OPERATING EXPERIENCES WITH AN AUSTRALIAN AIR CONDITIONING SYSTEM EMPLOYING AMMONIA REFRIGERANT

STEFAN S. JENSEN B.Sc.Eng. FIEAust, CPEng, NER, RPEQ, F.AIRAH
Managing Director
Scantec Refrigeration Technologies Pty. Ltd.
225 Queensport Road North, Murarrie QLD 4172
ssjensen@scantec.com.au

ABOUT THE AUTHOR

Stefan Jensen graduated in 1978 in Denmark with a Bachelor of Science degree in Mechanical Engineering. His professional career commenced in 1978 with Danfoss, Denmark followed by two years at SABROE Refrigeration A/S, Denmark as a Project Engineer. In 1983, he joined Wildridge & Sinclair, Brisbane, Australia as Technical Manager, Industrial Refrigeration. He later became co-inventor of the Rotadisk flake ice maker. In 1988, he joined the food machinery manufacturer Heat and Control Pty. Ltd. and was in 1992 appointed General Manager of the Heat and Control refrigeration division. In April 1996, Stefan Jensen co-founded Scantec Refrigeration Technologies Pty. Ltd. He currently holds the position of managing director. Stefan is a Fellow of AIRAH and an Engineers Australia Fellow. He is a Registered Professional Engineer in Queensland and registered on the National Engineering Register. He has authored over 40 technical papers for AIRAH, IIR and IIAR conferences. Stefan Jensen is a member of the Board of Directors of the International Institute of Ammonia Refrigeration (IIAR) in Washington, USA and a member of the Board of Directors of the Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH). Stefan served as a member of the scientific committee for the 8th International Ammonia and CO_2 Refrigeration Technologies conference held in Ohrid, North Macedonia in April, 2019.

ABSTRACT

The paper describes eight years of operating experiences with the ammonia based air conditioning system servicing the Logan City Council administration building in Queensland. The air conditioning system comprises two water-cooled water chillers each with a cooling capacity of approximately 600 kW and employing R717 (ammonia) refrigerant (class B2L). The two new chillers replaced two roof mounted air-cooled York R22 water chillers. In addition, the new ammonia system replaced two Carrier R22 compressors with air-cooled roof-mounted condensers. These compressors were connected to a 240 kW dry expansion air handling unit located in the basement of the administration building.

Between the commissioning of the air conditioning system in 2011 to this date, two service providers have carried out preventative maintenance, service and repairs to the plant. Between 2014 and present day, the original installation contractor has carried out preventative maintenance and repairs. Detailed service, maintenance and breakdown records exist for the period from 2014 to 2019. These, along with energy performance records, form the basis of the paper. Comparisons between actual maintenance costs and the projected maintenance costs prior to commissioning are made.

Finally, a comparison is included between the predicted return on investment and the actual return achieved. This is based on the actual energy consumption cost reductions between the systems that were replaced in 2011 and the last eight years of actual operating costs for the new ammonia plant.

INTRODUCTION

The global RACHP (Refrigeration Air Conditioning and Heat Pump) industries are facing unprecedented change over the next two decades. In some jurisdictions these changes started taking place more than two decades ago driven by local environmental legislation. The global technology transition will accelerate over the coming five to ten years, but the industry must prepare now for continuing technology evolution beyond 2040.

This technology transition is driven by two major events that took place in October 2016. These are the Kigali Amendment to the Montreal Protocol and the Paris Climate Treaty, which has now been ratified by a large number of developed economies (more than sixty) across the World. At least one nation (Norway) has responded by banning fossil fuels for space heating effective 2020.

The global hydrofluorocarbon (HFC) refrigerants phase-down that commenced globally in 2019 in accordance with the Kigali Amendment, is much more than a refrigerant transition. The refrigerant transition must at the same time consider the Paris Climate Treaty targeting a maximum temperature anomaly of 2K by the year 2100 and carbon neutrality by 2050.

In practice, this not only means minimisation of HFC use. It also means maximisation of energy efficiency at the same time. Direct emissions from leak-tight HFC refrigerant based refrigeration plants represent approximately 10% of total emissions over the life of the plant [1]. The balance of 90% is caused by indirect emissions when these refrigeration systems are driven by electricity generated by means of combustion of fossil fuels.

There are low global warming potential (GWP) synthetic refrigerant alternatives to HFC refrigerants. These are often referred to as 4th generation refrigerants and they generally belong to the hydrofluoroolefin (HFO) category or derivatives thereof.

The environmental impacts of HFO refrigerants are underexplored. In addition, HFO refrigerants offer no improvements in cycle efficiency compared with natural refrigerant alternatives [2]. The longevity of HFO refrigerants as long term, future proof working fluids is therefore questionable [3].

With very few exceptions, low GWP synthetic working fluids are flammable. This is a feature shared with natural refrigerants such as ammonia and hydrocarbons.

The proliferation of flammable refrigerants will increase the focus on refrigerant inventories of individual systems. This development is already evident in many jurisdictions and industry sectors. This is particularly the case in jurisdictions where refrigerant inventories beyond certain limits trigger costly compliance measures for refrigeration plant owners/users.

