DEMONSTRATION PROJECT FOR HFC-32 TECHNOLOGY IN THE MANUFACTURE OF SMALL-SIZED COMMERCIAL AIR-SOURCE CHILLERS/HEAT PUMPS AT TSINGHUA TONG FANG ARTIFICIAL ENVIRONMENT CO., LTD.

FINAL REPORT

March, 2014

Executive Summary

Demonstration project for HFC-32 technology in the manufacture of small-sized commercial air-source chillers/heat pumps at Tsinghua Tong Fang Artificial Environment Co., Ltd. was approved by the 60th Executive Committee meeting at a funding level of US$1,229,336.

This demonstration project was successfully implemented, and established the suitability of HFC-32 technology as a viable replacement for HCFC-22 as a refrigerant in the manufacture of commercial air-source chillers/heat pumps at Tsinghua Tong Fang Artificial Environment Co. Ltd.

The project activities includes product redesign and development, manufacturing equipment modifications and additional equipment, safety and other measures to handle the flammability and high discharge temperatures of HFC-32, laboratory testing and performance evaluation, product trials, prototype testing, production line conversion, technical assistance and training.

The successful completion of the demonstration project contributes towards promotion of this technology for unitary and multi-connected commercial air conditioning and heat pump equipment and enables cost-effective conversions at other similar manufacturers in this sub-sector.

1. Introduction

In 2007, the 19th Meeting of Parties of the Montreal Protocol agreed on accelerated phase-out of HCFCs. To achieve the compliance goal, China is implementing HCFCs phase-out sector plans in Industrial & Commercial Refrigeration and Air-conditioning (ICR) sector from 2012. The Tong fang project was established as a demonstration earlier in 2010 for preparation and support of the sector plan implementation.

The Executive Committee approved the Tong fang demonstration project in the 60th meeting in 2010 at a funding level of US $ 1,229,336. The project's implementing agency is UNDP. The national agency implementing this project is Foreign Economic Cooperation Office (FECO), Ministry Of Environmental Protection, China.

The objective of this demonstration project is to establish the suitability of HFC-32 technology as a viable replacement for HCFC-22 as a refrigerant in the manufacture of small-sized commercial air-source water chillers/heat pumps at Tsinghua Tong Fang Artificial Environment Co. Ltd.

As a result of the conversion project, about 61.9 tons of HCFC consumption will be phased out, reducing greenhouse gas emission by 170,000 tons CO2 eq.

1.1 Background

The Industrial and Commercial Refrigeration and Air Conditioning (ICR) Sector in China has experienced remarkable growth in the past two decades, averaging at about 12% annually, due to the steep growth in the demand for consumer, commercial and industrial products, resulting from rapid overall economic development. This sector includes several sub-sectors, namely: compressors, condensing units, small-sized air-source chillers/heat pumps, commercial and industrial chillers/heat pumps, heat pump water heaters, unitary commercial air conditioners, multi-connected commercial air conditioners, commercial and industrial refrigeration and freezing equipment, mobile refrigeration and air conditioning equipment and refrigeration and air conditioning components and parts. The 2008 estimated HCFC consumption in the sector based on field surveys was about 42,000 metric tonnes.

Small-sized commercial air-source chillers/heat pumps are typically used in commercial establishments such as hotels, restaurants, shops and offices, both for cooling and heating, with low energy consumption and no water use. The self-contained design requires no separate plant or machine room. With the current emphasis on energy

conservation and environment protection, the market for these products experiences rapid growth. Based on data from field surveys, the production of such small-sized air-source chillers/heat pumps in 2008 in China was about 110,000 units, with a total HCFC-22 consumption of about 1,200 metric tonnes in about 12-15 enterprises.

Tsinghua Tong Fang Artificial Environment Co. Ltd. was established in 1989 and is located in Zhongguancun Science and Technology Zone, Beijing. The enterprise is a state-owned company, specializing in research and development, manufacturing and sale of the environmental products and systems. In the air conditioning field, the company actively carries out research and development of environmental control products, green construction, energy efficiency in buildings and renewable energy technologies. The enterprise employs 554 persons, which includes 84 managerial staff and 81 technical and research staff. The enterprise has five national product inspection centers, laying the foundation for sound research and development in this field.

