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Testing of Purpose-built refrigerating Vaccine Storage Cabinets

Report number E175VC-01

Test Results - Tables & Comments

Prepared for the

Australian General Practice Network

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CONTENTS

1 EXECUTIVE SUMMARY

● Eight purpose-built vaccine storage cabinets were tested in laboratory conditions to check how well they would perform under a range of conditions and situations.
● Many performance tests were undertaken with significant differences in results. Energy consumption was also measured.
● When operated in a normal non stressful environment, the tested models generally provided acceptable storage for vaccines in line with the 'Strive for 5' guidelines.
● In severe conditions some products didn't maintain suitable vaccine storage temperatures, either in specific locations within the cabinet, or worse, for the average of the whole compartment taken from many sensors.
● Tests were also conducted to see how well these products would handle power loss or interruption, and while big differences in performance were found, even the better ones would only provide a very limited protection period without power, before vaccines would be at risk.
● This testing suggests that careful management practices are generally very important in maintaining acceptable storage requirements even with these purpose-built vaccine storage products.
● This testing provides evidence for the need for an Australian standard covering the performance of vaccine storage cabinets.

2 INTRODUCTION

2.1 Aims, project background and scope

The aim of this project was to provide a table of comparative performance results for eight vaccine storage cabinets in various strictly controlled laboratory tests. This included investigating how well the products would maintain vaccines in both general and adverse, but not unlikely conditions, in normal use around Australia.

There is no specific Australian standard for temperature testing of these products (at the time of this report, as understood by the Australian General Practice Network (AGPN) & this lab). This laboratory was required to devise appropriate methods using its experience and expertise to test the products provided, relative to appropriate vaccine storage needs.
The tests used here have been based on a number of factors including: - requirements within the National Vaccine Storage Guidelines (Strive for 5); some details and aspects of the performance standard for household refrigeration[1]; this laboratory's testing experience in thermal testing and research; and consultation with the AGPN.

Testing scope was limited to a specific amount of laboratory time, but necessarily included method and general research in addition to conducting the result generating test runs and analysing data produced. Testing and data analysis therefore, while giving a good perspective on performance of these products, is not necessarily fully comprehensive. Further method development, test programs and additional data analysis might yield additional useful information, particularly regarding the possible production of any future Australian standard related to the performance of vaccine storage cabinets.

[1] AS/NZS4474 Performance of household electrical appliances – Refrigerating appliances; Part 1: Energy consumption and performance.

2.2 The products under test

Eight purpose-built vaccine storage cabinets were provided to Test Research by the client, the Australian General Practice Network (AGPN). The units, from four suppliers i.e. two cabinets from each, included small to large units (with claimed net volumes (or capacity) between 135 and 500 Litres); two with solid metal faced doors, six with glass (see-through) doors.

1.) **ICS Pacific G135L** (135 L)	5.) **Rollex (LEC$^+$) PE 507** (137 L)
2.) **ICS Pacific G400L** (377 L)	6.) **Rollex (LEC$^+$) PE 907** (275 L)
3.) **Quirk's FKG 311** (281 L)	7.) **Thermoline TEPR-230-1-GD** (230 L)
4.) **Quirk's FKG 371** (351 L)	8.) **Thermoline TEPR-500-1-GD** (500 L)

2.3 The testing laboratory - Test Research

Test Research is an independent laboratory wholly owned and operated by the Australian Consumers' Association (which provides 'Choice' independent product testing, consumer services and publications). The laboratory is accredited by the National Association of Testing Authorities (NATA) for performance testing of 'Household refrigerating appliances' to AS/NZS 4474.1 (accreditation number 1702). Test Research conducts tests for external clients including: the government for refrigerator performance and energy labelling check-testing; for manufacturers to enable registration of their products for sale within Australia; and for other bodies in various areas of temperature related research. Test Research has also developed, and conducts special performance tests, for various household refrigeration products for publication by Choice. A representative from this laboratory is also a member of the committee for the existing household refrigerating appliance standard (Standards Australia), and has had involvement with the current development of a new international standard.

2.4 The tests

Tests were conducted to determine the comparative performance of these specific cabinets in a controlled laboratory environment. They included operation while under various conditions including: - operation in normal and more stressful room temperatures; ambient temperature change including hot and cold conditions; warm-up tests after power has been turned off, and also power interruptions; cooling strength or recovery checks; plus the effects of the door being open; for each test unit. Test runs generally included any periodic defrosting operation the cabinet might do, if applicable.

Information sought from these tests included: - compartment temperatures combined with temperature uniformity; temperature fluctuations under normal running; and the ability of the test units to handle more extreme conditions. Temperatures within vaccine packaging and other situations were checked. Energy consumption was also measured. A number of extra test-runs were trialled to further research temperature aspects of these units' performances and to aid in formulating possible appropriate future tests for these products.

For a brief description of each of the final reported tests refer to each of the individual headings and accompanying comments under THE TEST RESULTS. The 'THE TEST METHOD & BACKGROUND INFORMATION' section below includes information on the positions were temperature sensors where placed. This will be important for readers to fully understand the results tables, particularly the details and how they are indicators for conclusions. Important also for understanding possible ramifications that could apply, where reported temperatures indicate less than ideal results particularly those for specific locations inside the cabinets.

3 SUMMARY & COMMENTS

3.1 General Overview of Results

Significant differences were found between products when a range of eight vaccine storage cabinets were tested in controlled laboratory conditions.

Generally, all tested units operated satisfactorily in our tests under non-demanding conditions with a continuous electricity supply and the door closed. That is they operated in line with the "Strive for 5" guidelines maintaining internal temperatures between 2°C and 8°C in a 25°C room.

All maintained acceptable 'average' compartment temperatures with warm ambient temperatures of 32°C.

However two units were not able to maintain acceptable average compartment temperatures in hot ambient temperatures of 43°C.

Furthermore, significant temperature differences were found within the compartments of some cabinets, particularly when operating in warm and hot conditions. In particular cabinets in stressful conditions, some storage locations would be acceptable for safe storage of vaccines while others would not. The lack of compartment uniformity also presents the risk that monitoring only one position within a cabinet could give a misleading picture. These results indicate that it would be generally advisable to monitor multiple positions within cabinets storing vaccines to ensure that acceptable conditions are maintained across the compartment.

The units did not cope well when the door was left open for an extended period. We opened the door for times of 8, 12 and 15 minutes in a 25°C room. When the door was left open for 15 minutes all gave very unacceptable vaccine storage conditions. In 7 minutes the average compartment temperature of one unit reached 12°C. This test could be an alternative indication of cooling strength.

Recovery times, or cooling strength performance relating to door openings and power interruptions, varied significantly over the models tested.

A test simulating a power failure in a room at 32°C can indicate insulation properties and showed considerable performance differences. One of the tested models was much better than the others, but even so, none were very good. Even the best wouldn't be able to maintain cool temperatures suitable for vaccine storage for very long in a black-out.

In a power failure the warming air rises to the top of the compartment, making storage there worse than that lower down and to some extent for the general average of the compartment. The circulation fan in these cabinets generally runs continuously, however with a power failure, this fan no longer operates and temperature uniformity suffers further.

Energy efficiency also was relatively poor for most tested units, and this needn't be so: efficient compressors can provide strong cooling as evidenced by some household refrigerator/freezer models. The likely running cost for some of the worst of these tested models could be two and a half times that for a typical new large Australasian produced refrigerator freezer[2].

Temperature fluctuation, as a result of compressor cycling, was one area where many of the tested units performed quite well.

[2] A number of popular 500 litre Australasian made refrigerator/freezers have energy labels of just over 500 kWh/year, refer energyrating.gov.au.

Temperature performance aspects are important requirements in judging the suitability of appliances for storing vaccines safely in a wide range of conditions and situations.

3.2 Brief summary of specific test results

1. All of the tested products performed acceptably in a non-demanding environment (25°C). The average of the 7 sensors was within 1°C of the target temperature (5°C) for all models. This comment excludes the temperature range or differences across the individual sensors.

