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Short Report

The first 100 000 HC-290 split air conditioners in India ☆

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ABSTRACT

In 2012, Godrej & Boyce Mfg. Co. Ltd. launched their first HC-290 split air conditioners, which was the first in India. Since then, more than 100 000 air conditioners have been placed on the market. This article provides an overview of the development process and challenges and provides an analysis of the current situation in terms of safety and reliability. The development of these products involved an iterative process of charge minimisation, performance optimisation and integration of safety features, and the results of these are detailed within the article. Subsequent to the sales of these machines, data were obtained from field technicians as well as end users in order to evaluate the reliability and robustness of the installed systems and associated service activities. The present paper summarises the results of the findings.

Les 100 000 premiers conditionneurs d'air split utilisant le HC-290 en Inde

Mots clés : Frigorigène hydrocarbure ; HC-290 ; Conditionneur d'air split ; Sécurité

1. Introduction

As an article 5 country, the use of HCFC-22 in India is permitted for new split air conditioners (SACs) and this practice represents the majority of the products currently being sold. However, with the impending phase-out of HCFCs, suppliers will in the near future have to switch to non-ozone depleting substances. The consensus view of the enterprises which currently produce SACs within India is that there is no suitable option; R-410A, R-407C and similar HFC blends have high global warming potential (GWP), are likely to be subject to restrictions in the near future and – specifically for R-410A – have poor performance at high ambient temperatures. HFC-32 also

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Nomenclature

COP	coefficient of performance
EER	energy efficiency ratio
EHSR	essential health and safety requirement
GWP	global warming potential
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IDU	indoor unit of the air conditioner
LVD	low voltage directive
MSD	machinery safety directive
ODU	outdoor unit of the air conditioner
PED	pressure equipment directive
QRA	quantitative risk assessment
SAC	split air conditioner
SOI	source of ignition
TEWI	total equivalent warming impact
WAC	window air conditioner

has a high GWP; its performance under high ambient conditions is substantially worse than HCFC-22 and system concepts for higher efficiencies are bounded by a large number of patents. Nevertheless, some manufacturers are starting to develop R-410A products and one foreign company has begun to produce its own HFC-32 products. Many enterprises also viewed hydrocarbons (HCs), such as HC-290, as unsuitable on the basis of inhibitions arising from flammability and lack of safety-related experience. Nevertheless, at least two enterprises have begun development of ACs using HC-290 and this article provides an overview of the experiences of one such manufacturer.

In 2012, the annual production capacity of air conditioners in India was about 10.5 million, while the demand was 3.4 million (Gloël et al., 2014), with annual growth rate at around 10%. Approximately one-third of the demand is for window units, while the majority of the remainder is for SACs. Among the SACs, approximately 95% of the market is for so-called "1TR" and more so "1.5TR" models[1], which correspond to a nominal cooling capacity of around 3.5 kW and 5.0 kW, respectively. Thus, the main products to target are 1.5TR SACs, 1TR SACs and then similarly sized window-type air conditioners (WACs).

2. Products

A number of products have been developed specifically for HC-290. The main criteria for successful introduction are: achieve at least the same efficiency as the current Indian five-star efficiency label, minimisation of refrigerant charge and avoidance of excessive cost. A summary of the earlier activities to develop design measures to optimise the performance is provided in an earlier article (Padalkar et al., 2010). Starting with an HCFC-22 model as the baseline, the outcome was principally increasing compressor displacement by about 10%, optimising condenser design (to narrow tubes and mini-channels, depending upon the model) as well as optimisation of capillary tube and charge amount. The development led to a number of products which correspond to different efficiency levels, according to the respective cost markets. The main current products are summarised in Table 1. Other models for the 3-star and 4-star markets are in progress. As well as having good efficiency at rated conditions, measurements also showed that the performance of the HC-290 is within a couple of percent of that expected with HCFC-22 (Colbourne et al., 2013b). For example, the cooling capacity of the HCFC-22 model at an ambient of 52 °C was 79% of the rated capacity, while the HC-290 model achieved 78% of the rated capacity. Similarly, the HCFC-22 had 61% of the efficiency at rating conditions and 59% for the HC-290 model. Considering that the uncertainty for the measurements is around ±3%, the comparison implies that the performance under high ambient conditions is essentially the same.

Table 1 – Different HC-290 SAC products.