The focus on minimisation of system refrigerant inventories causes a phenomenon often referred to as multiplexing. Multiplexing is when a relatively large number of small/smaller systems combined deliver sufficient cooling capacity to refrigerate or cool a large facility that could otherwise have been cooled or air conditioned by means of a central plant of identical capacity to the sum of the individual system capacities.

Examples of such multiplexed concepts are 1) Several hundred split air conditioning systems servicing multi-storey apartment buildings, 2) Large numbers of air-cooled roof top units servicing temperature controlled industrial facilities or 3) several CO_2-based transcritical systems servicing a retail or distribution facility.

If multiplexed systems cannot deliver equal to or better energy performances overall than equivalent central plant, they violate the intent of the Paris Climate Treaty unless these systems are powered by renewable energy sources eliminating indirect emissions.

In this context, centralized reticulated chilled water air conditioning plant employing minimal inventories of NH_3 refrigerant present themselves as potentially superior solutions both in terms of energy efficiency, but also in terms of safety, future proofing, industry knowledge and environmental acceptability. The operating NH_3 inventories in mid capacity range (500-1000 kW cooling capacity) water chillers range from 0.03 to 0.05 kg/kW. For larger capacity chillers, the specific NH_3 inventories are often even less.

Ammonia is self-alarming. The odour of ammonia is detectable by the human nose at concentrations from 3 to 5 ppm by volume in air. The ammonia concentration needs to be around 100 times higher than that concentration to present a risk to humans (IDLH or Immediate Danger to Life and Health value for NH_3 is 300 ppm). Ammonia belongs to flammability category 2L (same as R32 and HFO1234yf). Ammonia is in widespread use for applications other than refrigeration. Its refrigeration applications are covered by mature and well-developed technical/safety standards and it is often referred to as ”the other hydrogen“ being the only fuel other than pure hydrogen that combusts without emitting CO_2.

1. THE AMMONIA (NH_3) BASED AIR CONDITIONING SYSTEM

The reticulated chilled water air conditioning system comprises two identical water cooled, low refrigerant inventory water chilling units employing refrigerant ammonia (NH_3), refer to figure 1.

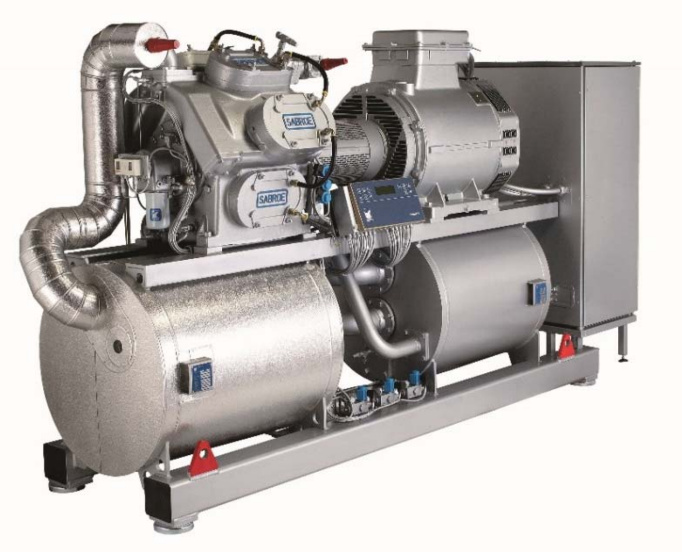


Figure 1. *SABROE HeatPAC Packaged Water Chiller employing NH_3 refrigerant*

The compressors are of the industrial, open reciprocating type. The cooling capacities of the chillers are controlled by a combination of compressor rotational speed control and cylinder unloading. A sophisticated proprietary control system determines the optimum combination of rotational speed and cylinder unloading ensuring maximum energy efficiency while minimising the probability of resonance frequencies. The combined refrigeration capacity of the two units is approximately 1,200 kW. Each chiller is fitted with a shell and tube discharge gas desuperheater. These heat exchangers recover heat from the discharge gas leaving the compressors prior to the gas entering the condensers. The heat recovery system is shown in figure 2.