2. Temperature uniformity (the difference over the seven sensors) was relatively good in 25°C except for the **ICS Pacific G400L** (2ICS), which was only border-line, with the coldest and warmest sensors at 2.9°C and 8.1°C respectively (or a 5.8°C difference). Half of the models had all their seven sensors within a difference of only 1.6°C. The situation changed when the ambient temperature was warmer (see below).

3. All models maintained their set temperatures quite well when the ambient temperature changed from 25°C to 10°C and 32°C (all models had factory set controls).

4. The two **ICS Pacific** models were unable to maintain temperatures when tested in an ambient temperature of 43°C. This means they started to have problems at a temperature warmer than 32°C, but cooler than 43°C, and this was particularly so for the **ICS Pacific G135L** (1ICS); its compartment average exceeded 28°C in the 43°C test. The two **Thermoline** models had some sensor readings that exceeded 8.0°C even though their average temperatures remained close to 5°C in the 43°C ambient temperature.

5. Temperature uniformity was less good generally in the tests in warmer rooms; compared to cooler conditions. Many had problems in the 43°C test, with some individual sensor temperatures above 8°C. The **Rollex** models were generally the best, and the **Quirk's** next. Refer to later specific 'Operation test' results for details.

6. Temperature fluctuations were generally small (good) for the tested models. The worst sensor result for each cabinet was most commonly a fluctuation of less than 2°C. The **ICS Pacific G135L** (1ICS) had the worst overall result with a 3.0°C fluctuation in the 25°C test; with the **Thermoline TEPR-230-1-GD** (7THE) the next worse with results from 2.2 to 2.8°C. As detailed under the following section, the fluctuations for our lagged sensors roughly equate with what a packaged vaccine dose might experience.

7. One of the two models with a solid door, the larger **Rollex (LEC$^+$) PE 907** (6ROL) performed considerably better than the others for the warm-up test. These tests can indicate insulation performance and/or a large thermal mass, which can resist the affects of external warming. Some models performed notably better than others. All of these tested models only provided a limited time in our tests, to maintain vaccine-acceptable temperatures when there was an extended power failure.

8. A pull-down test, which is a basic cooling strength test used for household refrigerating appliances, was conducted but may not be good for testing 'ideal' vaccine storage cabinets. It can give an indication of cooling strength unless the system also cools a large thermal mass, probably a desirable feature. We tested cooling speed from when the warm unit was switched on, while situated in a warm room. The two **Quirk's** models and the **Thermoline TEPR-230-1-GD** (7THE) were the fastest and the **Rollex** models the slowest.

9. Door opening tests can be another indicator of cooling strength. One test was where the door was opened for a lengthy 15 minutes then closed, while the units were operating; and then left to recover. The results show how quickly the interior temperatures warm with the door open. The15 minute test indicated that all the cabinets would subject vaccines to temperatures above

8°C, and generally 12°C too, for significant times (based on the 'average' compartment temperature). The two **Quirk's** models were the best: their 'average' temperature remained above 8°C for 22 minutes (and peaked at around 13°C), while not good, this was much better than some of the others.

10. Tests simulating a power interruption and resumption (i.e. power off and recovery in a 32°C room) relate to a cabinet's ability to resist warming and then the need for good cooling strength to recover back to normal. This is a complex test that combines warm-up resistance with cooling strength among other possible factors. Our test aim being to find the approximate time that power could be lost, without, or almost without an adverse vaccine storage condition occurring; based on only the cabinet's 'average' temperature. The best performers could only support a relatively short black-out; the best, at approximately 33 minutes was the **Rollex (LEC$^+$) PE 907** (6ROL) with the two **Quirk's** models a little less. The worst time for this test was from the **ICS Pacific G135L** (1ICS) with only a 13 minute power loss being a risk; and with the two **Thermoline** models and the other **ICS Pacific**(2ICS) model only modestly better. These results are using the average of all sensors; generally locations at the top of the compartment would fare less well.

11. Exploratory testing was briefly looked at, in relation to the possibility of improving warm-up performance. The premise being that by adding a thermal mass to the top shelf of a compartment, this might help vaccines stored below, by providing a convection cooling source to slow the compartment's warm-up rate in case of a black-out. However a brief exploratory test undertaken wasn't conclusive and more experimentation would be needed to confirm that a suitable method to do this was possible and practical.

12. Energy consumption for appliances is a factor for both cost, and environmental considerations. When compared to modern refrigerator/freezers that do a much greater cooling job, the vaccine storage cabinets compared very poorly with one exception. The **Rollex (LEC$^+$) PE 907** (6ROL) was much lower than the others for power consumption; refer to results for our test in a 25°C room. The two **Thermoline** models used the most power; with the smaller 230 litre model using virtually the same power as its 500 litre sibling. This was roughly 4 ¾ times that of the 275 litre Rollex.

13. A number of significant differences were found between the models tested. In particular tests, a few were much better than others, and a few were generally poorer performers overall. The two **ICS Pacific** models did not operate acceptably in hot conditions and could not be recommended for locations that hot operating environments could be possible. Even other models had areas within their cabinets where stored vaccines could be placed at risk in some circumstances.

14. Overall the large **Rollex (LEC$^+$) PE 907** (6ROL) with a non-glass door, although not good in all our tests, was the best performer generally for maintaining acceptable vaccine temperatures, and did so using the least energy by far.

4 THE TEST METHOD & BACKGROUND INFORMATION

4.1 The starting point

This test project included the need for some preliminary investigative testing and then the development of specific tests to supply answers in accord with the aims of the testing. The lack of any known existing performance test procedure for purpose built vaccine storage cabinets meant starting almost afresh. This point also influenced the direction a little because of the possibility that our development efforts could provide further benefit, should a specific Australian standard be developed in the future.

- The first factor in understanding our test method and the specific results, is the method for placing temperature measuring sensors within each test cabinet (see 4.3 below).
- The next factor was the way, or how we would conduct the testing. This is an area of speciality and an existing standard (for household refrigerating appliances) is well suited to the environmental or test room requirements for vaccine cabinets[3].
- The third factor was what we would test for. It was agreed that this project would start by looking at general operation in a normal room and then test for more extreme ambient temperature environments, both warm and cool, the same as required for household fridges. It was asked that the project also include if possible, some checks relating to the disruption of the electricity supply and also if possible to consider aspects of product cooling strength or recovery after a power loss. The tests we carried out and reported on are under section 5 THE TEST RESULTS. Refer to the various table headings and comments for details.

4.2 Background information about refrigerating products, performance & Australian conditions

Environmental conditions, particularly very hot and cold room temperatures can impact considerably on how well refrigerating systems perform. This applies generally to a system's strength to overcome hot conditions and to recover from the addition of warm loads, doors being open too long, or after an interruption to the electricity supply to the product. Cold room temperatures can also be problematic. A cabinet with only a refrigerating system might only operate infrequently or not at all in the cold; and internal compartment temperatures as well as temperature uniformity, can be adversely affected.

Generally environmental conditions can be the cause of changes to internal temperatures and the distribution pattern of cooling air within the cabinet itself and so affect how well correct storage conditions are maintained, for all parts of the compartment. Australia has considerable extremes that can be very difficult for refrigerating appliances.

4.2.1 Performance requirements for adequate cooling

Vaccines in general practices have been or continue to be, stored in a range of refrigerating appliances, including household fridges, and because there are basic similarities with vaccine storage cabinets, the testing needs of the cabinets have been considered alongside what is already regulated for household refrigerating appliances.

All household refrigerators, freezers and refrigerator/freezers[4] sold in Australia need to meet specific performance requirements and comply with minimum energy performance standards; otherwise their sale is not allowed. This includes energy efficiency, (measured in 32°C), which for popular configurations is very strict, and very importantly, they must be able to operate satisfactorily in ambient temperatures of 10°C and 43°C. The Australian standard provides a minimum performance level that

[3] The general testing, test room specifications, measuring equipment/instrumentation, calibration and most general requirements have been carried out in accordance with AS/NZS4474.1:2007 (Performance of household electrical appliances – Refrigerating appliances Part 1: Energy consumption and performance. Some statements made in the report also refer partly to part 2 of the same standard: Part 2 Energy labelling and minimum energy performance standard requirements. Also refer to the introduction which includes reference to our general approach to testing.