Tsinghua Tong Fang Artificial Environment Co. Ltd. is the national leader in heat pump technology. The enterprise comprises a unique amalgam of industry, academia and research, and is abreast of the latest scientific progress on technology and environment.

Tsinghua Tong Fang Artificial Environment Co. Ltd. currently manufactures a range of heating and cooling products, with production capacity valued at about US$ 3 billion and manufactured on six production lines for various products as tabulated below:

Production Line	Products	Refrigeration Capacity	Installed Capacity	Actual production	Average refrigerant charge (kg)	HCFC-22 consumption (2009-tonnes)	Application
Water/ground source heat pumps/chillers	Water-source heat pumps	150 - 3000 kW	700 units	227	90	26.9	Heating/cooling in large buildings such as offices, malls, hotels
	Ground-source heat pumps	120 - 3000 kW		29	75		
	Chillers	400 - 2000 kW		54	80		
Large air-source heat pump/chillers	Screw	260 - 500 kW	700 units	34	75	2.55	
Medium air-source heat pump/chillers	Scroll	60 - 200 kW	1500 units	399	40	15.96	Heating/cooling in medium-sized buildings
Small air-source heat pump/chillers	Scroll	10 - 60 kW	5000 units	4073	15.2	61.9	Heating/cooling in small commercial spaces up to 1000 sqm
Air handling units	Central station air handling units	2000 to 20000 cum/hr	5000 units	NA	NA	NA	Large and medium sized buildings
Fan coil units	Various sizes	340 - 2380 cum/hr	5000 units	NA	NA	NA	Small buildings and individual spaces
Total						**107.31**	

Of these, one production line with a capacity of 5,000 units annually (as highlighted above) is for manufacturing small-sized commercial air-source chillers/heat pumps in the range of 10 to 60 kW. This production line was installed in 1999. The total production in 2009 was 4,073 units, with HCFC-22 consumption of 61.9 metric tonnes at an average HCFC-22 charge of 15.2 kg per unit. These units are manufactured in three models/configurations as below:

	60kW	30kW	13 kW
Unit Configuration			
HCFC-22 charge (kg)	24	12	5.1

This product range (small-sized air-source heat pump/chillers) has been selected for this project considering the relative small amount of refrigerant charge volumes, allowing flexibility for selection of alternative technologies.

1.2 Technical Choice

Some of the zero-ODP alternatives to HCFC-22 currently available for this application are listed below:

Substance	GWP	Application	Remark
Ammonia	0	Industrial refrigeration and process chillers	Flammability and toxicity issues. Material compatibility issues. Regulatory issues.
CO_2	1	Supermarket refrigeration in a secondary loop and in stationary and mobile air conditioning systems	Major redesign of system components needed. Investment costs are prohibitive
Hydrocarbons	<15	Small-capacity domestic and commercial refrigeration equipment	Flammability issues. Not widely used in large capacity systems
R-32	675	Small and medium-capacity commercial refrigeration and air conditioning applications	Single component refrigerant. Mildly flammable. Higher working pressures than HCFC-22. Higher refrigeration capacity per unit charge. Main component of R-410A
R-134a	1,300	Domestic, commercial refrigeration medium-temperature applications	Not efficient in low-temperature systems and industrial refrigeration applications. Needs synthetic lubricants
R-407C	1,520	Most air conditioning applications	Properties closely match R22. Temperature glide, synthetic lubricants needed, slightly less efficient than R22. Non-azeotropic mixture creates issues.
R-410A	1,710	Most air conditioning applications	Near azeotropic blend of R-32 and R-125. Higher pressures, better cooling capacity, low temperature glide, high GWP, synthetic lubricants needed
R-404A	3,260	Low temperature applications	High GWP, less efficient at medium temperatures, synthetic lubricants needed
R-507	3,900	Low temperature applications	Azeotropic non-flammable blend of HFC-125 and HFC-143a. Refrigerating capacity comparable to R-502. Good heat transfer characteristics at low temperatures

Tsinghua Tong Fang Artificial Environment Co. Ltd. carefully considered and applied the multiple factors and concluded that R-32 technology is most suited for application to its heat pump products, due to its expected technical performance and significant potential benefit with respect to global warming impact as compared to HCFC-22 (i.e., direct impact through adoption of low-GWP substance compared to HCFC-22 and indirect impact due to potential energy efficiency gains through system improvements). In addition, the enterprise had also carefully studied the international regulatory and market scenario, and noted that R-32 may potentially have wide acceptability in this particular market segment.