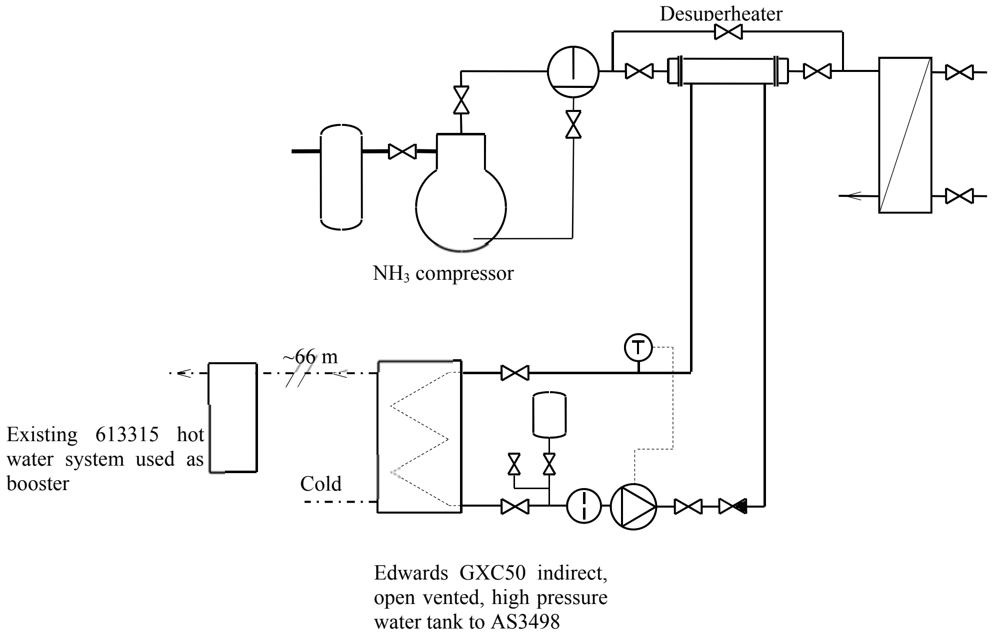


Figure 2. *Heat Recovery System*

Connection of the basement air handling unit to the NH_3 based air conditioning system required replacement of the existing dry expansion type R22 cooling coils with new coils suitable for chilled water reticulation.

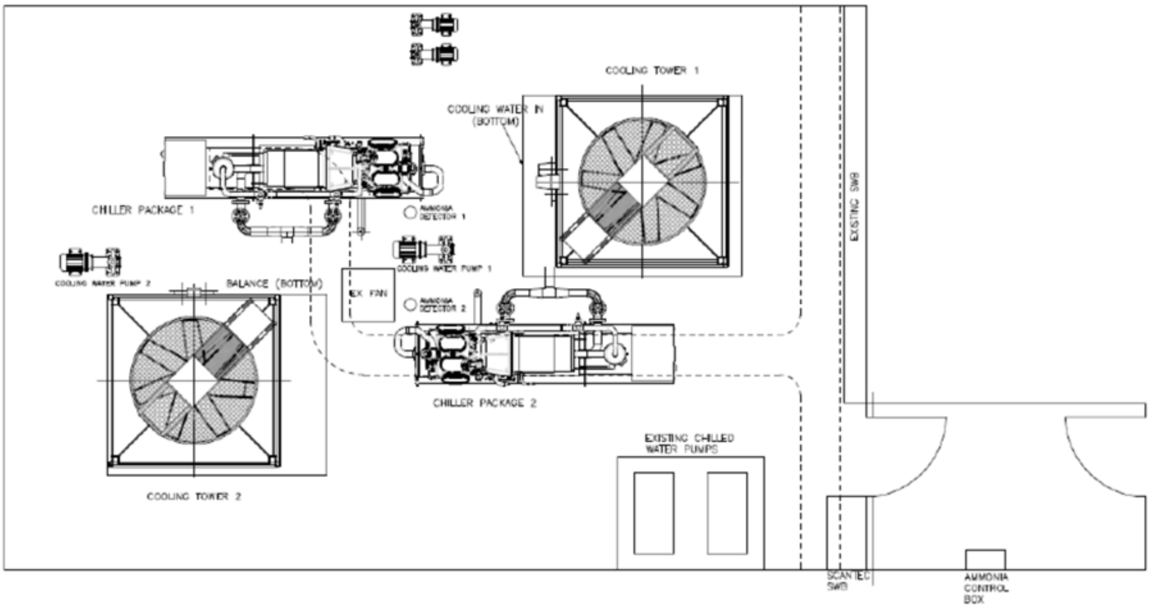


Figure 3. *Plant Room Layout Showing NH_3 Chillers and Cooling Towers*

The cooling towers supplying cooling water to the two packaged water chillers were installed within the plant room enclosure. These towers draw air through the same air intake louvers that were used for the previous air-cooled R22 chillers, refer to figure 3.

Ammonia is toxic and flammable in concentrations from 15 to 28% by volume (150,000-280,000 ppm) in atmospheric air. To analyse the potential fire risks associated with a catastrophic refrigerant release within the roof top plant room (room volume ~450 m³) and the actions necessary to mitigate that risk, the plant owner commissioned an independent consultant to model the NH_3 concentration as a function of time in the event of a major release, refer to figure 4.