[4] The term 'fridge' when used alone within this report is intended to mean any household refrigerating appliance including a refrigerator/freezer as found in most homes, a single compartment fresh food model (all-refrigerator), freezer, or bar fridge etc. Although the term "vaccine fridge" may be common we have generally used the term "vaccine storage cabinet" (or cabinet – for short) to describe the products under test. In some environments heating as well as cooling could be an appropriate requirement to ensure vaccine safety.

fridges must meet; however it is likely that climate conditions could exceed those of the standard test within homes or kitchens for parts of Australia for periods of time, on occasions.

Vaccine storage cabinet installations could cover a range of situations and might be operated in air-conditioned premises or less extreme situations typically; however in situations including very hot and very cold climates and at times when air-conditioning if available was not operational, then they could also be subjected to quite extreme conditions similar to that of household fridges, but with possibly much greater consequences, should they fail to perform. Therefore it might not be unreasonable to expect purpose built vaccine storage products to perform to the geographical requirements for household fridges or better.

This test project did not include performance testing of any household refrigerating appliances as to their suitability or lack thereof for storing vaccines.

4.2.2 General description of vaccine storage cabinets under test (compared to household fridges)

The tested units included small and quite large cabinets. All had a single compartment and included a number of adjustable position coated-wire type shelves. Two models (the **Rollex's)** also had a wire basket at the bottom. All the tested models had traditional refrigeration systems, which operate with a compressor. Also these models have a cooling plate, some are exposed, some are behind a cover; and all had a fan, which appeared to operate continuously, to assist air movement past the cooling source and aid general air circulation around the compartment.

This is different to 'cyclic-defrost' model refrigerators that have a cooling plate (in the fresh food compartment) that relies solely on convection for circulating the cooled air from the rear plate). This plate is generally very cold, particularly at the lower rear and also beneath the plate. However the temperature can be quite warm at the top front of the cabinet where the rising warm air can collect due to convection. This type of fridge is different to frost-free refrigerator/freezers that use a fan, predominantly only while the compressor is running, to circulate very cold air in the freezer and then to the fresh food compartment. A refrigerator/freezer (if the freezer is at the top) however does have a source of extra cold air (from the freezer, particularly if loaded) that can help in the possibility of a power failure because the cool air can fall and cool the lower compartment via convection, while the fan is without power. The large majority of refrigerator/freezers sold currently in Australia are frost-free models and most do not have a rear cooling plate in the fresh food compartment, but instead receive their cooling air via the freezer from one of more fan(s) circulating the air. This air typically enters the fresh food compartment through vents in a duct and it can be quite cold, very close to the vent e.g. below 0°C. Unlike the vaccine cabinets, the fans in household frost-free fridges generally only operate while the compressor is cooling and is typically off when the compressor is off. Apart from very cold air entering the fresh food compartment, household refrigerating appliances can have other problems in relation to maintaining accurate set temperatures. Many have significant temperature variation as the room temperature changes without the controls being changed. This can be a very severe problem with some designs. Tests we've carried out on a number of bar fridges with simple ice compartments (termed a box evaporator) show these products could vary so much that even some day-to-night room temperature changes could cause air below the evaporator to vary from being quite warm to below 0°C and back again, in less than 24 hours.

Some vaccine cabinets come with a glass or solid door. Glass doors have the advantage that users can see the contents and perhaps minimise door opening times. However even though the glass door models in this test were at-least double glazed, they are likely to be less well insulated (although this is not necessarily so) than those with insulated solid doors. This aspect of performance was not a part of this particular test program.

4.3 Temperature Measurements and Sensor placement

Each vaccine storage cabinet was fitted with temperature sensors that were connected to calibrated measuring equipment, and operated inside temperature controlled test rooms. All readings were logged every minute, with tests running at least for many hours and in some cases, days.

4.3.1 Sensor Placement

Ten calibrated sensors for measuring air temperature were placed in each test unit. For all tests a minimum of seven sensors were placed around the compartment to record internal compartment air temperatures.

For a number of tests three additional sensors were located within and around a single vaccine package placed adjacent to the central measurement point (on the same shelf on the LHS). The dummy loads used were one single dose (either 0.5 or 1ml) contained inside an inner plastic enclosure with an outer light cardboard box.

Other test runs used these additional three sensors (previously from the vaccine packs) in selected locations checking for possible places with temperature extremes.

The main air temperature sensors: were placed at various positions within the compartment including its centre, at ¼ of the height from the top and bottom; at four peripheral and other selected locations. The main seven sensors were lagged with brass masses equivalent to a small amount of water to better represent the degree of fluctuation in temperatures that might be experienced by the actual vaccines within packaging. *For more on lagging etc. see below "Recorded data, Temperature Sensors & Test rooms".*

Temperature measurement positions for each cabinet – the general placement for sensors 1 to 7 were as shown in the following table:

Sensor positioning for compartment temperature measurements

Sensor Number	Position within cabinet	Comments
Sensor 1	Centre of cabinet (above a shelf)	General central (representative?) position
Sensor 2	Top front LH side (50 mm down from top surface)	50 mm in from each corner surface/door
Sensor 3	Top rear LH side (50 mm down from top surface)	50 mm in from each corner surface
Sensor 4	Bottom front RH side (50 mm above floor surface)	50 mm in from each corner surface/door
Sensor 5	Bottom rear RH side (50 mm above floor surface)	50 mm in from each corner surface[5]
Sensor 6	Front centre at ¾ height (at front edge of shelf)	
Sensor 7	Rear centre at ¼ height (at rear edge of shelf)	This is below the cooling plate of some models
Refer also to other information in this section regarding sensors.		

4.3.2 Compartment Temperature Uniformity

The seven sensors positioned at various locations inside each cabinet, provide a good indication of the degree of temperature uniformity likely to exist throughout the compartment. While the products have a fan to circulate the air around the compartment this is no guarantee that the temperature measured at the centre of the compartment, or at any particular location, will be the same as all others. Compare the temperature for each sensor (where shown in the results tables following) to see how even the temperatures are maintained over all sensors. Also consider the specific sensor location (see the table above) for those that vary significantly (colder or warmer) to that of the average, or to that measured in the centre of the compartment (sensor 1). All the tests are, in practical terms carried out with an empty cabinet: uniformity could not be assumed to improve when the products are filled with vaccines and air movement could be further restricted

[5] Some exceptions: - if this position was outside a bottom basket the measurement was increased beyond 50 mm so that the sensor was inside this storage container, where vaccines could be stored.

4.3.3 Recorded data, Temperature Sensors & Test rooms

Data was logged: - from the sensors placed in each cabinet for compartment temperatures, for room temperatures and for energy used by each product; at one minute intervals onto computer files. The general requirements of testing household refrigerating appliances to AS/NZS 4474.1 were applicable to this testing, including specifications for test rooms and instrumentation.
The sensors were placed in consistent relevant positions as shown in the sensor placement table above. These sensors generally were in positions where vaccines could be stored; although there were a few possible exceptions for one sensor for some units[6] and even these were indicative or likely to give an equivalent result to a nearby location where vaccines could be stored.
Where the compartment top was uneven or a header at the top of the opening protruded below the cabinet ceiling the lower location was used for the sensor to be more practical for vaccine storage.

As mentioned above three additional sensors were initially used within and around a sample vaccine package to give an indication of the temperature the actual dose was experiencing. For later test runs they were relocated to check extremity locations inside the cabinet.

