Contents

AUSTRALASIAN REFRIGERATOR ROUND ROBIN TO IEC62552-3
Results of a round robin of six Australasian test laboratories testing four refrigerating appliances to IEC62552-3 in 2013/14

Introduction

This report summarises the data and results from the Australasian round robin of refrigerators tested to the CDV version of the new International Electrotechnology Commission standard, IEC62552-3. The round robin was initiated and funded by the Department of Industry (now the Department of Industry and Science) and the E3 Committee, with two manufacturer and four independent test laboratories participating. Refrigerator-freezer test units supplied by Electrolux (Westinghouse) and Fisher & Paykel were subject to test in each supplier facility and shipped to the NATA accredited test laboratories participating in the round robin. Each facility undertook extensive additional measurements as well as meeting the requirements of the IEC test method.

The round robin had many goals including to:

- Provide experience for those facilities charged with undertaking verification testing to Australian and New Zealand laws to gain practical testing experience with the forthcoming IEC test procedure for household refrigerators, which is the proposed testing basis for MEPS and energy labelling from not earlier than 2017;
- Generate data to be used as technical input from test laboratory personnel into the IEC process in order to improve the IEC test method prior to its publication as the IEC Final Draft International Standard version (FDIS);
- Assess the reproducibility and repeatability of the IEC test method and provide expert opinions as to its technical suitability as a basis for future regulation in Australia and New Zealand;
- Build testing capacity building in local test laboratories; and
- Give stakeholders confidence that the new test procedure and related issues give sound results suitable for regulation enforcement.

The Australian and New Zealand governments have long standing policies of adopting IEC and ISO test methods wherever possible. Australia and New Zealand energy efficiency agencies have proposed adopting the new IEC test method for energy consumption and performance of household refrigeration appliances (IEC62552-3) in the future.

In order to “road test” the new IEC standard, the round robin used the IEC Committee Draft for Voting test method as published in May 2013 (published as IEC 59M/49/CDV). This enabled the participating test laboratories to examine the draft IEC test procedure very closely and highlight any practical issues surrounding testing for the international committee. Participating facilities provided specific feedback to the IEC Committee about their experience in conducting tests as part of the round robin. The relevant committee, IEC SC59M, accepted their comments at their December 2013 meeting. The final IEC standard was published in February 2015 and has been improved by incorporating feedback from testing under this round robin.

The round robin yielded substantial information about the proposed test method and benchmarked it to the current Australian and New Zealand test used for local regulation. A range of additional instrumentation was specified in the round robin and additional test points measured to collect energy consumption at both the IEC and AS/NZS conditions. As these facilities are expert in testing to the local standard, the comparison across test methods also provided useful data informing the IEC test method development.

The results were extremely encouraging in the context of the possible policy goal of using the IEC test for regulatory purposes in the future. Apart from one test station in one laboratory which was found to be non-compliant with test conditions, all of the laboratory results were within 1.5% at an ambient of 32°C and within 2.5% at 16°C. Defrost and recovery data, while slightly variable across laboratories, was also within acceptable measurement limits. Load processing results were also found generally acceptable but minor unidentified factors affected results. These parameters, however, contribute only a modest proportion to the overall energy consumption of the refrigerating appliances. The IEC test committee may explore this aspect further.

The round robin of Australasian refrigerator testing laboratories enabled test laboratories to provide feedback on the IEC test method with a range of practical suggestions on how the standard could be improved and clarified. The round robin also gave local test laboratories the opportunity to increase their skills and capacity when testing to the new global IEC standard which in time is likely to be used in our region.

The round robin demonstrated the IEC test method generates results within validity tolerances and should ensure that sound and reliable data is produced when used in the future. The round robin showed that the results across test laboratories (with one exception) were within expected and acceptable ranges of variability. The round robin should provide confidence to regulators and industry stakeholders that the IEC test method provides a sound basis for re-regulation of household refrigerating appliances in our region sometime after 2016.

Regulatory Context

IEC committee SC59M (household refrigeration) has been working on a new global test method for household refrigerators for some time. A Committee Draft for Voting (CDV) stage was released in May 2013 and was unanimously supported by all world standard bodies in August 2013. The Final Draft International Standard (FDIS) was released in October 2014 and the final standard was published in February 2015.

Australia and New Zealand energy efficiency agencies have proposed to implement more stringent Minimum Energy Performance Standards (MEPS) levels (based on US 2014 levels) in or around 2017 and also revise the approach used for energy labelling. As part of this regulatory change, Australia and New Zealand agencies have proposed the adoption of IEC62552-1, IEC62552-2 and IEC62552-3 as the future regulatory test method for energy consumption and performance. Australian and New Zealand government agencies funded this round robin using the IEC CDV as the base test method.

The most significant differences between the existing AS/NZS method and the new IEC test method are in the post-test data handling and calculation requirements. The IEC standard requires more data processing and contains more validity checks to ensure that data collected is robust and accurate. The increased complexity in calculations is offset by much greater flexibility in testing and scheduling for the testing laboratory. The IEC standard allows considerably more flexibility with respect to the sequence of events and measurements, as the components of energy consumption are quantified and reported separately (e.g. steady state power consumption, incremental defrost and recovery energy and temperature deviation, defrosting frequency are all reported as separate values under IEC, which are then combined into the required energy value later). All Australian and New Zealand stakeholders agree that such flexibility could result in lower testing cost through the removal of test rigidities.

The new IEC method does have additional tests and conditions that are to be measured over and above AS/NZS, most notably a separate measurement of the energy consumption at an additional lower ambient temperature condition (16°C) and a load processing efficiency test (a proxy for the energy required to extract user related heat loads during normal use). The energy test at the lower ambient will be included into the proposed regulatory change for energy labelling and the inclusion of processing efficiency is also proposed for energy labelling because these measurements give more reliable and internationally compatible results.

Refrigerators Tested in the Round Robin

Two models of refrigerator were chosen to be included in the round robin. They were representative of general market demand as well as providing features for testing that could produce useful results. They allowed full test method analysis and provided a sound basis for comparison between test laboratories. The products were selected with industry support as they were known to be reliable in their operation. Both models are said by their manufacturers to have stable operating characteristics, have fixed speed (HC-600a) compressors and use electronic controls. The models were:

- Fisher and Paykel model E442B (Group 5B bottom freezer);
- Electrolux (Westinghouse) model WSE6100 (Group 5S side by side).

The test units were selected from available stock by the relevant manufacturers. Three units were selected, of which two were tested by each manufacturer. Each manufacturer quarantined the remaining unit as a safeguard in case the round robin units were damaged or were no longer suitable for testing. On completion of testing at each manufacturers facility, one product was sent to Sydney based testing labs and one product was sent to Melbourne based labs participating in the round robin tests.

The Department of Industry and Science purchased the units from each the manufacturers.

Participating Test Laboratories

The laboratories which participated in the round robin:

- Choice, Sydney;
- Electrolux, Orange;
- Fisher & Paykel, Auckland;
- SAI Global, Melbourne;
- SGS, Melbourne;
- VIPAC, Sydney.

All of the test laboratories participating in the round robin have considerable experience in testing to AS/NZS4474.1 and all were equipped to deal with the requirements of that specific standard. Some of the technical requirements of the CDV version of IEC62552-1 were different to AS/NZS4474.1, and the participating test laboratories did not fully comply with all of the requirements of the proposed IEC standard. Most of the points of non-compliance however were minor in nature and are therefore unlikely to have any significant impact on the results. If the IEC becomes the mandated test method in Australasia, the test laboratories should have little difficulty in configuring their labs and equipment to fully comply with the requirements.

The IEC committee took feedback from the Australasian laboratories into consideration when subsequently making a number of changes to the setup and instrumentation requirements. This means that the level of technical non-compliance with the final IEC test method less changes will be less than with the CDV version.

Because the IEC method was under active development, the participating test Laboratories were given additional testing information ***(Refrigerator Round Robin Testing Specification: IEC62552)***, which documented the variations to the then proposed IEC version. This specification limited uncertainty surrounding the precise configuration for the round robin and general requirements regarding setup, data collection and analysis. This specification is included as **Appendix A** of this report.

The four independent test laboratories were all accredited to test in accordance with AS/NZS4474.1 by the National Association of Testing Authorities (NATA). The two manufacturer laboratories were not accredited at the time of testing. However, they have been used for development and compliance testing for many years which has established their expertise in testing refrigerators accurately.

Test Laboratory Interactions

All of the participating test laboratories were paid a fee for their work and to pool their experiences in testing to the proposed method. Participating test laboratories found the IEC standard to be usable and generally consistent and clear. All laboratories noted the complexity of data processing and verification in the IEC standard but were able to use the analysis tools provided or develop their own approaches.

The test labs were able to access expert advice when conducting their respective testing. This allowed issues to be handled consistently across facilities and provided a transparent process to manage feedback from labs to the IEC committee about the methodology.

Participating laboratories were asked to provide written feedback on their experiences with the new test method. In particular, they were asked to identify any text in the IEC (and AS/NZS 4474.2) documents that were incorrect, unclear or ambiguous. Suggestions on changes to the IEC method were made and this feedback formed part of the Australasian submission to the IEC in November 2013 which was considered at the IEC SC59M meeting in December 2013.

Testing Specification and Test Method

Variations to the IEC Draft Standards

The round robin used the IEC Committee Draft for Voting that was issued in May 2013 (59M/47/CDV, 59M/48/CDV and 59M/49/CDV). Participating test laboratories examined the draft IEC test procedure closely and highlight any practical issues in relation to their understanding of the methodology or equipment specification and use. The IEC used this input to make changes to the standards which have been published as IEC62552-1, IEC62552-2 and IEC62552-3 (Edition 1).

During the round robin, not all laboratories were able to comply with all technical aspects of the IEC drafts, though this non-compliance was mainly in relation to unfamiliar processes. Each of these elements of non-compliance has been carefully examined by independent reviewers and has been assessed as being non-critical in terms of the objectives and outcomes of the round robin.

Differences between IEC and AS/NZS

In terms of the physical testing requirements, the differences between IEC and AS/NZS are relatively minor, though some will have an impact on the measured results. The main differences are described below by category.

Energy determination: The most significant difference between IEC and AS/NZS methods are the equipment temperature specifications. IEC has energy target temperatures of fresh food +4°C and freezer -18°C while AS/NZS have fresh food +3°C and freezer -15°C. AS/NZS takes the energy from the start of a defrost cycle until the next defrost or 24 hours (maximum). IEC separately quantifies the incremental defrost and recovery energy and mathematically adds this into the energy calculation for any selected defrost interval. The IEC method not only allows the AS/NZS requirement to be accurately calculated from data collected for a given defrost interval, but also allows energy for longer or shorter defrost intervals to be estimated (without having to wait for defrosts to actually occur). Longer defrost intervals effectively allocate the fixed defrost and recovery energy over a longer defrost interval, reducing the impact of defrosting on overall energy consumption.

Test room: The IEC standard CDV mandated a test platform, while AS/NZS permitted either a platform or an insulated floor where the temperature lies within an allowable tolerance. A few Australasia facilities did not use platform or used a false floor. The IEC have accepted this AS/NZS experience by allowing for the alternative of an insulated floor and also clarified the requirements for a false floor in the final standard. The IEC specify ambient temperature sensors to the right and left of the appliance while AS/NZS specified a single sensor at the front. The IEC CDV positions were at the mid-point of the sides, but this has now been rationalised as a result of Australasian comments to be a fixed position on the sides. The IEC is more prescriptive regarding the use of side partitions and rear partitions – this has been clarified and simplified as a result of Australasian comments. These differences should generate few practical differences in energy measurements but will make setting up simpler when testing several products in in the same test room.

Temperature sensors: Unfrozen compartment temperature sensors for IEC are common for all configurations, which makes setup more consistent across different product types. However, these positions are slightly different to AS/NZS positions as follows:

- AS/NZS4474.1 sensors a 25mm, H/3, 2H/3 from bottom;
- IEC sensors at 50mm, H/2, 3H/4 from bottom.

Experts hypothesise that the IEC positions, being slightly higher in the compartment, should result in a slightly warmer compartment temperature (around 0.2K to 0.4K), although this expectation is also dependent on air flow and shelf placement in each model.

Most frozen compartment temperature sensors for IEC are the same as AS/NZS, except for freezers with a height of >1000mm, where IEC use 2 extra sensors. The average of all compartment sensors for IEC and AS/NZS is practically identical (even for freezers with a height of >1000mm). However, as AS/NZS measurements eliminate the coldest sensor from the compartment average, the AS/NZS freezer temperatures are about 0.3K warmer than IEC (opposite impact to fresh food).

The uncertainty of measurement for temperature sensors in IEC has subsequently been modified to 0.5K, which is now the same as AS/NZS. The IEC specify smaller copper masses, but these are within the permitted range specified in AS/NZS. The mass of the sensor has no impact on the average temperature, although it will affect the size of the temperature fluctuations during operation.

Testing Specification for the Round Robin

A testing specification document clarifying the IEC test was provided to the test labs prior to the start of testing. In addition, briefings and witnessing of tests were conducted for each lab to walk test personnel through the testing process and answer any staff questions. During or after the actual tests, the testing witness visited all facilities to document lab instrumentation, procedures and to answer any further questions generated by the testing.

The following documents were referenced for setup and testing purposes:

- IEC 59M/47/CDV - IEC 62552-1: Household refrigerating appliances - Characteristics and test methods - Part 1: General requirements;
- IEC 59M/49/CDV - IEC 62552-3: Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption and volume;
- AS/NZS4474 Performance of household electrical appliances – Refrigerating appliances Part 1: Energy consumption and performance, 2007 (including amendments 1 & 2);
- The latest draft of AS/NZS4474.2 Performance of household electrical appliances - Refrigerating appliances Part 2: Energy labelling and minimum energy performance standard requirements (committee draft dated August 2013) which included proposed energy labelling and testing requirements based on IEC62552-3 CDV.