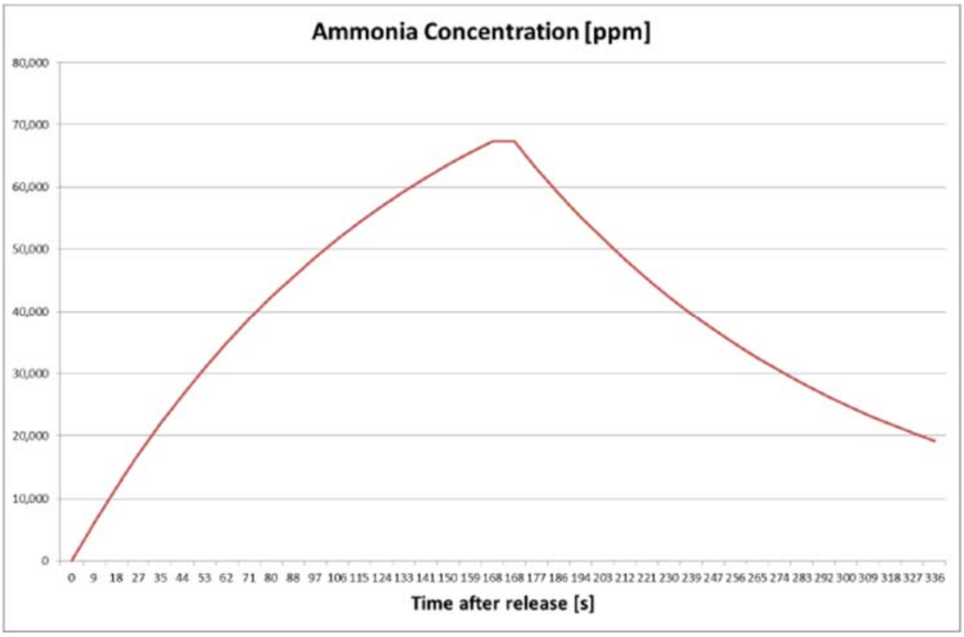


Figure 4. *Ammonia concentration as a function of time in the event of a catastrophic release of an entire refrigerant charge in liquid form.*

The worst-case scenario contemplated was the instantaneous release in liquefied form of the entire refrigerant charge of one chiller. This was taken to be 33 kg of NH_3 for the purpose of the analysis; the actual inventory per chiller charged during commissioning was approximately 20 kg. Figure 4 was based on the assumption that only the emergency ventilation (3 m³/s) and not the cooling tower fans were operating.

Although the predicted peak NH_3 concentration of 67,400 ppm shown in Fig. 4 is well below the lower explosive level (LEL) of 150,000 ppm, it is above the limit of 30,000 ppm (or 20% of LEL). The "Victorian Code of Practice for Ammonia Refrigeration 2011" prescribes this as the concentration that shall initiate operation of emergency exhaust fans.

The recommendation following this modelling was to include the two cooling tower fans in the emergency ventilation logic. Each fan has a unit capacity of 19.2 m³/s. Applying the same modelling principles as those used for the preparation of figure 4, this additional ventilation rate reduced the peak ammonia concentration to <7,000 ppm hence eliminating the need for specially protected electrical equipment within the plant room. In this emergency, the cooling towers would also act as scrubbers. Ammonia is readily absorbed in water so the cooling towers would therefore further reduce the ammonia concentration in the air being discharged to the atmosphere.

1.1 Power and energy consumption

The four main incentives for replacing the R22 air conditioning systems were:

- Elimination of the reliance upon R22, a hydrochlorofluorocarbon (HCFC) refrigerant, which was phased out in Australia in 2015
- Reduction in connected power
- Reduction in annual electrical energy consumption
- Reduction in routine and call-out maintenance requirements

The reduction in power consumption and installed electric motor power are detailed below, table 1.

Equipment that was removed	Installed Electric Motor Capacity	Peak Power Consumption	Apparent peak power consumption
	[kW]	[kW]	[kVA$_r$]
YORK YCAJ 66ST9:			
Compressors	364.0	252.0	315.2
Condenser fans	32.8	30.4	40.8
Carrier 5H40--149	74.0	65.6	86.4
Air cooled condenser fans	4.4	4.4	6.0
Total removed	475.2	352.4	448.4
Equipment that was added			
SABROE HeatPAC 108LR-A packaged water chillers	220.0	207.4	261.2
B.A.C. RCT 2176 cooling towers	15.0	13.8	17.6
Cooling water pumps	22.0	21.0	26.6
Chilled water pumps	11.0	4.7	6.2
Total added	268.0	246.9	311.6
Total reduction	**207.2**	**105.5**	**136.8**

Table 1. Reduction in connected power and power consumption associated with the replacement of the existing HCFC 22 air conditioning systems.

The full load coefficient of performance (COP) for the replaced R22 air conditioning systems was (448*2+235)/(315.2+40.8+86.4+6.0)=2.52. The COP for the replacement ammonia system is (596.3*2)/(261.2+17.6+26.6+6.2)=3.83.

Minimisation of annual system energy consumption requires selection of chiller units with good part load efficiencies and intelligent sequencing capability. This is demonstrated by comparing the difference in IPLV (Integrated Part Load Value) between chiller units with and without compressor speed control, refer to tables 2 and 3.

