporator cooling load and a store-wide annual refrigerant emissions rate of no more than 5%. or gold-, or silver-level certification. A store-wide annual refrigerant emissions rate of no more than 15%.	https://www.epa.gov/greenchill/greenchill-store-certification-program
	Medium	Refrigerant leaks	North America	U.S. EPA's GreenChill Partnership 10 Years of Progress	The Corporate Emissions Reduction Program (25% leakage reduced to 12.9%), • the Store Certification Program (11,257 stores by 2017), and • the Advanced Refrigeration Program - GreenChill's tools, calculators, and guidelines help industry partners assess the financial and environmental impacts of refrigerant leaks and identify best practices.	https://www.epa.gov/greenchill
	Medium	Best practice guide: Leaks	North America	Prioritizing Leak Tightness During Commercial Refrigeration Retrofits	Best Practices for Ensuring Leak-Tight installations	-
	Medium	Refrigerant leaks	North America	EPA Rule Changes - March 2020	This action revises some of the requirements—specifically, the appliance maintenance and leak repair provisions—so they apply only to equipment using refrigerant containing an ozone-depleting substance. i.e. removes the requirements for high GWP HFC refrigerants	-
	Medium	Refrigerant leaks	South America	Application of Adaptive Control in a Refrigeration System to Improve Performance	(focussed on frequency control but….) Situations of insufficiency of refrigerant charge result in high discharge temperatures of the compressor and high degree of superheating. Moreover, the coefficient of performance was sensitive to the variation of the refrigerant charge in the refrigeration system. Figure 5. (a) Coefficient of performance (COP) and mass flow rate (R22 m); (b) Refrigeration capacity (Qev) and power consumption (W)	-

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	Medium	Refrigerant leaks	EU and UK	TEWI analysis of a stand-alone refrigeration system using low-GWP fluids with leakage ratio consideration	• TEWI analysis of a stand-alone system is performed considering the leakage impact on energy consumption. • Experimental data of low-GWP refrigerants (R-454C, R-459B, R-457A, R-455A) are considered. • Classical TEWI underestimates the total CO2 emissions to the atmosphere, from 4.06 to 16.70%. • Mass span and energy span of the refrigeration system are the most influential parameters.	https://www.sciencedirect.com/science/article/abs/pii/S0140700720302528
	Medium	Refrigeration	North America	Numerical Simulation of Fault Impacts for Commercial Walk-in Freezers	However, the energy performance of the system is dependent on the refrigerant charge and thus on their annual leakage ratio. The leakage effect is not considered in the suggested methods to evaluate the environmental impact and requires an in deep analysis. We aim to extend the TEWI analysis of stand-alone refrigeration systems by considering a realistic evolution of their charge during its lifetime and to quantify the discrepancies of the classical methodology. For that, the performance of a stand-alone cabinet (four low-GWP refrigerants) has been considered as reference. It has been concluded that leakage consideration makes classical TEWI to underestimate emissions for any country, refrigerant or annual leakage ratio, up to 20% in this study. Deviation increases with higher leakage ratio, but especially for those values that do not imply a refilling during the lifetime of the system. Deviations are higher as mass and energy spans of the systems are. Direct emission as a consequence of refrigerant leakage is presented in Fig. 4. This can be expected to be independent of the hardware manufacturer. A GWP of 332.2 t eq CO2/year for HFC blend 507A is substantially larger than in the other cases. Fig. 6 e Economic loss per year due to refrigerant leakage	-
	Medium	Refrigeration	North America	Fault Detection and Diagnostics for Commercial Coolers and Freezers	4.2 Condenser and Evaporator Fouling. Figures 5 and 6 show the impacts of condenser and evaporator fouling level on virtual condenser and evaporator air flow rates. These features are very sensitive to the level of fouling and decrease by about a factor of two for about a 5% degradation in cooling capacity. Very similar results were obtained for the freezer. 4.4 Refrigerant Charge. Figure 9 shows the effect of refrigerant charge level on capacity degradation for the walk-in cooler. Overcharging the system has very little effect on performance because of the liquid line receiver. There is a small impact of very high charge levels at low ambient temperatures at the point where the receiver becomes full of refrigerant. Reduced charge does have an impact on cooling capacity once the charge is less than about 80% of the nominal charge. At this point, the liquid line receiver is empty and the TXV saturates at a fully open position. This leads to an increasing superheat and fault feature with decreasing charge as demonstrated in Figure 10. Similar results were obtained for the freezer. Systems that utilise a liquid line receiver and TXV are insensitive to charge until the system becomes starved and the TXV saturates open.	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1918&context=iracc