The facilities were given common testing specification advice and all the parties were encouraged to share views and experiences so that the round robin testing represented a fair assessment of the IEC methodology. The testing specifications included:

- Standard information on each product was provided to test labs (such as volume, recommended temperature control settings for testing and maximum and minimum defrost intervals at 32°C under IEC Part 3 Annex D);
- Test units were wired with fresh food temperature sensors in both the IEC and AS/NZS positions with parallel recording of data;
- Test units were wired with freezer temperature sensors in both the IEC and AS/NZS positions – for the 5B model these positions were common, but for the 5S model there were additional positions measured to cover both requirements (8 sensors in total);

- All defrosts were separately assessed and quantified using the IEC methodology;
- Energy tests were conducted at an ambient temperature of 32°C and 16°C plus a load processing test at an ambient temperature of 32°C;
- Laboratories were given standardised reporting spreadsheets for assessing and recording data, including detailed analysis tools from the experts witnesses, EES and ReGent (Martien Janssen);
- Energy consumption was estimated for a range of defrost intervals as set out in the specification (to reflect the likely range of intervals in normal use and regulatory requirements) using the method specified in the IEC standard;
- The overall objective was to measure sufficient data to triangulate to the energy requirements for both the AS/NZS target temperatures (+3°C and -15°C) and IEC conditions (+4°C and -18°C).

All laboratories supplied raw test data to EES for independent evaluation. EES provided some guidance to test laboratories as they undertook their own analysis as well as independent quantification of the data. While this type of support is not usually given to accredited test facilities, it ensured the round robin was as fair and accurate as possible. It also allowed deeper analysis of the raw data to reveal any important trends or relationships not already documented in the test procedure. A copy of the testing specification is included as **Appendix A** of this report.

Feedback to IEC

A report from the test laboratories on the IEC CDV version about the round robin was submitted to the IEC and AS/NZS standards committees. This was submitted to IEC SC59M in November 2013 (***Australasian Round Robin of Refrigerators Tested to IEC62552: Final Report for Submission to IEC SC59M*** (V6)). This specific technical feedback on the IEC test method was additional to the official Australian and New Zealand comments submitted to IEC on the CDVs in August 2013.

The key issues resulting from practical testing in the round robin by participating test laboratories were:

- Part 1: Temperature uncertainty of measurement – the submission was that the CDV requirement of 0.3K uncertainty was not practical – 0.5K was recommended;
- Part 1: Relative humidity of test room at 16°C ambient energy tests – the submission was that if the RH of 70% was exceeded, the test was only invalid if there was visible condensation on the test appliance;
- Part 1: Test Room Platform – clarification that a false floor was acceptable and that an insulated sub-floor with an additional surface temperature reading and associated tolerance be permitted;
- Part 1: Rear Wall or Partition – ensure that there is free air flow behind the rear partition;
- Part 1: Side Partitions – change the clearance to side partitions to ≥300mm, reorganise the text to clarify intent, ensure that test room walls are covered;
- Part 1: Ambient Sensor Location – rather than the centre of the appliance, a fixed position on each side was recommended, with some flexibility;
- Part 1: Rear Clearance – minor clarifications on wording and intent;

- Part 1: Shelf and temperature sensor placement – discrepancy regarding clearance clarified;
- Part 1: Shelf and temperature sensor placement – removal of shelves limited to a maximum of one;
- Part 2: Pull down test pass criteria – minor adjustments to clarify wording;
- Part 3: Rules regarding triangulation of data – inclusion of additional rules regarding to cover additional compartments not included in the triangulation;
- Part 3: Set up of shelves for load processing test – clarification of position of additional shelves and placement of loads.

IEC SC59M accepted all of these recommendations at their December 2013 meeting and the relevant changes were therefore included in the final standard. This will simplify testing requirements in some important areas (compared to the CDV tests undertaken by participating test laboratories). This outcome alone has justified the effort and resources put into the round robin.

Discussion of the Results

The test units were selected because they were recommended by their manufacturers as reliable and consistent, so therefore likely to be suitable for the round robin. When operating at the same temperature control setting for long periods, they gave very consistent values for internal temperatures and steady state power. As is the case with any large, complex electro-mechanical device, there were small variations in the operation between different test periods. Generally these variations were less than 0.5% (which is also comparatively very consistent), but this is another small variation that must be considered when comparing laboratory data. The F&P units tended to give more consistent results across laboratories for the same settings than the Electrolux units; it is unclear whether this is related to machine behaviour or other issues.

The results of the round robin gave all parties confidence in the test methodology.

Energy consumption of refrigerators is dominated by the steady state energy consumption – this generally accounts for more than 95% of the final energy value (excluding processing load). Apart from one testing station at one laboratory where the ambient conditions did not comply with the standard requirements, the steady state power values for the same units across all participating laboratories were generally well within 1.5% at an ambient of 32°C and within 2.5% at an ambient of 16°C. The variation at an ambient of 16°C is expected to be larger in theory and this proved to be the case in practice. Small changes or uncertainties in temperature measurement have a larger percentage impact at a low ambient (even though the absolute error in the power measurement itself is similar, the average power at the lower ambient is much smaller, making the relative error higher). Most measurements were well within these nominal ranges. This range includes small deviations that may have occurred due to variations in the operation of units from period to period as well as all uncertainties associated with energy and temperature measurements. Armed with this knowledge, it is reasonable to expect future concentration on this measurement may narrow the overall measurement uncertainty.

The data on defrost and recovery was more variable (generally within ±7%), but this is known to be somewhat variable from defrost to defrost in any case. Only about half of the defrost cycles were usable for a range of reasons, which is typical of refrigerator testing (this usable percentage could be improved with more active management and understanding of the testing process by the test laboratories, which will come with additional experience and expertise in using the new test method). While this is somewhat variable, it should be kept in perspective. The defrost energy only makes up less than 5% of total energy (less for longer defrosts), so this represents a variation in total energy consumption of around 0.35%. The defrost temperature variations were also reasonably consistent between laboratories (although these appeared to be partly influenced by control setting and other factors). It would appear that the measured differences in defrost and recovery energy between labs are real differences driven by differences in defrost heater on time, which in turn is driven by frost load on the evaporator. The data suggests that differences in the humidity in each laboratory test room and variations in the air leakage when sealing test leads through the door seals is likely to be the cause of these small variations. Some differences may have been due to the forcing of defrosts at more regular intervals than would naturally occur. An overview of all the round robin data suggests that laboratory forcing of defrosts, although not specifically disallowed in the IEC standard, should not be permitted for routine energy tests in Australasia.

Simple corrections, at least for verification testing, could be used to normalise such laboratory variations in defrost and recovery energy to give very reliable and robust results. Overall, the analysis showed that IEC method for the determination of the incremental defrost and recovery energy is highly accurate.

Due to the extensive data collected by each lab, it was possible to undertake sophisticated analysis and conduct a more detailed comparison of the laboratories than would normally be the case. The additional instrumentation included in the round robin (e.g. two sets of sensors in the fresh food to IEC and AS/NZS, three ambient sensors) allowed additional comparisons to be undertaken. In general terms, the data for all laboratories stood up to this more rigorous analysis and evaluation. However, there were some minor issues that became apparent from the detailed analysis performed.

Most of the test laboratories used highly accurate digital energy meters, and generally these are expected to have a very low level of uncertainty associated with power and energy measurements. One laboratory did not record energy using a complying energy meter, but this appeared to generate few issues. In general terms, energy consumption is a parameter that can generally be measured with high accuracy by test laboratories.

The most difficult measurement associated with energy consumption for refrigerators is temperature. There are many temperature sensors located inside compartments and also in the ambient air surrounding the appliance that need to be checked and monitored. Temperature (and temperature difference) is the primary driver of refrigerator energy consumption, so any uncertainty or error in these measurements could be significant. Most of the laboratories used thermocouples as they are robust and moderately accurate, but they require careful calibration prior to use. The thermocouple calibration process was found to vary by test laboratory, but it was not possible in this round robin to review this calibration process and the traceability of readings in any detail (this is an issue for accreditation bodies). Variations in these processes (and the resulting energy measurements) may have generated some anomalies in the data.

The inclusion of additional sensors allowed some internal comparisons to be made that would not normally be possible and helped minimise the impact of this issue. The round robin found:

- Differences between IEC and AS/NZS fresh food sensor placements varied between labs, even on the same test units – this tends to suggest, in part at least, some calibration issues in combination with shelf placement effects;
- Differences in ambient temperature measurement: most labs had differences between some of the ambient sensors. In some cases these were clearly instrument issues. However, further investigations showed that the Electrolux test unit (with a fan forced condenser underneath) may be emitting warm air at the side and thus influencing the ambient temperature sensors in some cases where there is a narrow space to the side partition. This was a subtle effect and not always obvious.

To assess the data in a more rigorous and objective way, power and compressor run time data was assessed for different control settings and different internal temperature settings. The large amount of data available allowed the use of a planar regression approach to assess inter-laboratory round robin data (see **Appendix B** and **C** for details). This highlighted some small differences in measured temperatures and allowed more objective comparisons between laboratories. This approach generally showed that:

- The test units were highly consistent and repeatable in their operation;
- There were no "outliers" for valid test periods using the IEC validity criteria, which confirms that the approach for selection of data in the standard is robust and sound;
- The energy consumption for a range of control settings and measured compartment temperatures is quite linear at and around the target temperatures. The variations between

laboratories were larger for very warm or very cold temperature settings (which are of less interest in any case), but this may be partly because there were fewer test points covering these settings and also because of non-linear effects at temperature extremes (impacts of changes in compressor COP due larger differences in evaporator and/or condenser temperatures);

- Therefore the use of triangulation is a highly accurate way to estimate the energy consumption of an appliance at the target temperature and is valid across a reasonable range of temperatures, as permitted in the standard.

Recommendations

The following recommendations are made regarding the round robin and associated outcomes:

- The new IEC standard can be adopted without local amendment or change in Australia and New Zealand as the basis for testing of future regulation;
- Future work with test laboratories and accreditation bodies (such as NATA) should concentrate on developing best practice approaches:
    - For temperature measurement (especially instrumentation and calibration procedures);
    - For factors impacting defrost, recovery energy and load processing efficiency results;
- Laboratories should be encouraged to test in accordance with the published IEC standards as part of a transition toward future regulation based on the IEC test standards.

Conclusions

The round robin of Australasian refrigerator testing laboratories enabled test laboratories to provide detailed feedback on the draft IEC test method. A range of practical suggestions were made on how the standard could be improved and clarified. All these recommendations were accepted and have been included in the final IEC standard. The round robin also gave local test laboratories the opportunity increase their skills and capacity with respect testing to the new global IEC standard.

The round robin showed that the IEC refrigerator test method is robust and reproducible. The validity requirements built into the test method produce sound and reliable data. The round robin showed results across test laboratories were within an acceptable range of variability for complying tests. The round robin has given confidence to Australasian regulators and industry stakeholders that the IEC test method provides a sound basis for reregulation of household refrigerating appliances in the future.

Appendix A: Refrigerator Round Robin Testing Specification: IEC62552-3

Prepared by Lloyd Harrington, EES for (the then) Department of Resources, Energy and Tourism, 5 August 2013, V2c (rev Oct 2013)
- Handed to round robin labs prior to starting testing, modified for inclusion in this report.

Purpose

The purpose of the round robin testing is to support the adoption of the International Electrotechnology Commission (IEC) test method IEC62552 (at CDV stage) in Australia and New Zealand as well as preparing testing facilities to adapt to testing to support the proposed US 2014 MEPS not earlier than 2017.

The round robin test will target the NATA accredited test facilities that are used to undertake verification testing on contract to DRET. The round robin will expose local testing laboratories to the new IEC test, to build capability and competency in using the IEC test methodology and will provide valuable feedback into the IEC process.

Products to be Tested

DRET is contracting Electrolux and Fisher & Paykel to supply products for the round robin as follows:

- Fisher and Paykel model E442B
- Electrolux (Westinghouse) model WSE6100

Both products are stable, have fixed speed (HC-600a) compressors and have electronic controls.

Overview of the Round Robin Tests

Products will be selected from available stock by the relevant manufacturers. A total of 3 products will be selected and two will be tested by each manufacturer. Each manufacturer will quarantine one product. One product will be sent to Sydney labs and one product sent to Melbourne labs.

Two products will be tested in parallel in each participating laboratory. The tests will be generally in accordance with the IEC test method except as noted in the setup and testing specification. Test points will be selected so that the measured data allows triangulation at target temperatures for both AS/NZS4474.1 (freezer -15°C and fresh food +3°C) and the IEC draft (freezer -18°C and fresh food +4°C).

On completion of testing, these products will be forwarded to other laboratory in the same city. On completion of testing at the second laboratory, each product will be returned to the original manufacturer for a closing test.

Test laboratories should contact the program manager if any elements of the test schedule are unclear.

General Conditions of Participation

All test laboratories are participating for a fixed fee as agreed with RET. Participation includes:

- Setting up the two nominated products in accordance with the setup specification;
- Completion of the energy tests set out in the testing specification;

- Provision of a test report that summarises the results of all testing;
- Provision of all raw data to EES and DI for further analysis (eg energy and temperature values for each sensor for each minute);
- Unpacking the test products on receipt and packing them up for shipment at the completion of testing;
- Organising shipment to the next tester (or, for the manufactories, after the round robin has been completed, retaining the units for a minimum of 3 months);
- Allowing access to a suitable person who is nominated to witness the tests (likely to be a staff member from EES and possibly an international laboratory expert);
- Attending the workshop on 15/16 October 2013 in Melbourne;
- Providing written comments on any issues regarding the application of the IEC standard for energy testing in a regulatory context in Australia;
- For the 2 manufacturers, supply of the test refrigerators and a second set of tests at the conclusion of the round robin.

Not included are:

- Transport costs;
  - Manufacturers – transport to the first of the test laboratories is to be organised and paid by the manufacturers. The transport costs are included in the lump sum payment to the manufacturers;
  - Test laboratories – transport to the next test laboratory or back to the manufacturers is to be organised and paid by the test laboratories and the cost of transport will be treated as a separate disbursement to be charged at cost and invoiced to EES;
- Performance tests – no performance tests are specified in the schedule;
- Volume measurement – no volume measurements are specified in the schedule;
- Freezer test packages are not used in these tests.

Information to be Supplied by Manufacturers

Manufacturers will supply a volume for fresh food and freezer compartments in accordance with IEC draft (Part 3 Annex H).

