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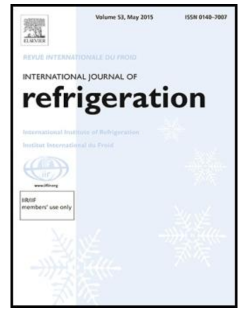

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Author: James K. Carson, Andrew R. East

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The cold chain in New Zealand – A review

James K Carson[1]*, Andrew R East[2]

[1] School of Engineering, University of Waikato

[2] Massey Institute of Food Science and Technology, Massey University

* corresponding author: j.carson@waikato.ac.nz

Highlights

- Approximately 45 % of all exports from New Zealand are food products or by-products.
- An estimated 60 % of food are exports are exported in the refrigerated state.
- New Zealand food exports form part of some of the longest cold chains in the world.
- Currently, the major research theme related to the cold-chain in New Zealand is focussed around optimising chilling and freezing processes for shelf-life extension. Improving energy efficiency in refrigeration processes is also a significant research theme.

Abstract

Approximately 45 % of all exports from New Zealand are food products or by-products, and an estimated 60 % of these are exported in the refrigerated state. The leading food sectors in terms of volume and income are in order: the dairy industry, the red meat industry, the horticultural industry and the seafood industry. Due to its geographic isolation, New Zealand food exports form part of some of the longest cold chains in the world. Responsibility for temperature integrity in the cold chain is placed on the processors and exporters and is overseen by the Ministry for Primary Industry of the Government of New Zealand. Currently, the major research theme related to the cold-chain in New Zealand is focussed around optimising chilling and freezing processes for shelf-life extension. Improving energy efficiency in refrigeration processes is also a significant research theme.

Keywords: Cold chain; refrigerated transport

1. Introduction

As a country, New Zealand is a similar age to mechanical refrigeration technology and it has been argued that without mechanical refrigeration New Zealand may have become part of Australia (Copland, 1972; King, 2003). Thanks to the successful transportation of a shipment of frozen mutton carcasses from New Zealand to the United Kingdom in 1882 farmers could sell not only the wool from sheep but also the meat, greatly increasing the financial viability of pastoral farming (Copland, 1972; Love, 2008). Since the first successful refrigerated export of frozen meat to the United Kingdom, New Zealand's industry and economy has continued to rely heavily on the food industry (Cleland, 2009). By the 1980s New Zealand had the largest refrigerated storage volume per capita of any country in the World. Currently, approximately 45 % of all exports from New Zealand are food products or by-products (Statistics NZ), and an estimated 60 % of these are exported in the refrigerated state (Fitzgerald et al., 2016).

Due to its geographic isolation, New Zealand industries and exporters have been forced to experiment and innovate, with the result that many of the technologies or practices developed in New Zealand have been pioneering and have spread worldwide. In the first part of the 20th Century, most effort tended to focus around improving reliability and energy efficiency in meat refrigeration (Cleland, 2009). Later on, more attention was paid to how refrigeration affected meat quality, and to the design of refrigeration rooms, not only in the meat industry but for horticultural products as well, where control of the atmosphere in addition to temperature is important.

This article reviews the current status of the cold chain and cold chain-related research in New Zealand.

2. Food production, imports and exports

Table 1 shows the quantities of the major food items produced in New Zealand which are likely to require refrigeration for the years 2015 and 2012 (Statistics NZ, 2016; MIA, 2015). In total it is estimated that between 2.5 and 3.0 million tonnes of food produced annually requires refrigeration, the vast majority of which is exported. It should be noted that some annual data are prepared for years ending 31st December, while other are for years ending 30th June. Effort was made to use a consistent basis, however, it was not always possible to determine from the source material what specific 'year' was being referred to. In general, export information for New Zealand goods is more readily available than total production data. The total production of sheep and beef meat has been estimated from the relative weights of sheep and beef animals that are slaughtered for the local and domestic markets, from which we can estimate that between 92 % and 98 % of meat produced is exported.

Beef and lamb products dominate the red meat exports, with the United States, the United Kingdom and China being the three largest export markets. The majority of meat is exported frozen, but approximately 5 % of beef and 15-20 % of lamb products are exported chilled. Chilled lamb in particular is a premium product, especially in the European market, where producers can achieve the highest sales price. The recent practice by shipping liners of travelling at less than the ship's rated steaming speed ('slow steaming') has jeopardised this lucrative market (Carson, 2016). So far exporters have been able to manage the reduction in speed from 24 knots (32 days in transit) to 18 knots (37 days in transit), any further reduction (e.g. 14 knots and 41 days in transit) could mean the European chilled lamb market is no longer viable (MIA, 2014; Carson et al., 2015). In addition to red meat, New Zealand also produces and exports poultry products, mainly chicken pieces and chicken preparations.

Cheese and butter are the major dairy exports that require refrigeration (although milk powder is the largest dairy export product by volume). Butter is commonly stored frozen to reduce the rate of lipid oxidation that causes spoilage (Bogh-Sorenson, 2006; Nahid et al., 2008). The storage temperatures for cheeses depends on the moisture content, with some varieties not requiring any active refrigeration, while others require chilling. Ice cream, another significant export product, is stored frozen.