Q_E [kW]	P [kW]	$T_{i,E}$ [°C]	$T_{o,E}$ [°C]	$T_{i,C}$ [°C]	$T_{o,C}$ [°C]	Time [%]	η_{MOT}	COP
579.4	96.5	12.2	6.7	29.4	33.9	0.0	0.932	5.59
434.5	58.0	10.8	6.7	23.9	27.1	0.4	0.923	6.92
289.7	29.8	9.4	6.7	18.3	20.4	0.4	0.889	8.63
144.8	15.6	8.1	6.7	18.3	19.4	0.1	0.863	8.04
COP(IPLV)								7.81

Table 2. IPLV values for SABROE HeatPAC LR-A without compressor speed control

Q_E [kW]	P [kW]	$T_{i,E}$ [°C]	$T_{o,E}$ [°C]	$T_{i,C}$ [°C]	$T_{o,C}$ [°C]	Time [%]	η_{MOT}	COP
608.9	99.5	12.2	6.7	29.4	33.9	0.0	0.930	5.69
456.6	56.2	10.8	6.7	23.9	27.1	0.4	0.930	7.55

Q_E [kW]	P [kW]	$T_{i,E}$ [°C]	$T_{o,E}$ [°C]	$T_{i,C}$ [°C]	$T_{o,C}$ [°C]	Time [%]	η_{MOT}	COP
304.3	25.1	9.4	6.7	18.3	20.4	0.4	0.930	11.27
152.3	14.1	8.1	6.7	18.3	19.4	0.1	0.930	10.07
COP(IPLV)								9.51

Table 3. IPLV values for SABROE HeatPAC LR-A with compressor speed control

Legend:

Q_E	Refrigeration capacity	[kW]
P	Shaft power	[kW]
$T_{i,E}$	Water temperature evaporator inlet	[°C]
$T_{o,E}$	Water temperature evaporator outlet	[°C]
$T_{i,C}$	Water temperature condenser inlet	[°C]
$T_{o,C}$	Water temperature condenser outlet	[°C]
η_{MOT}	Electric motor efficiency	[-]

The IPLV values are calculated in accordance with ARI Standard 550/590. The IPLV values provide an illustration of the efficiency gains possible by means of variable compressor rotational speeds for capacity control.

The combined annual electrical energy consumption of the previous air cooled R22 systems were estimated at approximately $4175/3 \approx 1400$ MWh [4]. Based on a full load COP improvement of the natural refrigerant based air conditioning system of $(1-2.52/3.83)*100=34\%$, the annual reduction in electrical energy consumption was estimated.

For the purposes of the Council's decision making process, this calculation of annual reduction in electrical energy consumption was simply carried out as $1400*0.34 \approx 500$ MWh. Any additional efficiency gains associated with the IPLV improvements illustrated in tables 2 and 3 were considered in the decision making process as a bonus.

The total installed cost of the new NH_3 based air conditioning system as described was around $1,000,000 as at the end of the 2010 calendar year. The cost of the NH_3 based chiller packages represented approximately one third of this total cost. The estimated reduction in CO_2e emissions annually was 680 tonnes. This reduction represents a combination of reduction in electrical energy consumption and elimination of fugitive gases from the R22 systems. Based on a carbon price of $23/ton of CO_2e that was being contemplated by the Federal Government at the time and a unit electricity cost of $200/MWh, the simple payback period for the investment was estimated at ~8.5 years.

Logan City Council did engage an independent refrigeration consultant for verification of the estimated energy savings associated with the replacement of the R22 air conditioning systems. This verification was in broad agreement with the simplified calculation described above.

1.2 Maintenance

To assist in the Council's decision making process, an estimate of the maintenance costs of the natural refrigerant based air conditioning system was prepared. This cost estimate covered the first 10 years following initial commissioning.

Annual maintenance plan, year 5:	Relative costs [%]
Monthly service visits	16
Annual water treatment averaged	17
Annual (or 5,000 hour) compressor service	26
Compressor service (40,000 hours) based on each compressor operating ≤5,000 hours annually	0
Operational faults, break-downs or other issues requiring the attention of a skilled technician (assumed 3 visits per month)	36
Consumables averaged	4
Oil PAO 68 averaged	1
Total	100

Table 4. Relative magnitude of the elements forming part of the comprehensive maintenance cost estimate

The elements included in the estimate are detailed in table 4 using the 5th year after handing over as an example. The allowance for operational faults was deliberately conservative. It reflected the relative inexperience of the Council maintenance staff regarding natural refrigerants (particularly NH_3), the relative novelty of the general application in the Australian market and the relative novelty of the electronic control and monitoring system.

Period	**NPV**
Annual maintenance costs year 2nd year after handing over	$40,555
Annual maintenance costs year 3rd year after handing over	$36,166
Annual maintenance costs year 4th year after handing over	$36,518
Annual maintenance costs year 5th year after handing over	$37,230
Annual maintenance costs year 6th year after handing over	$40,644
Annual maintenance costs year 7th year after handing over	$42,232
Annual maintenance costs year 8th year after handing over	$63,141
Annual maintenance costs year 9th year after handing over	$45,372
Annual maintenance costs year 10th year after handing over	$51,026

Table 5. Net present values (NPV) for annual maintenance costs

The NPV of the annual maintenance costs projected in 2010 are summarized in table 5. These assume a consumer price index (CPI) of 3% p.a. with the calendar year 2010 as the base year.

2. OPERATING EXPERIENCES

From March 2014 to present date, the contractor that installed the plant in 2010/11 has carried out the preventative service and maintenance to the ammonia system. Extensive service records exist for this period. Prior to March 2014, service records indicate that a cooling tower clean was carried out in September 2013, a change to auto dialler numbers was implemented in January 2014 and a chiller power fault was attended to during March 2014. This work evidences a certain transition period between the previous service provider and the present contractor.