Manufacturers will supply nominal values for defrost minimum and maximum intervals for ambients of 32°C and 16°C in accordance with IEC 59M/49/CDV D.4.1 to enable energy consumption to be determined in accordance with the IEC standard.

Manufacturers will supply ice cube trays with the product that are suitable for processing load tests in accordance with IEC 59M/49/CDV Annex G.

Manufacturers will supply suggested temperature control setting points to give sufficient data to triangulate for IEC and AS/NZS target temperature conditions (while it may be possible to construct one triangle surrounding both sets of conditions with all of the points still within 4K of their respective target temperatures, it is expected that a “kite” of 4 test points will be needed to cover both conditions). Test laboratories are free to use these control settings or other settings as they wish.

Relevant Test Standards

The following documents are referenced for setup and testing purposes:

- IEC 59M/47/CDV - IEC 62552-1: Household refrigerating appliances - Characteristics and test methods - Part 1: General requirements;
- IEC 59M/49/CDV - IEC 62552-3: Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption and volume;
- AS/NZS4474 Performance of household electrical appliances - Refrigerating appliances Part 1: Energy consumption and performance, 2007 (including amendments 1 & 2);
- The latest draft of AS/NZS4474.2 Performance of household electrical appliances - Refrigerating appliances Part 2: Energy labelling and minimum energy performance standard requirements (committee draft dated August 2013).

Copies of the IEC and AS/NZS 4474.2 drafts can be obtained from RET if required. Test laboratories are expected to have an up to date version of AS/NZS4474.1.

Setup Specification

Products will be supplied in packaging suitable for transport. Laboratories are to unpack the products and retain the packaging for re-use when the products are shipped to the next laboratory.

Generally all test setup will be in accordance with IEC 59M/47/CDV - IEC 62552-1 except where otherwise noted.

Energy measurement uncertainty: IEC 59M/47/CDV Clause A.2.1. Please contact the project manager if you are unable to meet this specification (in which case AS/NZS4474.1 B5.3 shall apply).

Humidity: This should be measured and RH needs to be kept below 75% for all tests (refer A.3.5).

Temperature sensor uncertainty: IEC 59M/47/CDV Clause A.2.5. Please contact the project manager if you are unable to meet this specification (in which case AS/NZS4474.1 B5.2 shall apply).

Temperature sensors: All temperature sensors shall be inserted into solid brass or tin-covered copper masses as per IEC 59M/47/CDV Clause A.2.5. Note that these are within the permitted range specified in AS/NZS4474.1 (B6.2), but at the smaller end. IEC sensors are brass or copper masses of 25g = 5g water equivalent, AS/NZS allow 2.3g to 20g of water equivalent. Please contact the project manager if you are unable to meet the IEC specification (in which case AS/NZS4474.1 B6.2 shall apply). Laboratories must state the mass of brass used for their sensors in these tests. Manufacturer laboratories may elect to undertake comparative tests with IEC and heavier sensors where possible.

Ambient Temperatures: energy tests shall be conducted at ambient temperatures of 16°C and 32°C and shall meet requirement of IEC 59M/47/CDV Clause A.3.1.2.

Electricity supply shall be 230V and 50Hz as per IEC 59M/47/CDV Clause A.3.2. Power should be provided via a voltage regulator.

Test room shall be as specified in IEC 59M/47/CDV Clause A.4. Note that there are some differences from the test setup in AS/NZS4474.1. Note that 2 temperature sensors are placed each side of the appliance and in the case of the F&P model shall be shielded from radiation from the side wall condensers. A common sensor can be used between appliances. An additional ambient sensor to AS/NZS4474.1 Paragraph C3 should also be installed for each appliance.

The appliance shall be installed and operated prior to testing in accordance with IEC 59M/47/CDV Annex B. Manufacturers should run in the new appliance according to 59M/47/CDV B.2.2 but subsequent test labs do not need to perform this run in period (although 12 hours of running prior to formal measurements is recommended).

IEC 59M/47/CDV Annex C – test packages are not used for these tests.

IEC 59M/47/CDV Annex D – compartment temperature sensor placements. This is very similar to AS/NZS4474.1 but there are some differences. For these tests, each test refrigerator is to have additional temperature sensors installed to allow a value to be determined for IEC and AS/NZS at the same time. The following notes set out the differences and additional sensors required:

- Temperature sensor placements fresh food – dual positions for fresh food – AS/NZS4474.1 Figure D2 1(a) (with crisper at 25mm, H/3, 2H/3), IEC 59M/47/CDV Figure D1 1(a) (at 50mm, H/2, 3H/4). Total of 6 temperature sensors;

- Temperature sensor placements freezer – Electrolux Side by Side, AS/NZS4474.1 Figure D6 (b) 5 sensors (t12+t13 top left, t11 H/2, t14 H/4, t15 bottom middle right), IEC 59M/47/CDV Annex D Figure D5 (b) 7 sensors as specified (T12+T13 top left (SAME as t12 and t13), T11 H/2 (SAME as t11), T17 H/4 (SAME AS AS/NZS t14), T14+T15 bottom right – (different to AS/NZS t15), T16 3H/4 IEC EXTRA. Total of 8 temperature sensors;

- Temperature sensor placements freezer – F&P E442B, AS/NZS4474.1 Figure D5 (b) Type 2: 5 sensors (T12+T13 top, T11 H/2, T14+T15 bottom), IEC Part 1 Annex D Figure D4 (b) Type 2 ALL THE SAME. Total of 5 temperature sensors.

Temperatures determined in accordance with AS/NZS4474.1 shall have the coldest sensor eliminated for freezers as per AS/NZS4474.1 D4.3.2. For IEC all temperatures are the average of all applicable sensors.

Test laboratories are to supply 500ml PET water bottles for the load processing test in IEC 59M/49/CDV Annex G (drinking water). Bottles with square sides are preferred to stop them rolling around where they have to be positioned horizontally.

Prior to the commencement of tests, laboratories shall report to the project manager with the following information for each product:

- Picture of temperature sensor positions;

- What sensors are being used (AS/NZS or IEC) and mass of brass/copper;

- Calculations on processing load water volume for freezer and fresh food and proposed position of load elements for the load processing test;

- Picture of rear clearance of the appliance and a description;
- Description of the voltage regulator being used;
- Details on the energy meter specifications;
- Details on the temperature sensor specifications.

Testing Specification

The objective of this round robin testing is to provide sufficient test data to allow an accurate estimate of energy consumption to the new IEC test method and AS/NZS target temperatures with a general test setup that is compliant with IEC requirements. At the 32°C ambient it is expected that 4 test points will be sufficient (allowing 2 triangles or a square surrounding both pairs of target points to be drawn). A load processing test at 32°C ambient also has to be conducted.

Testing summary is:

- Steady state tests at sufficient temperature control setting combinations to allow interpolation for IEC and AS/NZS at both 32°C and 16°C ambient (expected that 4 points will be sufficient at each ambient);
- Collection of at least 3 valid defrost and recovery periods for each ambient temperature;
- Load processing test at 32°C ambient;
- Laboratories are not required to initiate the test period with a defrost as per AS/NZS. Steady state periods and defrosts are separately documented. These elements can be combined to accurately calculate energy to AS/NZS4474.1 after the tests are completed.

Testing details: Test shall be in accordance with AS/NZS4474.2 Draft Section 2. Specific variations to these requirements for these test are set out below.

- Steady state at 32°C ambient: IEC 59M/49/CDV Annex B SS1 (3 blocks) (up to 4 control settings);
- Processing load test: IEC 59M/49/CDV Annex G – single control setting combination at 32°C ambient (should be at a control setting where both compartments are below target temperature – recommend at end of 32°C testing and at start of a weekend);
- Defrosts at 32°C ambient: IEC 59M/49/CDV Annex C – min 3 clear valid defrosts;
- Steady state at 16°C ambient: IEC 59M/49/CDV Annex B SS1 (3 blocks) (up to 4 control settings);
- Defrosts at 16°C ambient: IEC 59M/49/CDV Annex C – min 3 clear valid defrosts;
- IEC 59M/49/CDV Annex C nominally requires 4 defrost and recovery periods, or defrosts for each temperature control setting. Data collected will be used to assess these criteria.

The products selected for the round robin are stable and should yield a valid result for steady state power in 15 hours or less (3 block method SS1 in Annex B). The defrosts will probably be concluded within about 3 to 4 hours and a further 3 hours of clear steady operation on each side of the defrost is required to established validity and the incremental defrost and recovery energy and temperature change (Annex C).

The test laboratories are free to undertake the tests as they wish. However, given the relatively short time allowed for testing, the following approach and sequence is recommended for consideration.

1. After initial setup and confirmation of testing parameters with the project manager, operate the product for 24 hours in the test room at the first temperature control setting. Ideally, this should be just before a weekend so it can stabilise and achieve the first test result.
2. At 08:00, change the temperature control settings to a new value (this can be checked in 3 hours to ensure that it is close to the new test point required).
3. At 17:00 on the same day, force the product to undertake a defrost (see notes below).
4. Repeat steps 2 and 3 as required for each subsequent test point (yielding one test point per working day).
5. After the last energy test point at 32°C ambient, undertake a load processing test (see notes below). Ideally, this should be just before a weekend so it can stabilise and fully recover (recovery takes 15 to 20 hours then some period for stability is then required).
6. Change the ambient temperature to 16°C and allow to stabilise for at least 12 hours.
7. Undertake 4 energy tests as required (steps 2 to 4 above).

Forcing defrosts: The products selected for testing have electronic controls and under both normal use and laboratory conditions will have relatively long intervals between defrosts (of the order of 35 to 60 hours). If test laboratories have to wait for naturally occurring defrosts, the testing time could be quite long. The IEC standard allows defrost and recovery events from various tests on different samples of the same model to be compiled in order to get a representative value for defrost and recovery energy. This is not applicable for these tests as only a single product is being tested by the contract test laboratories. Data gathered during these tests will be used to assess these criteria. The recommended test sequence includes forcing a defrost on each day (approximately 24 hour intervals). The IEC standard does not preclude such an approach but if defrosts are too frequent they will tend to give unrealistically low values as the amount of frost will be quite low (test laboratory conditions will yield lower than normal use values in any case). For these tests, forced defrosts should not be initiated by the test laboratory more frequently that once each 24 hours (or where they are, the results should be reported but not included in the averaged defrost and recovery values until further analysis is undertaken). Where naturally occurring defrosts occur, these should be included in the test results wherever possible. The test report should note whether a defrost is forced or naturally occurring and the elapsed clock time since the last defrost.

To initiate a forced defrost for the test products, undertake the following sequence:

- Fisher and Paykel model E442B – wait until the product turns the compressor OFF under its own control – after 5 minutes, quickly open the fresh food door and press the compartment change button (top left) and while continuing to hold this down press the colder button (ve). Press and hold the compartment button, then press and hold -ve colder button (while continuing to hold compartment button). Hold both buttons for up to 10 secs (until there is a beep). Close the door as quickly as possible (15 seconds for this operation is a good target time). A defrost sequence will start when the next compressor on is scheduled to occur (probably within 20 minutes). Initiating a defrost this way is preferred as there is always a full compressor run before the defrost. Forcing the defrost during compressor ON (not recommended) will force the compressor to stop and it will immediately enter a defrost (with a random length of compressor on time). (If unsure that a forced defrost has been initiated, press the buttons in sequence again and if the defrost has been activated, a series of beeps will sound);

- Electrolux (Westinghouse) model WSE6100 – It is important to note that when the power is turned on, the product goes into a test mode for one cycle - this is more or less a fixed length compressor run and has a 2 minute defrost operation at the end. This should be avoided for testing purposes. So here is revised advice regarding forcing defrost on the Electrolux;

  1. Examine the previous compressor cycles to determine a typical off period at the current conditions.
  2. Select a part of the compressor cycle where the unit has recently turned OFF (say 5 min after last compressor OFF).
  3. Turn off the power for >10 secs at the selected time.
  4. Insert a small block into the fresh food door (just big enough to make the light come on to minimise air loss) and then turn on the power.
  5. Wait 10 seconds and quickly have a peek that the control temperatures are displayed, close the door. The compressor should not come on.
  6. The compressor should start at its normal time for the test condition. A defrost sequence will be initiated in about 3 hours (so if you want the defrost to start at 17:00, this should be done at 14:00).

- The product in test mode means that the temperature control is not operating. So if you say turn the power off say 5 min into the compressor off and then on again with the door closed, it will immediately start and run for a fixed time which will make the compartments too cold, then the next cycle will have a long off. This little perturbation will mean that it is harder to get stability between periods D and F. (the data examined so far will certainly be rejected under IEC criteria, so it is of no value). There is also a compressor lock out that stops the compressor starting for 6 minutes after the last start.

Load Processing Test: In this test a specified load of water (in PET bottles and ice cube trays) is placed into the relevant compartment in specified positions. The refrigerator energy is measured until all of the energy in the water is removed and stability can again be established using the 3 block method in Annex B (SS1) (water is at compartment temperature). The load processing test must be preceded by a valid defrost and recovery event or by a valid steady state condition (3 blocks of SS1 in Annex B). This test is only conducted at 32°C ambient (IEC does specify this test at both ambient temperatures but only 32°C ambient is required). A load processing test at a 16°C ambient would be a welcome additional optional test if this can be organised with the test schedule (raw data can be provided without processing to save laboratory time, just place the same water load at the end of the energy testing at 16°C ambient and leave the appliance to run).

The water load should be measured out and prepared early in the 32°C energy test series. It should be placed in the test room at least 24 hours before the anticipated load processing test (the ice cube water should be in a separate bottle /bottles and should only be placed in ice cube trays just before the start of the test). As noted before, the exact water load and the proposed position of the load elements in accordance with Annex G has to be confirmed with the project manager prior to testing.

Wait until a compressor ON event occurs and note the time (this is the start of the load processing test). The load is placed in the cabinet shortly after the compressor on event (while the compressor is running). The same requirements apply if a load processing test at 16°C ambient is undertaken.

Analysis of Test Data

Data collection shall be as per IEC 59M/49/CDV (effectively this is the same as AS/NZS4474.1 – 1 minute intervals or less).