4.3.3.1 Sensor lagging

Lagging was used with the main seven sensors but not the three additional ones. The lagging on the sensors comprised brass masses with a thermal mass equivalent of approximately 10 grams of water (or a small amount of liquid) for dampening the temperature fluctuations to some degree.
The un-lagged sensors also measure air temperature but have a very fast response time when subjected to changes in temperature. Items stored with encapsulated air around them have some thermal mass and varying degrees of insulation, and this includes very small vaccine doses inside packaging. They don't achieve exactly the same instantaneous temperature of the outside air that their packs are exposed to, as the surrounding air temperature is changing. In almost all refrigerating appliances the air temperature is constantly varying, cooling and warming, while the average temperature may be constant over time. These fluctuations can be important because they can impact on the temperature of the stored vaccines. Temperatures that go up and down and contain high peaks, particularly if they occur for a significant time period might be more detrimental to vaccines than a steady (unvarying) temperature, where both averages over time are identical.
Measurements of fluctuations taken from the un-lagged sensors placed inside packaging next to vaccines were very similar to the results of the lagged number 1 sensor, outside and alongside the vaccine pack.
Therefore the lagged sensors show temperatures and their fluctuations very similarly to what is likely to be experienced by a vaccine dose that is inside its packaging.

[6] The top front sensor (number 2) was located with consistent dimensions for all units. This position in many of the units was only a little above the highest practical shelf position and a vaccine on a very low stack could easily be stored here. For the **ICS Pacific G400L** (2ICS) however, the stack would need to be quite high, the highest shelf position was about 150 mm below the sensor. Also three other units have shelves that do not extend as close to the door surface as most, the **Rollex (LEC$^+$) PE 507** (5ROL), the **Rollex (LEC$^+$) PE 507** (5ROL) and the **Thermoline TEPR-500-1-GD** (8THE). For these three, the sensor was forward and above the shelf and particularly for the latter two it would be less likely that vaccines would be stored here. However the consistent sensor position for these could give an equivalent result to nearby areas where vaccine could be stored. For instance, while the **Thermoline TEPR-500-1-GD** (8THE) had its top sensor forward of the top shelf, it has a relatively large space higher than the door opening and the top shelf can be mounted near or higher than the sensor height and, vaccines could be stored there.

5 THE TEST RESULTS

5.1 Test and Table Notes

5.1.1 Tested products

Code used	Brand/Supplier	Model	Door type	Net volume (capacity - claimed or stated)	Size comment
1ICS	ICS Pacific	G135L Medical	Glass	135 litres	Small (bench)
2ICS	ICS Pacific	G400L	Glass	377 litres	Tall
3QUI	Quirk's	FKG 311	Glass	281 litres (306 gross)	Medium tall
4QUI	Quirk's	FKG 371	Glass	351 litres (381 gross)	Very tall
5ROL	Rollex (LEC^{+})	PE 507	Solid	137 litres (153 gross)	Small (bench)
6ROL	Rollex (LEC^{+})	PE 907	Solid	275 litres (286 gross)	Medium tall
7THE	Thermoline	TEPR-230-1-GD	Glass	230 litres	Tall
8THE	Thermoline	TEPR-500-1-GD	Glass	500 litres	Very tall
The code shown in the first column is used in some following tables as an abbreviation for each tested model.					

All products were supplied with pre-set controls and tested as supplied. Volumes are from web sites and product labels.

5.1.2 Notes used with tables

1. Codes for products: Some of the following tables include only a code to identify each tested model, for space reasons, to include extra columns as shown below:

CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD

2. The term 'adverse event' is used in tables and comments. This is an abbreviation for "Adverse vaccine storage event" as per "Strive for 5", and based on temperature excursion limits to +12°C lasting no longer than 15 minutes.
   (For an adverse event in our testing we used either constraint: that temperatures exceed 8.0°C for longer than 15 mins or alternatively reach/exceed 12.0°C. Generally for the purposes of this document these 'adverse event' criteria have been applied to the average of seven sensors placed throughout each cabinet under test. However it is important to note that it would be most likely that some individual sensors or locations will experience temperatures that exceed that of the average.)

3. Specific formatting and other notes that apply to most tables are shown within the first table under 5.2.2, see NOTE 1, NOTE 2 & NOTE 3, and other table notes can also apply to following tables, e.g. see the bottom row of the table under 5.2.4 (e.g. the use of bolding, underlining and colours for warm and cold temperature results etc.).

4. Colours are used in many of the tables to highlight specific results, usually the average temperature, or to assist interpretation generally. The following legend applies to the ambient room temperature tests; the product identification code (used in place of the full brand & model identification to allow more columns to fit in some tables) applies to all tables.

Colour used for :- Test result in a 25°C room	Colour used for :- Test result in a 32°C room	Colour used for :- Test result in a 43°C room	Colour used for :- Test result in a 10°C room	Product ID (code)

5. Note: N/a = 'Not applicable' throughout this report

Detailed Results (Tables & comments)

5.2 Normal Operation test (in a 25°C room)

The following table shows the indicative compartment temperature of each tested model from different viewpoints when operated in a non-demanding environment. Two ways of looking at the compartment temperature could be: using averages of specific sensors, and another from just one sensor e.g. being the one in the centre of the compartment. If the air inside was perfectly circulated, all these readings would be identical, however clearly this is not the case. For this test project we have generally used an average of 7 sensors as the basis for comparisons.

5.2.1 Average Temperatures

Table of Average temperatures (°C) when in a 25°C room

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
For sensors:								
Av All 7	5.4	5.8	4.5	4.4	5.7	4.7	5.5	5.4
Av 1, 6 & 7	5.2	**6.5**	4.8	5.0	5.8	4.6	6.2	6.0
1 (centre)	5.3	4.8	**3.9**	**3.8**	5.5	4.4	5.3	5.3

The factory pre-set controls for all the tested models gave acceptable temperatures based on the various average of the sensor combinations or the central senor reading, as shown above.

The following table shows temperature uniformity - the temperatures recorded at each of seven sensors placed around the compartment, many being near extremity locations plus the average of all seven sensors, and the temperature variation between the warmest and coolest sensor.

[The locations within the cabinets for each sensor are shown in the table in 4.3.1 Sensor Placement*.]*

5.2.2 Temperature Uniformity within the compartment when in a 25°C room

Table - Individual sensor Average Temperatures (°C) when in a 25°C room: Temperature Uniformity

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Sensor 1	5.3	4.8	3.9	3.8	5.5	4.4	5.3	5.3
Sensor 2	5.3	**8.1**	5.5	5.8	6.2	5.0	**7.0**	**7.1**
Sensor 3	4.9	6.6	5.1	5.4	5.7	4.3	6.1	5.5
Sensor 4	6.3	5.6	4.4	3.9	5.5	5.3	4.8	4.9
Sensor 5	5.6	6.1	4.4	3.8	5.7	5.4	4.4	4.7
Sensor 6	5.5	6.3	4.5	4.4	5.5	4.4	6.0	5.3
Sensor 7	4.9	**2.9**	4.0	3.8	5.5	4.2	5.0	4.8
Ave. All 7	**5.4**	**5.8**	**4.5**	**4.4**	**5.7**	**4.7**	**5.5**	**5.4**
NOTE 1: For this and following individual sensor tables, formatted results (bolded, coloured etc) are used to highlight the warmest & coldest sensor and any area of concern (generally **bolded**). Results shown in **bolded red** and **red** underlined show results that are close to, or exceed acceptable limits.								
Variation 1-7	1.4 K	**5.2 K**	1.6 K	2.0 K	0.7 K	1.1 K	**2.7 K**	2.4 K
Uniformity (25°)	Fairly good	Very Poor	OK	Not very good	Good	Fairly good	Not good	Not very good
NOTE 2: The temperature variation results shown above and in following tables (e.g. 1.0 K) are temperature differentials, rather than specific temperatures and therefore expressed as Kelvins (K) rather than degrees Celsius (°C).								
NOTE 3: The comment relating to the "Uniformity" results above (re temperature variation 1-7) are subjective and provided for indicative purposes only.								
Run time*	40%	43%	31%	29%	31%	26%	34%	33%
*** Note:**	The row above shows the approximate average percentage of the time that the compressor is running, i.e. on and cooling.							