The New Zealand fruit industry, with the exception of unrefrigerated wine, is dominated by the export of whole fresh product. Kiwifruit, apple and avocado represent the bulk of the products, while other export markets for products such as blueberry and cherry are emerging. Due to the relatively low volumetric efficiency (kg/m^3) of packing that is a constraint of fresh produce, the volume of maritime cool-chain equipment used is substantial. In 2016, 68 chartered, refrigerated ships and a further 10,500 refrigerated containers where required to export New Zealand kiwifruit to 58 countries. Other fresh fruit industries tend to be very heavily dominated by, and constrained to export via refrigerated shipping, partly due to the relatively low volume of airline cargo space exiting the country (Freshfacts, 2016).

The vegetable industry is represented by an approximately 50:50 mix of fresh vegetable to processed vegetable. Fresh vegetable exports are dominated by squash and onion, neither of which require active refrigeration, but have a form of temperature control through the use of dry goods containers in which one door has been removed in order to fit a fan that enables air exchange. Of the processed vegetable category, frozen products such a frozen peas and potato products dominate.

While the majority of food is exported by maritime freight, select, high-value products such as live crustaceans are air-freighted. A more recent emergence has been the chartering of aircraft to enable large volume direct targeted export of high value product, such as cherry destined for Chinese New Year celebrations (Cropp, 2017).

Table 2 provides estimates of quantities of foods likely to require refrigeration that were imported to New Zealand in the Calendar year 2015 (Statistics NZ, 2016). A comparison of the data for exports (Table 1) and imports (Table 2) for the year 2015 shows that refrigerated food exports from New

Zealand exceed imports by more than a factor of ten. As a consequence of this imbalance, there is generally a large requirement for backhaul of empty refrigerated containers to New Zealand.

Globally the supply of reefer vessels is reducing, resulting in increased pressure to move more exports into containerised format (Dekker, 2014, Drewry, 2016. For the growing kiwifruit and apple industries this represents a significant challenge and additional risk to the supply chain given the known benefits to temperature control of using reefer vessels in comparison to containers (Smale, 2004; Tanner and Amos, 2002). Additional challenges of shifting to containerisation are the increased time length of supply chains due to non-direct shipping, and potential for gas contamination (ethylene or flavour tainting) given that containers of different products may be placed adjacent to each other.

3. Energy and refrigerant usage

3.1 Energy Usage

Table 3 shows the energy used for refrigeration for different sectors related to food production and storage (EECA, 2016). The largest individual sector for refrigeration usage is domestic, which is unsurprising given that the vast majority of households in New Zealand have at least one refrigerator. The retail trade sector is the second largest user.

It is interesting to note that the dairy industry uses more refrigeration energy than the meat sector, despite the fact that less than half of dairy product tonnage requires refrigeration, while the vast majority of meat products and many co-products require either chilled or frozen transportation and storage. The explanation for this observation is that substantial volumes of milk are required to be stored and transported under refrigeration prior to the start of processing at the factory, while meat products only require refrigeration post-slaughter.

3.2 Refrigerant Usage

It is estimated that between 800 and 1000 tonnes of refrigerant is imported to New Zealand annually (Tapp, 2016), with an estimated 40 to 45 % entering pre-charged in refrigeration systems being imported (Bowen, 2016). Due to its commitment under the Montreal Protocol, New Zealand has phased out the import of ozone-depleting refrigerants including halons (1994) and chloro-fluoro-carbons (CFCs), hydro-chloro-fluoro-carbons (HCFCs) via the Ozone Layer Protection Act of 1996 (MFE, 2016). In addition, the *Trust for the Destruction of Synthetic Refrigerants* (http://www.refrigerantrecovery.co.nz) has been collecting and destroying CFCs, HCFCs, and HFCs (hydro-fluoro-carbons). The quantities collected and destroyed over the past ten years are shown in Table 4 (Tapp, 2016). Based in the small quantities collected in recent years, it would appear that the quantities of highly ozone-depleting CFCs (e.g. R11, R12) remaining in New Zealand are small.

4. Cold chain management, regulations and auditing

The New Zealand Food Safety Authority (NZFSA) within the Ministry for Primary Industries of the Government of New Zealand regulates and audits processes and procedures in the manufacture, distribution and export of food products within and from New Zealand. The implementation of the regulations along with logistical management of the cold chain is the responsibility of the food manufacturing and transportation companies. The Ministry for Primary Industries performs regular audits (at least annually, and often more frequently) to ensure compliance with the regulations.

4.1 Meat, meat preparations and meat co-products (non-seafood)

The regulations for manufacture, storage and export of meat products are covered by the New Zealand Food Safety Authority's Industry Standard/Industry Agreed Standard 6 (NZFSA, 2004). New Chillers and freezers must be validated against performance criteria in terms of cooling times for given air temperature, fan speed and cooling load (or alternatively against some process hygiene index measurement). The performance of carcass chillers is required to be verified not less than daily for each day they are in use.