Figure 5 shows the interior of the engine room approximately eight years after commissioning. The two water chilling units are in the foreground; one of the two cooling towers is visible in the background.

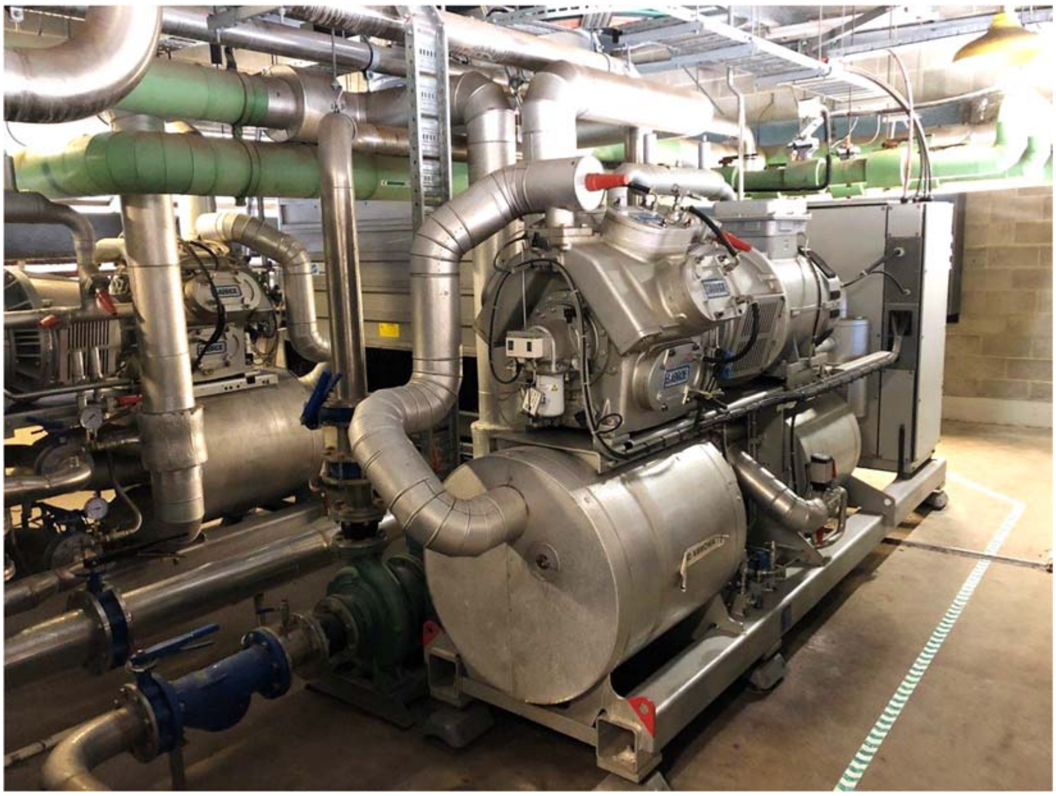


Figure 5. *Plant room interior showing two chillers and a cooling tower in the background.*

Table 6 compares the estimated relative costs for the various repair and maintenance tasks with the actual relative costs for the years 2014 to 2019 where the last year is only partly accounted for. It is evident that the main discrepancies are in the water treatment costs and compressor services. The 12% for compressor service do not represent a compressor repair, but repairs to an electric motor driving one of the chiller compressors. It is believed the motor damage was caused by overheating – the plant was experiencing motor thermistor tripping prior.

Annual maintenance – years 2014-2019:	Estimated Relative costs [%]	Actual Relative costs [%]
Monthly service visits	16	21
Annual water treatment averaged	17	5
Annual (or 5,000 hour) compressor service	26	21
Compressor service (40,000 hours) based on each compressor operating ≤5,000 hours annually	0	12
Operational faults, break-downs or other issues requiring the attention of a skilled technician	36	41
Consumables averaged	4	0
Oil PAO 68 averaged	1	0
Total	100	100

Table 6. Comparison between estimated and actual relative costs of maintenance tasks

For additional clarity, table 7 below divides the repair and maintenance tasks into chiller faults and system faults. Significant elements of the mechanical and electrical systems were not interfered with during the retrofit of the new water chilling packages.

Annual maintenance – years 2014-2019:	Actual Relative costs [%]
Monthly service visits	21
Annual water treatment averaged	5
Chiller faults, repairs and maintenance	41
Mechanical system faults and repairs	24
Electrical system faults and repairs	9
Total	100

Table 7. Comparison between chiller faults and system faults

Of significant importance to the Council is whether the reduction in routine maintenance and call-out costs actually materialized in absolute terms. Achieving this reduction was one of the major decision making elements. Table 8 compares the projected annual maintenance costs with actual costs where the NPV values shown originate from Table 5.