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	Medium	Refrigerant leaks	Japan	Assessment of Total Equivalent Warming Impact (TEWI) of supermarket refrigeration in Japan	The aim of this paper is to present a methodology of assessing such systems in terms of refrigerants, machinery and operational protocol to minimise the total equivalent warming impact (TEWI). Another perspective is painted for the refrigeration industry to ameliorate environmental impact. Air-cooled refrigeration system is analysed for low temperature (LT) evaporation at 20 degrees Celsius and medium temperature one (MT) at zero degrees Celsius with condensation at 40 degrees Celsius. The effects of suction superheat and subcooling have also been accounted for. Current levels of leakage are around 10-15% of stock on site per year [19], most of which is held on the high-pressure side of the system it is estimated that 10-15% of liquid inventory is recharged each year [19]. Actual leakage rate depends on the type of refrigerant and operating pressure. For example, for HFC 134a it can be relatively lower than HFC blend 507A because the former has substantially lower system pressures than the latter. Direct emission of the refrigerants can be calculated from leakage rate and initial refrigerant charge using equation (1). The economic loss due to the refrigerant leakage per annum is shown in Figure 6.	https://www.researchgate.net/publication/311439231_Assessment_of_Total_Equivalent_Warming_Impact_TEWI_of_supermarket_refrigeration_in_Japan
	Medium	Refrigeration	North America	An Evaluation of the Environmental Impact of Different Commercial Supermarket Refrigeration Systems Using Low Global Warming Potential Refrigerants	Commercial refrigeration systems consumed 1.21 Quads of primary energy in 2010 and are known to be a major source for refrigerant charge leakage into the environment. A sensitivity analysis is performed to determine the impact of system charge and power plant emission factor on the LCCP results. A typical supermarket with a traditional multiplex direct expansion (DX) refrigeration system requires 1400- 2300 kg of refrigerant and has an average annual charge loss of 30% (Southern California Edison, 2004). Table 2: Refrigerant leakage rates and system operating parameters. 5.2 Sensitivity Analysis A sensitivity analysis of the effect of a 10% change in the refrigerant charge and the hourly emission rate for electricity production on the total CO2eq emissions of the system in Chicago, Seattle, and Miami was performed. Figs. 5a and 5b show a comparison of the results for the three refrigerants in the three cities. (VA note LLCP does not account for reduction in system efficiency due to refrigerant loss. i.e. direct emissions are increased but indirect are not??)	-
	Medium	Commercial air conditioning	North America	Prediction of Air-Side Particulate Fouling of HVAC&R Heat Exchangers	Fouling of a heat exchanger is determined by a variety of parameters such as the dimensions of the heat exchanger, physical properties of the airborne particulates, and airflow conditions over the heat exchange surfaces. A comprehensive model is developed to deterministically calculate the extent of fouling of a heat exchanger as a function of these parameters by accounting for each of the possible deposition mechanisms. prediction and assessment of air-side fouling is complicated by the variety of particulate types potentially present in the air stream, the irregular outer fin and tube surface geometries, and the dependence of the deposition mechanisms on these factors. 2. LITERATURE REVIEW The increase in pressure drop across the heat exchanger due	-

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					to fouling is likely determined by deposition in the frontal region due to the greater local intensity of fouling. Similarly, if the front rows of the heat exchanger are heavily blocked due to dust deposition, the remaining rows of the heat exchanger could potentially remain clean even though the heat exchanger would not function properly.	