All animals slaughtered for meat are required to be cooled within certain time constraints that vary according to the size of the animal. It is the responsibility of the processor to monitor the cooling process with temperature sensors calibrated according to NZFSA Industry Standard 8 (NZFSA, 1999). Typically, these regulations specify a time post-slaughter for the surface of the carcass to reach 7 °C before further processing (e.g. de-boning, cutting, packaging), or 10 °C if the carcass is subsequently to be frozen, as well as maximum times allowed from time of slaughter before the product must reach its final storage and transportation temperature. In a continuous chiller, it is required that there be sufficient separation between hot carcasses entering the chiller and cold carcasses already in the chiller to prevent reheating of the cold carcass and/or condensation of moisture from the hot carcass on the cold carcass. De-boning and packaging typically occurs in rooms maintained at or below 10 °C. Processors are required to monitor microbial counts according to procedures outlined in NZFSA Industry Standard 8 (NZFSA, 1999)

The majority of meat products are exported in the frozen state, with approximately 10 % being chilled product. Chilled storage temperatures are required to be below 1 °C. Chilled product for export is held as close as possible to the initial freezing temperature of the meat (approximately -1.5 °C). At this temperature the meat is safe for about 9 - 10 weeks after slaughter (Mills et al. 2014). Recent research has shown that initial freezing temperature is significantly dependent on meat pH, with higher pH meat having higher initial freezing temperatures (Farouk et al., 2013). By grading meat according to its pH, storage/transportation temperatures may be optimised. Frozen product is exported at different temperatures, depending on the requirements of the importing country (OMAR, 2016), but IS6/IA6 requires that once frozen the product temperature must not exceed -

12 °C at the centre position during further processing, and must not exceed -12 °C during storage/transportation.

Offals that have been exposed to microbial populations within the animal's gastro-intestinal tract are considered high risk for contamination and are required to be handled separately from other meat products. Their temperature-time management for hygiene is covered by NZFSA Industry Standard 2 (NZFSA, 1997).

4.2 Poultry

The regulations for slaughtering, plucking, primary and secondary processing of poultry products are provided by the New Zealand Food Safety Authority's *Poultry processing - Code of practice*. Chapter 5 of this code (NZFSA, 2009) covers the temperature regulations for both immersion and air-chilling of poultry carcasses after slaughter and removal of feathers. For immersion chilling potable water/ice is to be used, with the additions of 3 -5 ppm chlorine to restrict microbial growth. The water temperature and flow rate and bird throughput and dwell time are adequate to achieve an "internal bird temperature" of 10°C or less when exiting from the immersion chiller. It is recommended that for carcasses weighing less than 2.5 kg that a minimum water flow of 1.5 litre/carcass is used, while for carcasses weighing between 2.5 and 5 kg a minimum water flow of 2.5 litre/carcass is used.

For air-chilling, air-flow rates, temperatures and humidities must be sufficient that the achieve an internal bird temperature of 10°C or less when exiting from the air chiller.

Poultry offal for human consumption must be rinsed using potable water with an antimicrobial processing aid before or during chilling, with continuous cooling to 7°C or colder within 4 hours of its removal from the bird. Chicken feet must be cooled to 10 °C within 4 hours of removal from the carcass.

During secondary processing it is recommended that processing areas be maintained at 12 °C or less (NZFSA, 2009b), and as far as possible carcass temperatures should not exceed 10 °C. The average carcass temperatures should reduced to –12 °C or colder prior to being transferred to cold storage.

4.3 Dairy products

The on-farm storage of raw milk is regulated by the Ministry for Primary Industries Code of Practice NZCP1: Design and Operation of Farm Dairies (NZFSA, 2015). It is recommended that after milking the milk is cooled to 7 °C or below as quickly as possible. It is currently required either that milk be cooled to 18 °C at the completion of the first milking and should not rise above 13 °C in the storage tank after subsequent milkings; or alternatively, milk is to be cooled to and maintained at 7 °C or below within 3 hours of the completion of milking and kept at or below 7 °C until it is collected, or until the next milking.

From 1st June 2018 the requirements will be for milk to be cooled to 10°C or below within four hours of the commencement of milking. It will need to be cooled to 6°C or below either within six hours from the commencement of milking, or two hours from the completion of milking, whichever is sooner. It will be required to be held at or below 6°C without freezing until collection or the next milking, and must not exceed 10°C during subsequent milkings (DairyNZ, 2016). Milk will not be able to be collected from a farm if it has not been maintained at or below 7 °C, unless it has been collected within 3 hours after milking.

4.4 Fruit and vegetables

Fruit and vegetables are considered less 'hazardous' than protein-rich, animal-derived foods by the New Zealand Food Safety Authority. Refrigeration guidelines are generally determined more by quality maintenance concerns than by food safety concerns, and storage and transportation temperatures tend to be product-specific (Heap, 2010). The majority of New Zealand fruit and vegetables exported are transported in the chilled state. Industry Standard 9 (NZFSA, 2001) does require that fruits and vegetables that produce odours or respiratory gases should not be transported with animal products unless both are wrapped.

4.5 Seafood

Regulations for the processing of seafood products are provided by the Code of Practice: Processing of Seafood Products – Part 2: Good Operating Practice (MAF, 2011). Processing temperature regulations vary with fish species, and whether the fish is intended for export or consumption within New Zealand. Generally, whole fish are required to be cooled 'rapidly' to between –1 °C and +1 °C for chilled product, and not greater than –18 °C for frozen product. Shellfish that are intended for canning need not be cooled to the same extend (e.g. New Zealand abalone, 'paua' intended for canning need only be cooled to 6 °C). The storage and transportation regulations for seafood are similar to those for meat (NZFSA, 2001). Export licensed stores are not required to make the distinction between types of product, e.g. fishmeat rather than sheep or beef meat.

