

This paper seeks to take a focused look at the subject of refrigerant containment and economic impacts that refrigerant leaks have on the bottom line, We also take a brief look at maintenance practices that can ensure peak performance at minimum total cost of ownership. Our research over the past 2 years has indicated that maintenance costs are primarily invested in repairing and not preventing the failure, although we have noticed great success where maintenance shifts from repair to prevention.

Introduction

Refrigerants "Bat above the average" and act as the canary in the mine when trying to detect trouble. Although presently regulations are driving the awareness, energy consumption is a significant cost factor when evaluating the impacts that result from leaks, but it is not the only performance impact and this brief paper studies these impacts.

What is the Problem?

Regulations are not harmonized across, federal, state & local regions and as federal programs retract their engagement, local regulations are rising to meet the challenge. Owner and operators have responsibility to monitor and adhere to the proliferation of regulations and varied definitions drive confusion and challenge engagement. HVAC/R systems occupy more than 30% of average building energy needs and that number varies based on property types and applications. The EUI for the top 5 energy consuming building types include a few surprises and HVAC/R is higher for these groups:

1. Data centers	1,800/KW/ Sq. Ft.
2. Convenience Stores	560 /Kw/Sq.Ft
3. Grocery Stores	480 / Kw/ Sq. Ft.
4. Colleges & Universities	262 / Kw / Sq. Ft.
5. Hospital	389 / Kw / Sq. Ft.

A traditional office space has an EUI (energy Use Intensity) of 140, providing indication of the significance of the energy needed to operate these types of locations[Data extracted from U.S. Energy Use Intensity by Property Type, published March 2016]

Energy prices are increasing and today more than 30 Energy reporting programs have be initiated in markets from California to Alabama with varying levels of requirements and thresholds. Some of these markets have even instituted a cap on energy consumption at the Building level and forced a dialogue between owners, managers & tenants in order to control consumption that is impacting carbon emissions.

HVAC/R systems have a significant impact on energy and this study was conducted to show the financial impact that a leak can cause to the bottom line.

Basic Definitions

Refrigerant Containment is the prevention or minimisation of a refrigerant fluid leaking to the atmosphere. Is Zero Leakage Possible? A leak is defined as: 'A leak is a hole or porosity in an enclosure capable of passing a fluid from the higher pressure side to the lower pressure side.' A leak may be the tail-end of a weld fracture, a speck of dirt on a gasket or a microgroove between fittings. **All sealed systems leak.**

In 1994, The US consumed an estimated 125 Million pounds of refrigerant and had an installed base of roughly 500 Million pounds. There has been a 400% growth in HVAC/R systems since the mid 90's, and with more than 2 Billion pounds of HVAC/R systems installed in the US, the present demand for refrigerants has skyrocketed to 540 Million pounds yearly. It is also important to note that based on Bureau of Labor Statistics Numbers in 2014 there were a reported 250,000 (estimated) technicians in the US licensed to do HVAC/R work. Our research revealed that this is the same number of licensed technicians in 1994, indicated that a 400% growth in market demand has not seen a correlating growth in employment. This is placing heavy demands on the time of contractors

What is an Acceptable Leakage Rate? It depends on where you are and the type of system. A sealed system which operates for its useful life (say 20 years) without ever needing additional refrigerant to be added, in order to keep it running within normal operating parameters is considered to be 'leak tight'. That means that it has not leaked enough refrigerant to effect system performance (typically less than 10% of original charge, although some studies show that this may be as high as 20% before performance loss can be detected. Below this 10% lifetime 'benchmark' the system leaks are not practically measurable – and it is deemed a 'leak tight' system []).

It is possible however, and indeed is a critical priority, that we adopt a '**zero tolerance of leaks**' as California has done for refrigeration systems, and for Air conditioning Systems in Southern California.

Appliance Type	Allowable leak rate presently - Federal	Allowable Leak Rates 2019 - Federal	Allowable Leak Rate California
Industrial Refrigeration	35%	30%	0%
Refrigeration	25%	20%	0%
Comfort Colling	15%	10%	0%

Figure 3 – Refrigerant and Technology Choices for Commercial and Retail Refrigeration [12] Courtesy of Emerson

If we are totally committed to minimising our environmental impact, then we would choose case 11, 12, 13 or 14; but the short term investment costs would range from 17% to 48% higher. We would also pay penalty for increased running costs of 7% to 12%. Lowest short term investment would select case 5 or 6, but the environment will suffer from our short term focus.