	Medium	Refrigerant leaks	Asia (excl. Japan)	Optimum Refrigerant Charge of Refrigerator Working with Alternative Refrigerants for R12	The coefficient of performance and maximum consumption amperes are taken as function to evaluate the optimum charge of these refrigerants. The results imply that the over refrigerant charge will reduce the system performance. Fig. (5) shows the relationship between the heat rejected from condenser with mass of refrigerants charge. Fig (6) shows the relationship between the mass refrigerant charge with refrigerating effects. At low refrigerant charge the system give low refrigerating effect, and as the refrigerant charge increased the refrigerating effect increased also until an optimum value of the refrigerant charge Fig(7) show that when increasing the refrigerant charge the condenser pressure will be increased , this will increase pressure ratio which decrease the compressor volumetric efficiency Fig. (9) there is one charge that give maximum value of COP ,and this charge can be taken as the optimum refrigerant charge	-
	Medium	Commercial air conditioning	North America	Impact of air-filter condition on HVAC equipment	As the filter becomes clogged, the airstream will bypass around the edges of the filter. This fact is evidenced by observing that when a dirty evaporator is found, the edges are usually the first place where dirt begins to accumulate. Also, as the filter becomes clogged, the airflow velocity on the face of the evaporator is greatly reduced. what minimum quality of air filter (and what conditions) is necessary to keep the evaporator surface clean? If a lower-quality, inexpensive filter is suitable, additional savings can be realised by reduced blower-fan requirements and using less-expensive filters.	-
	Medium	Commercial air conditioning	North America	Thermoeconomic diagnosis of air conditioning systems: experimental assessment of performance for improved reliability	Thermoeconomic diagnosis is an exergy-based fault detection and diagnosis technique which has been recently extended to air conditioning systems. The RTU was tested in psychrometric chambers under a wide range of operating conditions and fault levels. The following faults were investigated: (i) evaporator fouling, (ii) condenser fouling and (iii) evaporator fouling along with condenser fouling. As concerns its quantitative performance, it is satisfactory for condenser fouling, but it becomes poor when evaporator fouling, and multiple faults are considered. Results showed that: (i) the diagnostic technique is able to detect a single fault, but its quantitative performance is satisfactory only for the condenser fouling, (ii) The performance of the technique depends upon the level of fault imposed, and specifically it decreases when the fault level increases and this trend was verified regardless of the type of tested fault, (iii) for evaporator fouling, the performance of the diagnostic technique is sensitive to the relative humidity of the air entering the evaporator coil. A rooftop unit (RTU) was considered in this study having a rated capacity of 17.5 kW (5 ton) and a SEER rating of	-

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					20.0. The refrigerant used is R410a. The unit can be operated in a staged mode or in a variable speed mode	
	Medium	Refrigerant leaks	Asia (excl. Japan)	Prediction of effect of refrigeration system parameters on the performance of a vapour compression refrigeration system using design of experiments	The aim of the present work is to study the effects of refrigeration system parameters namely, Evaporating temperature (Teva), Condensing temperature (Tcon) and mass of the refrigerant charge used (m), on the performance of the system using mathematical models. Based on these mathematical models developed for predicting the values of responses, the effect of individual system variables and their significant interaction effects on responses were calculated using MINITAB software. The direct effect of the system variables on the performance was calculated and plotted graphically for the refrigerants R290/R600, R290/R600a, and LPG5.1. Effect of Parameters on Refrigerating Effect (RE) Figure 5.1: Effect of Parameters on RE in Pareto Chart The figure reveals that the factor A (evaporating temperature) which extends beyond the reference line is a most important influencing factor on refrigerating effect. Though factor C which represents the mass of the refrigerant to be charged does not cross the line, but closer to the line indicates the next influencing factor on refrigerating capacity. Factor B represents condensing temperature is the least influencing factor on refrigerating capacity. 5.2. Effect of Parameters on Compressor Power (CP) 6. CONCLUSIONS· Among the selected parameters, the evaporating temperature is the most influencing factor on refrigerating capacity than the mass of the refrigerant and condensing temperature. As the evaporating temperature increases, the refrigerating capacity of the refrigerant increases due to the higher latent heat of evaporation.	-