5. Research related to the cold chain

The New Zealand Government has two corporatized research institutes ('Crown Research Institutes') with a strong emphasis on food production, processing, safety and preservation; these are *AgResearch Limited* and *Plant and Food Research*. The largest private research institute related to the food industry is the *Fonterra Research and Development Centre*, which is focussed on the dairy industry. In addition, there are a number of small private research/innovation/development companies related to the food industries

Amongst the eight New Zealand universities (i.e. research-led, tertiary education providers), the University of Auckland, AUT University, the University of Waikato, Massey University, Lincoln University and the University of Otago have staff engaged in food-related research. Historically much of the refrigeration-related work has focussed on meat and horticultural produce, followed by dairy products and seafood industries.

Recent research initiatives related to meat products have focussed around shelf-life extension for chilled product, much of which is commercially sensitive and unpublished. Most of the recent work that has been published has investigated the effects of variations in time-temperature regimes during aging, chilling/freezing and thawing processes on meat quality (Rosenvold and Wiklund, 2011, Kim et al., 2011, Jacob et al., 2012, Kim et al., 2012a, Kim et al., 2012b, Kim et al., 2013, Farouk et al., 2014, Choe, et al. 2015, Kim et al., 2016). Modelling thermal properties of foods (including meats) has also been investigated (Wang, et al. 2008, Wang et al., 2009, Wang et al., 2010, Carson, 2015, Carson et al., 2016).

The use of phase-change materials for low temperature thermal energy storage is another area of research (Oro, et al. 2012a, 2012b, 2014), while drop-in replacements for HCFCs in on-farm milking equipment has also been investigated (Cleland et al., 2009).

The Centre for Postharvest and Refrigeration Research at Massey University has a strong tradition of conducting research with New Zealand's fruit export industries, and strengthening the cool chain of these industries. Foci of this research are associated with design of packaging to assist cooling and temperature control of fresh produce, (Defraeye et al., 2015; East et al., 2013b; Olatunji et al., 2016; O'Sullivan et al., 2013; O'Sullivan et al., 2016; O'Sullivan et al., 2017; Tanner et al., 2002), development of new methods to measure and cool chain systems (East et al., 2009; O'Sullivan et al., 2014; Redding et al., 2016; Huang et al., 2017; Olatunji et al., 2017), measurement of real world cool chain scenarios (East et al., 2003a; Bollen et al., 2015; O'Sullivan, 2016; Shim et al., 2016; Tanner and Amos, 2002; Smale, 2004) and their subsequent influence on produce quality (East et al., 2008;

Paniagua et al., 2014; East et al., 2013a; East et al., 2013c; Paniagua et al., 2012; Zhao et al., 2015) culminating in the development of mathematical models to predict fruit quality based on supply chain temperature information (Hertog et al., 2016; East et al., 2016; East, 2011).

Another research theme is the investigation of energy efficiency improvements for industrial refrigeration systems on large processing sites (Cleland et al., 2015; East et al., 2003b; East et al., 2013c; East, 2010; Milgate, 2011, Werner et al. 2006). This includes efforts to quantify energy associated with refrigerated and dry goods transport to and from New Zealand (Fitzgerald et al., 2011a; Fitzgerald et al., 2011b). The research on developing sustainable practices for large processing sites has resulted in leading authorship for the latest ASHRAE book on the topic (Love et al., 2017) and conducting recent workshops in Singapore.

6. Case study – optimisation of kiwifruit carton design and stacking arrangement

A recent example of cold-chain research focussed on understanding and improving airflows within and around palletised kiwifruit cartons (O'Sullivan et al., 2013; O'Sullivan et al., 2016; Shim et al., 2016). Unlike many other horticultural products kiwifruit are placed within a polyethylene bag ('polylined') prior to being placed in the carton. While there are holes to allow for airflow within the carton, there are no holes or perforations in the liner bag, and thus pockets of stagnant air are located between the fruit and the liner, comprising a significant heat transfer resistance. In this study, a 3-D computational fluid dynamics (CFD) model was developed to describe and predict the temperature profiles in and around polylined kiwifruit packages undergoing forced-air cooling. The geometrical configuration of the kiwifruit, polyliner and cardboard box were explicitly modelled. The model was quantitatively validated against experimental data and was then used to determine the optimum pallet orientation with respect to the incoming air, and the optimum air-speed in terms of energy consumption by air-circulation fans and cooling rate. The presence of the polyliner means that the maximum economic air-speed was considerably lower than would have been the case if the kiwifruit were not poly-lined.

Another outcome of the study was a proposed alternative package designed that aimed to redistribute the incoming refrigerated airflow to channel cool air through the pallet layers before directing it towards the slowest cooling packages, located at the back of the pallet (O'Sullivan et al., 2017). Evaluating the new design at the optimal conditions for the current package showed that at constant flowrate both pressure drop and energy requirement to achieve half-cooling time (HCT) were reduced by 24%, while improving cooling uniformity and pallet throughput per week. Alternatively, keeping the pressure drop constant required a similar energy input, while further increasing the cooling uniformity throughout the pallet.