Period	**NPV**	**Actual**
Annual maintenance costs year 2nd year after handing over	$40,555	
Annual maintenance costs year 3rd year after handing over	$36,166	$7,184
Annual maintenance costs year 4th year after handing over	$36,518	$19,759
Annual maintenance costs year 5th year after handing over	$37,230	$17,417
Annual maintenance costs year 6th year after handing over	$40,644	$30,864
Annual maintenance costs year 7th year after handing over	$42,232	$14,188
Annual maintenance costs year 8th year after handing over	$63,141	$42,585
Annual maintenance costs year 9th year after handing over	$45,372	
Annual maintenance costs year 10th year after handing over	$51,026	

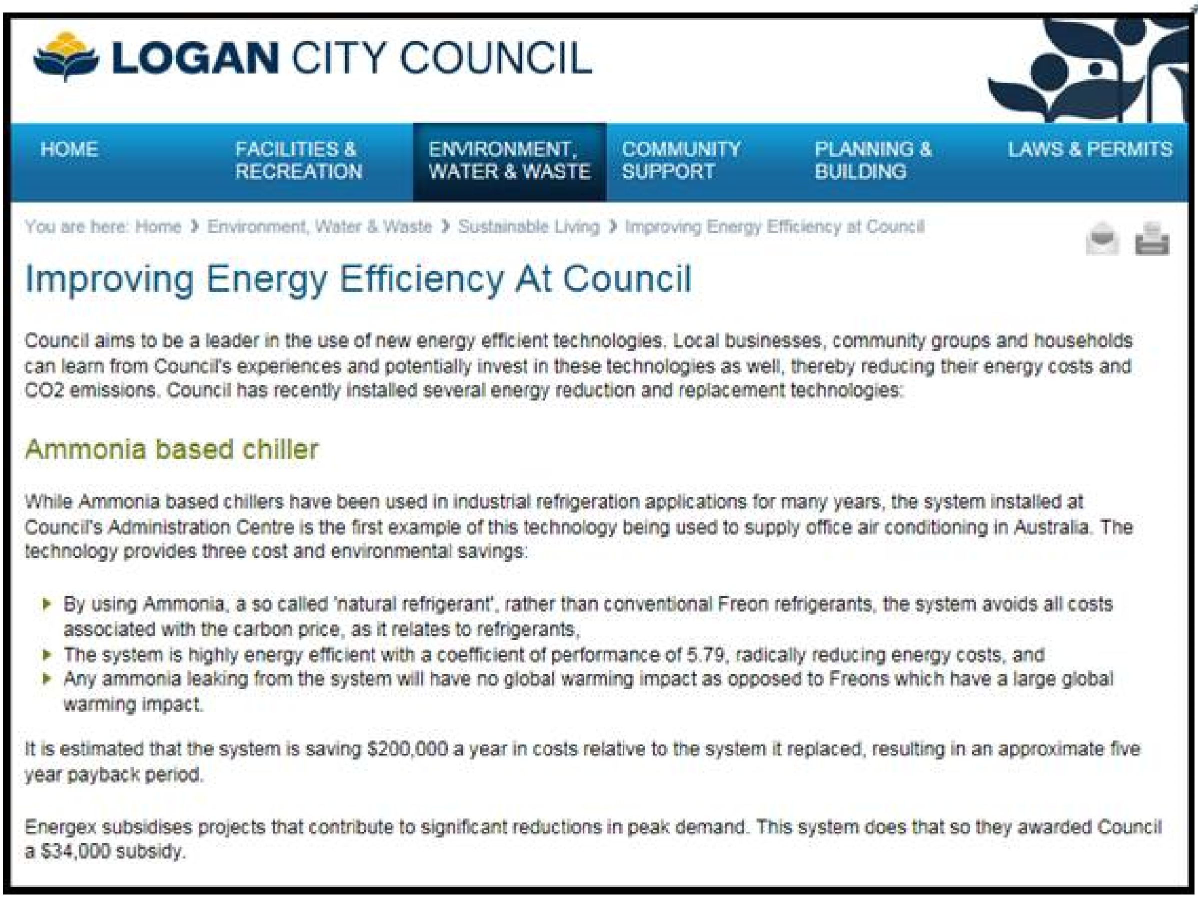
Table 8. Comparison between projected and actual annual maintenance costs.

Despite the electric motor repair to one chiller package, it is evident that the actual maintenance costs are significantly lower (close to 50% lower) than the projections at the start of the project. In fairness, the early projections were conservative for reasons outlined previously. This was deliberate and reflected the wishes of the Council technical staff at the time.

The facilities management of the Council has been very pleased with the performance of the ammonia system between 2011 and now. The noise emission from the new chillers is considered to be less than was the case with the previous units. More importantly for the staff, the vibration levels throughout the building are also judged to be less.

The chilled water reticulation pumps that were not included in the chiller retrofit were also not integrated into the SCADA system used for the control and monitoring of the replacement chillers. This has since been rectified as a measure to reduce maintenance costs further. Prior to the integration of the pumps into the SCADA system, identifying and rectifying system alarms was often not possible without a technician attending to the site.

The actual energy cost savings as recorded by the Council are displayed on the Council's website, refer to Figure 6.