2. Project Implementation

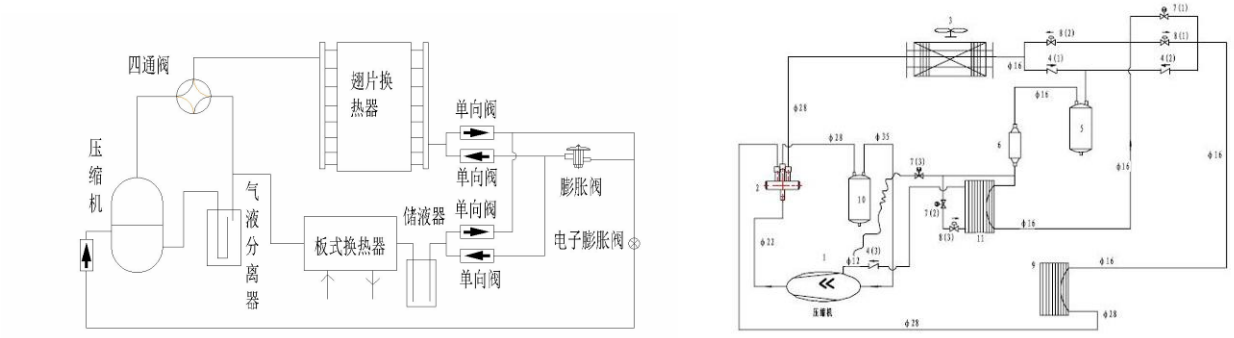
The project was approved by 60th Executive Committee meeting in 2010 at a funding of US $ 1,229,336. The project implementation started at 2011, the conversion project was completed by the end of 2012, and all the progress milestones required were reached and verified by the end of 2012. The project successfully passed national acceptance in December, 2013.

According to the project implementation plan, the following activities were carried out: Product and process redesign, Conversion of production lines, Prototype production trails and testing, and Processing and safety training, etc.

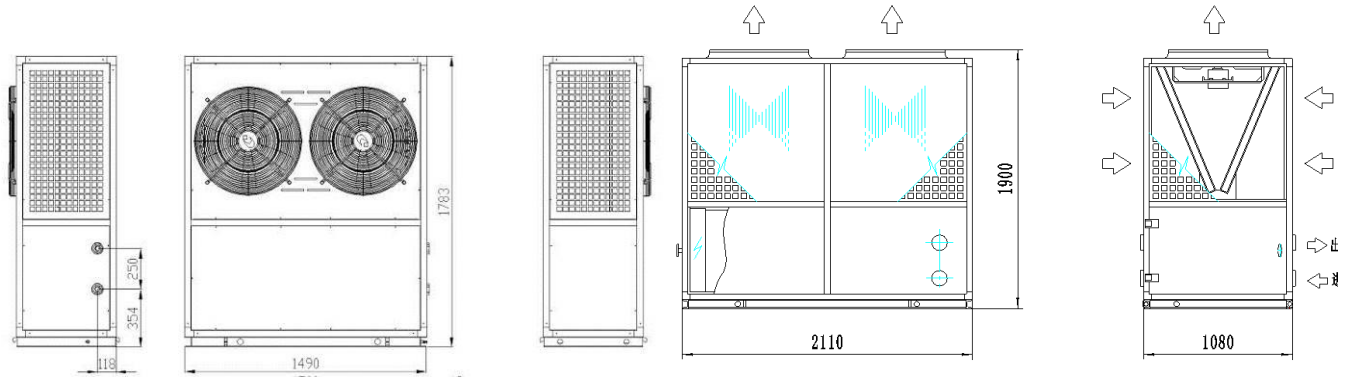
2.1 System, Components and Process Redesign

Three models (60kW, 30kW and 13 kW) of R32 systems redesign was completed in 2011, The redesign work included design and calculations, simulation and control software, remodeling of the compressors, expansion valves, finned tube heat exchanger, water-side heat exchanger, unit structure, electrical systems, prototype

manufacturing, test runs, compilation of production process, blueprint and complete bill of materials. Two kinds of design proposal was designed, one is liquid injecting cooling, and the other is air-supplying enthalpy-adding The redesign program passed evaluation of sector experts' team in October 21.