Test laboratories are free to undertake the analysis specified in IEC 59M/49/CDV if they wish. However, this can be somewhat complex and could take some time to set up and verify. To assist test laboratories in the short term, Martien Janssen of ReGent test laboratory in the Netherlands (and member of IEC SC59M) has kindly agreed to supply each test laboratory with software that he has developed to undertake analysis of data to IEC 59M/49/CDV Annex B and Annex C. Software will be provided to each lab directly. There are instructions on how to use it. It is recommended that Excel 2010 be used (or Excel 2007) – note that the software uses macros so these must be enabled. The software should provide the value for steady state and defrost and recovery in accordance with IEC 59M/49/CDV. It is strongly recommended that energy data to 0.1Wh or better be recorded as well as instantaneous or average power for each sampling period.

Test laboratories must agree to supply raw test data to the project manager for further analysis.

Once valid test data has been obtain for each of the temperature control settings, the data needs to be assembled into relevant energy test values. These are set out in the test report format below.

Information to be Supplied and Test Report

Test laboratories should prepare a test report that contains all the normal data that would be supplied for an AS/NZS4474.1 test report. This includes information about the product tested, test laboratory details and equipment and a general description of the tests undertaken.

In addition, this section sets out specific data that is also to be supplied as part of the standardised reporting for this round robin.

For each steady state test point:

- Size of each steady state block (number of cycles);
- Average steady state temperature for each sensor over the selected test period;
- Start time and total duration of the selected test period (hours) (for 3 blocks);
- Average steady state temperature for each compartment – IEC sensors;
- Average steady state temperature for each compartment – AS/NZS sensors (note coldest sensor is excluded for freezers);
- Average steady state power Pss1 for the selected test period (W);
- Average measured ambient temperature during the selected test period;
- Corrected average steady state power Pss for the selected test period in accordance with 59M/49/CDV Annex C Equation 15;
- Confirmation that validity criteria for IEC SS1 Annex B have been met (spread and slope for temperatures and power).
- Figures showing selected periods should be provided.

For each defrost and recovery period (refer to 59M/49/CDV Annex C Figure C.2):

- Start time the defrost heater on;
- Whether the defrost was natural for forced;
- Elapsed time since the last defrost heater on (hours);
- Duration of the defrost heater on (minutes) and average heater on power (W);
- Nominal centre of the defrost and recovery period (time = 2 hours after defrost heater on);
- Length of period D and F (hours), number of control cycles;
- Average power during periods D and F (and average of D and F);
- Spread of power for D and F (W and %);
- Average temperature during periods D and F in each compartment (and average of D and F) for IEC sensors;
- Spread of temperature for D and F (K) IEC sensors;
- Average temperature during periods D and F in each compartment (and average of D and F) for AS/NZS sensors;
- Length of period D1 and F1 (hours);

- Additional energy associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 19;
- Temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for IEC temperature sensors;
- Temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for AS/NZS temperature sensors;
- Figures showing selected defrost periods should be provided.

For all the valid defrost and recovery periods selected calculate representative values for:

- Average additional energy associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 19 for all defrosts for an ambient temperature of 32°C;
- Average temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for IEC temperature sensors for all defrosts for an ambient temperature of 32°C;
- Average temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for AS/NZS temperature sensors for all defrosts for an ambient temperature of 32°C;
- Average additional energy associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 19 for all defrosts for an ambient temperature of 16°C;
- Average temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for IEC temperature sensors for all defrosts for an ambient temperature of 16°C;
- Average temperature change in each compartment associated with the defrost and recovery period as per 59M/49/CDV Annex C Equation 20 for AS/NZS temperature sensors for all defrosts for an ambient temperature of 16°C;
- Defrost interval for 32°C ambient as per 59M/49/CDV Annex D Equation 27 based on values supplied by the manufacturers;
- Defrost interval for 16°C ambient as per 59M/49/CDV Annex D Equation 27 based on values supplied by the manufacturers.

Calculations of energy for each test point (includes data at 16°C and 32°C ambient as applicable):

- Energy to be calculated for AS/NZS (32°C ambient), MEPS2017 (32°C ambient) and IEC/energy labelling (16°C and 32°C ambient);
- Assumed defrost intervals are: AS/NZS = 24 hours, MEPS2017 = 60 hours, IEC energy at 32°C 24/36/48 hours plus calculated value from Annex D, IEC energy at 16°C 36/48/60 hours plus calculated value from Annex D;

- Daily energy consumption is based on 59M/49/CDV Equation 2 for each test point for the defrost intervals specified above. All energy calculations include energy during defrost and recovery;
- AS/NZS temperatures: Average temperature in each compartment for AS/NZS temperature sensor positions based on 59M/49/CDV Equation 3 for each test point assuming a defrost interval of 24 hours (32°C ambient only);
- MEPS2017: Average temperature in each compartment for IEC temperature sensor positions without any defrost and recovery temperature correction for each test point (steady state only) (this value is used for MEPS2017 and will be a useful comparison to corrected value above) (32°C ambient only);
- IEC: Average temperature in each compartment for IEC temperature sensor positions based on 59M/49/CDV Equation 3 for each test point assuming defrost intervals specified above;
- Interpolation of energy using triangulation at each ambient temperature (values to be supplied separately for 16°C and 32°C as applicable);
- Based on daily energy consumption and IEC compartment temperatures (corrected for defrost and recovery), calculate interpolated energy at the IEC target temperatures of freezer -18°C and fresh food +4°C (59M/49/CDV Annex E);
- Based on daily energy consumption and AS/NZS compartment temperatures (corrected for defrost and recovery), calculate interpolated energy at the AS/NZS target temperatures of freezer -15°C and fresh food +3°C (59M/49/CDV Annex E) (32°C ambient only);
- Based on daily energy consumption and IEC steady state compartment temperatures (NOT corrected for defrost and recovery), calculate interpolated energy at the IEC target temperatures of freezer -18°C and fresh food +4°C (59M/49/CDV Annex E) (32°C ambient only);
- Figures showing each interpolation should be provided.

Note that triangulation in 59M/49/CDV Annex E is the same as AS/NZS4474.1 Appendix M, so existing procedures and routines can be used. A sample spreadsheet set up for matrices and/or manual triangulation can be supplied on request. Where matrices are used, report the values for E0, A and B derived from the data for each case listed above.

Load processing efficiency test:

- Validity prior to commencement (valid defrost or valid steady state period);
- Mass of water in fresh food and number of bottles;
- Mass of water in freezer and number of ice cube trays;
- Photos showing load in situ after placement (can be at the end of the test);
- Steady state power and compartment temperature prior to the load processing test;

- Time of the start of the load processing test;
- Time of the end of the load processing test;
- Validity at the end of the load processing test (steady state or defrost – see 59M/49/CDV G.4.4);
- Steady state power and compartment temperature at the completion of the load processing test;
- Note whether any defrost and recovery periods occurred during the load processing test;
- Calculate test input energy in the fresh food compartment as per 59M/49/CDV Annex G Equation 48;
- Calculate test input energy in the freezer compartment as per 59M/49/CDV Annex G Equation 49;
- Calculate the additional energy used to process the load as per 59M/49/CDV Annex G Equation 50;
- Calculate the load processing efficiency as per 59M/49/CDV Annex G Equation 51;
- Figures showing the load processing test should be provided.

Laboratory Feedback

Participating laboratories should provide written feedback on their experiences with the new test method. In particular, any text in the IEC or AS/NZS 4474.2 draft documents that is not clear or where there are mistakes, typos or ambiguous text should be noted. Any suggestions on structural changes to facilitate use should also be noted.

END OF SPECIFICATION

Appendix B: Refrigerator Round Robin Unit Testing Results

Round Robin Unit Results

The following four pages contain the round robin testing results for the Electrolux units (page 1 and 2) – E1 (left) and E2 (right), and then the Fisher & Paykel units (3 and 4) – F1 and F2.

This analysis uses the raw steady state round robin measurements provided by the labs (but including ambient temperature corrections), and calculates the steady state power and compressor run time for each selected combination of compartment temperatures (fresh food and freezer) and control setting for each ambient temperature. The power and compressor run time values are calculated using the planer regression analysis, as compiled by EES. Refer to **Appendix C** for more details on this analysis approach. Not all laboratories conducted a test at each of the conditions or control settings listed. Using the Electrolux units as an example, the first page (red and blue figures) provides the steady state findings (no defrost cycles) for a range of control settings. The data has been split into blocks, for ease of reading. The first block (top, left) outlines the temperature readings for a 32°C ambient and is split in to columns:

- Column 1 – the fresh food temperature i.e. 2°C;
- Column 2 – the freezer temperature i.e. -15°C;
- Column 3 – the estimated power (planar regressions) for these temperatures for Lab 1;
- Column 4 – the estimated power (planar regressions) for these temperatures for Lab 2;
- Column 5 – the estimated power (planar regressions) for these temperatures for Lab 3;
- Column 6 – the mean of these power measurements;
- Column 7 – the estimated runtime of the compressor for these temperatures for Lab 1;
- Column 8 – the estimated runtime of the compressor for these temperatures for Lab 2;
- Column 9 – the estimated runtime of the compressor for these temperatures for Lab 3;
- Column 10 - the mean of these compressor runtime percentages.

The second block of data contains the same data for fresh food and freezer control settings (as opposed to measured compartment temperatures) at 32°C ambient. While the third and fourth blocks correspond the first and second blocks but at an ambient temperature of 16°C.

The yellow highlighted line at +4°C and -18°C for ambient temperatures of 32°C and 16°C shows the comparative results if only triangulation to IEC was performed. This shows that the results for all the labs are very close for these specific measurements. The exception for this is F-E2 (the power is around 5% lower at both ambient temperatures). A range of investigations has shown that this measurement was not compliant with the ambient test conditions during the test. It appears likely that the unit may also have been subjected to a low temperature heat sink close to one side (which is also non-compliant), which explains the low power measurement (this result should be excluded).

The second page (green figures) provides the difference from the mean for each lab, for the specific temperature measurements or control setting. This helps to show how the measurements from each laboratory compare. This enables any discrepancies in the data to be clearly seen. Again, the yellow highlighted line at compartment temperatures of 4°C and -18°C for ambient temperatures of 32°C and 16°C, are of most interest. The data on pages 3 and 4 is for the F&P units, which is shown in the same format as the data for the Electrolux units.

Comparison of Products and Labs for Selected Settings

Based on planar regression

Electrolux control settings are in nominal compartment temperatures

IEC target Temperatures

D-E2 non-complying test

E1	A	-0.984216	-0.998946	-0.547989		-0.002905	-0.011983	-0.008855	
	B	-1.645751	-1.460257	-1.311478		-0.023061	-0.019327	-0.014889	
	E0	43.243727	45.1962	46.288048		0.1283447	0.2347136	0.2928449	
Ambient 32C									
Measured Temp		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF Temp	**FZ Temp**	**A-E1**	**B-E1**	**C-E1**		**A-E1**	**B-E1**	**C-E1**	
2	-15	66.0	65.1	64.9	65.3	46.8%	50.1%	49.8%	48.9%
2	-18	70.9	69.5	68.8	69.7	53.8%	55.9%	54.3%	54.6%
2	-21	75.8	73.9	72.7	74.1	60.7%	61.7%	58.8%	60.4%
4	-15	64.0	63.1	63.8	63.6	46.3%	47.7%	48.1%	47.3%
4	-18	68.9	67.5	67.7	68.0	53.2%	53.5%	52.5%	53.1%
4	-21	73.9	71.9	71.6	72.5	60.1%	59.3%	57.0%	58.8%
6	-15	62.0	61.1	62.7	61.9	45.7%	45.3%	46.3%	45.8%
6	-18	67.0	65.5	66.6	66.4	52.6%	51.1%	50.8%	51.5%
6	-21	71.9	69.9	70.5	70.8	59.5%	56.9%	55.2%	57.2%

	A	-1.110959	-0.846397	-0.383247		-0.005458	-0.010053	-0.006465	
	B	-1.54978	-1.408136	-1.341332		-0.021718	-0.018627	-0.015365	
	E0	39.245444	40.800926	41.696244		0.0869094	0.1772469	0.2351127	
Ambient 32C									
Control Setting		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF control	**FZ control**	**A-E1**	**B-E1**	**C-E1**		**A-E1**	**B-E1**	**C-E1**	
1	-17	64.5	63.9	64.1	64.2	45.1%	48.4%	49.0%	47.5%
1	-20	69.1	68.1	68.1	68.5	51.6%	54.0%	53.6%	53.1%
1	-23	73.8	72.3	72.2	72.8	58.1%	59.6%	58.2%	58.6%
3	-17	62.3	62.2	63.3	62.6	44.0%	46.4%	47.7%	46.0%
3	-20	66.9	66.4	67.4	66.9	50.5%	52.0%	52.3%	51.6%
3	-23	71.6	70.6	71.4	71.2	57.0%	57.6%	56.9%	57.2%
5	-17	60.0	60.5	62.6	61.0	42.9%	44.4%	46.4%	44.5%
5	-20	64.7	64.7	66.6	65.3	49.4%	50.0%	51.0%	50.1%
5	-23	69.3	69.0	70.6	69.6	55.9%	55.5%	55.6%	55.7%

	A	-0.887512	-0.874896	-0.481058		-0.00783	-0.008006	-0.004467	
	B	-1.157733	-0.959632	-1.478993		-0.014342	-0.013272	-0.018764	
	E0	20.991623	23.780136	11.852368		0.0994421	0.1270176	-0.007002	
Ambient 16C									
Measured Temp		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF Temp	**FZ Temp**	**A-E1**	**B-E1**	**C-E1**		**A-E1**	**B-E1**	**C-E1**	
2	-15	36.6	36.4	33.1	35.4	29.9%	31.0%	26.6%	29.2%
2	-18	40.1	39.3	37.5	39.0	34.2%	35.0%	32.2%	33.8%
2	-21	43.5	42.2	41.9	42.6	38.5%	39.0%	37.8%	38.4%
4	-15	34.8	34.7	32.1	33.9	28.3%	29.4%	25.7%	27.8%
4	-18	38.3	37.6	36.6	37.5	32.6%	33.4%	31.3%	32.4%
4	-21	41.8	40.4	41.0	41.1	36.9%	37.4%	36.9%	37.1%
6	-15	33.0	32.9	31.2	32.4	26.8%	27.8%	24.8%	26.4%
6	-18	36.5	35.8	35.6	36.0	31.1%	31.8%	30.4%	31.1%
6	-21	40.0	38.7	40.0	39.6	35.4%	35.8%	36.0%	35.7%

