University of South Australia

SHORT REPORT:

Evaluation of a Novel R744 Refrigeration System with Integrated Dew Point Cooling in South Australia

Prepared for: Glaciem Cooling Technologies
Building M
University of SA, Mawson Lakes Campus
Mawson Lake Boulevard
Mawson Lakes, SA 5095

Attention: Julian Hudson
Managing Director
Telephone: 0417 920 434
Email: julian@glaciemcooling.com

Prepared by: Dr Alemu Alemu
Dr Martin Belusko*
Prof. Frank Bruno
School of Engineering
University of South Australia
Telephone: +618 8302 3767
Facsimile: +618 8302 3380
Email: martin.belusko@unisa.edu.au

Date of issue: 11 April 2018

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Important Notice

Report Disclaimer

INTRODUCTION

With a global shift away from HFC refrigerants, reflected in Australia with the HFC phase down, the development of efficient natural refrigeration systems becomes significant. This phase down is particularly relevant to Australia with a growing need for refrigeration for food production. Carbon dioxide (R744) is the most attractive natural refrigerant being non-toxic, inflammable and potentially low cost. However its use has been limited to low temperature climates and applications where low efficiency transcritical operation is minimised. The current approach is to apply R744 in a cascade configuration with the HFC, R134A, replacing the traditional HFC system consisting of two parallel fridge and freezer systems with R404A. However, with R134A having a global warming potential (GWP) of 1430, this represents a far from ideal outcome, exposing customers to significant refrigerant costs into the future.

Glaciem Cooling Technologies (Glaciem) has developed a novel R744 system, where condenser inlet air is pre conditioned using dew point cooling. Dew point cooling applies unique indirect evaporative cooling technology to reduce air temperatures approaching the dew point. This is particularly valuable for advancing R744 for refrigeration applications in hot climates, as it minimises inefficient operation.

Testing conducted at the University of South Australia has confirmed the efficiency of this system subject to a range of conditions. This report provides an evaluation of the annual energy savings that this novel R744 system achieves for refrigeration customers. An investigation is conducted for a freezer/fridge configuration subject to Adelaide weather conditions.

SIMULATION PARAMETERS

A simulation was conducted of a direct expansion air cooled refrigerated fridge/freezer cold store combination with a peak load of 150 kW / 50 kW for the medium and low temperature load, respectively. Outdoor cold stores were modelled subject to transmission load and a solar load, with infiltration and product load ignored. The Typical Meteorological Year (TMY) was applied for Adelaide which has a maximum temperature of 44 ^{o}C, which defines the average year suitable for a thermal energy analysis.

The refrigeration systems considered were a conventional cascade R134A/R744, the novel R744 booster system with dew point cooling, a standard R744 booster system as well as a conventional parallel R404A fridge and freezer system. Dew point cooling is applied optimally as per the configuration specified by Glaciem. In order to model the Coefficient of Performance (COP) of all systems, compressor information was derived from Bitzer (www.bitzer.de), as specified in Table 1 and appropriate condenser fan power was determined. The COP of the Glaciem R744 system was derived from Bitzer for compressor data and measured test results conducted at the University of South Australia. A normalised part load COP function was developed for the allowable ranges of frequencies using the data obtained from Bitzer. A suitable number of compressors were selected with only the lead compressor fitted with a variable speed drive.

Table 1. Specifications of simulated air cooled refrigeration systems.

	Conventional cascade R134A/R744	R744 conventional and novel booster	Conventional R404A separate fridge/freezer
Low temperature: Bitzer compressor model and number	3 x model 2ESL_4k	3 x model 2ESL_4k	4 x 4HE-18Y
Medium temperature: Bitzer compressor model and number	5 x model 6GE-30Y-40P	4 x model 4FTC-30K	3 x 4G-2Y
Low temperature evaporator temperature (room at -21 °C)	-28 °C	-28 °C	-28 °C
Low temperature condenser saturation temperature	-1 °C	-4 °C	7 °C above ambient, minimum 40 °C.
Medium temperature evaporator temperature (room at 2 °C)	-6 °C	-4 °C	-4 °C
Medium temperature condenser temperature	7 °C above ambient, minimum 40 °C	Subcritical: 7 °C above ambient, minimum 13 °C Transcritical: Gas outlet 1 °C above air inlet	7 °C above ambient, minimum 40 °C.