Liquid injecting cooling program and air-supplying enthalpy-adding program



Structure design

2.2 Conversion of the Production Line

The production line conversion is composed of Heat Exchanger Processing, Sheet Metal Processing, Product Assembly, and Quality inspection, testing and finishing, etc. the whole conversion was completed by the end of 2012.

2.2.1 Heat Exchanger Processing

Due to the lower charge and higher pressure with HFC-32, the finned tube diameter was reduced from 9.52 mm to 7 mm. Accordingly the finned tube punch dies and tube expander changed either. The tube straightening/bending machine (fin threading) was modified. A new brazing line for the heat exchanger suited for HFC-32 was introduced. Since HFC-32 is flammable, the grease left on the heat exchanger was removed for fire safety. For this, degreasing and dehydrating equipment was introduced.

Φ7 vertical tube expanding machine

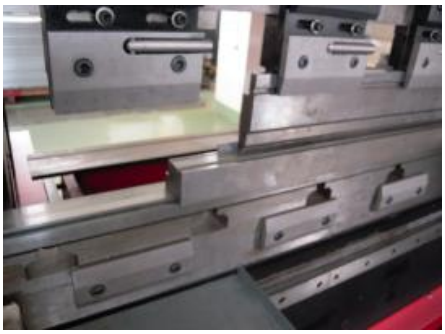
Φ7 tube bending machine

2.2.2 Sheet Metal Processing

The sheet metal processing dies changed, including dies for end-plate hole punching and dies for end-plate rim bending and dies for rim bending.

Die for end-plate hole-punching

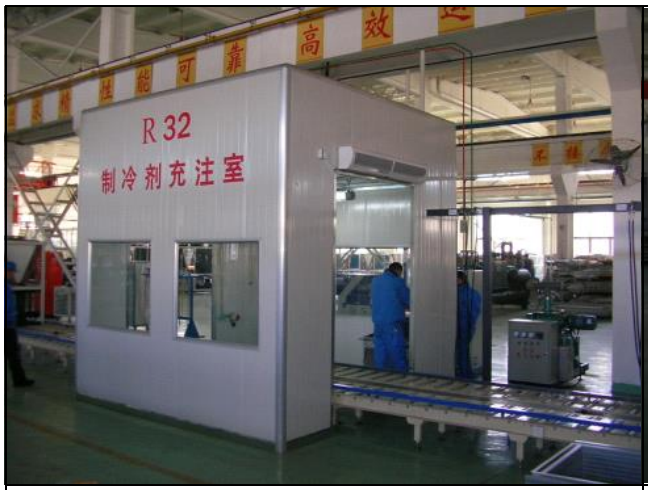
Die for end-plate rim-bending



Die for rim-bending

2.2.3 Product Assembly

Due to the flammability of HFC-32, the charging area was isolated, with adequate ventilation, fire safety and alarm systems and explosion-proof fittings. The existing Halogen leak detectors cannot be used with HFC-32, because it contains no Halogen. Therefore Helium leak detectors were introduced.



R32 charging room

R32 units assembly line

	
Helium leak detector	**Helium refrigerant recovery machine**

	
Roots vacuum pump	**R32 charging machines**

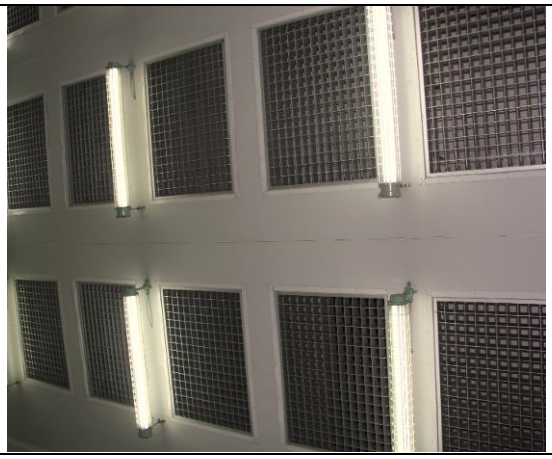
2.2.4 Quality inspection, testing and finishing