	A	-0.834006	-1.06199	-0.556773		-0.007209	-0.0096	-0.005228	
	B	-1.12158	-0.701825	-1.432565		-0.013881	-0.010795	-0.018235	
	E0	17.295613	26.031057	9.1891265		0.0573531	0.1356732	-0.041094	
Ambient 16C									
Control Setting		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF control	**FZ control**	**A-E1**	**B-E1**	**C-E1**		**A-E1**	**B-E1**	**C-E1**	
1	-17	35.5	36.9	33.0	35.1	28.6%	31.0%	26.4%	28.6%
1	-20	38.9	39.0	37.3	38.4	32.8%	34.2%	31.8%	32.9%
1	-23	42.3	41.1	41.6	41.7	36.9%	37.4%	37.3%	37.2%
3	-17	33.9	34.8	31.9	33.5	27.2%	29.0%	25.3%	27.2%
3	-20	37.2	36.9	36.2	36.8	31.3%	32.3%	30.8%	31.5%
3	-23	40.6	39.0	40.5	40.0	35.5%	35.5%	36.3%	35.8%
5	-17	32.2	32.7	30.8	31.9	25.7%	27.1%	24.3%	25.7%
5	-20	35.6	34.8	35.1	35.1	29.9%	30.4%	29.7%	30.0%
5	-23	38.9	36.9	39.4	38.4	34.1%	33.6%	35.2%	34.3%

E2	A	-1.174988	-1.319619	-1.124059		-0.007745	-0.009395	-0.006688	
	B	-1.162427	-1.577428	-1.701363		-0.022952	-0.021919	-0.021344	
	E0	48.513612	46.344732	42.630519		0.128336	0.1988003	0.1889029	
Ambient 32C					Excl D-E2				Excl D-E2
Measured Temp		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF Temp	**FZ Temp**	**D-E2**	**E-E2**	**F-E2**		**D-E2**	**E-E2**	**F-E2**	
2	-15	63.6	67.4	65.9	66.6	45.7%	50.9%	49.6%	50.2%
2	-18	67.1	72.1	71.0	71.6	52.6%	57.5%	56.0%	56.7%
2	-21	70.6	76.8	76.1	76.5	59.5%	64.0%	62.4%	63.2%
4	-15	61.3	64.7	63.7	64.2	44.2%	49.0%	48.2%	48.6%
4	-18	64.7	69.5	68.8	69.1	51.0%	55.6%	54.6%	55.1%
4	-21	68.2	74.2	73.9	74.0	57.9%	62.2%	61.0%	61.6%
6	-15	58.9	62.1	61.4	61.7	42.6%	47.1%	46.9%	47.0%
6	-18	62.4	66.8	66.5	66.7	49.5%	53.7%	53.3%	53.5%
6	-21	65.9	71.6	71.6	71.6	56.4%	60.3%	59.7%	60.0%

	A	-1.201436	-1.332436	-1.135662		-0.008995	-0.009748	-0.007287	
	B	-1.06384	-1.459263	-1.542454		-0.021343	-0.020412	-0.019498	
	E0	47.190291	41.529193	41.387792		0.1127969	0.1459939	0.1766255	
Ambient 32C					Excl D-E2				Excl D-E2
Control Setting		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF control	**FZ control**	**D-E2**	**E-E2**	**F-E2**		**D-E2**	**E-E2**	**F-E2**	
1	-17	64.1	65.0	66.5	65.7	46.7%	48.3%	50.1%	49.2%
1	-20	67.3	69.4	71.1	70.2	53.1%	54.4%	55.9%	55.2%
1	-23	70.5	73.8	75.7	74.7	59.5%	60.6%	61.8%	61.2%
3	-17	61.7	62.3	64.2	63.3	44.9%	46.4%	48.6%	47.5%
3	-20	64.9	66.7	68.8	67.8	51.3%	52.5%	54.5%	53.5%
3	-23	68.1	71.1	73.5	72.3	57.7%	58.6%	60.3%	59.5%
5	-17	59.3	59.7	61.9	60.8	43.1%	44.4%	47.2%	45.8%
5	-20	62.5	64.1	66.6	65.3	49.5%	50.5%	53.0%	51.8%
5	-23	65.7	68.4	71.2	69.8	55.9%	56.7%	58.9%	57.8%

	A	-0.973703	-0.763441	-0.880792		-0.011187	-0.006335	-0.008544	
	B	-0.85912	-1.269967	-1.131474		-0.013257	-0.015508	-0.015054	
	E0	23.123959	18.103521	21.008445		0.1253865	0.0987081	0.1062364	
Ambient 16C					Excl D-E2				Excl D-E2
Measured Temp		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF Temp	**FZ Temp**	**D-E2**	**E-E2**	**F-E2**		**D-E2**	**E-E2**	**F-E2**	
2	-15	34.1	35.6	36.2	35.9	30.2%	31.9%	31.5%	31.7%
2	-18	36.6	39.4	39.6	39.5	34.2%	36.5%	36.0%	36.3%
2	-21	39.2	43.2	43.0	43.1	38.1%	41.2%	40.5%	40.8%
4	-15	32.1	34.1	34.5	34.3	27.9%	30.6%	29.8%	30.2%
4	-18	34.7	37.9	37.9	37.9	31.9%	35.3%	34.3%	34.8%
4	-21	37.3	41.7	41.2	41.5	35.9%	39.9%	38.8%	39.4%
6	-15	30.2	32.6	32.7	32.6	25.7%	29.3%	28.1%	28.7%
6	-18	32.7	36.4	36.1	36.2	29.7%	34.0%	32.6%	33.3%
6	-21	35.3	40.2	39.5	39.8	33.7%	38.6%	37.1%	37.9%

	A	-0.902034	-0.6853	-0.796497		-0.009851	-0.005399	-0.007621	
	B	-0.94419	-1.166055	-1.116714		-0.014018	-0.014315	-0.014813	
	E0	18.967886	15.804304	17.874477		0.074354	0.0728705	0.0698941	
Ambient 16C					Excl D-E2				Excl D-E2
Control Setting		Power W	Power W	Power W	Mean	Runtime	Runtime	Runtime	Mean
FF control	**FZ control**	**D-E2**	**E-E2**	**F-E2**		**D-E2**	**E-E2**	**F-E2**	
1	-17	34.1	34.9	36.1	35.5	30.3%	31.1%	31.4%	31.2%
1	-20	36.9	38.4	39.4	38.9	34.5%	35.4%	35.9%	35.6%
1	-23	39.8	41.9	42.8	42.4	38.7%	39.7%	40.3%	40.0%
3	-17	32.3	33.6	34.5	34.0	28.3%	30.0%	29.9%	29.9%
3	-20	35.1	37.1	37.8	37.4	32.5%	34.3%	34.3%	34.3%
3	-23	38.0	40.6	41.2	40.9	36.7%	38.6%	38.8%	38.7%
5	-17	30.5	32.2	32.9	32.5	26.3%	28.9%	28.4%	28.6%
5	-20	33.3	35.7	36.2	36.0	30.5%	33.2%	32.8%	33.0%
5	-23	36.2	39.2	39.6	39.4	34.8%	37.5%	37.2%	37.4%

Comparison of Products and Labs for Selected Settings

Based on planar regression

Electrolux control settings are in nominal compartment temperatures

IEC target Temperatures

D-E2 non-complying test

E1

Ambient 32C — Measured Temp (Prelim only: Power C-E1)

FF Temp	FZ Temp	Power A-E1	Power B-E1	Power C-E1	Mean	Runtime A-E1	Runtime B-E1	Runtime C-E1	Mean
2	-15	1.0%	-0.3%	-0.7%	65.3	-4.2%	2.3%	1.9%	48.9%
2	-18	1.7%	-0.3%	-1.3%	69.7	-1.6%	2.2%	-0.6%	54.6%
2	-21	2.3%	-0.4%	-1.9%	74.1	0.5%	2.1%	-2.6%	60.4%
4	-15	0.6%	-0.8%	0.2%	63.6	-2.3%	0.7%	1.6%	47.3%
4	-18	1.3%	-0.8%	-0.5%	68.0	0.2%	0.8%	-1.0%	53.1%
4	-21	1.9%	-0.8%	-1.1%	72.5	2.2%	0.8%	-3.0%	58.8%
6	-15	0.1%	-1.3%	1.2%	61.9	-0.2%	-1.1%	1.2%	45.8%
6	-18	0.9%	-1.3%	0.4%	66.4	2.2%	-0.8%	-1.4%	51.5%
6	-21	1.6%	-1.3%	-0.3%	70.8	4.0%	-0.6%	-3.4%	57.2%

Ambient 32C — Control Setting (Prelim only: Power C-E1)

FF control	FZ control	Power A-E1	Power B-E1	Power C-E1	Mean	Runtime A-E1	Runtime B-E1	Runtime C-E1	Mean
1	-17	0.5%	-0.4%	-0.1%	64.2	-5.1%	1.9%	3.2%	47.5%
1	-20	1.0%	-0.5%	-0.5%	68.5	-2.8%	1.7%	1.0%	53.1%
1	-23	1.4%	-0.6%	-0.8%	72.8	-0.9%	1.6%	-0.7%	58.6%
3	-17	-0.5%	-0.6%	1.2%	62.6	-4.4%	0.8%	3.6%	46.0%
3	-20	0.0%	-0.7%	0.7%	66.9	-2.1%	0.7%	1.4%	51.6%
3	-23	0.5%	-0.8%	0.3%	71.2	-0.3%	0.7%	-0.4%	57.2%
5	-17	-1.6%	-0.9%	2.5%	61.0	-3.7%	-0.4%	4.2%	44.5%
5	-20	-1.0%	-0.9%	1.9%	65.3	-1.4%	-0.3%	1.8%	50.1%
5	-23	-0.4%	-1.0%	1.4%	69.6	0.4%	-0.3%	-0.1%	55.7%

Ambient 16C — Measured Temp

FF Temp	FZ Temp	Power A-E1	Power B-E1	Power C-E1	Mean	Runtime A-E1	Runtime B-E1	Runtime C-E1	Mean
2	-15	3.5%	3.0%	-6.5%	35.4	2.5%	6.4%	-8.9%	29.2%
2	-18	2.8%	0.9%	-3.7%	39.0	1.2%	3.6%	-4.8%	33.8%
2	-21	2.3%	-0.9%	-1.4%	42.6	0.2%	1.4%	-1.6%	38.4%
4	-15	2.8%	2.4%	-5.2%	33.9	1.9%	5.8%	-7.7%	27.8%
4	-18	2.2%	0.2%	-2.4%	37.5	0.6%	2.9%	-3.5%	32.4%
4	-21	1.7%	-1.5%	-0.2%	41.1	-0.4%	0.8%	-0.4%	37.1%
6	-15	2.0%	1.7%	-3.8%	32.4	1.2%	5.2%	-6.3%	26.4%
6	-18	1.5%	-0.4%	-1.1%	36.0	-0.1%	2.3%	-2.2%	31.1%
6	-21	1.1%	-2.2%	1.2%	39.6	-1.0%	0.1%	0.9%	35.7%

Ambient 16C — Control Setting

FF control	FZ control	Power A-E1	Power B-E1	Power C-E1	Mean	Runtime A-E1	Runtime B-E1	Runtime C-E1	Mean
1	-17	1.1%	5.0%	-6.1%	35.1	-0.1%	8.1%	-8.0%	28.6%
1	-20	1.3%	1.6%	-2.9%	38.4	-0.5%	3.8%	-3.3%	32.9%
1	-23	1.5%	-1.3%	-0.2%	41.7	-0.8%	0.6%	0.2%	37.2%
3	-17	1.1%	3.8%	-4.9%	33.5	0.0%	6.9%	-6.8%	27.2%
3	-20	1.3%	0.3%	-1.6%	36.8	-0.4%	2.6%	-2.1%	31.5%
3	-23	1.4%	-2.6%	1.1%	40.0	-0.7%	-0.7%	1.4%	35.8%
5	-17	1.0%	2.5%	-3.5%	31.9	0.1%	5.5%	-5.6%	25.7%
5	-20	1.2%	-1.0%	-0.2%	35.1	-0.4%	1.2%	-0.8%	30.0%
5	-23	1.4%	-4.0%	2.5%	38.4	-0.7%	-2.0%	2.7%	34.3%

E2

Ambient 32C — Measured Temp

FF Temp	FZ Temp	Power D-E2	Power E-E2	Power F-E2	Mean (Excl D-E2)	Runtime D-E2	Runtime E-E2	Runtime F-E2	Mean (Excl D-E2)
2	-15	-4.6%	1.1%	-1.1%	66.6	-8.98%	1.3%	-1.3%	50.2%
2	-18	-6.2%	0.8%	-0.8%	71.6	-7.26%	1.3%	-1.3%	56.7%
2	-21	-7.7%	0.5%	-0.5%	76.5	-5.88%	1.3%	-1.3%	63.2%
4	-15	-4.6%	0.8%	-0.8%	64.2	-9.16%	0.8%	-0.8%	48.6%
4	-18	-6.3%	0.5%	-0.5%	69.1	-7.36%	0.9%	-0.9%	55.1%
4	-21	-7.8%	0.2%	-0.2%	74.0	-5.94%	0.9%	-0.9%	61.6%
6	-15	-4.6%	0.6%	-0.6%	61.7	-9.34%	0.2%	-0.2%	47.0%
6	-18	-6.4%	0.2%	-0.2%	66.7	-7.47%	0.4%	-0.4%	53.5%
6	-21	-8.0%	0.0%	0.0%	71.6	-6.00%	0.5%	-0.5%	60.0%