Model	Cooling capacity	COP (EER)	Star rating (2013)	Charge size
GSC 12 FG 7 WMG	3375 W ("1TR")	3.72	7-star	0.31 kg
GSC 18 FG 7 WMG	5000 W ("1.5TR")	3.72	7-star	0.36 kg
GSC 18 FG 5 WMG	5000 W ("1.5TR")	3.45	5-star	0.36 kg

Table 2 – Competing SAC products.

Brand	Model	Cooling capacity	COP (EER)	Refrigerant
Brand #1	Model A	5050 W	3.51	HCFC-22
Brand #2	Model B	5300 W	3.58	HCFC-22
Brand #2	Model C	5200 W	3.55	R-410A
Brand #3	Model D	5275 W	3.60	R-410A
Brand #4	Model E	5200 W	3.60	HFC-32

There are a large number of products available on the Indian market, but a fairly small number with high efficiency levels; coefficient of performance (COP) or energy efficiency ratio (EER). Table 2 provides a summary of the comparative products from four different leading brands. This comparison indicated that the HC-290 products can achieve a high level of efficiency across the range of competing products. A further comparison of the environmental impact of these different products is shown in Fig. 1, on the basis of Total Equivalent Warming Impact (TEWI), calculated according to products data and standard published emissions factors. It can be seen that the use of a negligible GWP refrigerant has a significant reduction on the overall impact.

3. Product safety assessment

3.1. *Framework*

In addition to the performance criteria previously mentioned, product safety is also a critical matter. In order to ensure safety of the products, there are certain approaches that need to be taken. In one regard, all requirements associated with

[1] "TR" refers to the measure of capacity, Tonnes of Refrigeration.

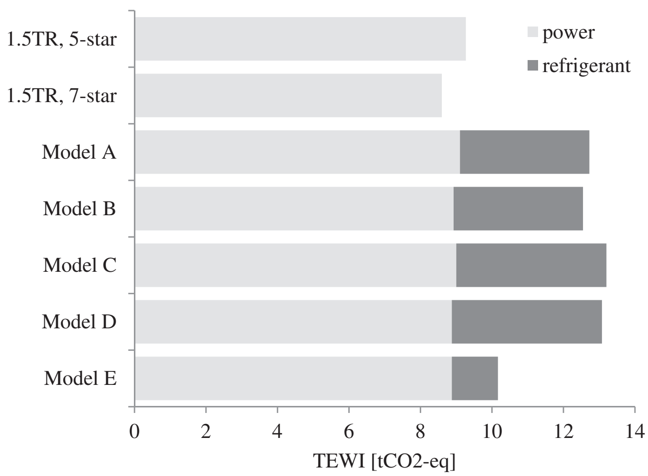

Fig. 1 – Comparison of TEWI of SAC products.

necessary legislation should be satisfied and in another, the appropriate risk analysis and risk assessments should be carried out; typically, such risk assessments are obligated by the legislation. These matters are discussed specifically with regard to the flammability hazard only. Within India, there is no clear regulation relating to the use of flammable refrigerants in such products and similarly, there are no national standards (or adopted standards) that apply to ACs using flammable refrigerants. Therefore, the approach for achieving a high level of safety was achieved through means of the appropriate European framework. The overriding legislation for such equipment is the Atex Directive (2013); this applies to any equipment that operates within, or could create its own potentially flammable atmosphere. Equipment that is intended to operate in a flammable atmosphere or is capable of creating its own flammable atmosphere has to meet the essential health and safety requirements (EHSRs) of the directive (as well as those of the other applicable directives). An overview of the approach and main requirements of Atex is given in Fig. 2. In order to meet the various requirements of Atex, harmonised standards can be followed; typically these are standards related to the identification of the extent of potentially flammable atmospheres (such as EN 60079-10-1: 2009) or which deal with the protection of components that could potentially be a source of ignition (such as EN 60079-7, EN 60079-15, EN 60079-18, etc). In terms of carrying out the overall flammability risk assessment for safety of the equipment, the standard EN 1127-1: 2011 should be applied.