Fig. 1 presents the system COP for each configuration subject to different conditions at dew point temperatures of 10 °C, 15 °C and 18 °C. The figure highlights how the COP for the Glaciem system varies non linearly. During mild and humid conditions the COP is marginally higher than other HFC systems, while dramatically higher during cold and, in particular, hot and dry, conditions when the load is significant. At a temperature of 45 °C and a dew point of 15 °C or 18% RH, the system COP of the novel R744 system is 2.6, which is 42% higher than the cascade system, 138% higher than a conventional R744 booster system, and 65% higher than a traditional R404A parallel system.

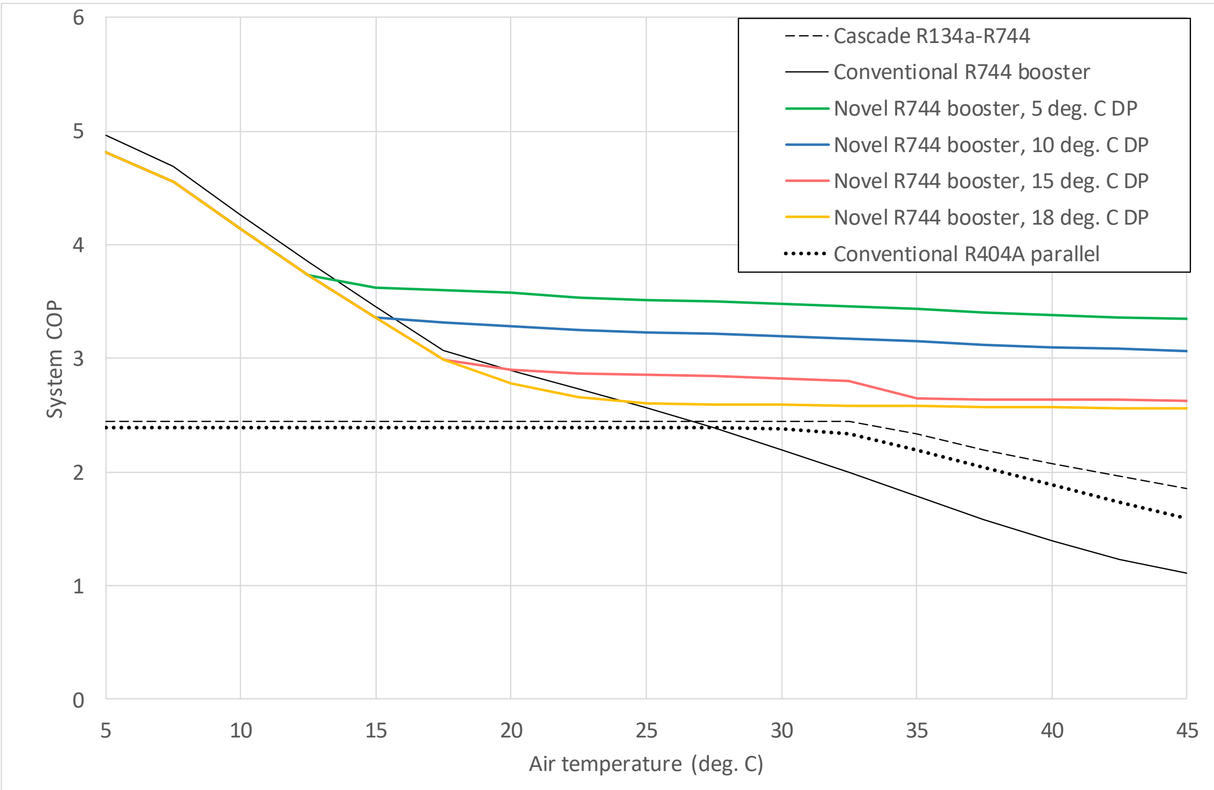

Fig. 1 Overall system COP for a constant low temperature and medium temperature load of 50 kW and 150 kW, respectively. For air temperatures below the dew point temperature, dew points are assumed equal to the air temperature (saturated air condition).

RESULTS

Table 2 and 3 presents the simulated energy usage and costs of the novel R744 system and savings relative to the conventional cascade, conventional R744 booster and conventional HFC system. The typical commercial monthly demand tariff was applied with a peak and off peak energy price of 23.46 c/kWh and 16.74 c/kWh, respectively and a monthly demand charge of $16.1/kVA amd $ 8.02/kVA for peak and for shoulder peak demand periods, respectively.

Overall, the Glaciem R744 system is able to deliver significant energy savings reducing annual energy consumption by 31%, 17% and 35% relative to a conventional cascade system, a conventional R744 booster system and a traditional HFC system, respectively. The novel R744 system is able to reduce peak demand relative to these systems by 19%, 47% and 29%, respectively. The very high peak demand of the conventional R744 booster system, demonstrates its lack of suitability in hot climates.