Ambient 32C — Control Setting

FF control	FZ control	Power D-E2	Power E-E2	Power F-E2	Mean (Excl D-E2)	Runtime D-E2	Runtime E-E2	Runtime F-E2	Mean (Excl D-E2)
1	-17	-2.5%	-1.1%	1.1%	65.7	-5.16%	-1.8%	1.8%	49.2%
1	-20	-4.2%	-1.2%	1.2%	70.2	-3.85%	-1.3%	1.3%	55.2%
1	-23	-5.7%	-1.3%	1.3%	74.7	-2.79%	-1.0%	1.0%	61.2%
3	-17	-2.5%	-1.5%	1.5%	63.3	-5.55%	-2.4%	2.4%	47.5%
3	-20	-4.3%	-1.6%	1.6%	67.8	-4.15%	-1.8%	1.8%	53.5%
3	-23	-5.8%	-1.6%	1.6%	72.3	-3.03%	-1.4%	1.4%	59.5%
5	-17	-2.5%	-1.9%	1.9%	60.8	-5.96%	-3.0%	3.0%	45.8%
5	-20	-4.4%	-1.9%	1.9%	65.3	-4.47%	-2.4%	2.4%	51.8%
5	-23	-6.0%	-2.0%	2.0%	69.8	-3.29%	-1.9%	1.9%	57.8%

Ambient 16C — Measured Temp

FF Temp	FZ Temp	Power D-E2	Power E-E2	Power F-E2	Mean (Excl D-E2)	Runtime D-E2	Runtime E-E2	Runtime F-E2	Mean (Excl D-E2)
2	-15	-5.2%	-0.8%	0.8%	35.9	-4.72%	0.6%	-0.6%	31.7%
2	-18	-7.3%	-0.2%	0.2%	39.5	-5.80%	0.7%	-0.7%	36.3%
2	-21	-9.1%	0.3%	-0.3%	43.1	-6.63%	0.8%	-0.8%	40.8%
4	-15	-6.3%	-0.5%	0.5%	34.3	-7.43%	1.3%	-1.3%	30.2%
4	-18	-8.4%	0.1%	-0.1%	37.9	-8.20%	1.4%	-1.4%	34.8%
4	-21	-10.2%	0.6%	-0.6%	41.5	-8.79%	1.4%	-1.4%	39.4%
6	-15	-7.6%	-0.2%	0.2%	32.6	-10.43%	2.2%	-2.2%	28.7%
6	-18	-9.6%	0.4%	-0.4%	36.2	-10.82%	2.1%	-2.1%	33.3%
6	-21	-11.3%	0.9%	-0.9%	39.8	-11.11%	2.0%	-2.0%	37.9%

Ambient 16C — Control Setting

FF control	FZ control	Power D-E2	Power E-E2	Power F-E2	Mean (Excl D-E2)	Runtime D-E2	Runtime E-E2	Runtime F-E2	Mean (Excl D-E2)
1	-17	-3.9%	-1.6%	1.6%	35.5	-3.09%	-0.5%	0.5%	31.2%
1	-20	-5.1%	-1.2%	1.2%	38.9	-3.17%	-0.7%	0.7%	35.6%
1	-23	-6.1%	-1.0%	1.0%	42.4	-3.24%	-0.8%	0.8%	40.0%
3	-17	-5.0%	-1.3%	1.3%	34.0	-5.46%	0.2%	-0.2%	29.9%
3	-20	-6.1%	-1.0%	1.0%	37.4	-5.24%	0.0%	0.0%	34.3%
3	-23	-7.1%	-0.7%	0.7%	40.9	-5.07%	-0.2%	0.2%	38.7%
5	-17	-6.2%	-1.0%	1.0%	32.5	-8.04%	1.0%	-1.0%	28.6%
5	-20	-7.3%	-0.7%	0.7%	36.0	-7.47%	0.6%	-0.6%	33.0%
5	-23	-8.2%	-0.5%	0.5%	39.4	-7.03%	0.4%	-0.4%	37.4%

Comparison of Products and Labs for Selected Settings

Based on planar regression

F&P control higher number is warmer (1 to 11)

IEC target Temperatures

F1 – Ambient 32C – Measured Temp

F1		Power W G-F1	Power W H-F1	Power W I-F1		Runtime G-F1	Runtime H-F1	Runtime I-F1	
	A	-0.762505	-1.133546	-0.968699		-0.007202	-0.011412	-0.008298	
	B	-1.855051	-1.895434	-1.870154		-0.028283	-0.030027	-0.031086	
	E0	27.479302	26.969961	26.321547		0.0862723	0.0641222	0.020034	
FF Temp	**FZ Temp**	**G-F1**	**H-F1**	**I-F1**	Mean	**G-F1**	**H-F1**	**I-F1**	Mean
2	-15	53.8	53.1	52.4	53.1	49.6%	49.2%	47.0%	48.6%
2	-18	59.3	58.8	58.0	58.7	58.1%	58.2%	56.3%	57.5%
2	-21	64.9	64.5	63.7	64.4	66.6%	67.2%	65.6%	66.5%
4	-15	52.3	50.9	50.5	51.2	48.2%	46.9%	45.3%	46.8%
4	-18	57.8	56.6	56.1	56.8	56.7%	55.9%	54.6%	55.7%
4	-21	63.4	62.2	61.7	62.4	65.1%	64.9%	64.0%	64.7%
6	-15	50.7	48.6	48.6	49.3	46.7%	44.6%	43.7%	45.0%
6	-18	56.3	54.3	54.2	54.9	55.2%	53.6%	53.0%	53.9%
6	-21	61.9	60.0	59.8	60.5	63.7%	62.6%	62.3%	62.9%

F2 – Ambient 32C – Measured Temp

F2		Power W J-F2	Power W K-F2	Power W L-F2		Runtime J-F2	Runtime K-F2	Runtime L-F2	
	A	-0.878942	-0.733866	-0.824521		-0.008163	-0.004422	-0.007339	
	B	-1.617333	-1.698046	-1.569945		-0.024743	-0.025272	-0.022751	
	E0	31.412475	28.104767	30.514602		0.1317515	0.1020435	0.145312	
FF Temp	**FZ Temp**	**J-F2**	**K-F2**	**L-F2**	Mean	**J-F2**	**K-F2**	**L-F2**	Mean
2	-15	53.9	52.1	52.4	52.8	48.7%	47.2%	47.2%	47.7%
2	-18	58.8	57.2	57.1	57.7	56.1%	54.8%	54.0%	55.0%
2	-21	63.6	62.3	61.8	62.6	63.5%	62.4%	60.8%	62.2%
4	-15	52.2	50.6	50.8	51.2	47.0%	46.3%	45.7%	46.4%
4	-18	57.0	55.7	55.5	56.1	54.4%	53.9%	52.5%	53.6%
4	-21	61.9	60.8	60.2	61.0	61.9%	61.5%	59.4%	60.9%
6	-15	50.4	49.2	49.1	49.6	45.4%	45.5%	44.3%	45.0%
6	-18	55.3	54.3	53.8	54.4	52.8%	53.0%	51.1%	52.3%
6	-21	60.1	59.4	58.5	59.3	60.2%	60.6%	57.9%	59.6%

F1 – Ambient 32C – Control Setting

		Power W G-F1	Power W H-F1	Power W I-F1		Runtime G-F1	Runtime H-F1	Runtime I-F1	
	A	-0.689192	-0.853403	-1.179968		-0.005997	-0.008163	-0.011639	
	B	-1.37188	-1.456944	-1.46717		-0.02126	-0.023501	-0.024469	
	E0	71.32113	72.200155	74.904232		0.7431448	0.7709293	0.8033669	
FF control	**FZ control**	**G-F1**	**H-F1**	**I-F1**	Mean	**G-F1**	**H-F1**	**I-F1**	Mean
3	10	55.5	55.1	56.7	55.8	51.3%	51.1%	52.4%	51.6%
3	7	59.7	59.4	61.1	60.1	57.6%	58.2%	59.7%	58.5%
3	4	63.8	63.8	65.5	64.4	64.0%	65.2%	67.1%	65.4%
6	10	53.5	52.5	53.2	53.0	49.5%	48.7%	48.9%	49.0%
6	7	57.6	56.9	57.6	57.3	55.8%	55.7%	56.2%	55.9%
6	4	61.7	61.3	62.0	61.6	62.2%	62.8%	63.6%	62.9%
9	10	51.4	50.0	49.6	50.3	47.7%	46.2%	45.4%	46.4%
9	7	55.5	54.3	54.0	54.6	54.0%	53.3%	52.7%	53.4%
9	4	59.6	58.7	58.4	58.9	60.4%	60.3%	60.1%	60.3%

F2 – Ambient 32C – Control Setting

		Power W J-F2	Power W K-F2	Power W L-F2		Runtime J-F2	Runtime K-F2	Runtime L-F2	
	A	-0.636602	-0.657609	-0.606304		-0.006048	-0.004143	-0.005026	
	B	-1.46933	-1.403218	-1.22983		-0.021877	-0.020278	-0.017298	
	E0	70.464343	68.566318	68.750635		0.7213559	0.6882346	0.6855452	
FF control	**FZ control**	**J-F2**	**K-F2**	**L-F2**	Mean	**J-F2**	**K-F2**	**L-F2**	Mean
3	10	53.9	52.6	54.6	53.7	48.4%	47.3%	49.7%	48.5%
3	7	58.3	56.8	58.3	57.8	55.0%	53.4%	54.9%	54.4%
3	4	62.7	61.0	62.0	61.9	61.6%	59.5%	60.1%	60.4%
6	10	52.0	50.6	52.8	51.8	46.6%	46.1%	48.2%	47.0%
6	7	56.4	54.8	56.5	55.9	53.2%	52.1%	53.4%	52.9%
6	4	60.8	59.0	60.2	60.0	59.8%	58.2%	58.6%	58.9%
9	10	50.0	48.6	51.0	49.9	44.8%	44.8%	46.7%	45.5%
9	7	54.4	52.8	54.7	54.0	51.4%	50.9%	51.9%	51.4%
9	4	58.9	57.0	58.4	58.1	57.9%	57.0%	57.1%	57.3%

F1 – Ambient 16C – Measured Temp

		Power W G-F1	Power W H-F1	Power W I-F1		Runtime G-F1	Runtime H-F1	Runtime I-F1	
	A	-0.452	-0.571109	-0.62235		-0.006828	-0.006169	-0.007163	
	B	-1.145627	-0.954485	-0.97482		-0.017243	-0.013318	-0.015114	
	E0	12.744256	16.328239	17.226367		0.0033705	0.0743354	0.0529278	
FF Temp	**FZ Temp**	**G-F1**	**H-F1**	**I-F1**	Mean	**G-F1**	**H-F1**	**I-F1**	Mean
2	-15	29.0	29.5	30.6	29.7	24.8%	26.2%	26.5%	25.8%
2	-18	32.5	32.4	33.5	32.8	30.0%	30.2%	31.1%	30.4%
2	-21	35.9	35.2	36.5	35.9	35.2%	34.2%	35.6%	35.0%
4	-15	28.1	28.4	29.4	28.6	23.5%	24.9%	25.1%	24.5%
4	-18	31.6	31.2	32.3	31.7	28.6%	28.9%	29.6%	29.1%
4	-21	35.0	34.1	35.2	34.8	33.8%	32.9%	34.2%	33.6%
6	-15	27.2	27.2	28.1	27.5	22.1%	23.7%	23.7%	23.2%
6	-18	30.7	30.1	31.0	30.6	27.3%	27.7%	28.2%	27.7%
6	-21	34.1	32.9	34.0	33.7	32.5%	31.7%	32.7%	32.3%

F2 – Ambient 16C – Measured Temp

Prelim only

		Power W J-F2	Power W K-F2	Power W L-F2		Runtime J-F2	Runtime K-F2	Runtime L-F2	
	A	-0.537676	-0.505663	-0.646457		-0.00523	-0.006209	-0.006703	
	B	-1.008495	-1.160268	-0.897018		-0.016941	-0.014374	-0.013422	
	E0	16.049487	14.28824	18.689098		0.0068364	0.0718731	0.0763781	
FF Temp	**FZ Temp**	**J-F2**	**K-F2**	**L-F2**	Mean	**J-F2**	**K-F2**	**L-F2**	Mean
2	-15	30.1	30.7	30.9	30.5	25.0%	27.5%	26.4%	26.3%
2	-18	33.1	34.2	33.5	33.6	30.1%	31.8%	30.5%	30.8%
2	-21	36.2	37.6	36.2	36.7	35.2%	36.1%	34.5%	35.3%
4	-15	29.0	29.7	29.6	29.4	24.0%	26.3%	25.1%	25.1%
4	-18	32.1	33.2	32.2	32.5	29.1%	30.6%	29.1%	29.6%
4	-21	35.1	36.6	34.9	35.5	34.2%	34.9%	33.1%	34.1%
6	-15	28.0	28.7	28.3	28.3	23.0%	25.0%	23.7%	23.9%
6	-18	31.0	32.1	31.0	31.4	28.0%	29.3%	27.8%	28.4%
6	-21	34.0	35.6	33.6	34.4	33.1%	33.6%	31.8%	32.9%

F1 – Ambient 16C – Control Setting

		Power W G-F1	Power W H-F1	Power W I-F1		Runtime G-F1	Runtime H-F1	Runtime I-F1	
	A	-0.582588	-0.651693	-0.685396		-0.008802	-0.007215	-0.008568	
	B	-0.83100	-0.820058	-0.992987		-0.012484	-0.011418	-0.011943	
	E0	39.80096	39.841544	42.398547		0.4106047	0.3972463	0.4239345	
FF control	**FZ control**	**G-F1**	**H-F1**	**I-F1**	Mean	**G-F1**	**H-F1**	**I-F1**	Mean
3	10	29.7	29.7	30.4	29.9	25.9%	26.1%	27.9%	26.7%
3	7	32.2	32.1	33.4	32.6	29.7%	29.6%	31.5%	30.2%
3	4	34.7	34.6	36.4	35.2	33.4%	33.0%	35.0%	33.8%
6	10	28.0	27.7	28.4	28.0	23.3%	24.0%	25.3%	24.2%
6	7	30.5	30.2	31.3	30.7	27.0%	27.4%	28.9%	27.8%
6	4	33.0	32.7	34.3	33.3	30.8%	30.8%	32.5%	31.4%
9	10	26.2	25.8	26.3	26.1	20.7%	21.8%	22.7%	21.7%
9	7	28.7	28.2	29.3	28.8	24.4%	25.2%	26.3%	25.3%
9	4	31.2	30.7	32.3	31.4	28.1%	28.7%	29.9%	28.9%