It is noted that there are certain standards relevant to AC equipment that contain requirements for flammable refrigerants; these are EN 378: 2008 and EN 60335-2-40: 2003+A2: 2009. EN 378: 2008 is harmonised to the pressure equipment directive (PED) and machinery safety directive (MSD) and EN 60335-2-40: 2003+A2: 2009 is harmonised to the Low Voltage Directive (LVD); however, neither are harmonised to Atex and therefore they have little relevance or standing with regard to legislative requirements for equipment that contains flammable refrigerants (except within the context of additional protection for equipment under pressure). Nevertheless, these

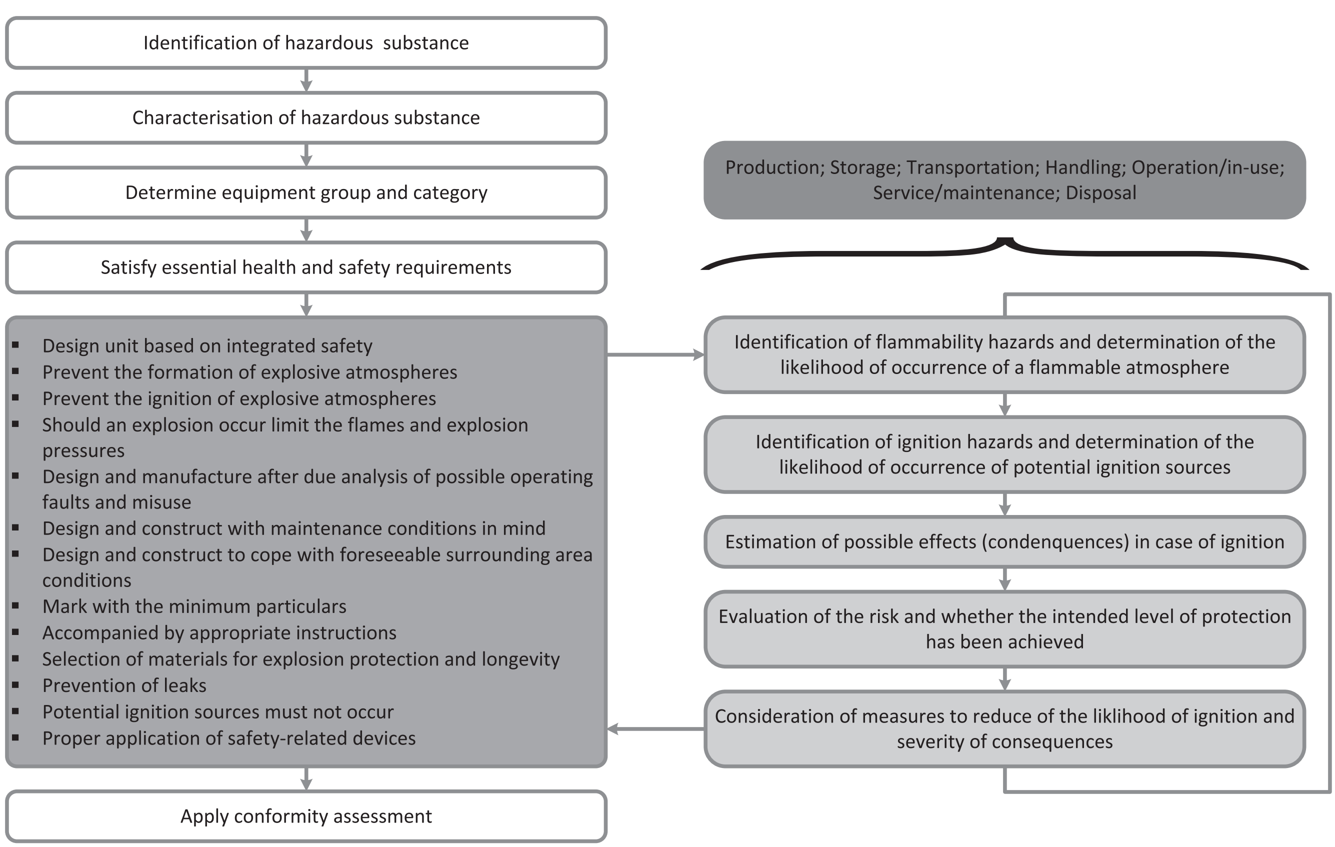

Fig. 2 – Flow chart summarising the requirements of the Atex directive.

standards contain a disparate selection of requirements that can be used as a means of achieving some of the EHSRs.