Table 2: Annual techno-economic performance of the novel R744 booster refrigeration system.
(Low temperature annual thermal load=244.3MWh, Medium temperature annual thermal load=461.5 MWh)

Annual electrical energy consumption (MWh)	211.7
Annual energy usage charges	$ 44879
Annual demand charges	$ 8911
Annual electricity charges	$ 45770
Peak demand (kW)	85

Table 3. Relative energy and cost savings of the novel R744 system compared to a cascade, conventional booster system and R404A parallel system.

Parameter	Cascade R134a-R744	Conventional R744 booster	Conventional R404A parallel configuration
Annual energy consumption reduction	31%	17%	35%
Annual energy usage cost savings	30%	18%	34%
Annual demand cost savings	26%	44%	32%
Annual electricity cost savings	30%	18%	34%
Peak demand reduction	19%	47%	29%

The variation in annual and peak energy savings relative to other systems is attributable to the unique COP characteristics of the Glaciem CO_2 system. Figs. 2 and 3 presents the relative difference in the COP of the Glaciem system with respect to the cascade and parallel R404A system, respectively, for each hour over the TMY, weighted to the electrical load. R744 enables lower condensing temperatures than HFCs resulting in consistently higher COPs at low ambient temperatures. The difference in COP is sometimes small during mild conditions, consistent with periods of high humidity. However, during hot conditions, when refrigeration loads are maximum a significant improvement in efficiency is achieved relative to both conventional systems when dew point cooling is most effective.

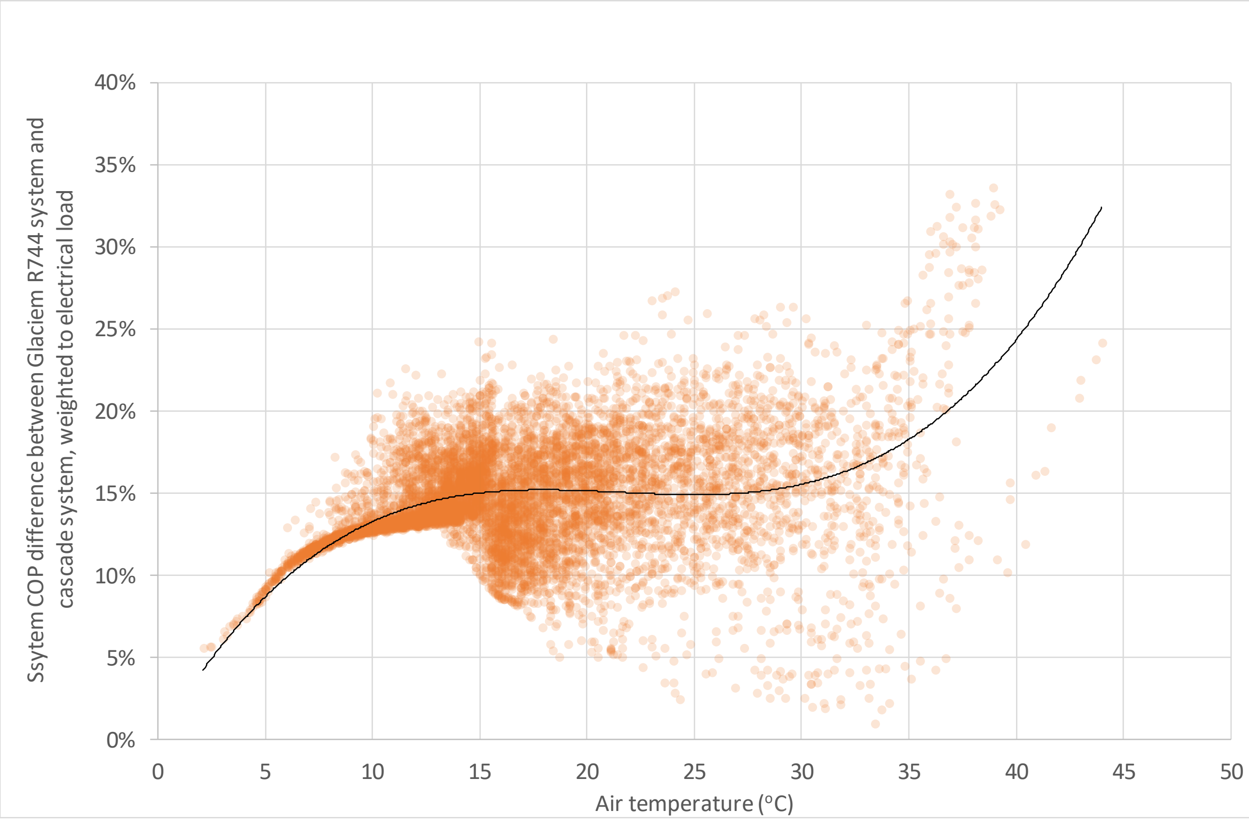

Fig. 2 Relative improvement in system COP between the novel R744 system and cascade system for each hour of the year, weighted against the electrical load.