The choice of course depends on our priorities.

The Real Cost of Refrigerant Leaks

When a leak occurs from a refrigeration system, there are a number of consequences. Figure 4 shows these major factors and effects.

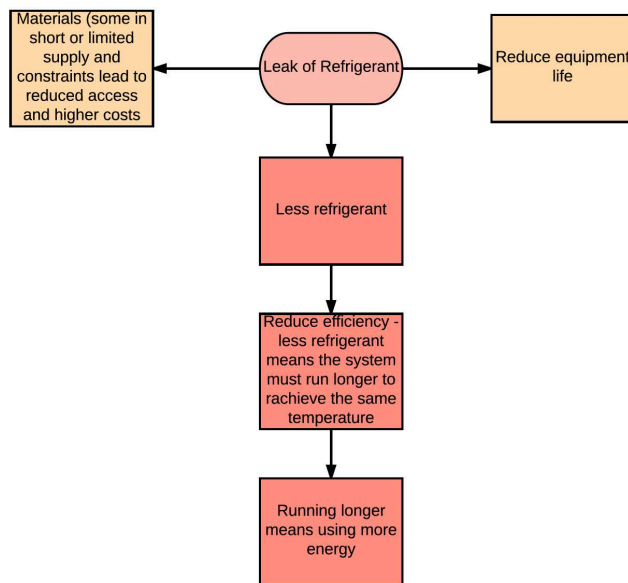


Figure 1 – The Consequences of a Refrigerant leak [13]

There are 4 main areas that this report will analyze

1. Material Costs
2. Energy
3. Maintenance
4. Equipment life

This study is a synthesis of results extracted from the Woohyun Kim study released in 2010. In order to remain consistent, the data was used to extrapolate results and then test against the model to certify results.

The Kim study used 6 systems identified here, with varying charge types, air flow, capacity and features.

System Size	Size	Refrigerant Type	Expansion Device	Accumulator	Assembly Type	Air Flow	Charge Level
System 1	4 ton	R-22	EEV	50 ounces	split	Nominal	80 - 100%
System 2	4 ton	R-22	FXO	no	split		60 - 110%
System 3	4 ton	R-22	FXO	no	split		60 - 100%
System 4	4 ton	R-22	FXO	33 ounces	split	800 CFM	80 - 100%
System 5	3 ton	R-22	TXV	yes	split		70-130%
System 6	3 ton	R-410	TXV/FXO	yes	split		40-130%

Impact to Efficiency

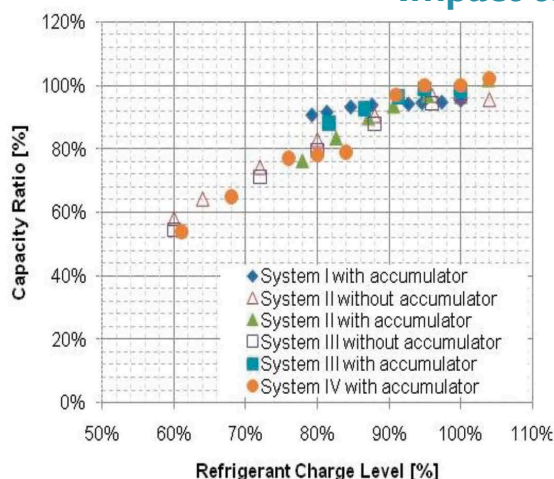


Fig. 1 Impact of charge on capacity for existing test data

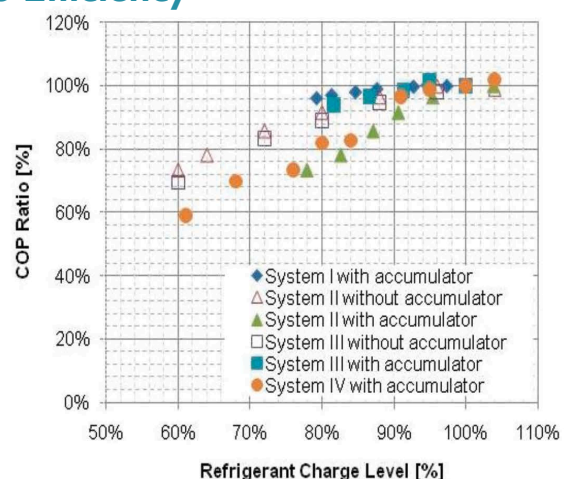


Fig. 2 Impact of charge on COP for existing test data

This graph in figure in flbelow charts the aggregate impact from a refrigerant leak and provides a scope for the discussion presented in the sections below. Keep in mind that the intention of the report is to assist in the process of converting various reports and measurements into a financial formula that users can rely in order to predict costs and identify opportunities for savings.