3.2. Meeting ESHRs

Consistent with the requirements of Atex, various measures are applied to the indoor unit (IDU), outdoor unit (ODU) and interconnecting piping of the SACs in order to achieve a sufficient level of integrated safety:

- Refrigerant charge is greatly minimised, possibility of leakage is reduced, minimum installation height and room sizes are specified, and conditions for positioning of the ODU are given in order to prevent the formation of flammable atmospheres.
- All potential SOIs are reasonably eliminated from the IDU and ODU to prevent ignition of flammables.
- The construction of IDU and ODU are such that overpressures (and thermal radiation) will be minimal.
- Sensors and controls are applied and configured to account for possible operating faults (and misuse).
- Appropriate warnings and positioning of critical electrical items are applied with regard to unintended service and maintenance behaviour.
- Flammability risk evaluation is carried out with regard to all foreseeable surrounding area conditions.
- Appropriate marking, such as "flammable gas" signs, minimum room sizes, refrigerant type are applied.
- Technicians service and installation instructions contain relevant flammable safe handling information.
- All construction materials are selected with regard to explosion protection and longevity.
- The pressure system is designed for minimal leakage (such as factory-made flare joints) and subject to extensive sequential factory testing for each unit (i.e., achieving demands for "durably technically tight").
- All electrical items and non-electrical parts are assessed with regard to their potential to act as an ignition source for the refrigerant used and eliminated where appropriate.

In addition, the products nevertheless comply with all applicable requirements in EN 60335-2-40: 2003+A2 (2009) and those relating to flammable refrigerant within EN 378: 2008, which are not overridden by the Atex-harmonised standards.

3.3. Risk assessment

According to EN 1127-1 (2011), a quantitative risk assessment had been carried out on the SACs under different scenarios. For the quantitative assessment of the in-use stage, established methodologies and sub-models were used, as detailed elsewhere (Colbourne and Espersen, 2013; Colbourne and Suen, 2004, 2008). Table 3 contains some basic input data for the scenarios. Although the appliance and associated instructions state minimum room sizes and installation technicians are taught about this parameter as part of the training, installation of the units within room that are smaller than intended is also considered.

3.3.1. Operation

The compressors (and condenser fans) are assumed to operate for 12% of the time, with the IDU airflow being present for 26%. Operating faults are also considered, such as the effect of external mechanical impact, airflow failures or safety-related controls relying upon certain operating parameters that could result in the development of excessively high pressures and thus increases in leakage are also accounted for.

3.3.2. Sources of ignition

For domestic occupancy, various SOIs are assumed for the space of 10 m^2, equating to 36 arcs/sparks of sufficient energy per 24 h and one continuous SOI (a candle) for 1 h per 24 h. For larger room areas, the number of SOIs is increased proportionally. For a release to the outside, it is assumed for another condensing unit with an open contactor (20 active events per 24 h) and a person lighting cigarettes. While no normally active SOIs are present inside the IDU or ODU, there is a possibility of various electrical items becoming a SOI in the event of a fault (e.g., compressor relay, circuit boards, fan/motor, terminals, wires, thermal overload, capacitor). Empirical failure rates were used to determine fault probabilities. While various electrical items are selected to avoid SOIs, it is feasible that with a fault, an unaware technician may replace it by non-protected components; it was assumed this would occur in every instance.

3.3.3. Leakage

The leak frequency is calculated from the method based on supermarket systems and assumed seven different hole sizes. Leak frequency ranged from 2.7×10^{-4} for small leak hole diameters (~0.1 mm) to 3.1×10^{-5} for large holes (~4 mm), with an overall leak frequency of 6.9×10^{-4} per year. For the 15 m piping, the leak frequencies are 30% higher. According to other studies, these values are considered rather conservative. A high value is also assumed for the leak rate, being 15% per year; one quarter of the leaks is expected to originate from the IDU. Throughout, the leakable mass is about 85% of the charged amount, which was determined by testing (e.g., Colbourne et al., 2013a).

3.3.4. Flammable quantities

Flammable volumes, masses and times were modelled for the various leak sizes, into the rooms, IDU, ODU and the outside area surrounding the ODU, both for modes with and without airflow.

Table 4 presents a summary of the outputs from the QRA. These results indicate that there would be one ignition event for every 1400 million units per year for the 1TR unit and one ignition event per 300 million per year for the 1.5TR unit. In either case, such values are so vanishingly small that they have no significance. The most severe consequence is when there is a very large leak hole, at the time of there being no airflow from the IDU. Under these conditions, the overpressure could

Table 3 – QRA inputs data.