This table indicates the uniformity or lack thereof of temperatures inside the cabinets. Even-temperatures throughout gives a greater safety margin for vaccines, because a single temperature monitor, or the cabinets own control sensor would be more representative for vaccines stored on any part of any shelf. However as noted above there can be significant temperature differences over the seven different sensor locations used in this testing. Also the temperatures shown are averaged over time and exclude minute-to-minute peaks and troughs as the cabinet's compressor cycles on-and-off to maintain its set temperature. Therefore for short times, the air temperatures will vary (temperature

fluctuations) above and below the recorded averages and can further exacerbate any problems of lack of uniformity.

The temperature uniformity results for the tested models in a non-demanding 25°C room, were generally acceptable for most, but the larger **ICS Pacific G400L** (2ICS) had areas of possible concern, a warm temperature at around the 8°C limit for acceptable vaccine storage at the top front LHS sensor, and also one that was quite cool at the back of the shelf at 1/4 height. The two **Thermoline** models weren't particularly good for uniform temperatures across all sensors, while the best for uniformity were the two **Rollex** models.

NOTE: For uniformity in other test room temperatures - see later 'Operation tests' and note the individual sensor temperatures and uniformity results when tested in warmer and cooler room environments.

5.2.2.1 Average compressor run times & cooling reserve

The percentage of the time that the compressors were running is shown in the table above with an accompanying note, for operation in a 25°C room. As the ambient temperature increases the compressor should operate more frequently (a higher percentage of the time) if able to provide the necessary extra cooling effort. If the compressor "on" or run time percentage is relatively low, as it should be in 25°C, this is an indication that the system should have reserve capacity to handle warmer and more difficult environments.

5.2.2.2 Vaccine placement with respect to uniformity considerations

The results from many of the tests including temperature uniformity, demonstrate that some locations within vaccine cabinets may provide less security for vaccine storage than others. This consideration would probably be most important for particularly warm environments and locations that might be subject to any power supply problems, although not limited to these situations. Some locations that might not be best choices could include: -
The higher areas, (particularly the top shelf) are more likely to be a risk for overly warm storage, or provide less safety margin, and would be most at risk with a power failure. Positions very near and particularly under a cooling plate might become too cold at times. A general rule is not to store anything directly against a surface, be it a wall, door surface or rear wall, to allow air circulation; and definitely not against an exposed cooling plate.
For more on this see 'Operation test' results and particularly 5.2.5 and also 5.5 *Power failure (warm-up) and other tests*.

5.2.3 Operation with Ambient Temperature Change and in Temperature Extremes

This is a series of tests to check how well the tested models will handle more severe conditions. Ambient situations that the tests emulate can include those from normal diurnal, seasonal, and annual variation to special occurrences, such as weather abnormalities, air-conditioning failures, human error or anything that can affect the room environment in which a vaccine storage cabinet might be expected to function.

5.2.4 Ambient change Test (25°C, 32°C, 43°C and 10°C)

This test checks the ability of the pre-set controls of the tested models to maintain average compartment temperatures as the room temperature changes. This test pre-supposes that the products are capable of operating in the range of temperatures that household refrigerators are required to do, however this was not so in these tests. The two **ICS Pacific** models were not able to satisfactorily operate in 43°C, and the smaller **G135L** (1ICS) not even close. The other models were OK relating to maintaining their set temperatures, but this is not the full story.
From the results shown later we can see there were problems for some locations that weren't obvious when just looking at the compartment average (from all seven sensors) as shown in the table below, or even a one-location temperature reading (e.g. sensor 1 near to the compartment's centre).

Ambient change test – average temperature from all seven sensors (°C)

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
In 25°C	5.4	5.8	4.5	4.4	5.7	4.7	5.5	5.4
In 32°C	5.5	5.3	4.4	4.2	5.9	4.9	5.8	5.3
In 43°C	**28.5**	**9.8**	4.1	3.7	5.4	5.1	6.1	5.2
In 10°C	5.1	5.7	4.8	4.9	5.3	4.7	5.3	5.5

The above and following tables have been colour shaded relative to the room temperature of the test: - green for 25°C, yellow/pale orange for 32°C, richer orange for 43°C and blue for 10°C.

Two problem results are indicated here, (see bolded temperatures for the two **ICS Pacific** models), but for a better picture of all the tested models see the following tables showing detailed individual sensor results.

5.2.5 Operation Test 32°C

This table shows the temperatures throughout the compartment when the tested units are exposed to moderately warm room conditions.

Individual sensor Average Temperatures (°C) when in a 32°C room: Temperature Uniformity

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Sensor 1	5.5	4.0	3.6	3.5	5.7	4.4	5.4	5.2
Sensor 2	5.4	**8.4**	5.7	5.9	**6.8**	5.4	**7.8**	**7.7**
Sensor 3	4.9	6.6	5.2	5.6	6.1	4.4	6.9	5.5
Sensor 4	6.7	5.4	4.2	3.6	5.6	5.5	4.8	4.6
Sensor 5	5.8	5.1	4.3	3.4	5.8	5.7	4.1	4.4
Sensor 6	5.7	6.1	4.5	4.2	5.7	4.4	6.3	5.1
Sensor 7	4.9	**1.6**	3.6	3.4	5.6	4.2	5.1	4.5
Ave. All 7	**5.5**	**5.3**	**4.4**	**4.2**	**5.9**	**4.9**	**5.8**	**5.3**
Variation 1-7	1.8	**6.8**	2.1	2.5	1.2	1.5	**3.7**	**3.4**
Uniformity comment	OK	Very Poor	Not very good	Not good	Fairly good	OK	Poor	Fairly poor

The **ICS Pacific G400L** (2ICS) has major uniformity problems at this temperature, with an area at the top front going beyond 8.0°C and at the same time being too cold on a lower shelf (at the rear); a point that is below its exposed cooling plate. The two **Thermoline** models also had temperatures that weren't very uniform and were quite warm at one or more top sensor locations. The two Rollex models had the best uniformity.

- This test indicates that it is important for the user to be aware of the temperature characteristics within a purpose-built vaccine storage cabinet, to ensure that vaccine are not stored in possibly unsuitable locations. This test does not show the effects of any loading arrangements. It is reasonable to expect worse results when packed close to its limits.
- Generally storage at the very top of the cabinet is probably not advisable (this possible uniformity problem can be amplified if a power failure occurs) and this also applies to locations very close to, or below a cooling plate; and if used, the particular location should be checked for acceptability.
- As a general rule it is also important not to over fill, or stack against walls or door surfaces and ensure that there is plenty of air space for circulation around the outside of stored items inside a refrigerating appliance. This would particularly apply to vaccines because of their specific storage requirements.

5.2.6 Operation Test 43°C

This ambient temperature test is quite severe but is a temperature that occurs in many parts of Australia on some days during summer, and can be exceeded from time to time in many areas. Even in moderate climate locations, plant failure or other occurrences could mean products could be exposed to extreme conditions at times. Operation in 43°C is a requirement for all household refrigerators.

Individual sensor Average Temperatures (°C) when in a 43°C room: Temperature Uniformity

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Sensor 1	28.5	8.1	2.9	2.7	5.0	4.5	5.6	5.2
Sensor 2	28.3	13.6	5.9	5.9	6.8	6.0	8.9	8.7
Sensor 3	28.1	11.5	5.3	5.7	5.8	4.5	7.8	5.5
Sensor 4	29.3	9.9	3.8	2.8	4.9	5.8	4.6	4.2
Sensor 5	28.7	9.4	3.9	2.6	5.1	6.1	3.6	3.9
Sensor 6	28.6	10.8	4.2	3.7	5.1	4.5	6.8	5.1
Sensor 7	28.1	5.2	2.9	2.5	4.8	4.3	5.1	4.1
Ave. All 7	28.5	9.8	**4.1**	**3.7**	**5.4**	**5.1**	**6.1**	**5.2**
Variation 1-7	N/a	**8.5**	**3.0**	**3.4**	2.0	1.8	**5.3**	**4.8**
Uniformity comment	Unable to cope	Unable to cope	Fairly poor	Fairly poor	Not very good	OK	Very Poor	Very Poor

Both **ICS Pacific** models were unable to handle this ambient temperature and did not maintain satisfactory compartment temperatures in our test. The two **Thermoline** models also had problems, because the top section of the compartments were too warm, even thought the average of all sensors indicates a relatively good result. The two **Quirk's** models tended to get colder and the coldest sensor measured was tending towards being too cold. The **Rollex (LEC$^+$) PE 907** (6ROL) was clearly the best model to handle these conditions in this test, maintaining a very good average as well as relatively good uniformity throughout its compartment.