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	Medium	Best practice guide: Refrigeration	International	CHILLING PROSPECTS: Providing sustainable cooling for all	6. OPPORTUNITIES FOR PROVIDING ACCESS TO COOLING Two of the critical needs for making cooling efficient and sustainable are improvements in technology and behavioural changes to make efficient use of technology. The two are often closely related. Achieving Cooling for All means deploying the most efficient current technology as well as developing new, innovative, efficient solutions for those most in need. This will require new business models, the training of a new workforce, and collaboration across government, industry, finance, and civil society. With 9.5 billion appliances entering operation, training on installation and maintenance must increase rapidly and ahead of the demand curve if an environmentally friendly industry is to be maintained. Behaviour change can be a powerful means of helping to curb energy demand from cooling and responding to climate change. In Japan, a national energy-saving campaign by the Ministry of Environment called Cool Biz started in 2005 and runs from May until September or October. A highly visible awareness program with support from the prime minister successfully promoted behavioural changes. Offices and retailers are asked to keep thermostats at 28°C or above and to allow employees to come to work in less formal attire. Government buildings— including schools, community centers, and libraries—are mandated to lead by example. Although initially met with scepticism—and some resistance, including from the necktie business—Cool Biz has become one of Japan's most successful environmental initiatives. China has a policy that the settings for air conditioners in summer be no lower than 26°Clxx and promotes a high-level of awareness with respect to the potential for reducing energy demand through measures that focus on lifestyle changes. example, a program in Mexico between 2009 and 2012 encourage replacement of inefficient refrigerators and air conditioners more than 10 years old through rebates and consumer financing. While the program successfully replaced 167,000 ACs, a rebound effect led to increased energy consumption and higher energy bills for people, as the lower hourly operating costs allowed for increased operating hours, reflecting unmet demand for comfort. Unintended consequences of programs like these will need to be anticipated and accurately assessed when considering costs and benefits.	http://www.foodcoldchain.org/wp-content/uploads/2019/03/SEforALL_CoolingForAll-Report.pdf
	Medium	Best practice guide: AC	North America	Database of State Incentives for Renewables & Efficiency® (DSIRE)	DSIRE is the most comprehensive source of information on incentives and policies that support renewable energy and energy efficiency in the United States. Established in 1995, DSIRE is operated by the N.C. Clean Energy Technology Center at N.C. State University. Search for 'HVAC' 'Heat Pump' 'energy efficiency'	https://programs.dsireusa.org/system/program

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	Medium	Refrigerant leaks	North America	Comparison of Hermetic Scroll and Reciprocating Compressors Operating Under Varying Refrigerant Charge and Load	An experimental rig has been built to test a horizontal scroll compressor and a reciprocating compressor of similar size and capacity. Both compressor types exhibit the same general characteristics with respect to system charge. COP is reduced with significant under- and over-charging. Superheat and subcooling are shown to be functions of system charge level for both compressors and thus may be used as a general indicator of charge level, irrespective of the compressor type. Superheat and subcooling are shown to be functions of system charge level for both compressors and thus may be used as a general indicator of charge level, irrespective of the compressor type. A simple water-water chiller facility. The scroll compressor is a rotary positive-displacement machine used at present in small (5-35kW) air conditioning and heat pump units, and car air conditioning systems. reciprocating compressor are the most common type of compressor and are positive-displacement machines. The effect of refrigerant charge level on air-conditioning system was also examined by Goswami et.al. (1997). The authors concluded that charge level has a significant effect on the performance of air-conditioning systems at levels below 80% of normal. For a charge level of 90% of normal, the effect of COP and cooling capacity was found to be negligible.	-