Model	1TR		1.5TR	
Piping length	7 m (standard)	15 m	7 m (standard)	15 m
Charge amount	0.31 kg	0.35 kg	0.36 kg	0.42 kg
Room area	10 m^2	10 m^2	30 m^2	30 m^2
No. of occupants	2	2	6	6

Table 4 – Output values for the QRA.

Model	1TR		1.5TR	
Piping length	7 m (standard)	15 m	7 m (standard)	15 m
Ignition frequency (room, unit off) (y^{-1})	4.2E-10	5.0E-10	3.0E-09	3.4E-09
Ignition frequency (room, unit on) (y^{-1})	1.2E-10	1.3E-10	1.4E-10	1.5E-10
Ignition frequency (IDU) (y^{-1})	1.3E-16	1.5E-16	1.1E-16	1.2E-16
Ignition frequency (ODU) (y^{-1})	3.8E-13	4.3E-13	5.8E-13	6.3E-13
Ignition frequency (outside) (y^{-1})	1.3E-10	1.7E-10	2.1E-10	2.2E-10
Total ignition frequency (y^{-1})	6.7E-10	8.0E-10	3.5E-09	3.8E-09
Frequency of secondary fire (y^{-1})	7E-11	8E-11	4E-10	4E-10
Max overpressure (kPa)	4.5	5.8	5.1	6.0
Max thermal intensity (s $(kW\ m^{-2})^{4/3}$)	24	30	303	353

reach around 5–6 kPa, which is sufficient to blow out windows but not to cause substantial damage to people or property. For the 1TR unit, the thermal intensity is negligible and would be incapable of pain or injury, whereas for the 1.5TR unit, it would be sufficient for pain and blistering, but still several times lower than what would be needed for the possibility of fatality. It is also important to iterate that these values assume (then the IDU is off) there is no infiltration, room fans, human movement or thermal sources within the room that would ordinarily disperse a refrigerant leak more effectively. In this regard, the actual ignition frequency for these events would be smaller by orders of magnitude than those calculated using these conservative assumptions.

As required by EN 1127-1 (2011), the quantified risks must be considered within a certain context to help gauge the severity. First, with regard to UK government risk tolerances, the estimated values are extremely low (HSE, 2001). For example, an individual risk of fatality of one in a million per annum (workers or public) is considered as negligible – this is around 1000 times higher than the estimated values for only ignition of the SAC; the frequency of (indirect) fatality would be in the order of one hundredth or a thousandth of this. Secondly, the risk can be considered with respect to the background fire risk associated with such appliances. Data from Hall (2012) indicate a frequency of fires caused by ACs in USA to be about $2 \times 10^{-5}\ y^{-1}$; assuming that this is consistent for the global population, the additional probability of secondary fire from the 1TR and 1.5TR units due to the use of HCs would be less than 0.02%. In this respect, the conclusion from the risk assessment is that it easily achieves the criteria.

4. Production line

A dedicated production line was set up for the production of the HC-290 AC units. In summary, this comprised several elements:

- Refrigerant storage and feeding system, comprising a refrigerant supply pump, valve station, multi-cylinder cage, steel piping and refrigerant accumulator
- Evacuation lines, comprising vacuum pumps, electronic vacuum gauges, evacuation controllers and pump carousels
- Strength pressure test and tightness test, comprising high pressure dry air testing machine, evacuation/helium charging and recovery machine, helium and refrigerant detector, recovery unit
- Refrigerant charging equipment, comprising evacuation/charging machines, feed lines and charging guns and multi-gas detectors
- Performance and electrical test equipment, comprising electrical safety test units, performance test loggers and associated software, controlling software, transducers
- Repair area, comprising a complete discharge and evacuation machine, discharge line and ventilation duct and piercing pliers
- A safety monitoring system, comprising charging area enclosures, gas sensors, ventilation pressure sensors, flow sensors, alarms, emergency stop buttons, ventilation/ducting system, fire extinguishers, emergency lights and marking

In addition, calibration sets for gas detection and necessary spares were supplied. The entire facility was commissioned, subject to safety testing and received TUV approval. All workers were provided with comprehensive training for operation of the equipment and systems as well as safety training for handling of flammable refrigerants and appropriate documentation for working procedures. The selection of the safety monitoring system and the worker training and procedures were concluded in tandem with the risk assessment for the production and storage stages.