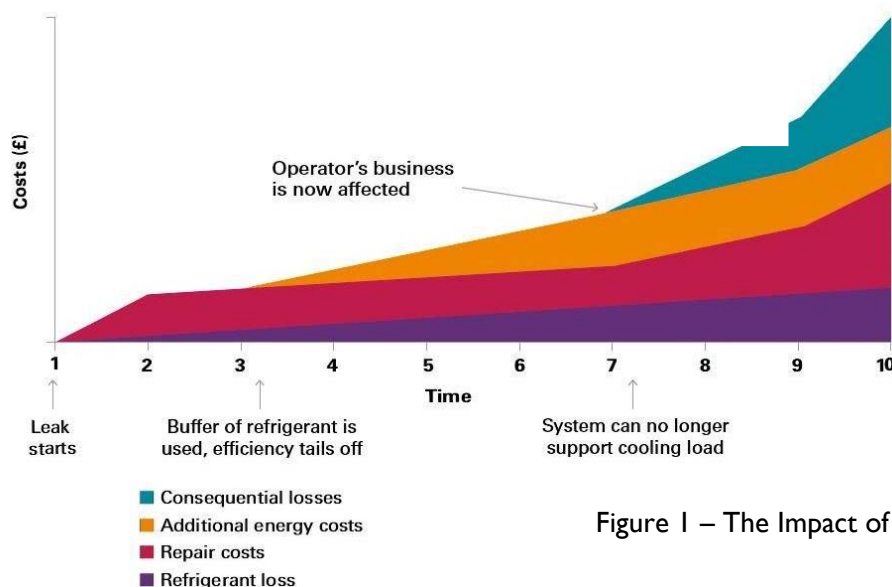


Figure 1 – The Impact of Refrigerant Leakage

Cost of increased energy consumption - \$6200 (reduced efficiency) - during the period of the leak.

This factor is very difficult to assess as there are a large number of variables to consider. If the system has a receiver installed (buffer of refrigerant charge), then of course the system could leak up to 30% (or more) of its initial charge before there is any measurable impact on system cooling capacity or efficiency. The relationship between the loss of performance (capacity and efficiency) is very difficult to predict but in results derived from experimental measurements taken by Woo Hyun Kim [15] shown in Figure 6, it can be seen that when the effective refrigerant charge is reduced to 85% of the correct amount, then annual running costs are increased by 10%. This annual running cost penalty increases in a non-linear manner so that at 60% correct charge, the running cost penalty is +45%.

Take the case that a typical system costs \$80,000 per year in electricity costs to run, then if the system charge is reduced to 80% (20% annual leakage rates still being typical in some applications), the operator incur a 15% annual running cost penalty. Assuming a linear leakage rate of 5% per 3 month period, then the running costs annualised amount to \$6,200 (see Table 2).

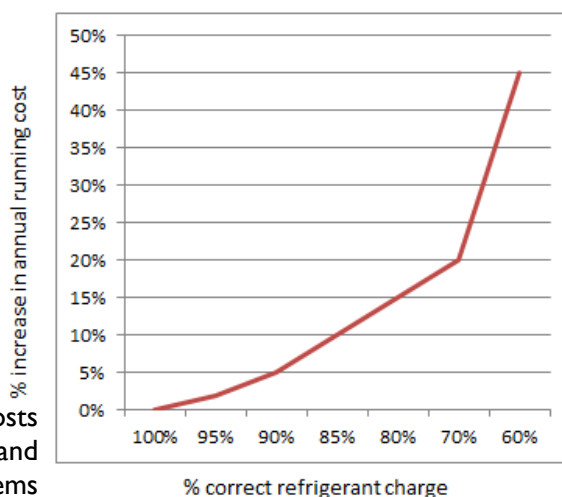


Figure 6 – Relationship between annual running costs and refrigerant leakage for small air-conditioning and commercial systems

	Thermal	Hydro	Nuclear	Renewables	kg CO ₂ /kWh
UK	74%	1%	24%	2%	0.64
France	8%	14%	77%	1%	0.09
Germany	62%	4%	30%	4%	0.61
USA	71%	6%	21%	2%	0.66
China	82%	17%	1%	0%	0.77

This report makes no effort to determine the CO₂ impact from refrigerant (F-gas) emissions, but we are publishing an energy mix chart in order to provide some idea about the extended scope and cause for the importance in reporting. Also assumption about costs were made but we realize each user has different costs and live in different regions which will effect run time, use and costs.