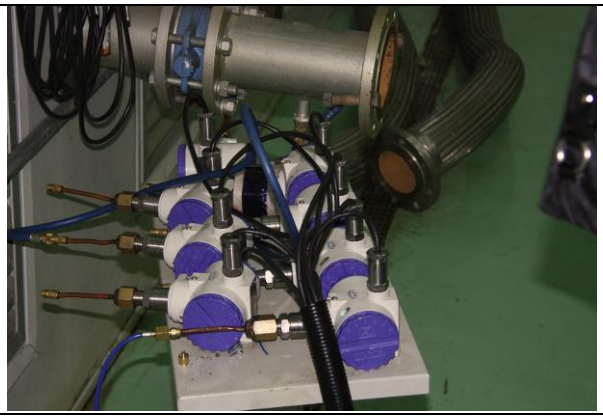
The safety inspection of electrical systems was enhanced by introducing appropriately sensitive devices with protective features. The inspection area was isolated with adequate ventilation, fire-safety and alarm systems and explosion-proof fittings. The existing test rig for HCFC-22 based products can be used with R32, and it modified such as test room ventilation and fire-safety, high-pressure sensor and sensor for monitoring HFC-32 concentration levels.

Assembly line inspection modification:

	
R32 products operating testing room	**Testing equipment for electronic safety performance**

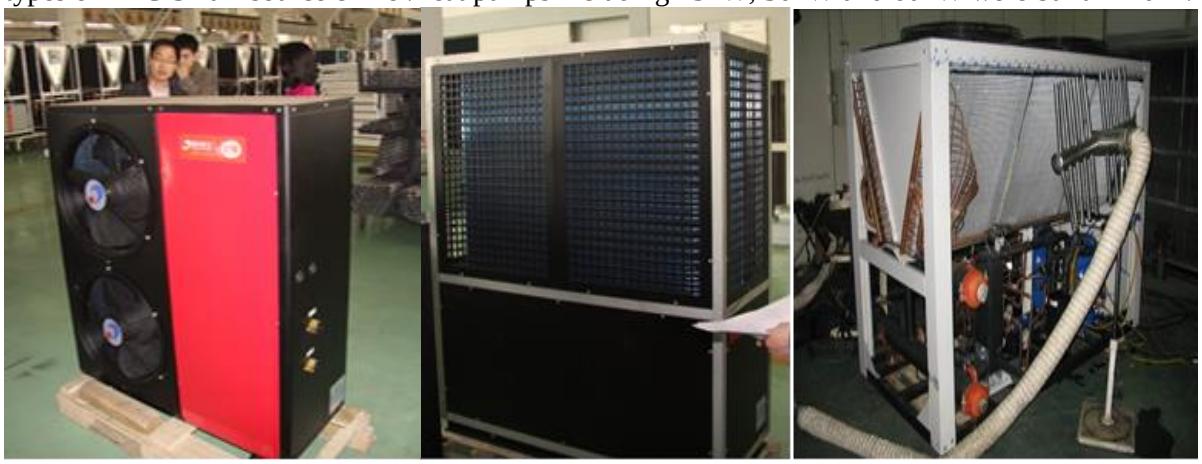
Testing room modification:

	
Electric explosion-proof cabinet	**Explosion-proof lamps**
	
Explosion-proof exhaust fans	**Explosion-proof motor**

	
Explosion-proof pressure sensors	**Explosion-proof RH testers**

2.3 Prototype production trials and testing

A pilot-level quantity of the selected models was subjected to prototype production, trials and testing to establish the process and fine-tune as needed and establish product performance through testing.
Three types of HFC-32 air-source chiller/heat pumps including 13kW, 30kW and 60kW were built in 2011.



13kW **30kW** **60kW**

The prototypes were tested by Tong Fang in 2011 and tested by third party test institution (Hefei General Machinery & Electrical Products Inspection Institute) in Feb 2012. The results of the test were qualified.

2.4 Process and safety training

Process and safety training were provided to the manufacturing, installation and maintenance personnel. It was verified that the internal technical acceptance were completed and technical commissioning and relevant personnel training were finished.

Tong fang Co. has organized 37 times of technical commission and personnel trainings under this project. Totally 23,202.5 class hours training were taken and 1454 persons/times were trained.