5. Infrastructure

5.1. *General considerations*

As with the in-use or operational stage, other stages throughout the equipment lifetime must also be considered within the context of ensuring a high level of safety. Fig. 3 provides a basic overview of the main stages within the lifetime of the equipment and the main considerations for the risk assessment process, for each of those stages. While aspects such as production, internal transferring and storage of products, transportation and removal are fairly straight-forwards to handle, some of the other stages – particularly installation and servicing/maintenance – require special consideration.

5.2. *Sales and supply scheme*

Within the content of the lifetime of the SAC, the area of most concern is the installation and servicing of the HC products by technicians who are not competent to do so. In this regard, it was deemed critical to implement schemes whereby the possible involvement of untrained technicians can be greatly minimised. The primary approach for doing these are to provide a finance-based incentive to the end user.

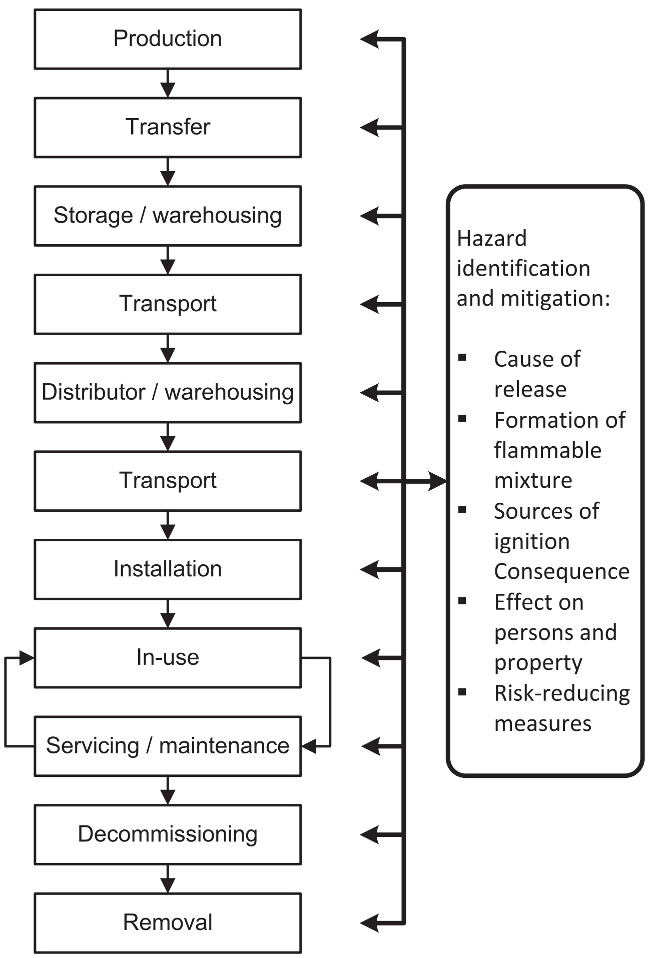

Fig. 3 – Main considerations for risk assessment throughout equipment lifetime.

When purchasing the product, the trained sales person or call centre staff always checks with the customer both the room size (in order to check that it is appropriate for the charge size and cooling capacity) and the desired location of the IDU and ODU (to ensure that the piping length is not excessive, thereby avoiding the possibility that higher refrigerant charges are used). Spot-checks are carried out in order to confirm that staff are following the appropriate procedure. Once the customer receives the AC, they are provided with a free-phone telephone number which they call to organise the installation. As such, the manufacturer then sends out a trained technician to carry out the installation. In this way, there is no reason for the customer to employ a non-trained technician to install the unit since they would otherwise incur unnecessary additional costs.

At the time of installation, the technician will again check room size and pipe lengths to ensure they are within the applicable constrains. Once the installation is complete, the technician records all of the necessary data and this is added to a central database. The customer is made aware that any changes, servicing, repositioning, or any other form of interference with the AC (i.e., by a non-trained technician) will result in the warrantee becoming void. Again, a free-phone number is provided to the customer in case of service or maintenance needs. With this approach, the possibility of a non-trained technician working on the AC is minimised.

To ensure that the HC-290 AC products are installed (and serviced) by trained technicians only, a particular system has been implemented. Firstly, all products are sold with (i) free installation, (ii) a one year products warrantee and (iii) a five year compressor warrantee. Furthermore, an extended multi-year service contract is always offered. In doing this, the customer is more likely to contact the manufacturer's designated service company to carry out any repairs. Initially, sales were limited to the major cities as the majority of the trained technicians were located in those areas; however, the entire network of technicians are now trained and sales are thus no longer limited to specific regions. Thus, presently, the HC-290 ACs are sold throughout the entire country.