	Medium	Refrigerant	Australia	Refrigerant Health Check by A-Gas: Information provided by email	Overview plus sample report	-
	Medium	Best practice guide: Refrigeration	International	Manual for Refrigeration Servicing Technicians	Very detailed guide - everything a technician needs to know	http://www.unep.fr/ozonaction/information/mmcfiles/7443-e-ref_manual_servicing_technicians.pdf
	Medium	Refrigerant	North America	Technology Issues Regarding Refrigerant Blends, Honeywell, Buffalo Research Laboratory, June 2014	Explains zeotropic blends, glide and the loss of capacity due to fractionation following a condenser leak	https://www.honeywell-refrigerants.com/europe/wp-content/uploads/2014/06/Technology-Issues-Regarding-Refrigerant-Blends-April-2014.pdf
	Medium	Refrigerant	EU and UK	Refrigerant Report by Bitzer, Report 20, September 2018	Technical and regulatory guide for refrigerants	https://www.bitzer-refrigerantreport.com/fileadmin/user_upload/A-501-20.pdf
	Medium	Refrigerant	North America	Glide - What you need to know, Honeywell, July 2017	Many of the new blends such as R448A have glide, note setting them up correctly can result in efficiency loss.	https://www.fluorineproducts-honeywell.com/refrigerants/wp-content/uploads/2017/07/Refrigerants-Glide-brochure-LR.pdf

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	Medium	Refrigerant	EU and UK	Retrofit and High Glide Refrigerants by Danfoss, 2017	Very technical review of retrofitting high glide refrigerants	https://assets.danfoss.com/documents/DOC235186444204/DOC235186444204.pdf
	Medium	Commercial air conditioning	North America	ENERGY STAR tools and resources - HVAC design and commissioning checklists	ENERGY STAR tools and resources help businesses identify cost-effective approaches to managing energy use in their buildings and plants—enabling the private sector to save energy, increase profits, and strengthen their competitiveness. From commercial properties such as hospitals, schools, and offices, to industrial facilities such as cookie and cracker bakeries and integrated steel mills, thousands of businesses and organisations look to ENERGY STAR for guidance on strategic energy management. The program's popular online tool, ENERGY STAR Portfolio Manager®, was used to measure and track the energy, water, and/or waste and materials of more than 260,000 commercial properties, comprising nearly 24 billion square feet of floorspace, across the nation in 2019. For eligible buildings, the tool calculates a 1–100 ENERGY STAR score, which has become the industry standard for rating a facility's energy performance. EPA's ENERGY STAR tools for industrial plants include industry-specific Energy Performance Indicators (EPIs), which provide companies with the information they need to make smart investment decisions. Learn more about ENERGY STAR for commercial buildings and industrial plants. ENERGY STAR certified homes are at least 10% more energy efficient than homes built to code and achieve a 20% improvement on average while providing homeowners with better quality, performance, and comfort. Twenty-eight hundred builders, developers, and manufactured housing plants are ENERGY STAR partners, including all the nation's 20 largest home builders. Over 2 million ENERGY STAR certified homes have been built, including nearly 100,000 in 2019 alone. Through the ENERGY STAR program, EPA also provides trusted guidance and online tools to help homeowners make smart decisions about improving the energy efficiency of their existing homes. In addition, more than 98,000 homeowners retrofitted their homes through the Home Performance with ENERGY STAR program in 2019, for a total of more than 870,000 to date. Learn more about ENERGY STAR for the residential sector.	https://www.energystar.gov/about
	Medium	Refrigerant leaks	North America	Impacts of Refrigerant Charge on Air Conditioner and Heat Pump Performance	The impacts of improper refrigerant charge amount on capacity vary for different units and operating conditions. Low refrigerant charge levels can cause significant reductions in both cooling and heating capacity. Also, running equipment at low or high refrigerant charge levels may shorten its lifespan. To evaluate the economic value, Seasonal Energy Efficiency ratio (SEER) and annual cost of electricity were determined for some case studies based on the tested units. The results imply that charging inaccuracies could cause significant decreases in SEER, leading to increases in the operating costs. When the refrigerant was charged to 75 percent of normal, the SEER value decreased by 16	-

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					percent and annual operating cost was increased by US$ 100 per tons, on average for all systems considered.	