Conclusions

New Zealand's economy relies heavily on food exports, and due to its geographic isolation, its refrigerated exports form part of some of the longest cold chains in the world. As a consequence, New Zealand food producers and exporters have been forced to experiment and innovate in order to maintain or increase their export volumes and markets. Currently, the majority of refrigeration-related research is focussed on the meat and horticultural products industries, with a consistent theme being the increase of storage-life via optimised chilling and freezing processes. Responsibility for temperature integrity in the cold chain is placed on the processors and exporters and is overseen by the Ministry for Primary Industry of the Government of New Zealand.

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References:

Bollen, A.F., Tanner, D.J., Soon, C.B., East, A.R., Dagar, A., Sharshevsky, H., Mowat, A.D., Heyes, J.A., Pelech Y., 2015. Wireless temperature monitoring system in a global kiwifruit supply chain. Acta Horticulturae 1091:205-212

Carson, J. K. (2015) Thermal conductivity measurement and prediction of particulate foods, International Journal of Food Properties, 18(12), 2840 – 2849

Carson, J. K, (2016) The Implications of Slow-steaming for Shipping Customers, Elsevier Reference Series, Reference Module in Food Science, First Edition, 1–6

Carson, J. K., East, A. R., Cleland, D. J. (2015). The impact of slow-steaming on refrigerated exports from New Zealand, in: Proceedings of the 24th IIR International Congress of Refrigeration, Yokohama, August 2015, Paper # 153.

Carson, J. K., Wang, J. F., North, M. F., Cleland, D. J. (2016) Effective thermal conductivity prediction of foods using composition and temperature data, Journal of Food Engineering, 175, 65 – 73

Choe, J-H., Stuart, A., Kim, Y. H. B, (2016). Effect of different aging temperatures prior to freezing on meat quality attributes of frozen/thawed lamb loins, Meat Science, 116, 158–164

Cleland, A. C. (2009) Refrigeration: underpinning the New Zealand economy for over 125 years, 3rd Australasian Engineering Heritage Conference 2009, 1 – 7

Cleland, D. J., Keedwell, R. W., Adams, S. R. 2009, Use of hydrocarbons as drop-in replacements for HCFC-22 in on-farm milk cooling equipment International Journal of Refrigeration, 32(6) 1403-1411

Cleland, D.J., East, A.R., and Jeffery, P. 2015. Air infiltration into walk-in cold rooms through doors, Proceedings of the 24th International Congress on Refrigeration, Yokohama, August 2015.

Copland, M. J. (1972), Refrigeration: its impact upon New Zealand 1882-86, Essay, University of Otago HD9428.N45C66

Cropp, A. (2017) Four chartered 747s carry cherries to Asia for Chinese New Year, Stuff news article 17 January 2017, http://www.stuff.co.nz/business/88379099/four-chartered-747s-carry-cherries-to-asia-for-chinese-new-year

DairyNZ, (2016) Milk Cooling, http://www.dairynz.co.nz/milking/the-milking-plant/milk-cooling/

Defraeye, T., Cronje, P., Berry, T., Opara, U.L., East, A., Hertog, M., Verboven, P., Nicolai, B. 2015. Towards integrated performance evaluation of future packaging for fresh produce in the cold chain. Trends in Food Science and Technology, 44, 201-225.

Dekker, N. (2014) Global reefer trades – 2014, https://www.joc.com/sites/default/files/u221106/SpeakerPresentations/March3/Dekker_Neil_Cool_Cargoes_Presentation.pdf

Drewry (2015) Refrigerated Containership Fleet Grows While Specialized Reefer Vessels Decline in Number, SupplyChainBrain, August 12, 2015 http://www.supplychainbrain.com/content/latest-content/single-article/article/refrigerated-containership-fleet-grows-while-specialized-reefer-vessels-decline-in-number/

East, A.R., Sabarez, H.T., Tanner, D.J., and Cleland, D.J., 2003a. Validation of a packaging design tool: case study for apple packaging, Proceedings of the 21st International Institute of Refrigeration Congress, August 2003, Washington, USA.

East, A.R., Jeffery, P.B., and Cleland, D.J., 2003b. Air infiltration through loading dock truck-trailer doors, Proceedings of the 21st International Institute of Refrigeration Congress, August 2003, Washington, USA.

East, A.R., Tanner, D.J., Jobling, J.J., Maguire, K.M., Mawson, A.J., 2008. The influence of breaks in storage temperature on 'Cripps Pink' (Pink Lady™) apple physiology and quality, HortScience, 43(3), 818-824.

East, A.R., Smale, N.J., and Kang, S.P. 2009. A method for quantitative risk assessment of temperature control in insulated boxes, International Journal of Refrigeration, 32: 1505-1503.

East, A.R. 2010. Energy efficient postharvest storage and handling. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resource. 5. No 61. doi: 10.1079/PAVSNNR20105061.

East, A.R. 2011. Accelerated libraries to inform batch sale scheduling and reduce postharvest losses of seasonal fresh produce. Biosystems Engineering 109:1-9.

East, A.R., Jabbar, A. and Heyes, J.A. 2013a. Approaches to prediction of storage out-turn for units of fresh produce. Acta Horticulturae 1012, 1303-130

East, A.R., Jeffery, P.B., Love, R.J. 2013b. Investigating asymmetrical packaging a technique to reduce heterogeneity during pre-cooling of fresh produce. Proceedings of the 2nd IIR Conference on Sustainability and the Cold Chain, Paris, France, April 2013.East, A.R., Smale N.J. and Trujillo, F.J. 2013c. Potential for energy cost savings by utilising alternative temperature control strategies for controlled atmosphere stored apples. International Journal of Refrigeration, 36, 1109-1117.