Lastly, for the end-of-life stage, use is made of the "E-waste" rules, which is an extended producer responsibility scheme that has been recently introduced. Under this scheme, it is mandatory for all producers to take responsibility in collecting and recycling or disposing of any such appliance according to the relevant guidelines. As such, the framework is harnessed so that when an end user advises the company that an AC needs to be removed, an appropriately trained technician will be assigned the task of decommissioning.

5.3. *Technicians*

It is critical to ensure that all technicians are competent in handling flammable refrigerant. Therefore, a technician ranking system is operated. Initially, technicians are recruited through an examination process. Successful candidates will be provided with general refrigeration and AC training, which is then followed by another assessment; passing this yields a 1-star rank. After at least two years, experienced technicians can opt for a shift to a 2-star rank, which is also subject to an assessment. It is only these higher level technicians who will then be provided with training for handling flammable refrigerants; again, the HC-290 training is punctuated with an appropriate assessment. A comprehensive training manual, with a focus on flammable refrigerant handling and also good refrigeration practice, has been developed and this is used for the HC-290 training. Technicians are also provided with a pocketbook, which is essentially a summary of the key points for safe refrigerant handling. Currently, out of a total of 1000 in-house technicians, about three-quarters are qualified to handle HC-290. (The remainder are not eligible since they are at the 1-star rank.) The trained technicians cover a full geographical distribution across the entire country. They will carry out installation, repairs and maintenance activities.

Technicians generally utilise standard refrigeration service tools and equipment. Leak detection is carried out using soapy water and technicians are issued with handheld HC gas detectors. Standard vacuum pumps are used, while following the appropriate safety procedures. When removing refrigerant from a system, safe venting practice is used; this therefore avoids the need for recovery machines and associated risks of using them and transporting a flammable gas. Standard manifold/gauge sets are used and where necessary, HC-290 comparators are available. For servicing, re-charging, etc., the HC-290 is supplied in small cylinders or cans. The use of these small cans is convenient for technicians (in terms of carriage, etc) but also presents a reduced flammability risk, compared to using a cylinder containing several kilogrammes of refrigerant.

6. Final remarks

To date, over 100 000 HC-290 SACs have been sold and installed within the Indian market.

Based on the reports back from the retailers, the reception of end users is largely ambivalent (or unaware) of the issue of the products using HC-290. In some cases, it is reported that some consumers query the "flammable triangle" warning sign that are placed on the products. Conversely, many consumers are allured to the products "green" credentials. One practical hindrance has arisen in cases where the installation would demand excessively long additional pipework between the ODU and IDU, thereby substantially increasing the refrigerant charge and thus exceeding the guideline limits.

The company operates a quality database that includes a service history feedback, where all complaints and faults are systematically recorded. Experience so far has shown excellent reliability and safety record. From this quality database, the main problems can be identified:

- A small number of complaints (less than 30) have arisen due to insufficient cooling, which in terms of the percentage of units sold, is almost identical to HCFC-22 models.
- Electrical faults occurred in less than 90 units, comprising problems with fan motors and circuit boards.
- A small number of compressors have failed (about 80); however, all of these were at the time of commissioning and are likely to be as a result of mishandling of the packaging, i.e., storing the ODU on its side or upside down. Compared to the population of equivalent HCFC-22 models, the proportion of such faults for the HC-290 units is marginally lower.
- Dents and other external damage to the housing in around 80 cases, which were solely aesthetic and have not affected the security of the equipment
- The most dominant fault is leakage, which has occurred in less than 500 units; this corresponds to an annual leakage rate (in terms of the proportion of units exhibiting leak faults) of less than 0.3% and is considered to be extremely low (typically around 10–15% for Article 5 countries). Most significantly, there have been zero leaks from the IDU or the joint between the IDU and interconnecting pipe; majority of the leaks have occurred from the service valve, with the remainder from the condenser or compressor piping. It is useful to note that the leakage rate for HCFC-22 models is over ten times the value for HC-290 products, which is probably due to improved design and construction in the system piping and jointing, more sophisticated leak tightness test equipment and more thorough tightness test procedures and more comprehensive training of installation technicians.