	Medium	Best practice guide: RAC	North America	California EnergyWise	Website promoting energy efficiency equipment (replacements) providing calculators and tools	https://caenergywise.com/
	Medium	Maintenance	International	A modified total equivalent warming impact analysis-Addressing direct and indirect emissions due to corrosion	Includes 'corrosion' in a Total Equivalent Warming Impact (TEWI) model of efficiency losses and leaks	https://doi.org/10.1016/j.scitotenv.2020.140312
	Medium	Maintenance	International	NOT FOCUSING ON HVAC Maintenance for Energy efficiency - A Review	Reviews the importance of maintenance and common approaches for energy efficiency: detailed energy monitoring is required to improve maintenance procedures	https://doi.org/10.1088/1757-899X/530/1/012047
	Medium	Maintenance	International	The role of maintenance in energy saving in commercial refrigeration	A means of identifying refrigerant loss at an early stage is needed	https://www.emerald.com/insight/content/doi/10.1108/13552511211265848/full/html
	Medium	Refrigeration	International	ior-evaluation-of-available-refrigeration-systems-retail-sector	A gas loss strategy combined with the use of R407F benefits the environment greater than any other [natural refrigerant] technology due to its efficiency and reduced GWP	https://www.honeywell-refrigerants.com/india/?document=evaluation-of-available-refrigeration-systems-in-the-retail-sector-ior-october-2012
	Medium	Refrigerant leaks	Asia (excl. Japan)	Maintenance for Energy efficiency: A Review	Review of maintenance opportunities over all technology. Includes Chiller faults detection and diagnosis (Chiller FDD). Concludes that the heart of maintenance for energy efficiency is predictive maintenance.	https://iopscience.iop.org/article/10.1088/1757-899X/530/1/012047/pdf
	Medium	Refrigerant leaks	North America	Emissions and environmental impacts from air-conditioning and refrigeration systems	Seminal	https://www.sciencedirect.com/science/article/abs/pii/S0140700701000676?via%3Dihub

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	Medium	Refrigerant leaks	Japan	Assessment of total equivalent warming impact (TEWI) of supermarket refrigeration systems	Supermarket refrigeration contributes significantly to direct and indirect global warming. An air-cooled system is analysed for low temperature evaporation at -20 degree Celsius and medium temperature one at zero degree Celsius with condensation at 40 degree Celsius. Trans-critical carbon dioxide refrigeration systems with conceivably higher coefficient of performance (COP) in the operating conditions are found to be the best from the TEWI perspectives with minimum economic loss due to refrigerant leakage because of its abundant availability.	https://doi.org/10.1016/j.ijhydene.2017.07.035
	Medium	Commercial air conditioning	Australia	A Guide to Good Practice for Energy Efficient Installations of Residential Heating, Cooling & Air Conditioning Plant & Equipment	Best practice standard for small to medium AC	-
	Medium	Refrigeration	EU and UK	Fitters Notes, Danfoss 2005.	Detailed training notes for technicians	https://assets.danfoss.com/documents/DOC000086438272/DOC000086438272.pdf
	Medium	Commercial air conditioning	Australia	HVAC System Size - Getting it right	Australian case studies into oversizing impacts and barriers to right sizing	-
	Medium	Maintenance	North America	The Importance of Clean Coils in Commercial Equipment	Coil cleaning	-
	Medium	Refrigeration	Australia	Fact Sheet - Screw compressor wear	Degradation of compressor performance due to wear over time	-
	Medium	Refrigeration	International	Validation of a vapour compression refrigeration system design model	Validation of charge vs COP in model and experimental data	https://www.researchgate.net/publication/266280430_Validation_of_a_vapour_compression_refrigeration_system_design_model
	Medium	Refrigeration	International	Optimal Charge Amount for Different Refrigerants in Air-to-Water Heat Pumps	Study on heat pump performance and compressor suction pressure to find the optimal refrigerant charge amount for different refrigerants	https://www.researchgate.net/publication/305458581_Optimal_Charge_Amount_for_Different_Refrigerants_in_Air-to-Water_Heat_Pumps

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	Medium	Refrigeration	International	Refrigerant charge amount in heat pump systems and evaluating optimal amount of gas	Study focused on optimisation of the charge amount in a heat pump using refrigerants R134a, R404a and R22, including outcomes as COP diagrams	https://www.researchgate.net/publication/282604680_REFRIGERANT_CHARGE_AMOUNT_IN_HEAT_PUMP_SYSTEMS_AND_EVALUATING_OPTIMAL_AMOUNT_OF_GAS
	Medium	Refrigeration	International	Refrigerant Charge Amount in Heat Pump Systems and Evaluating Optimal Amount of Gas	Optimisation of the charge amount in a heat pump using several refrigerants as R134a, R404a and R22	https://www.researchgate.net/publication/282604680_REFRIGERANT_CHARGE_AMOUNT_IN_HEAT_PUMP_SYSTEMS_AND_EVALUATING_OPTIMAL_AMOUNT_OF_GAS