Table 3 Annual Maintenance Cost Increase for a 20% Annual Leakage Rate

annual run cost =\$80,000	12 month period				
	Q1	Q2	Q3	Q4	Total
% correct charge	95%	90%	85%	80%	-
% run cost penalty	2%	5%	10%	15%	-
actual penalty cost per Q	\$ 390	\$ 975	\$ 1,950	\$ 2,925	\$ 6,240

The COST of Maintenance - \$910

Cost of the repair – the Carbon Trust [14] uses a typical cost for the labor time to repair a leak as \$910. This is of course a cost per leak, and the labor cost is not likely to be significantly higher for most commercial sized systems, unless the location is particularly difficult to isolate from the rest of the system, or the reason for the leak requires replacement of a high cost component.

Using the Carbon Trust typical repair cost of \$910, the operator could better invest this cost to preventative leak detection (and repair on the same day); and could then visit twice per year (cost \$1,820 total) and limit the annual leakage rate to 5%, and therefore save \$4,420. This saving could even be invested in hardware and software to track service activity, that would expose the leak and allow mgmt. to guide staff to make the repair. The beneficial side effect is that we also reduce both direct and indirect emissions of CO₂ (equivalent). The amount would of course depend on the refrigerant gas and the emission rate of the power source (see Table 3).

There are other methods of leak detection that could be used, and for example by installing instrumentation it is possible monitor and data log the running conditions of the plant, and with a pre-defined 'baseline', abnormal conditions (which would result in a loss of performance and efficiency) can be detected and an alarm could be raised. The problem with this approach is the large variance in the running conditions and load, ambient conditions etc. that would make establishing a practical baseline very difficult to achieve. For smaller systems, the cost of the necessary instrumentation may add 30% to 50% to the cost of the system. There is also the option to add a 'stenching agent' to any gas (that does not have a natural, strong smell). This is of course done with natural gas that is piped into our homes, to give us an ALD in the form of the human nose. Would such a thing be possible for refrigerant gases?

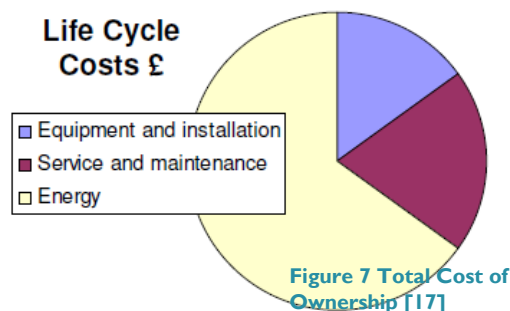
The most cost effective means of monitoring leaks is to use a system of software that will both project the leak and notify stakeholders to the use of refrigerant and follow up service. The data that would expose the leak and its impact is likely documented on the invoice and/or on the panel of the AC or Refrigeration unit, but this data is no accessible to proper decision makers or staff. Additional maintenance would be eliminated since the leak will have been resolved before the service event is allowed to be closed.

Life Cycle Costing: - \$400 / unit or \$ 2400 - for reasons explained: assuming a 10 year system (10% reduction in life expectancy for the unit or for any part), with an expected lifetime of 20 years and a present market value of \$8000 each .

These means that we need to focus on the long-term issues – the Total Cost of Ownership (TCO), rather than the short-term capital costs. Figure 7 shows a typical split between the 3 major elements of TCO (there is a fourth item – disposal costs, but we will not discuss that issue in this paper). In most applications the cost of the energy to run the refrigeration system can be up to 90% of the TCO. It is clear long-term benefit to invest upfront in more efficient, higher quality (leak tight), easy to maintain systems, with planned preventative maintenance programs in order to reduce TCO and the Lifetime CO₂ emissions of the system.

Reduced life cost of Equipment

If the charge of the system reduces to less than 80% of capacity, then the unit will cycle more frequently, because there is not enough refrigerant to pull across the compressor. When this happens the unit will cycle on and off, and it is these on / off cycles that will degrade the life-cycle faster than either heat from reduced cooling or ambient temperature changes. The charge decreases by an amount equal to the annual slow leak rate based on the nominal charge for every year if charge is 20 lbs and leakage rate is 5%, then after the first year the charge is 19, and after the second year it is 18, and so on) until servicing is performed (at that point charge is restored to 20 lbs). This is repeated over the lifetime of the system. The results documented that 10% extra cycle time will directly correlate to a reduction in life of system by 10%



For the cases shown earlier in Figure 3, we can clearly see from Figure 8 impact of leakage on the overall lifetime Co2 emissions or TEWI number. An annual leakage rate of 10-15% dependant on the system type has been assumed. Improved leakage reduction programmes would of course reduce the TEWI value for the systems using higher GWP refrigerant gases such as R404a. We are including the CO₂ cost of ownership as a reference.