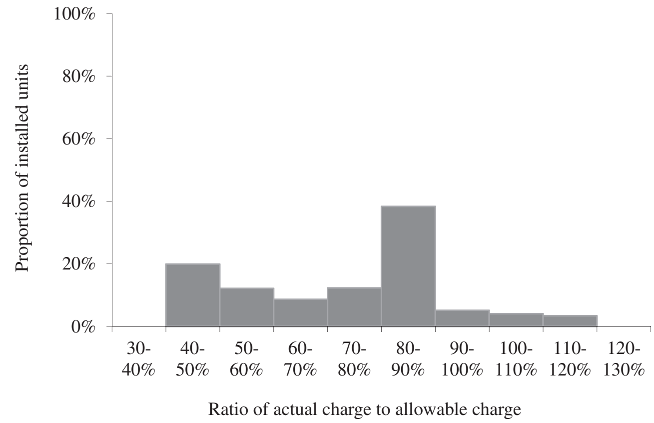

Fig. 4 – Sample of installations, showing ratio of actual charge to allowable charge in AC standards.

With a fault rate of <0.5% per year, the level of safety and general reliability of HC-290 SACs are favourable and significantly better than equivalent HCFC-22 models.

Related to the flammability safety is consideration of the placement of products in relation to their charge size and the corresponding room size (since this is a factor that can affect the level of risk). Fig. 4 shows the distribution of the proportion of SACs that have been installed within a room, for the ratio of the actual charge against the maximum allowable charge as specified in EN 60335-2-40: 2003+A2 (2009). It can be seen that the majority of units were installed in rooms where the maximum charge assigned by the standard was not exceeded by 10–20%. There are also a fairly large proportion of cases where only about half of the charge limit was reached; in these cases, the rooms normally housed two units. There were a small number of cases where the installation exceeded the maximum limit by a marginal amount. However,

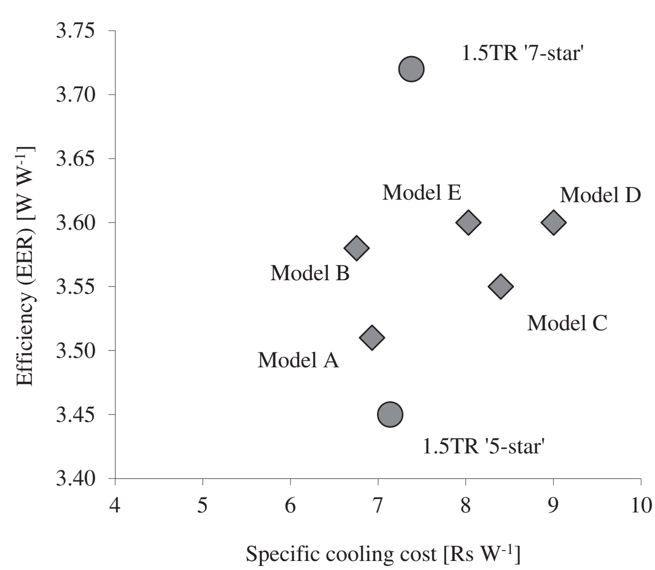

Fig. 5 – Comparison of specific cost and efficiency with competing products.

these were within the tolerance of the amount of refrigerant that would be retained within the unit in the SAC in the event of a catastrophic leak, i.e., the "releasable" refrigerant charge was still within the prescribed limits. Nevertheless, the risk assessments carried out indicated that the risk associated with such cases is still significantly less than negligible. This is supported by there being zero incidents related to the flammability of HC-290 reported to date.

Activities are ongoing to expand the range of products. Furthermore, developments are progressing in order to integrate designs and functionality to further reduce the flammability risk associated with the appliances, such as integrated safety systems.

Manufacturing of products containing flammable refrigerants imposes a new and significant responsibility on manufacturers in terms of the safe practices adopted during production, both for equipment and processes. Additions and changes to the existing processes and products, wherever necessary, must be done to ensure a safe environment. The retraining of service technicians to handle the challenges of installing and servicing such products must be concurrent with the development of the product and manufacturing processes. Finally, the benefits of shifting to HC 290 must be adequately highlighted to the end consumer. As an example, Fig. 5 compares the rated efficiency and the specific cost (Indian Rupees per Watt of cooling capacity, based on lowest price Internet search) for the competing products in Table 2. Although the HC-290 products are not the cheapest, they are within the lower half and the "7-star" model offers significant efficiency advantage for the money compared to all of the others. Thus, with respect to the CO_2-eq emissions (Fig. 1), the environmental and the energy-related cost-effectiveness of HC products are particularly favourable.

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