East, A., Zhao, M., Jabbar, A., Samarakoon, H., Bollen, F., Adkins, M., Bronlund, J., and Heyes, J. 2016. Why is predicting kiwifruit quality in the cool chain so difficult? Proceedings of the 4th IIR Conference on Sustainability and the Cold Chain, Auckland, New Zealand, April 2016.

EECA (2016) Energy Efficiency and Conservation Authority (New Zealand) - Energy end use database https://www.eeca.govt.nz/resources-and-tools/tools/energy-end-use-database/

Farouk, M. M., Kemp, R. M., Cartwright, S., North, M. (2013), The initial freezing point temperature of beef rises with the rise in pH: A short communication, Meat Science, 94, 121–124

Fitzgerald, W.B., Howitt, O.J.A., Smith, I.J. (2011a). Greenhouse gas emissions from the international maritime transport of New Zealand's imports and exports, Energy Policy, 39:1521-1531.

Fitzgerald, W.B., Howitt, O.J.A., Smith, I.J. and Hume, A. (2011b). Energy use of integral refrigerated containers in maritime transportation. Energy Policy, 39:1885-1896.

Heap, R. (2010), Guide to Refrigerated Transport, 2nd Ed., International Journal of Refrigeration, Paris

Hertog, M.L.A.T.M., Jeffery P.B., Gwanpua S.G, Lallu, N., East, A. 2016. A mechanistic model to describe the effects of time, temperature and exogenous ethylene levels on softening of kiwifruit. Postharvest Biology and Technology, 121, 143-150.

Huang, H., Tunnicliffe, M., Shim, Y.M., Bronlund, J.E. (2017). Model based development of fruit simulators. Proceedings of the ESAFORM2017, April 2017, Dublin, Ireland.

Jacob, R., Rosenvold K., North, M., Kemp, R., Warner, R., Geesink, G. (2012), Rapid tenderisation of lamb M. longissimus with very fast chilling depends on rapidly achieving sub-zero temperatures, Meat Science, 92(1), 16-23

Kim, Y. H. B, Frandsen, M., Rosenvold K., (2011), Effect of ageing prior to freezing on colour stability of ovine longissimus muscle, Meat Science, 88(3), 332-337

Kim, Y. H. B, Stuart, A., Black, C., Rosenvold K., (2012a), Effect of lamb age and retail packaging types on the quality of long-term chilled lamb loins, Meat Science, 90(4), 962-966

Kim, Y. H. B, Stuart, A., Nygaard, G., Rosenvold K., (2012b), High pre rigor temperature limits the ageing potential of beef that is not completely overcome by electrical stimulation and muscle restraining, Meat Science, 91(1), 62-68

Kim, Y. H. B, Luc, G., Rosenvold K., (2013), Pre rigor processing, ageing and freezing on tenderness and colour stability of lamb loins, Meat Science, 95(2), 412-418

Kim, Y. H. B, Liesse, C., Kemp. R., Bhalan, P. (2015), Evaluation of combined effects of ageing period and freezing rate on quality attributes of beef loins, Meat Science, 110, 40–45

Kim, Y. H. B, Kemp. R., Samuelsson, L. M., (2016) Effects of dry-aging on meat quality attributes and metabolite profiles of beef loins, Meat Science, 111, 168-175

King, M. (2003) A Penguin history of New Zealand, Penguin, Auckland

Love, R.J.,(2008) Early Refrigerated Meat Shipping in New Zealand, ASHRAE Transactions 114, 404-408

Love, R.J., Cleland D.J., Jekel, T., Reindl, D., Davis, J., (2017), Guide for Sustainable Refrigerated Facilities and Refrigeration Systems, ASHRAE: Atlanta, GA. (*in press*)

MAF (2011) Ministry of Agriculture and Forestry, Code of Practice: Processing of Seafood Products Part 2: Good Operating Practice http://www.foodsafety.govt.nz/elibrary/industry/code-practice-seafood/part-2.pdf

MFE (2016) New Zealand Government Ministry for the Environment, Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer, http://www.mfe.govt.nz/more/international-environmental-agreements/multilateral-environmental-agreements/key-multilateral-7

MIA (2014), Annual Report – Meat Industry Association of New Zealand, downloadable from http://www.mia.co.nz/docs/publications/AR2014.pdf

MIA (2015), Annual Report – Meat Industry Association of New Zealand, http://www.mia.co.nz/docs/annual_reports/MIA_Annual_Report_2015.pdf

Milgate, S.M. 2011, Development and application of a model for estimating the efficiency and carbon footprint of refrigeration systems by considering the impact of fouling on condenser performance M.Phil thesis, Massey University, Palmerston North, New Zealand.