F2 – Ambient 16C – Control Setting

		Power W J-F2	Power W K-F2	Power W L-F2		Runtime J-F2	Runtime K-F2	Runtime L-F2	
	A	-0.871604	-0.464408	-0.756238		-0.010759	-0.00528	-0.010931	
	B	-0.61824	-0.856603	-0.519402		-0.010408	-0.011642	-0.005471	
	E0	41.253561	40.886653	40.894225		0.420311	0.4051328	0.4013176	
FF control	**FZ control**	**J-F2**	**K-F2**	**L-F2**	Mean	**J-F2**	**K-F2**	**L-F2**	Mean
3	10	32.5	30.9	33.4	32.3	28.4%	27.3%	31.4%	29.0%
3	7	34.3	33.5	35.0	34.3	31.5%	30.8%	33.0%	31.8%
3	4	36.2	36.1	36.5	36.3	34.6%	34.3%	34.7%	34.5%
6	10	29.8	29.5	31.2	30.2	25.2%	25.7%	28.1%	26.3%
6	7	31.7	32.1	32.7	32.2	28.3%	29.2%	29.7%	29.1%
6	4	33.6	34.7	34.3	34.2	31.4%	32.7%	31.4%	31.8%
9	10	27.2	28.1	28.9	28.1	21.9%	24.1%	24.8%	23.6%
9	7	29.1	30.7	30.5	30.1	25.1%	27.6%	26.5%	26.4%
9	4	30.9	33.3	32.0	32.1	28.2%	31.1%	28.1%	29.1%

Comparison of Products and Labs for Selected Settings

Based on planar regression
F&P control higher number is warmer (1 to 11)
IEC target Temperatures

F1

Ambient 32C — Prelim only (I-F1 Power)

Measured Temp FF Temp	FZ Temp	Power G-F1	Power H-F1	Power I-F1	Mean	Runtime G-F1	Runtime H-F1	Runtime I-F1	Mean
2	-15	1.2%	0.0%	-1.3%	53.1	2.1%	1.2%	-3.3%	48.6%
2	-18	1.0%	0.1%	-1.2%	58.7	1.0%	1.1%	-2.1%	57.5%
2	-21	0.9%	0.2%	-1.1%	64.4	0.2%	1.1%	-1.3%	66.5%
4	-15	2.0%	-0.7%	-1.4%	51.2	3.0%	0.2%	-3.2%	46.8%
4	-18	1.7%	-0.5%	-1.3%	56.8	1.7%	0.3%	-2.0%	55.7%
4	-21	1.5%	-0.3%	-1.2%	62.4	0.7%	0.4%	-1.1%	64.7%
6	-15	2.9%	-1.4%	-1.5%	49.3	3.9%	-0.9%	-3.0%	45.0%
6	-18	2.5%	-1.1%	-1.4%	54.9	2.4%	-0.6%	-1.8%	53.9%
6	-21	2.2%	-0.9%	-1.2%	60.5	1.3%	-0.4%	-0.9%	62.9%

Ambient 32C — Prelim only (I-F1 Power)

Control Setting FF control	FZ control	Power G-F1	Power H-F1	Power I-F1	Mean	Runtime G-F1	Runtime H-F1	Runtime I-F1	Mean
3	10	-0.4%	-1.2%	1.7%	55.8	-0.7%	-0.9%	1.5%	51.6%
3	7	-0.7%	-1.0%	1.7%	60.1	-1.5%	-0.5%	2.1%	58.5%
3	4	-0.9%	-0.8%	1.8%	64.4	-2.2%	-0.3%	2.5%	65.4%
6	10	0.8%	-1.0%	0.2%	53.0	0.9%	-0.6%	-0.3%	49.0%
6	7	0.4%	-0.8%	0.4%	57.3	-0.2%	-0.3%	0.5%	55.9%
6	4	0.1%	-0.6%	0.5%	61.6	-1.0%	-0.1%	1.1%	62.9%
9	10	2.1%	-0.7%	-1.4%	50.3	2.6%	-0.4%	-2.2%	46.4%
9	7	1.6%	-0.5%	-1.1%	54.6	1.3%	-0.1%	-1.2%	53.4%
9	4	1.2%	-0.4%	-0.8%	58.9	0.2%	0.1%	-0.3%	60.3%

Ambient 16C

Measured Temp FF Temp	FZ Temp	Power G-F1	Power H-F1	Power I-F1	Mean	Runtime G-F1	Runtime H-F1	Runtime I-F1	Mean
2	-15	-2.3%	-0.7%	3.0%	29.7	-3.9%	1.3%	2.6%	25.8%
2	-18	-1.0%	-1.3%	2.3%	32.8	-1.3%	-0.8%	2.1%	30.4%
2	-21	0.1%	-1.8%	1.7%	35.9	0.6%	-2.3%	1.8%	35.0%
4	-15	-1.7%	-0.9%	2.6%	28.6	-4.2%	1.8%	2.4%	24.5%
4	-18	-0.4%	-1.5%	1.9%	31.7	-1.5%	-0.5%	1.9%	29.1%
4	-21	0.7%	-1.9%	1.3%	34.8	0.5%	-2.1%	1.6%	33.6%
6	-15	-1.1%	-1.1%	2.2%	27.5	-4.6%	2.4%	2.2%	23.2%
6	-18	0.2%	-1.7%	1.5%	30.6	-1.6%	-0.1%	1.7%	27.7%
6	-21	1.3%	-2.1%	0.9%	33.7	0.5%	-1.8%	1.4%	32.3%

Ambient 16C

Control Setting FF control	FZ control	Power G-F1	Power H-F1	Power I-F1	Mean	Runtime G-F1	Runtime H-F1	Runtime I-F1	Mean
3	10	-0.7%	-0.9%	1.6%	29.9	-2.7%	-1.9%	4.6%	26.7%
3	7	-1.1%	-1.4%	2.5%	32.6	-1.8%	-2.2%	4.1%	30.2%
3	4	-1.4%	-1.8%	3.2%	35.2	-1.2%	-2.5%	3.6%	33.8%
6	10	-0.1%	-1.1%	1.2%	28.0	-3.7%	-0.9%	4.6%	24.2%
6	7	-0.6%	-1.6%	2.2%	30.7	-2.7%	-1.4%	4.0%	27.8%
6	4	-1.0%	-2.0%	3.0%	33.3	-1.8%	-1.7%	3.5%	31.4%
9	10	0.5%	-1.3%	0.7%	26.1	-5.0%	0.4%	4.6%	21.7%
9	7	0.0%	-1.8%	1.8%	28.8	-3.6%	-0.3%	4.0%	25.3%
9	4	-0.5%	-2.2%	2.7%	31.4	-2.6%	-0.8%	3.5%	28.9%

F2

Ambient 32C

Measured Temp FF Temp	FZ Temp	Power J-F2	Power K-F2	Power L-F2	Mean	Runtime J-F2	Runtime K-F2	Runtime L-F2	Mean
2	-15	2.1%	-1.3%	-0.8%	52.8	2.0%	-1.0%	-1.1%	47.7%
2	-18	1.9%	-0.9%	-1.0%	57.7	2.0%	-0.3%	-1.7%	55.0%
2	-21	1.7%	-0.5%	-1.2%	62.6	2.0%	0.2%	-2.3%	62.2%
4	-15	1.9%	-1.1%	-0.8%	51.2	1.4%	0.0%	-1.4%	46.4%
4	-18	1.7%	-0.6%	-1.1%	56.1	1.5%	0.5%	-2.0%	53.6%
4	-21	1.5%	-0.2%	-1.3%	61.0	1.6%	1.0%	-2.5%	60.9%
6	-15	1.7%	-0.8%	-0.9%	49.6	0.8%	0.9%	-1.7%	45.0%
6	-18	1.5%	-0.3%	-1.1%	54.4	1.0%	1.4%	-2.4%	52.3%
6	-21	1.3%	0.0%	-1.3%	59.3	1.1%	1.7%	-2.8%	59.6%

Ambient 32C

Control Setting FF control	FZ control	Power J-F2	Power K-F2	Power L-F2	Mean	Runtime J-F2	Runtime K-F2	Runtime L-F2	Mean
3	10	0.3%	-2.1%	1.8%	53.7	-0.1%	-2.5%	2.6%	48.5%
3	7	0.8%	-1.8%	0.9%	57.8	1.0%	-1.9%	0.9%	54.4%
3	4	1.3%	-1.5%	0.2%	61.9	2.0%	-1.5%	-0.4%	60.4%
6	10	0.3%	-2.3%	2.0%	51.8	-0.7%	-2.0%	2.7%	47.0%
6	7	0.8%	-1.9%	1.1%	55.9	0.5%	-1.5%	1.0%	52.9%
6	4	1.3%	-1.6%	0.3%	60.0	1.5%	-1.1%	-0.4%	58.9%
9	10	0.3%	-2.5%	2.2%	49.9	-1.4%	-1.4%	2.8%	45.5%
9	7	0.9%	-2.2%	1.3%	54.0	0.0%	-1.0%	1.0%	51.4%
9	4	1.3%	-1.8%	0.5%	58.1	1.0%	-0.6%	-0.4%	57.3%

Ambient 16C

Measured Temp FF Temp	FZ Temp	Power J-F2	Power K-F2	Power L-F2	Mean	Runtime J-F2	Runtime K-F2	Runtime L-F2	Mean
2	-15	-1.5%	0.4%	1.0%	30.5	-4.9%	4.5%	0.4%	26.3%
2	-18	-1.4%	1.6%	-0.2%	33.6	-2.2%	3.3%	-1.1%	30.8%
2	-21	-1.4%	2.6%	-1.2%	36.7	-0.2%	2.4%	-2.2%	35.3%
4	-15	-1.3%	0.9%	0.5%	29.4	-4.4%	4.6%	-0.1%	25.1%
4	-18	-1.3%	2.1%	-0.7%	32.5	-1.7%	3.3%	-1.6%	29.6%
4	-21	-1.3%	3.0%	-1.7%	35.5	0.3%	2.4%	-2.7%	34.1%
6	-15	-1.2%	1.3%	-0.1%	28.3	-4.0%	4.7%	-0.7%	23.9%
6	-18	-1.2%	2.5%	-1.3%	31.4	-1.2%	3.4%	-2.1%	28.4%
6	-21	-1.2%	3.5%	-2.3%	34.4	0.8%	2.4%	-3.2%	32.9%

Ambient 16C

Control Setting FF control	FZ control	Power J-F2	Power K-F2	Power L-F2	Mean	Runtime J-F2	Runtime K-F2	Runtime L-F2	Mean
3	10	0.6%	-4.2%	3.6%	32.3	-2.2%	-6.0%	8.1%	29.0%
3	7	0.1%	-2.2%	2.1%	34.3	-0.8%	-3.1%	3.9%	31.8%
3	4	-0.3%	-0.5%	0.8%	36.3	0.3%	-0.7%	0.4%	34.5%
6	10	-1.1%	-2.1%	3.3%	30.2	-4.4%	-2.4%	6.8%	26.3%
6	7	-1.5%	-0.2%	1.7%	32.2	-2.7%	0.4%	2.3%	29.1%
6	4	-1.8%	1.5%	0.3%	34.2	-1.3%	2.7%	-1.4%	31.8%
9	10	-3.1%	0.2%	2.9%	28.1	-7.1%	2.1%	5.1%	23.6%
9	7	-3.3%	2.1%	1.2%	30.1	-5.0%	4.7%	0.3%	26.4%
9	4	-3.6%	3.8%	-0.2%	32.1	-3.3%	6.8%	-3.5%	29.1%

Note that at am ambient temperature of 16°C, the power required for unit operation is almost halved compared to an ambient temperature of 32°C. This means that any instrumentation accuracy issues (variability in measurements, uncertainty of temperature measurements) are exaggerated in a relative sense. This is why the percentage differences from the mean for this ambient temperature appear larger than for a 32°C ambient (the absolute differences are similar, but the relative differences are larger). There were also less available test points to use in the planer regression analysis at a 16°C ambient as the length of testing at this ambient temperature was shorter in most labs, increasing the chances of data variability or a less robust regression. For some laboratories and some ambient temperatures, the selection of test points (control settings) was somewhat limited. This can lead to variations in the estimated values for E0, A and B for the planar regression. Despite the variations in the estimated values, the power estimates at the IEC target temperatures are generally extremely close across all the laboratories.

While these tables only show steady state power at the defined conditions, it is important to note that the steady state power makes up 95% or more of the energy consumption after the inclusion of defrost energy (but excluding user loads) and is the most important part of the IEC energy measurement.

Defrost and Recovery Analysis

The table below shows a summary of the validity defrost and recovery data by unit and laboratory. The key comparison to make is for the same unit (i.e. E1) at the same ambient temperature (i.e. 32°C).