Improving Energy Efficiency At Council

Council aims to be a leader in the use of new energy efficient technologies. Local businesses, community groups and households can learn from Council's experiences and potentially invest in these technologies as well, thereby reducing their energy costs and CO2 emissions. Council has recently installed several energy reduction and replacement technologies:

Ammonia based chiller

While Ammonia based chillers have been used in industrial refrigeration applications for many years, the system installed at Council's Administration Centre is the first example of this technology being used to supply office air conditioning in Australia. The technology provides three cost and environmental savings:

- By using Ammonia, a so called 'natural refrigerant', rather than conventional Freon refrigerants, the system avoids all costs associated with the carbon price, as it relates to refrigerants,
- The system is highly energy efficient with a coefficient of performance of 5.79, radically reducing energy costs, and
- Any ammonia leaking from the system will have no global warming impact as opposed to Freons which have a large global warming impact.

It is estimated that the system is saving $200,000 a year in costs relative to the system it replaced, resulting in an approximate five year payback period.

Energex subsidises projects that contribute to significant reductions in peak demand. This system does that so they awarded Council a $34,000 subsidy.

Figure 6. *Recorded Energy Cost Savings*

The published simple payback period of five years represents a significant improvement compared with the estimated payback of 8.5 years that the Council originally based its investment decision on. There is little doubt that the improvement in actual energy cost savings versus estimated largely is a result of the improved part load efficiency of the new water chilling packages. This was achieved through the provision of variable frequency drives for the compressor motors and through the selection of reciprocating compressors. Not only do reciprocating compressors feature better full load efficiency than equivalent screw compressors. The isentropic and volumetric efficiencies of reciprocating compressors improve as a function of reducing rotational speed whereas for screw compressors the reverse is the case.

CONCLUSION

The Logan City Council’s decision-making process in 2010 was difficult and time consuming [5]. Various psychological hurdles pertaining to ammonia refrigerant that had to be overcome did not assist in expediting the decision-making process. Misinformation relating to ammonia and ammonia-based equipment being suitable for industrial refrigeration applications only caused confusion and doubt among decision makers. Unsubstantiated and to some extent biased claims of significantly higher service and maintenance costs for industrial ammonia equipment as compared with equivalent HCFC refrigerant based unitary equipment initiated requests for additional information. This took time to deliver and it took time for the decision makers to verify the credibility of the information provided.

The fact is that since the installation was commissioned in 2011, the service records indicate that there has only been one minor ammonia leak. This was detected automatically by the ammonia detection system. The problem was found to be caused by a faulty gasket on one of the compressors. It has never been necessary to replenish the ammonia refrigerant charges in the two packaged water chillers since these were commissioned in 2011.

There were initial commissioning issues. These related to:

- General building vibration caused by the new chiller packages,
- Low temperatures in the building segment serviced by the basement air handling unit,
- Vibration and noise in selected offices at certain rotational compressor speeds.

A detailed investigation of the suitability of the vibration dampers fitted under the new chiller packages was conducted. The dampers were found to be unsuitable for the suspended slab under the rooftop plant room and were replaced.

Very limited performance records for the existing R22 dry expansion coils in the basement AHU were available prior to the retrofit. To determine the required capacity for the replacement chilled water coils, the performances of the existing R22, dry expansion evaporators were modelled based on first principles following evaluation of the coil geometries and the circuiting on site. These modelling results were used to determine the design capacity for the replacement chilled water coils. Following staff complaints pertaining to uncomfortably low temperatures in the areas serviced by the basement air handling unit (AHU), the chilled water supply temperature to the AHU was increased. There is therefore some indication that the replacement chilled water cooling coils may have been designed with an excessive safety margin or that the previous R22 based evaporators did not deliver the modelled performances in practice.

Following these initial commissioning issues and their rectification, the ammonia based air conditioning system has over approximately eight years operated at significantly lower energy and maintenance costs than the R22 based systems it replaced. The new plant has more than paid for itself since it was installed. What is probably most important to the Council staff, who on a daily basis work in the air conditioned environment provided by the new air conditioning system, is that there has been no change to their comfort levels over the last eight years.

ACKNOWLEDGEMENTS

The author would like to thank the staff of Logan City Council for their continued support since 2010 and their kind assistance in the preparation of this paper. Special thanks to Allan Wilson, Program Leader, City Administration.

REFERENCES

1. Guus J.M. Velders et al, Future atmospheric abundances and climate forcings from scenarios of global and regional hydrufluorocarbon (HFC) emissions, Atmospheric Environment 123 (2015) 200-209, Elsevier Ltd.
2. McLinden, M.O. et al, Hitting the Boundaries of Chemistry: Limits and Trade-Offs for Low-GWP Refrigerants, Proceedings International Congress of Refrigeration 2015, August 16-22, Yokohama, Japan.
3. Kauffeld, M., Technologies Needed to Cope with HFC Phase-Down and Climate Change, Proceedings eurammon Symposium, 28 June 2018, Schaffhausen, Switzerland.

4. Jensen, S.S., NH_3 for Air Conditioning – Fact or Fiction? Proceedings AIRAH Refrigeration Conference, "Adapting to Our Low Carbon Reality, Brisbane, Australia, 2012.
5. Spolc, D. A Local Government Journey to a Cheaper, Greener Air Conditioning Future. Proceedings AIRAH Refrigeration Conference, "Adapting to Our Low Carbon Reality, Brisbane, Australia, 2012.