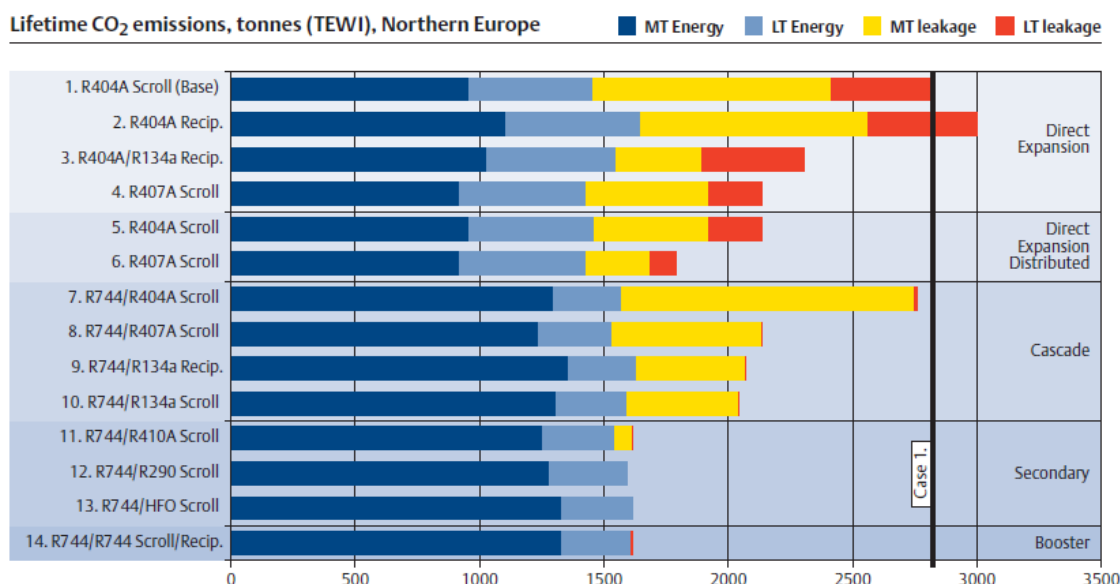


Figure 8 – Commercial and Retail Refrigeration Systems Lifetime Emissions – Courtesy of Emerson

Material Costs - Cost of refrigerant gas – \$1,220 Gas prices range dramatically depending on whether it is in production, patented or under a tariff restriction (this happens frequently) shown in Table 2. This does not include any additional taxes which as previously mentioned are now applied in many countries.

System Size	Size (tons)	Refrigerant Type	20% Lost refrigerant	price per ton
System 1	4	R-22	\$240.00	\$60.00
System 2	4	R-22	\$240.00	\$60.00
System 3	4	R-22	\$240.00	\$60.00
System 4	4	R-22	\$240.00	\$60.00
System 5	3	R-22	\$180.00	\$60.00
System 6	3	R-410	\$81.00	\$27.00

Refrigerant	Market Cost/LB
R134a	\$10-\$40
R22R	\$75-\$100
R404a	\$20 - \$35
HFO-1234	\$50 - \$125
R407F	\$20 - \$40
R290	\$10 - \$25
R123	\$15-\$45
CO2	\$5 - \$15

Table 2 – Refrigerant Cost

Conclusion

HVAC/R systems play a significant role in keeping us comfortable, our food safe, and helping us produce a variety of important items. The world has seen a massive amount of growth since the initiation of the Montreal Protocol, more than 400% growth here in the US alone - global growth is much larger. But science has exposed the risk that leaking refrigerant has on the environment and brought attention to the impact the chemicals inside can have on our environment and quality of life.