Summary of Validity Defrost and Recovery Data by Unit and Lab

Unit	Lab	Ambient	Valid Defrosts	DF1 $\Delta E_{D\&R}$ (Wh)	DF1 FZ ΔTh_{df} (K.h)	DF1 FF ΔTh_{df} (K.h)	Heater Energy (Wh)	Heater - $\Delta E_{D\&R}$ (Wh)
E1	A	32°C	5	97.5	6.5	-0.13	69.4	28.2
E1	A	16°C	5	101.8	6.7	-1.2	69.8	32.0
E1	B	32°C	8	89.5	6.7	0.17	64.2	25.2
E1	B	16°C	2	107.5	7.1	-3.6	72.0	35.5 (1)
E1	C	32°C	11	98.0	7.1	0.03	79.9	29.1
E1	C	16°C	7	118.2	9.8	-0.51	80.9	37.2
E2	D	32°C	7	93.3	5.8	-0.66	64.5	28.8
E2	D	16°C	5	96.0	5.7	-1.2	68.5	27.5
E2	E	32°C	9	97.3	5.8	-0.52	66.3	31.0
E2	E	16°C	4	108.5	7.6	-0.7	73.3	35.2
E2	F	32°C	14	111.4	9.2	-0.38	80.9	30.6
E2	F	16°C	3	115.3	10.2	-1.7	81.0	34.3
F1	G	32°C	5	102.2	5.6	2.6	73.8	28.4
F1	G	16°C	3	107.8	6.3	1.4	87.1	20.7
F1	H	32°C	8	121.5	7.3	0.5	87.3	33.7
F1	H	16°C	1	111.1	4.8	0.34	91.0	20.1 (1)
F1	I	32°C	9	113.6	4.0	0.8	79.0	34.7
F1	I	16°C	5	108.7	4.3	-0.5	87.5	21.2
F2	J	32°C	3	99.9	5.3	1.4	72.3	27.7
F2	J	16°C	3	102.4	5.8	0.9	82.6	19.2
F2	K	32°C	8	98.1	4.0	1.0	66.8	31.3
F2	K	16°C	2	106.2	3.9	0.2	82.2	24.0 (1)
F2	L	32°C	8	111.2	4.9	1.0	78.0	33.2
F2	L	16°C	4	105.9	4.5	-0.4	80.3	25.6

Notes: In some cases, the initial defrost was excluded where this was significantly lower than a typical defrost (the evaporator is quite dry when first started). IEC62552-3 precludes any defrost within the first 16 hours of operation. Heater energy in column 8 is an indicator of the relative frost load on the evaporator for each valid defrost, which appears to vary somewhat between labs and sometimes by ambient. (1) Few valid defrosts.

The fifth column in the table shows the extra energy (Watt-hours) to undertake a typical defrost and recovery cycle ($\Delta E_{D\&R}$) as per IEC62552-3 Annex C. The sixth and seventh columns show the temperature deviation[1] (in Kelvin-hours) for each compartment for a defrost and recovery cycle as per IEC62552-3 Annex C. The eighth column shows the total heater energy during a typical valid defrost event (in Wh) while the last column shows the difference between the $\Delta E_{D\&R}$ and the typical heater energy.

A 16°C ambient temperature generally results in a slightly larger value for $\Delta E_{D\&R}$ result than a 32°C ambient (although this is not always the case for the Fisher & Paykel unit – see discussion below). The differences in this value between laboratories are clearly driven to a large extent by variations in the average defrost heater energy, which in turn is an indicator of the frost load on the evaporator during each defrost.

Test room humidity may be a key factor that is driving the differences in defrost heater energy. The heater on time and heater energy (which is a function of frost load on the evaporator) is the primary driver for small differences in the incremental defrost and recovery energy between laboratories and between individual defrosts within a test laboratory. This suggests that the moisture load on the cabinets is varying somewhat. This could be a function of the room humidity as well as the ingress of ambient air through the door seals (where temperature sensor cables enter). The previous defrost interval also has some impact. Some variations in heater energy are likely to have been generated because some laboratories forced defrosts during the round robin, so the frost load may have been lower in these cases. Further investigations could reveal the impact of forcing defrosts on this measurement. The general conclusion is that forcing defrosts artificially lowers the measured value of $\Delta E_{D\&R}$ so this is not recommended for complying tests, even though IEC62552-3 is silent on this issue.

These test units always had a short compressor run just prior to the activation of the defrost heater. The length of this compressor run varied as did the period between the compressor off and the defrost heater on. The length of this compressor run is somewhat random from defrost to defrost and this may also have a small influence on the measured value of $\Delta E_{D\&R}$, but this is yet to be examined in detail.

A very useful finding is that for most valid defrosts, the difference between $\Delta E_{D\&R}$ and the defrost heater energy is a relatively fixed value, at least for a specific refrigerator in a specific ambient temperature. This provides a useful check and provides a rough way of estimating a value for $\Delta E_{D\&R}$ where the defrost is not strictly compliant with the requirements of IEC62552-3 Annex C. Conceptually, this difference is the extra energy required to bring the refrigeration system back to equilibrium after the defrosting process is completed less any net energy savings accrued while the refrigeration system has stopped during the defrost.

For the Electrolux unit, this difference at an ambient of 32°C was around 27Wh to 30Wh, while for the F&P unit this difference was around 29Wh to 33Wh. For the Electrolux unit, the difference for the low ambient temperature of 16°C increased slightly to 32Wh to 35Wh. For the F&P unit, the difference decreases at the lower ambient temperature. This is because the F&P unit has a low ambient compensation heater that operates in steady state conditions at an ambient temperature of 16°C. This turns off during the recovery period so it tends to reduce the overall value of $\Delta E_{D\&R}$ because the steady state base is higher (with the heater on) before and after the defrost.

[1] The temperature deviation during a defrost and recovery event is the determined as the difference between the steady state temperature and the measured temperature during the defrost and recovery period multiplied by the time taken for the defrost and recovery. This value can then be used to estimate the temperature impact of a defrost and recovery event over any defrost interval.

Tracking the heater energy for each defrost provides a useful indicator of the characteristics of a defrost that occurs during unsteady conditions, such as any defrosts that may occur during a load processing test. This is discussed in more detail in the next section.

The good thing to note is that the test method itself appears to be extremely accurate, with the measured differences being a function of the product operation under test, which is driven by the operating conditions in the laboratory.

It is important to remember that the incremental defrost and recovery energy only makes up a few percent of the overall energy for a refrigerator, so some variation in this parameter is of relatively minor concern. However, it would be useful to understand the key influences in more detail and to develop a method for normalising defrost and recovery results between laboratories.

Load Processing Tests

The table below shows the load processing results by unit and laboratory. The key takeaway message is that these measurements show reasonably robust findings, but there are some issues that need to be investigated. Factors that appear to affect the results are defrosts (if they occur during load processing) and the control settings used (the freezer compartment and hence evaporator temperature is a key driver of refrigeration system efficiency). More analysis is required to understand these influences in detail and whether some simple corrections can make the data more reliable and accurate. For example, a shorter than average heater on time and heater energy for a defrost that occurs during a load processing test can be readily determined from the test data and this provides a sound basis for a more accurate defrost correction to the load processing calculations for the specific defrost event that occurs during the load processing test. At this stage, the IEC test method does not include such a specific correction (it specifies that a standard or average defrost be used), but data from the round robin makes it clear that such an adjustment is warranted.

Note that laboratories often find it difficult to predict when a defrost event may occur, so it is inevitable that some load processing tests will include a defrost event. The Electrolux unit used for the round robin was configured so that it entered a defrost shortly after any major processing load was added (almost irrespective of the elapsed time since the last defrost). This was perhaps less than ideal in terms of the round robin, but it did illustrate that the IEC method can cope with defrosts and it highlighted where some further analysis may improve the approach. But it also highlighted the importance of understanding the characteristics of any defrost that occurs during the load processing test and ensuring that this is taken into account.

Load Processing Results, ambient temperature of 32°C

Lab/Unit	Load Processing Efficiency W/W	Comments
A-E1	1.54	1 defrost, roughly typical
B-E1	1.64	Very warm setting, 1 defrost smaller than average
C-E1	1.34	1 defrost, very small energy defrost
D-E2	1.43	No defrosts, stability not established
E-E2	1.55	2 defrosts smaller than average
F-E2	1.50	1 defrost smaller than average
G-F1	1.07	1 defrost much larger than average
H-F1	1.13	No defrosts, stability not established
I-F1	1.05 No	defrosts
J-F2	1.09 No	defrosts
K-F2	1.12 No	defrosts
L-F2	1.10	1 defrost slightly larger than average

Notes: Actual defrost and recovery energy during each load processing was estimated using the defrost heater energy plus the additional energy for the lab and unit shown in the previous table. Some labs used non-standard water volumes but this appeared to have no significant effect, as expected. One lab used thick walled plastic bottles.

The calculation of the load processing efficiency is extremely sensitive to the assumed defrost and recovery energy, where a defrost event occurs during the load processing test period. This is why it is very important to take account of the actual energy consumption of any such defrost rather than assuming that the incremental defrost and recovery energy is a typical value, as is currently specified in IEC62552-3 Annex G. The estimated energy consumption of defrosts that occurred during a load processing test varied from extremely small (less than half a typical value) to significantly larger than a typical defrost (around 50% larger than typical). Rarely were they close to a typical value.

Some labs undertook load processing tests at an ambient temperature of 16°C. This provided very useful comparative data. The load processing efficiency at an ambient temperature of 16°C was similar to the 32°C value for the Electrolux unit, while the value for the Fisher & Paykel unit was much higher (with a value of over 2). The higher value was in part due to the presence of a low temperature ambient heater for this particular model, which was present during the steady state measurement before and after the load processing test but was absent for much of the load processing test itself, thus making the apparent load processing efficiency quite high. This is a real effect as small ongoing user loads during normal use will cause the low ambient heater to remain off (under the control design for this model). However, the heater does make the steady state power consumption somewhat higher at the lower ambient temperature than it would otherwise be, so this is taken into account in the overall calculation of energy through a higher steady state power. Correcting for the presence of the heater brings the measured value down to a value that is closer to the expected range.

Appendix C: Results Analysis Methodology

Testing Methodology

The objective of this round testing was to provide sufficient test data to allow an accurate estimate of energy consumption to the new IEC test method and AS/NZS target temperatures with a general test setup that is compliant with IEC requirements. At the ambient temperature of 32°C it was expected that 4 test points would be sufficient (allowing 2 triangles or a square surrounding both pairs of target points to be drawn). A load processing test at 32°C ambient was also conducted. Testing summary was:

- Steady state tests at sufficient temperature control setting combinations to allow interpolation for IEC and AS/NZS at both 32°C and 16°C ambient (4 carefully selected test points could be sufficient at each ambient);
- Collection of at least 3 valid defrost and recovery events;
- Load processing test at 32°C ambient;
- Laboratories were not required to initiate the test period with a defrost cycle as per AS/NZS. Steady state periods and defrosts were separately documented. These test elements can be combined to accurately calculate energy to AS/NZS4474.1 after the tests are completed.

In practical terms, most laboratories collected a lot more data than this minimum requirement as they familiarised themselves with the test standard and the general requirements. Most laboratories ran the units for around a month.

Testing outputs were required to be input into a standardised reporting template (provided to the labs by the project manager). This template also outlines the process for the labs to follow during the course of the round robin. Seven sheets were included in this template:

- A – Manufacturer's information supplied: contains information as supplied by the manufacturers on unit volume, suggested set points for testing and defrost interval data for Part 3 Annex D calculation;
- B – Temperature sensors: lists the temperature sensors as specified in each standards, labs required to fill in the reference ID for each sensor (this has to be recorded as the raw data is to be supplied);
- C – Test result summary: summary of results, steady state at 32°C and 16°C ambient temperature and a summary of all defrost events at 32°C and 16°C ambient temperature;
- D – Calculations: for all selected test results from sheet C, this sheet calculates daily energy for each defrost interval as required and corrects for deviations in ambient temperature during the test;
- E – Interpolation: provides equations for triangulation of results for 3 selected test points, include manual interpolation and matrix approach in Part 3 Annex E;
- F – Load processing: records key data for load processing tests;
- Charts – Example charts: show triangulation results graphically.

As test points were completed and data recorded, raw data was provided to the EES for analysis. By undertaking analysis of this data while the testing was being conducted, feedback to the test lab was given enabling adjustments and corrections to be made as required.

Test labs were provided with a copy of two data analysis tools that allowed quick computation of set points and defrost sequences. These tools were also used by EES to analyse the data.

EES Analysis of Raw Data

A requirement of participation in the round robin was that all raw test data be provided to EES. This was independently assessed and analysed. This allowed a great deal of additional analysis and investigation to be undertaken, beyond that which would normally be undertaken in a typical test.

For triangulation, only 3 points are normally required. The round robin specified that test data should encompass the requirements of AS/NZS target temperatures (+3°C and -15°C) and IEC temperature (+4°C and -18°C), so more data than normal was required. However, at each ambient temperature, it was possible to extract as many as 15 compliant steady state periods from the raw data for each test unit (some of these were at the same control settings). This provided a lot of additional information.

In order to assess this additional data, a so called "planar regression" was developed with the assistance of Martien Janssen. For each test period, a function of the expected steady state power was derived (in a manner similar to that used for matrices in Part 3 Annex E), so that:

$E_n = E_0 + A \times T_{1n} + B \times T_{2n}$

Where:

E_0 is a fixed value for the refrigerator and ambient temperature

T_{1n} and T_{2n} are the measured temperatures in compartment 1 and 2 for test period n

A and B are constants to be estimated for the refrigerator and ambient temperature

E_n is the measured energy (or steady state power) for test period n

Where there are 10 to 15 independent (n) test points, a least squares approach[2] can be used to estimate a best fit value for E_0, A and B across all the data. The same approach can be used to estimate the compressor run time by compartment temperature and also the steady state power and compressor run time as a function of temperature control setting (effectively ignoring the measured temperature, which is another useful way of making comparisons across laboratories as these test units should provide highly consistent internal temperatures for each control setting).

In order to provide the most robust comparison, it was necessary to adjust the power and compressor run time estimated by the regression in accordance with the ambient temperature correction given in Part 3 of the IEC standard. This ensures that variations due to test room temperature drift were corrected beforehand.

There are a number of advantages to this approach. Firstly it allows all the data to be independently evaluated to see if there were any test periods that were outliers or where there were data

[2] In Excel the function SUMXMY2 returns the sum of squares of differences of corresponding values in two arrays. The solver function in Excel can then provide best estimates for the variables.

anomalies within the data set for each laboratory. Generally all the data was found to be very consistent, which indicates that the test units were consistent in their behaviour, the laboratory measurements were repeatable and the IEC data analysis methods are sound.

The second great advantage of using the planar regression was that it allowed both power and compressor run time to be accurately and independently estimated for specified internal temperatures and specified control settings, which in turn allowed direct comparison between laboratories across a wide range of conditions. While there were a range of “recommended” temperature control settings for the round robin, some laboratories selected their own control settings and most laboratories selected additional control settings as well. In many cases there were few or even no common control settings selected for tests, making direct comparisons more difficult. This analysis approach effectively allows the sophistication of triangulation to be applied to a much wider set of conditions in order to develop a more robust comparison.