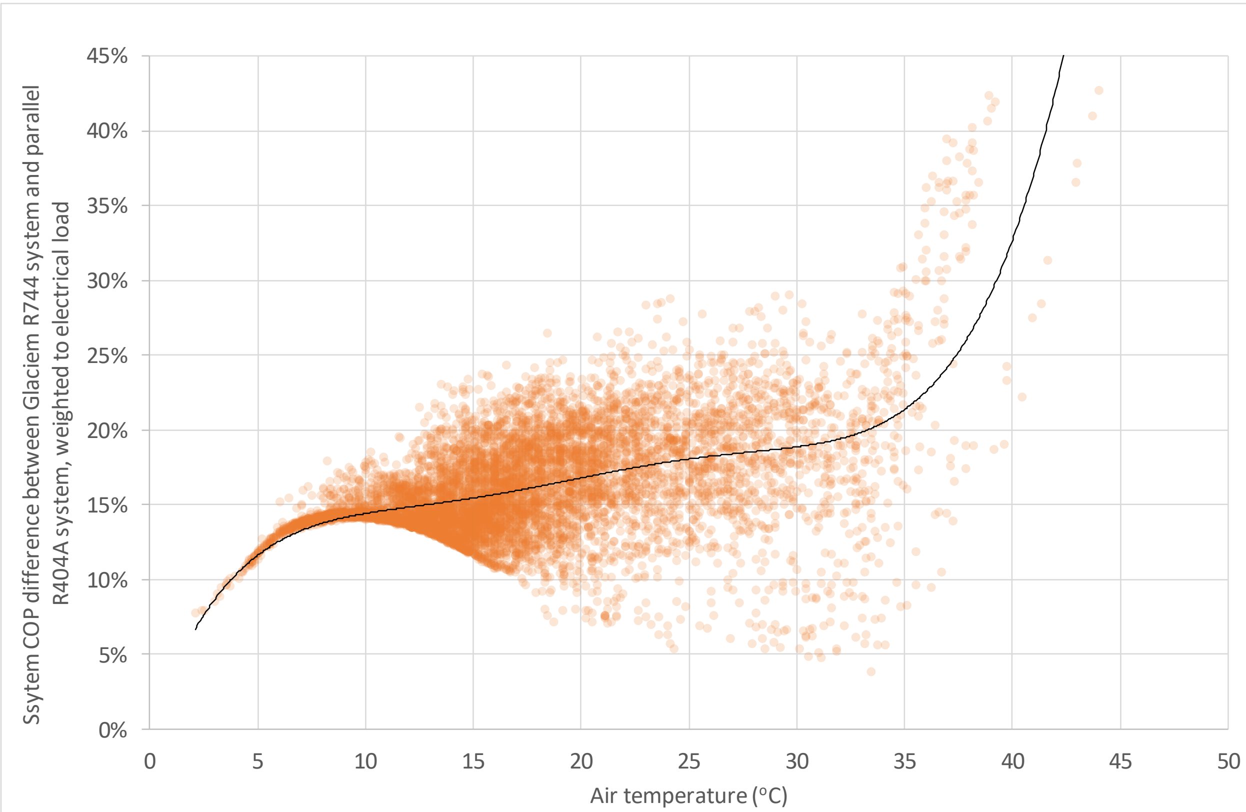

Fig. 3 Relative improvement in system COP between the novel R744 system and conventional parallel R404A system for each hour of the year, weighted against the electrical load.

CONCLUSIONS

The novel R744 Glaciem refrigeration system can achieve significant savings in energy relative to conventional air cooled refrigeration systems. With the transition away from HFC refrigeration systems, this technology represents an effective solution. The system achieves maximum savings during hot conditions. The significance of reducing energy demand during these conditions, corresponding to peak grid electrical demand, cannot be understated. With more cost reflective tariffs likely in the future, the price of energy during peak demand times will rise relative to typical periods. Furthermore, climate change has shown that South Australia will experience more periods of hot conditions. Finally, new improvements in dew point cooling technology will increase energy savings. Consequently, the energy and cost savings relative to conventional refrigeration systems determined in this study represent the lower end of estimates with actual savings likely to be higher into the future.