However the most significant impact that refrigerant does have, is on our financial health. We have synthesized the data from 3 very significant studies to document the cost impacts that result from a combination of poor maintenance and a lack of awareness of multi servicer work activities. Leaks directly impact 5 key performance indicators

1. Material needs
2. Maintenance Activities
3. LifeCycles of the equipment
4. Energy costs
5. Environment

As awareness grows, so do regulations that limit flexibility of handling these gases. The intent of the regulators is to curb emissions, reduce the need for more power and slow the impact to the environment. However this paper was more concerned with financial impacts and exposing the impact so we could convert Kw, labor, materials and equipment life into (\$) dollars and cents. The leak from 6 small systems can impact an operation in a significant way, exposing owners of these appliances to more risk and if not well understood, it will reduce their ability to control costs and manage expectations. Readers should take the results and apply best practices to reduce leaks and shift maintenance budgets so that less is spent on repairs and more on prevention.

The Bottom Line:

Cost Center

Cost related to the leaking systems

Energy	\$6,200.00
Maintenance	\$910.00
Life Cycle	\$2,400.00
Materials	\$1,220.00

Total Cost to a 20% leak from 6 small systems \$10,730

Additional Non-Financial Considerations

Cost of the lost productivity - . Whether you call this down time, tenant non renewal, lost food, spoilage, this is all waste. This can vary from mere inconvenience for a comfort cooling system; to truly staggering costs for high value factory production processes. A grocery store must sell 20,000 gallons of milk to cover just the material cost of a 100LB leak of R-404.

Environmental : The impact on the climate of a leak – this is a combination of the direct emission effect of the amount of refrigerant leaked to the atmosphere and of course the GWP value of the gas, which range from a low of 300 to a high of 3,400 pounds of carbon for every pound of refrigerant leaked. In the US, refrigerant accounts for 15% of all carbon in the US. .

The direct emissions amount is however usually (in the UK) dwarfed by the impact of the indirect emissions. The indirect effect is the amount of the additional energy consumed due to inefficient running with the system refrigerant charge at less than correct design level. In the UK, 74% of the electrical power generated comes from thermal (fossil fuel) power station with a very high rate of CO₂ emitted per kWh of electrical power generated. In France by contrast only 8% of their electrical power comes from a fossil fuel thermal station (77% comes from nuclear power). Clearly the environmental impact of reduced efficiency resulting from leaks is much lower in France, where the direct emission effects (from a GHG perspective) will be a much higher proportion of the total environmental impact.

Best Practices – a Global Perspective

From the author's personal experience (mostly in industrial refrigeration) it has been observed that the best practices to solve particular problems are very similar regardless of local geographic location. Different geographic locations however have very different priorities based on local conditions. They all follow the same principles as described above, but implement them in different priority sequences. Large organisations (Nestle, Coca-Cola, Unilever, Tesco, Walmart, Huur, JCI, GEA, Bitzer, Daikin, Carrier etc. tend to transmit best practices between their organisations in different countries. The information then spreads within a country, usually accelerated by contractors and equipment manufacturers following large end-user best practices and specifications, and local organisations and institutions such as the IoR, ASHRAE etc. Local regulations, climate conditions, industry and market norms all set different driving forces behind local decision makers and the paths they follow.

For industrial refrigeration for example, the Russian market has a preference for screw compressor based technologies, considering the design more 'modern' than piston compressors, even though in many applications piston compressors are more efficient than screw compressors

High ambient conditions make CO₂ transcritical less attractive compared to HFC based solutions.

Single stage ammonia piston compressor chillers for sub-zero secondary fluid cooling applications, popular in Northern Europe, as a highly efficient natural refrigerant solution, are not suitable for hotter climates.

Air-conditioning systems are becoming more and more common in large cities in India and China, where income levels are rising and cost of AC systems is reducing. Window mounted systems cover the sides of many old buildings and these systems are unlikely to be properly maintained. Population and income growth in Asia and Africa will lead to a huge increase in the number of such systems installed, and these (in the author's opinion) are likely to become a major source of refrigerant leakage in the future. Only economic effects (high prices) or legislation will prevent this happening.

Conclusion

Whatever the refrigerant in a system is, it is good practice to keep the fluid contained within the pressure system. This helps us achieve our long term vision – protecting our environment.

It is the authors opinion that there is a place for synthetic refrigerants in applications where there is no better alternative, assuming we can minimise leaks to a 'sustainable level' for the environment. Perhaps we should stop debating the natural versus synthetic refrigerant fluid argument, and focus on the best long term SUSTAINABLE refrigerant fluid, that achieves the best result for our overall target of carbon emissions reduction. Ensuring a practical minimum fluid leakage – refrigerant containment – is a key element in achieving this long term goal, as well as our own personal short term goals– so refrigerant containment is certainly a 'good thing' for everyone.

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