5.2.7 Operation Test 10°C

This test shows performance in moderately cool conditions, but is a temperature where the products still requiring cooling to maintain the required temperatures. It is expected that colder ambient temperatures might present a problem for vaccine storage, unless the cabinets had inbuilt heating. Some wine storage cabinets do have heating (as well as cooling) to maintain internal temperatures even in very cold ambient temperatures.

Individual sensor Average Temperatures (°C) when in a 10°C room: Temperature Uniformity

BRAND	ICS	ICS	Quirk's	Quirk's	Rollex	Rollex	Thermoline	Thermoline
MODEL	G135L	G400L	FKG311	FKG 371	PE 507	PE 907	TEPR-230-1-GD	TEPR-500-1-GD
CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Sensor 1	5.1	5.4	4.6	4.7	5.3	4.6	5.3	5.5
Sensor 2	5.1	6.4	5.0	5.3	5.2	4.7	5.7	5.8
Sensor 3	5.0	6.1	4.9	5.1	5.1	4.5	5.6	5.5
Sensor 4	5.3	5.5	4.7	4.7	5.4	5.1	5.1	5.4
Sensor 5	5.2	5.8	4.7	4.7	5.5	5.1	5.0	5.4
Sensor 6	5.2	5.9	4.7	4.8	5.2	4.6	5.5	5.5
Sensor 7	5.0	4.9	4.7	4.8	5.3	4.6	5.2	5.3
Ave. All 7	**5.1**	**5.7**	**4.8**	**4.9**	**5.3**	**4.7**	**5.3**	**5.5**
Variation 1-7	0.3	1.5	0.4	0.6	0.5	0.6	0.7	0.5
Uniformity comment	Good	OK	Good	Good	Good	Good	Good	Good

All of the tested models handled the 10°C well.

While no testing was done in temperatures colder than 10°C, it is likely that cabinets (without any heating ability) could still provide acceptable vaccine storage at temperatures somewhat colder than this. Providing the cooling system didn't inadvertently operate, the cabinet might still provide acceptable storage if the room was down to 2°C. Also because the cabinets have a degree of insulation they should also provide some additional protection against even colder short term room temperatures, although this aspect has not been tested. Generally typical habitable rooms are likely to remain at temperatures less extreme than outside minimum and maximum temperatures; however this is much less so for some other rooms, including garages and the like, such areas would not be recommended for any refrigerating cabinet because of the increased the risk for reliable performance. Vaccine storage

cabinets without a heating ability (and particularly so for household refrigerator/freezers) would not be suitable for vaccine storage in rooms with consistent very-cold to below freezing point[7] temperatures.

5.3 Temperature fluctuation tests (in 25°C)

The following table shows the greatest temperature fluctuation or variation from one sensor as it does its normal cooling cycles and any periodic variation or defrosting operation. These temperature fluctuations (minimum and maximum temperatures as the compressor is cycling) are normally not displayed because each sensor's temperature is reported as an average over time. However these temperature fluctuations, (temperature swings or peaks and troughs) can affect the temperature of vaccines over and above the average temperature the vaccine experiences. Temperature fluctuations can also add to the effect of any compartment uniformity differences.

Some[8] models appeared to have an in-built **defrosting mode**, where the compressor would periodically stay off for a longer period than usual and this produced an increased temperature peak, which therefore increased the overall temperature fluctuation amount.

An important aspect of measuring air temperature fluctuations is lagging on the temperature sensors. Brass masses were used for the seven general sensors that provided these test results. This lagging approximated the temperature fluctuation effect of the air that would be next to a small amount of vaccine as packed in a sealed enclosure within a cardboard package.

See more on this in Sensor lagging under 4.3.3 *Recorded data, Temperature Sensors & Test rooms*.

Temperature fluctuations in 25°C room (normal running without door openings)

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Sensor 1 (centre sensor)	Min °C	5.0	4.7	3.5	3.3	5.2	4.0	5.0	5.1
	Max °C	7.2	6.0	4.5	4.7	5.8	4.8	5.8	5.6
	Difference K	**2.2**	**1.3**	**1.0**	**1.4**	**0.6**	**0.8**	**0.8**	**0.5**
Sensor 2	Min °C	4.8	7.9	5.2	5.4	5.9	4.6	6.8	6.8
	Max °C	7.5	**8.9**	5.8	6.2	6.4	5.6	7.3	7.4
	Difference K	**2.7**	**1.0**	**0.6**	**0.8**	**0.5**	**1.0**	**0.5**	**0.6**
Sensor 3	Min °C	4.4	6.5	4.9	5.2	5.5	3.8	5.9	5.2
	Max °C	7.4	7.7	5.3	5.7	6.0	5.0	6.4	5.8
	Difference K	**3.0**	**1.2**	**0.4**	**0.5**	**0.5**	**1.2**	**0.5**	**0.6**
Sensor 4	Min °C	6.0	5.4	4.0	3.3	5.1	4.8	4.2	4.3
	Max °C	7.8	6.6	4.9	4.8	6.0	5.9	5.6	5.6
	Difference K	**1.8**	**1.2**	**0.9**	**1.5**	**0.9**	**1.1**	**1.4**	**1.3**
Sensor 5	Min °C	5.2	6.0	4.1	3.1	5.3	5.0	3.2	4.2
	Max °C	7.3	6.7	4.9	4.8	6.1	5.8	5.7	5.3
	Difference K	**2.1**	**0.7**	**0.8**	**1.7**	**0.8**	**0.8**	**2.5**	**1.1**
Sensor 6	Min °C	5.1	6.1	4.3	3.9	5.2	3.9	5.8	5.0
	Max °C	7.3	7.1	4.8	5.0	5.7	4.9	6.3	5.6
	Difference K	**2.2**	**1.0**	**0.5**	**1.1**	**0.5**	**1.0**	**0.5**	**0.6**
Sensor 7	Min °C	4.4	2.7	3.3	3.2	5.2	3.8	4.7	4.3
	Max °C	7.3	4.4	4.9	4.7	5.8	4.7	5.5	5.3
	Difference K	**2.9**	**1.7**	**1.6**	**1.5**	**0.6**	**0.9**	**0.8**	**1.0**
Fluctuations (worst sensor)	**°C**	**3.0**	**1.7**	**1.6**	**1.7**	**0.9**	**1.2**	**2.5**	**1.3**
Av cycle time	Minutes	12	9	12	14	23	36	11	10
Average of 7 sensors	°C	**5.4**	**5.8**	**4.5**	**4.4**	**5.7**	**4.7**	**5.5**	**5.4**
Coldest sensor	°C	4.9	2.9	3.9	3.8	5.5	4.2	4.4	4.7
Warmest sensor	°C	6.3	**8.1**	5.5	5.8	6.2	5.4	7.0	7.1
Fluctuations Include an apparent defrosting mode		Yes	Yes	No	No	No	No	No	No
CODE		**1ICS**	**2ICS**	**3QUI**	**4QUI**	**5ROL**	**6ROL**	**7THE**	**8THE**

The temperature fluctuation results shown are for the test in a 25° room, and will differ for other ambient temperatures, see the table below. The table above shows the worst temperature fluctuations (difference between minimum and maximum measured temperatures) as well as those for all sensors. The maximum fluctuation recorded was either generally represented in multiple areas throughout the

[7] Relating to water (0°C).

[8] The two ICS models had this.

compartment or as in the case of the 7THE only one or two locations had large fluctuations. At the bottom of the table above, additional information is shown for interest, including the average cycle time (i.e. the duration of each compressor on and off period), which directly relates to temperature fluctuations other than those caused by less frequent periodic variations (refer to the information about "defrosting mode" (above in bold) & its footnote). Also the average temperatures for all seven sensors are shown as well as those for the warmest and coldest sensors. The following table provides information for the tests in other ambient temperatures, (in all the test room temperatures).