2.5 Management

The project was under the overall management and coordination of the Foreign Economic Cooperation Office, Ministry of Environment Protection of China. UNDP was the implementing agency for the project, which provided international coordination and technical assistance.

The project employs the Performance-based Payment (PBP) mechanism in its implementation. Under the PBP mechanism, the enterprise tasked to carry out the conversion would play the role as a key executer, which is responsible for all the activities related to the conversion. The procurement was organized fully in line with the marketing principle ensuring cost-effective and timely installation of equipment for R-32 based manufacturing operations.

FECO and UNDP were not involved in the procurement activities of the enterprise by any means other than make payment to the enterprise in tranches for the costs of procurement and conversion, at agreed payment dates given in the payment schedule, and when milestones prerequisite for the tranche have all been achieved on time.

Before each payment, FECO invited independent experts to verify whether the performance for each milestone that the payment depends on have been satisfying. The verification reports were submitted and accepted by UNDP as the main supporting documents for requesting the installment of payment.

During the projects implementation, FECO and UNDP organized 4 verification missions combined with monitoring and evaluation at Tong Fang factory - once in 2011 and thrice in 2012. The experts group included technology experts and finance experts, FECO staff and UNDP staff as well. The experts team traced the project implementation situations, evaluated the project technical issues and progress, and verified whether the performance for each milestone that the payment depends on have been satisfying. Each verification activity was carried out in a process of planning, preparation, data confirmation, technical material checking, on-the-spot investigation, result confirmation and conclusion.

3. Outcomes

The project has been completed and has successfully passed national acceptance in December 2013. The production line is commercial running, and the IOC will be disbursed to enterprise in the next 2 years according to new products sales quantity. The suitability of HFC-32 technology as a viable replacement for HCFC-22 as a refrigerant in the manufacture of small-sized commercial air-source water chillers/heat pumps at Tsinghua Tong Fang Artificial Environment Co. Ltd. was established

The following are the salient outcomes of the project.

- The enterprise completed the redesign of system, components and production process in 2011.
- The performance test rig was modified to meet the requirements of testing products with flammable refrigerants in 2011.
- The prototypes were manufactured, tested and adjusted in 2011.
- Training, technology communication, and advertisement were finished in 2012.
- Equipment for modification of heat exchanger and sheet metal processing was procured in 2012.
- Product assembly line and testing facilities converted and verified in 2012.
- Technical commissioning was completed successfully and relevant personnel were trained in 2012.
- The project successfully passed national acceptance in December 2013

4. Technical performance

- R-32 has ODP of 0.
- R-32 has GWP of 675, about a third of that of R-410A.
- R-32 is a mature refrigerant with a large knowledge base on its properties.
- R-32 is produced domestically and has assured commercial availability as reasonable prices.
- R-32 is a single substance with good heat transfer capacity, volumetric refrigerating capacity and theoretical energy efficiency.
- For the same refrigeration capacity, the charge quantity for R-32 is 60-80% of that of R-22 depending on the application.
- The actual efficiency of R32 system in this project is 3%-5% higher than former R22 system, and the performance efficiency will grow along with optimizing in deeper application and promotion of compressors and other accessories.
- The cost of system is over 20% than R22 system, but the cost will reduce along with large-scale applications of R32.
- The R32 compressors of this project were supplied by several compressor companies in China. The compressors were redesigned and modified based on R410A, and the performance has potential to be

promoted.

5. Project management and monitoring

5.1 Project progress

The project was implementing smoothly according to the program schedule, and was completed by the end of 2012. It successfully passed national acceptance in December 2013. The capacity of the production line has been converted to use substitute refrigerants and is capable of manufacture the converted products.

Each of milestones was achieved and verified, the details are as follows:

Milestones		Status
1st	Signing of the contract	FECO and the enterprise signed contract in January 2011
2nd	Completion of designs of products and pass the evaluation of experts	Finished in October 2012
3rd	Completion of the test facilities	Finished and verified in April 2012
4th	Prototypes are built and tested	
5th	Completion of conversion heat exchanger and metal plate process	Finished and verified in December 2012
6th	Assembly line and delivery inspection process are completed	
7th	Technical commissioning completed successfully and relevant personnel trained	Finished and verified in December 2012

5.2 Conversion cost

Total Project Costs

The total contract amount with the enterprise is US$ 1,122,870, including ICC US$ 733,530, and IOC US$ 389,340.