Mills, J., Donnison, A., Brightwell, G. 2014, Factors affecting microbial spoilage and shelf-life of chilled vacuum-packed lamb transported to distant markets: A review Meat Science, 98(1) 71–80

Nahid, A., Bronlund, J. E., Cleland, D. J., Philpott, B., (2008), Modelling the freezing of butter International Journal of Refrigeration, 31, 152–160

NZFSA (1997) New Zealand Food Safety Authority Industry Standard 2 / Industry Agreed Standard 2 (IS2/IAS2), http://www.foodsafety.govt.nz/industry/sectors/meat-ostrich-emu-game/meatman/manual-2v/industry-agreed-standard-2-design-construction.pdf

NZFSA (1999) New Zealand Food Safety Authority Industry Standard 8 / Industry Agreed Standard 8 (IS8/IAS8) http://foodsafety.govt.nz/industry/sectors/meat-ostrich-emu-game/meatman/is8/is8.pdf

NZFSA (2001) New Zealand Food Safety Authority Industry Standard 9 Storage and Transport, http://www.foodsafety.govt.nz/industry/sectors/meat-ostrich-emu-game/meatman/is9/is9-all.pdf

NZFSA (2004) New Zealand Food Safety Authority Industry Standard 6 / Industry Agreed Standard 6 (IS6/IAS6) http://www.foodsafety.govt.nz/industry/sectors/meat-ostrich-emu-game/meatman/is6/is6.pdf

NZFSA (2009a) Code of Practice - Processing of Poultry Part 2: Good Manufacturing Practice - Chapter 5: Slaughter and Dressing http://www.foodsafety.govt.nz/elibrary/industry/processing-code-practice-poultry/2009-poultry-cop-part-2-chap-5-slaughter-dressing.pdf

NZFSA (2009a) Code of Practice - Processing of Poultry: Part 2 – Good Manufacturing Practice - Chapter 9: Secondary Processing http://www.foodsafety.govt.nz/elibrary/industry/processing-code-practice-poultry/2009-poultry-cop-part-2-chap-9-secondary-processing.pdf

NZFSA (2015) http://www.foodsafety.govt.nz/elibrary/industry/dairy-nzcp1-design-code-of-practice/amdt-2.pdf

OMAR (2016) New Zealand Food Safety Authority, Overseas Market Access Requirements, http://www.foodsafety.govt.nz/industry/exporting/market-access/omars.htm

Olatunji, J., Shim, Y. M., Ferrua, M.J., Love, R.J. and East, A.R. 2016. Toward a fast and flexible heat transfer model for horticultural products packaged into boxes. Proceedings of the 4th IIR Conference on Sustainability and the Cold Chain, Auckland, New Zealand, April 2016.

Olatunji, J., Love, R.J., Shim, Y.M., Ferrua, M.J., and East, A.R. 2017. Quantifying and visualising variation in batch operations: a new heterogeneity index, Journal of Food Engineering, 196, 81-93

Ojo, E., Miro, L., Farid, M. M. Cabeza, L. F. 2012a Improving thermal performance of freezers using phase change materialsOriginal Research Article, International Journal of Refrigeration, 35(4), 984-99

Ojo, E., Miro, L., Farid, M. M. Cabeza, L. F. 2012b, Thermal analysis of a low temperature storage unit using phase change materials without refrigeration system, International Journal of Refrigeration, 35(6), 1709-171

Ojo, E., Miro, L., Farid, M. M., Martin, V., Cabeza, L. F. 2014, Energy management and CO_2 mitigation using phase change materials (PCM) for thermal energy storage (TES) in cold storage and transport International Journal of Refrigeration, 42, 26-35

O'Sullivan, J.L., Ferrua, M.J., Love, R.J., Verboven, P., Nicolai, B.M., East, A.R. 2013. Performance of the forced-air cooling process of fruit packed in polyethylene liners as a function of pallet orientation. Proceedings of the 2nd IIR Conference on Sustainability and the Cold Chain, Paris, France, April 2013.

O'Sullivan, J., Ferrua, M., Love, R., Verboven, P., Nicolaï, B., East, A. 2014. Airflow measurement techniques for the improvement of forced-air cooling, refrigeration and drying operations, Journal of Food Engineering, 143, 90-101.

O'Sullivan, J., 2016. Significant factors effecting the forced-air cooling process of polylined horticultural produce, Massey University, Palmerston North, New Zealand (PhD thesis).

O'Sullivan, J., Ferrua, M.J., Love, R., Verboven, P., Nicolaï, B., East, A., 2016. Modelling the forced-air cooling mechanisms and performance of polylined horticultural produce, Postharvest Biology and Technology, 120, 23-35.

O'Sullivan, J., Ferrua, M.J., Love, R., Verboven, P., Nicolaï, B., East, A., 2017., Forced-air cooling of polylined horticultural produce: Optimal cooling conditions and package design, Postharvest Biology and Technology, 126, 67-75

Paniagua, A.C., East, A.R., and Heyes, J.A. 2012. Effects of delays in cooling on blueberry quality outcomes, Acta Horticulturae 1012, 1493-1498 Paniagua, A.C., East, A.R., Heyes J.A. 2014. Interaction of temperature control deficiencies and atmosphere conditions during blueberry storage on quality outcomes Postharvest Biology and Technology, 95, 50-59.

Redding, G., Yang, A., Shim, Y-M., Olatunji, J., and East A.R. 2016. A review of the use and design of produce simulators for horticultural forced-air cooling studies. Journal of Food Engineering 190, 80-93.