Temperature Fluctuations in all tested ambient temperatures (worst sensor only)

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
In a 10°C room	°C	2.0	0.5	2.0	2.3	1.3	1.6	2.2	0.9
In a 25°C room	°C	3.0	1.7	1.6	1.7	0.9	1.2	2.5	1.3
In a 32°C room	°C	1.0	0.2	1.4	1.6	0.9	1.4	2.8	1.5
In a 43°C room	°C	N/a	N/a	1.3	1.5	1.4	0.9	2.4	1.5

5.4 Pull-down testing

Pull-down testing can be a way of checking cooling strength. It can be from a warm start-up in a warm room, or another method.

Household refrigerators need to prove cooling ability by passing a pull-down test, which is a test within a 43°C room, where the product is started and cools from 43°C to a temperature a little above its normal operating temperature in a time that must be within 6 hours. This test typically checks that the cooling strength is sufficient.
We tested the vaccine cabinets in a similar fashion, although we changed the room to 32°C because not all models functioned in the hotter temperature. This test can be a general indicator of cooling strength, and also insulation to some degree; however a unit that also has a large thermal mass can be slower in this test if the cooling effort also cools an additional mass within. Therefore this particular test method would not necessarily be appropriate for any vaccine storage cabinets that incorporated a large thermal mass to help maintain a source of stored cooling energy, to use in case of a power failure.

Also results of this test need to be considered together with any warm-up tests and or 'recovery after a power off' test.

Pull-down test – time; from 32°C to 8°C average for all sensors

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
In a 32°C room	minutes	50	78	**33**	**32**	92	83	**32**	41
	This is a pull-down test starting with all test units switched off in a warm room, then switched on and timed.								

There was a significant difference in time between tested models for the average of all 7 sensors in each to reach 8°C after being switched on.

5.5 Power failure (warm-up) and other tests

A number of different tests were conducted, in this area.
The first was a warm-up test, which simulates a power failure and typically is a test of the insulation performance of a cabinet. This can be a good test for household freezers, but again if this type of test is used for appliances that have extra thermal mass then this will also come into play too. A warm-up test can be a good indicator for likely performance in general use, but this test is probably most useful to see the effects of a longer term power failure.
Another warm-up related test we conducted was where we observed the consequences when the door was left open for 15 minutes during normal running.
A third test conducted was a series of test runs which combined warm-up and recovery factors. This was based on the disruption of power for a relatively short period and then allowing the unit to restart and recover temperature. An advantage of this type of test, particularly over a pull-down test is that it can combine the effects of all of the attributes of insulation, cooling strength and thermal mass together. This means that their apparent advantages and disadvantages seen in other tests tend to cancel out in this situation to show a more realistic overall picture. One method proved to be particularly informative, and this is detailed later.

5.5.1 Power failure (warm-up in 32°C) test

These test runs show the speed that internal temperatures warm when the power supply is disconnected, in a moderately warm environment (32°C room).
Warm-up test performance (timing the temperature rise after the power has been turned off) can directly relate to its insulation performance (and thermal (or cold) mass to a varying degree). Good insulation will contain the cold inside; a strong cooling system will recover more quickly; however a cold source (mass) contained within can slow the warm-up but also slow recovery too.
Warm-up results naturally will vary depending on when the power interruption occurs relative to the normal cooling and warming cycles of the refrigerating system (compressor on & offs). With our tests we selected a uniform method being a worst case time scenario, i.e. having the power fail (turning the power off), at a point when the compressor was due to re-start after it had been off for a full normal off-cycle period.
This test is a good indicator of how well a model is likely to cope with a significant power supply failure.

Warm-up test - from the default temperature setting - in a 32°C room (temperature reached is the average for all sensors)

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
To 8°C	minutes	15	21	23	23	23	**34**	16	21
To 15°C	minutes	54	59	62	62	80	**110**	54	68
To 25°C	minutes	157	156	177	180	**217**	**315**	157	194
To an adverse event*	minutes	30	36	38	38	38	**49**	31	36
*12°C or >8°C 15 mins	The times above indicate the resistance to warming from external (room) heat when the power was turned off for the average internal temperature (of 7 sensors). The test started from a point in the cooling cycle for each model, when the compressor was about to re-start. In all cases the adverse event was 15 minutes after the 8°C result, which occurred before 12°C was reached.								

There was a significant difference between models. Some models maintained internal (average) temperatures for much longer than others. However the results above only show the average temperature for all seven sensors in the cabinet. Some individual positions will be worse.
The two test runs of particular interest are: -

1) The time to reach 25°C test - gives a good general indication of warm-up performance, because the longer period minimises the affects from slightly different starting temperatures between tested units (i.e. the default temperature setting and temperature cycle size).
2) The time to an adverse vaccine storage event test – gives a good indication of the limited time stored vaccines might remain safe, after a black-out. However, the table above only shows the average for all sensors; the situation will be worse for vaccines in specific locations (at and near the top of the cabinet) because these will warm more quickly and reach adverse event status before that of the average of all sensors.

For additional information also see below 5.5.4 "Warm-up with added thermal load at the top".

5.5.2 Door opening test

While operating normally in a very moderate 25°C room, we opened the door and left it open for 15 minutes to see how detrimental this would be. The door was then closed and recovery allowed.
The table below shows the warming that took place for the average of all seven sensors, and timing.

Door open for 15 minutes test - within a 25°C room

CODE	1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Time to reach/exceed 12°C after opening (mins)	11	12	14	13	10	12	7	8
Maximum temperature reached °C	14.6	13.7	12.8	13.4	16.8	14.9	18.2	17.7
Time above 8°C -door open & recovery (mins)	33	46	22	22	59	47	30	34
This is based on the average temperature for all 7 sensors, some sensors (locations) will be warmer, others cooler than this average. During normal running the door was opened for 15 minutes and then closed with recovery then occurring.								

In the 25°C room, the average of all seven sensors warmed to 8°C in a very short time, between 3 & 6 minutes for all tested models (table not shown). If the door is left open, vaccines would reach 12°C (an adverse event) in less than 15 minutes (much less for some); for all the tested models in out test even in a 25°C room. The test was also carried in a 32°C room with poorer results. The worst performer reached an average of 12°C in 4 minutes when in 32°C. It could be even worse for some storage locations than those recorded for the average.

5.5.3 Power off and recovery test (32°C room)

This is a test which includes a period where the power supply is cut then restored and represents a situation that could occur in real operational situations. However reproducing the most appropriate performance comparison in a laboratory test method was somewhat complicated.
The method we found most meaningful used individually predetermined power-off times with recovery; with the aim of just avoiding, or almost avoiding an adverse vaccine storage event; based on an average temperature from all sensors. The duration of the power disruption for each unit had to be obtained by experimentation and some interpolation.
The results give a good indication of the approximate maximum length power loss, in a warm room, for each tested unit with vaccine storage risks being around the borderline point.

It is important to remember the following table shows the average of all sensors and the upper locations are likely to be warmer than the average and vaccines stored there to be more at risk. On the other hand the power-off point was timed to coincide with when the compressor was just re-starting to begin its normal cooling cycle, a worst case situation in regards to timing. In regard to the time when the sensors reached peak temperature, this is usually some time after power has resumed, while warming is still occurring and the cooling system is yet to balance this out and cause the average temperatures to start falling. (The target adverse event period was average temperatures over 8.0°C for 15 minutes or if the average reached or exceeded 12°C.)

Maximum power supply interruption time test (32°C – based on average for all sensors – aiming to avoid an adverse storage event)

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Maximum power interruption time	minutes	13	19	**27**	**27**	19	**33**	16	18
	This is a special test where all units have the power supply interrupted for the amount of minutes as shown above and then reconnected and temperature recovery achieved in a warm environment (32°C room). The time in this table is an approximate maximum power loss time where an adverse storage event is likely to be just avoided if based on only the average temperature from all 7 sensors.								