Incremental Capital Costs

The actual incremental capital costs for conversion was US$ 830,344.71, among which US$ 733,530 was funded by the MLF, and the US$ 96,814.71 was co-financed by the enterprise.

The details of ICC are as follows:

No	Cost Head		Actual cost (US$)
1	**System, component and process redesign**		
	Redesign	Product redesign	21,313.82
	Software	Outsourced simulation and control software	13,071.90
		sub-total	**34,385.72**
2	**Prototype testing**		
	Prototype materials	Cost of materials/process for 3 prototypes	34,596.34
	Testing	Third party laboratory testing	17,017.72
		sub-total	**51,614.06**
3	**Production line conversion-**		
	Heat exchanger processing	Dies for 7 mm diameter tubes	80,065.36
		Modification of tube bending machine	5,538.24
		New vertical tube expanding machine	208,428.10
		Degreasing furnace	-

	Sheet Metal Processing	Die for end-plate hole-punching	1,895.42
		Die for end-plate rim-bending	561.27
		Die for rim-bending	2,941.18
	Product Assembly	Suction gun Helium leak detector	74,017.65
		Charging room isolation/fire protection	84,542.11
		Two R-32 concentration sensors	56,045.75
		R-32 automatic charging machine	70,261.44
		Refrigerant recovery machine for R-32	8,006.54
	Quality inspection, finishing and testing	Testing equipment for safety performance	10,294.12
		Two R-32 concentration sensors	
		sub-total	**602,597.17**
4	**Prototype production trials and testing**		
	Testing	Modification of performance test rig	45,751.63
		Isolation of test rig room/fire protection	57,189.54
	Trial production	Cost of trial production for 3 units	20,958.54
		sub-total	**123,899.72**
5	**Process and safety training**		
	Manufacturing	Training for 233 manufacturing personnel for 86 training hours	17,848.04
	Installation and maintenance	Training for 86 installation and maintenance personnel for 30 training hours	
		sub-total	**17,848.04**
6	**Contingency**	for enterprise	**0**
ICC for enterprise		**TOTAL**	**830,344.71**
		Total fund by MLF	**733,530**
		Co-financing by enterprise	**96,814.71**

Incremental Operating Costs

The agreed total incremental operating costs calculated for one-year duration amount to US$ 389,340.
The production line is commercial running, and the IOC will be disbursed to enterprise in the next 2 years according to new products sales quantity. The data of IOC is preliminary value.

The cost for the baseline HCFC-22 based two-stage systems are summarized as below:

1. HCFC-22 price is US$ 2.20/kg
2. HFC-32 price is US$ 2.94/kg
3. HFC-32 charge quantity for the three models is 16 kg (for 60 kW), 8.4 kg (for 30 kW) and 3.5 kg (for 13 kW)

Incremental Operating Cost Source	**Incremental Costs/Savings (US$/unit)**		
	60 kW unit	**30 kW unit**	**13 kW unit**
Compressors	236.00	118.00	96.00
Finned tube heat exchangers	(19.00)	(9.50)	(4.50)
Tube-in-tube/plate heat exchangers	(13.50)	(6.80)	(3.10)
Refrigerant	(5.90)	(2.90)	(1.00)
Electrical components (ex-proofing)	88.40	78.20	75.60
Net costs (savings)	**286.00**	**177.00**	**163.00**
Agreed	**73.93**	**45.75**	**42.13**

Incremental Operating Costs	Amount (US$)
60 kw unit: US$ 151.19/unit X 1,858 units/year	280,917
30 kw unit: US$ 75.56/unit X 858 units/year	64,827
13 kw unit: US$ 32.13/unit X 1,357 units/year	43,596
Total	**389,340**

6. Impact

The project was completed and 61.9 metric tonnes of HCFC-22 usage was phased out. Over a 15-year life-span of the refrigeration systems manufactured by the enterprise and covered by this project, direct and indirect emission reductions amounting to about 170,000 CO2-eq tonnes will be achieved, thus contributing to protection of both the ozone layer and the climate system.

The successful implementation of this demonstration project provides an environmentally safe and cost-effective alternative for enabling replication of this technology in similar applications in this sub-sector in China.