Rosenvold K., Wiklund, E., (2011), Retail colour display life of chilled lamb as affected by processing conditions and storage temperature, Meat Science, 88(3), 354-360

Shim, Y.M., Olatunji, J.R., Zhou, J., Love, R.J., Ferrua, M.J. and East, A.R. 2016. Industry survey on the pressure drop across palletized horticultural produce. Proceedings of the 4th IIR Conference on Sustainability and the Cold Chain, Auckland, New Zealand, April 2016.

Smale, N. J. 2004, Mathematical modelling of airflow in shipping systems: model development and testing. Massey University, Palmerston North, New Zealand (PhD thesis).

Statistics NZ (2016) Data retrieved from the website of the New Zealand Government's Statistics department: http://www.stats.govt.nz/

Tanner, D. J., and N. D. Amos., 2002, Temperature variability during shipment of fresh produce. Acta Horticulturae, 599, 193-203

Tanner, D. J., Cleland, A. C., Opara, L. U., Robertson, T. R. 2002, A generalised mathematical modelling methodology for design of horticultural food packages exposed to refrigerated conditions: part 1, formulation. International Journal of Refrigeration 25(1): 33-42.

Tapp, R. (2016) *Trust for the Destruction of Synthetic Refrigerants*, Personal Communication

Wang, J. F., Carson, J. K., North, M. F., Cleland, D.J. (2008). A new structural model of effective thermal conductivity for heterogeneous materials with co-continuous components, International Journal of Heat and Mass Transfer, 51(9-10), 2389-2397

Wang, J. F., Carson, J.K, Willix, J., North, M. F., Cleland, D. J. (2009). Application of a co-continuous composite model of effective thermal conductivity to ice-air systems, International Journal of Refrigeration, 32(3), 556-561

Wang, J. F., Carson, J.K, North, M. F., Cleland, D. J. (2010). Prediction of thermal conductivity for frozen foods with air voids, Proceedings of the 1st IIR International cold chain conference, Paper #173, Cambridge, UK

Werner, S.R., Vaino, F. , Merts, I., Cleland, D.J. 2006. Energy use in the New Zealand cold storage industry, in: IIR-IRHACE Conference, Auckland, Paper # 9.1, 313 - 320

Zhao, J.M., Bronlund, J.E., East, A.R. 2015. Effect of cooling rates on kiwifruit firmness and rot incidence in subsequent storage. Acta Horticulturae 1079:313-318.

Table 1: New Zealand production and exports of foods likely to require refrigeration. Sources: [a] Statistics New Zealand (www.stats.govt.nz), [b] Meat Industry Association (mia.co.nz), [c] Poultry Industry of New Zealand (pianz.org.nz), [d] Seafood New Zealand (www.seafood.co.nz)

NZ production of food likely to require refrigeration

	2015 tonnes		2012 tonnes	
	Total	Exported	Total	Exported
Meat				
Beef[a,b]	448,250	428,245	366,620	345,664
Sheep-meat[a,b]	386,689	378,247	318,364	310,825
Poultry[a,c]	211,040	201,593	176,778	168,865
Pork[a]	14,688	-	49,254	-
Other including co-products[a]		261,853		227,457
	1,060,667	1,269,938	911,016	1,052,810
Dairy				
Butter[a]		477,285		445,154
Cheese[a]		302,900		274,906
		780,185		720,060
Horticultural Produce				
Kiwifruit[a]		407,942		384,095
Apples[a]		308,072		274,533
Other[a]		763		696
		716,777		659,324
Seafood[a,d]		289,911		195,192
Total		5,823,711		5,059,580

Table 2: New Zealand food imports. Source: Statistics New Zealand (www.stats.govt.nz)

New Zealand Imports of Foods likely to require refrigeration

	2015 tonnes
Meat, offals chilled or frozen	61,175
Meat preparations	16,570
Dairy	51,042
Fruit and vegetables Chilled or frozen	213,229
Fruit and vegetable preparations	41,207
Seafood fresh or frozen	3,487
Seafood preparations	15,765
Other	334
Total	402,808

Table 3: New Zealand Refrigeration energy use by sector. Source: Energy Efficiency and Conservation Authority (www.eeca.govt.nz)

Refrigeration energy use by sector (J x 10^{12})

	2014	2012
Accommodation and Food Services	992.9	926.6
Dairy Cattle Farming	1358.8	1132.5
Dairy Product Manufacturing	1586.6	1350.1
Household	7289.7	7245.5
Meat and Meat Product Manufacturing and Seafood	1578.6	1574.2
Other Food Product Manufacturing	350.9	320.1
Retail Trade - Food sector	3902.2	3462.5
Wholesale Trade - Food	458.0	408.4
Other	209.7	372.3
Total	17,727.49	16,792.06

Table 4: New Zealand recovery rates of CFC, HCFC and HFC refrigerants. Source: refrigerantrecovery.co.nz

Year to March 31st	CFC	HCFC	HFC	Total
2007	1,112	10,154	3,524	14,790
2008	3,559	8,721	4,304	16,584
2009	1,070	15,814	8,030	24,914
2010	1,550	23,807	14,825	40,182
2011	2,712	16,498	12,700	31,911
2012	1,369	14,959	15,039	31,367
2013	566	10,243	23,189	33,998
2014	550	6,793	26,898	34,241
2015	54	3,346	13,765	17,165
2016	65	5,352	30,267	35,685