This test shows significant performance differences. In some cases a relatively short power supply interruption is all that can be tolerated without some intervention or protective measures for stored vaccines to remain safe.

The results from this test combine a number of performance factors into one. Insulation to stop heat gain from outside the cabinet, cooling strength from the cooling system to regain set temperatures quickly and the effects of any additional thermal energy (mass) contained within the cabinet.

5.5.4 Warm-up with added thermal load at the top

This area was beyond the scope of this project and while we did conduct a quick test run using a modest quantity of drink cans on the top shelf in one test unit, the results were inconclusive[9].
Theoretically having a cool thermal mass at the top of the cabinet should aid in slowing heat gain if power is lost because of convection (cold air falling) even if from only a limited cold source above. However the amount of the energy stored in the mass and its ability to transfer sufficient cooling into the air within the necessary time frame are factors necessary for it to be of substantial benefit.

[9] This work suggests research testing would be necessary before any definite conclusions could be offered. We used aluminium drink cans; but not of sufficient quantity nor spaced to allow best air movement. One possible suggestion from this quick test is that plastic containers of water may not be the best thermal mass if used with vaccine cabinets because the temperature transfer rate might be too slow.

5.6 Energy consumption

We measured energy consumption during normal temperature test runs. The measured energy will give an indication of energy consumed during undisturbed normal operation for comparative purposes. The first row shows the amount of energy we measured in a 25°C room projected for a period of one year. The second row indicates the approximated cost.

Measured Energy consumption during normal operation

CODE		1ICS	2ICS	3QUI	4QUI	5ROL	6ROL	7THE	8THE
Energy in a 25°C room	kWh/year	586.4	846.9	817.8	907.5	816.3	282.3	1339.7	1343.5
Running cost at a rate of 17cents/kWh in a 25°C room	$/year	$100	$144	$139	$154	$139	$48	$228	$228
Energy In a 32°C room	kWh/year	836.6	1275.2	1042.4	1189.7	1042.1	354.5	1704.6	1728.4
Claimed/stated net volume	Litres	135	377	281	351	137	275	230	500
	This is a cost comparison based on the measured energy only during normal closed door operation in a constant room temperature, as stated. Volume is a factor in energy consumption but typically not in a direct proportion.								

There were considerable differences in energy consumed between the test models. Most consumed a considerable amount of energy. Only one, the **Rollex (LEC$^+$) PE 907** (6ROL) used significantly less energy than the others.
See below for factors affecting efficiency and comments relating to volume.

5.6.1 Energy use compared to a household refrigerator/freezer

When compared to normal household refrigerator/freezer efficiency, the majority of the tested vaccine storage models compared very poorly.
All household refrigerating appliances are controlled by government for minimum efficiency performance standards, and cannot be sold unless registered and labelled and that they comply with low energy requirements. Energy labels for fridges are based on testing in a 32°C room without door openings but include any automatic defrosting operation. Most refrigerator/freezer models sold in Australia are frost-free and have a defrost operation included in their energy calculation. The measured energy is based on freezer compartments operating at -15°C and fresh food compartments at 3°C.

As a comparison to the vaccine cabinets, a large efficient household refrigerator/freezer (of around 500 litres total gross volume), can use around 500[10] kWh/year of electricity, which if costed at 17 cents per kWh, equates with around $85 per year, but this is in a 32°C room. Refer to the table and the relevant rows for comparison with the tested vaccine cabinets. Only the **Rollex (LEC$^+$) PE 907** (6ROL) compares acceptably.

Factors affecting 'energy efficiency' include: - compressor efficiency, insulation performance, cooling strength of the system; as well as size (volume), the set internal temperature, and the operating environment (including ambient temperature etc). While volume is definitely a factor when comparing energy consumption for different models, it typically is far from a direct proportion; i.e. double the volume will generally be significantly less than double the energy, when all other factors are equal. To meet specific performance requirements, a refrigerating appliance needs a balance of attributes to do the job properly and then be energy efficient to do that job. For example: - a very well insulated product with a tiny compressor might use little energy, but it won't have the cooling strength to cool quickly enough for times when the door is opened, new warmer loads are added or quick recovery is required after a power. The product needs to be able to do the job properly first, then secondly it needs to have good efficiency. Simplified, this could be the combination of good insulation with a particularly efficient compressor that doesn't sacrifice cooling strength. Generally larger volume products should use some more energy but notably be more efficient per litre, than smaller units.

[10] Both Australian refrigerator manufacturers (Fisher & Paykel and Electrolux) have popular models, with a top mounted freezer, that are almost 520 litres and have energy labels of 508 kWh/year (refer energyrating.gov.au).

6 OTHER DETAILS

Data equipment with the tested products
Some of the vaccine cabinets were supplied with thermometers. Some of these were built into their control systems, some were not. Some displayed readings and others also logged data that could be downloaded later. Models with data loggers were tested with these in place. The client also supplied eight separate data loggers and these where also included on the middle shelf. The laboratory made no use of the readouts and the logged data. The logged data was passed back to the client for analysis if required. It would be fair to say that any temperature measurement could be complicated by a number of factors. A study of the data loggers' information could show how accurate or inaccurate they might be relative to the laboratory test results. The laboratory test results show some uniformity problems and these coupled with any logging uncertainty could mean that getting accurate and representative temperature readings in the field would not be simple.

Client Details:
The Australian General Practice Network (AGPN)

Attention Helen Moore - Principal Advisor Immunisation.

25 National Circuit Forrest ACT 2603 (PO Box 4308 Manuka ACT 2603)

Product Stewardship/Sourcing

The products were provided to Test Research via arrangements made by the client.

Testing Laboratory Details
Test Research, a division of the Australian Consumers Association (Choice)
57 Carrington Road Marrickville NSW 2204

NATA accreditation No 1702 (Measurement Science & Technology) - household refrigeration testing to AS/NZS4474.1

Laboratory Manager: Klaus Neuscheler.
Report and method concept by: Geoff Day (Test co-ordinator, Technical) with the assistance of Ben Rossetto (Test co-ordinator).
Test room testing and data consolidation by Ben Rossetto and Joseph Ho (Test officer).

Project contact: Geoff Day (02) 9577 3205 (gday@choice.com.au).

Test Conditions – A regulated power supply used: – 230V (± 5%) and 50 Hz (±1%) and test rooms complying with the requirements of the Australian/New Zealand Standard for household refrigerating appliance performance testing.

7 GENERAL CONCLUSION

The tested models performed acceptably under normal non-stressful conditions. However some indicated significant negatives for appropriate vaccine storage in many possible situations. This included operation in warm to hot conditions, and also from lengthy door openings.
A power supply failure or even a relatively short power interruption could be problematic. Even the best of the tested models would not maintain appropriate temperature conditions for vaccines stored in all areas within its compartment for very long in a lengthy black-out.
Temperatures within cabinets are not necessarily consistent and in more adverse conditions these temperature differences can be magnified, which is of concern as is a number of other factors found during this testing.
It's suggested that careful temperature management for all vaccine storage cabinets, and certainly including these purpose built types, would be advised generally. This also includes temperature monitoring in more than one location to check possible problem areas such as the top front of the compartment, for possibly over-warm areas; and low locations at the rear, close to the bottom or under the cooling plate for possibly over-cold temperature areas.

The testing has discovered a number of areas where some of the tested products are not likely to perform adequately for their intended purpose in conditions that could arise in many locations within Australia. Considering how important the role of safely and confidently storing vaccines is, the need for an Australian vaccine storage appliance performance standard appears very urgent.

8 PRODUCT PHOTOGRAPHS

ICS Pacific G135L (1ICS) 	**ICS Pacific G400L** (2ICS) 	**Quirk's FKG 311** (3QUI) 	**Quirk's FKG 371** (4QUI) 
Rollex (LEC^{+}) PE 507 (5ROL) (shown with solid door open) 	**Rollex (LEC^{+}) PE 907** (6ROL) (shown with solid door open) 	**Thermoline TEPR-230-1-GD** (7THE) 	**Thermoline TEPR-500-1-GD** (8THE) 

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