Global LEAP Off-Grid Refrigerator Test Method

Draft Version 2 (2018-11-8)

1 Scope

This document defines methods to evaluate the quality, energy performance, and refrigerating/freezing performance of refrigerators and refrigerator-freezers intended to be used with off-grid energy systems (e.g. low-voltage DC stand-alone solar home systems, or AC or DC mini- or micro-grids).

The test method consists of the following major components:

- Overall **product quality** inspection and evaluation
- Evaluation of **energy performance** in normal operating conditions
- Evaluation of **refrigerating/freezing performance** in other operating conditions

The following international refrigerator test procedures have been referenced in the preparation of this document:

- IEC 62552-1,-2,-3: 2015: Household refrigerating appliances – Characteristics and test methods
- WHO/PQS/E003/RF05-VP.4: Refrigerator or combined refrigerator and water-pack freezer: Solar direct drive without battery storage
- IEC 60068-2-78:2012: Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state
- IEC 60335-1:2010: Household and similar electrical appliances - Safety - Part 1: General requirements
- IEC 60335-2-24: 2017: Household and similar electrical appliances - Safety - Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice makers

A technical working group was convened in late 2016 to further development of this first test method for off-grid domestic refrigerators. The authors express their gratitude to the many experts from around the world who contributed their time and expertise to this process.

2 Definitions

2.1 Refrigerating appliance

Insulated cabinet with one or more compartments that are controlled at specific temperatures and are of suitable size and equipped for household use, cooled by natural convection or a forced convection system.

2.2 Fresh food compartment

Compartment for the storage and preservation of unfrozen food and beverages, where the average storage reference temperature is 5°C (41°F).

2.3 Freezer compartment

Compartment for the storage and preservation of frozen food and beverages where the storage temperature is not warmer than –6°C (21.2°F).

2.4 Refrigerator

Refrigerating appliance having at least one fresh food compartment

2.5 Refrigerator-freezer

Refrigerating appliance having at least one fresh food compartment and at least one freezer compartment

2.6 Multi-Temperature Refrigerator

Refrigerator that has one or multiple compartments that can be operated either as a refrigerator or as a freezer by adjusting the thermostat control. Tests on the multi-temperature refrigerator shall be carried out in the refrigerator compartment mode

2.7 Energy performance

Energy consumption as determined from measurements taken when tested as specified in a medium temperature of 16°C (60.8°F), a high ambient temperature of 32°C (89.6°F) and a harsh ambient temperature of 43°C (109.4°F). For refrigerator-freezers, an additional test will be performed at a low ambient temperature of 10°C (50°F).

2.8 Ambient temperature

Measured temperature in the space surrounding the refrigerating appliance under test

2.9 Autonomy

Measured duration of time (in hours) for a refrigerator compartment temperature to rise from 5 to 12°C after the refrigerator is disconnected from the power supply. The test simulates how a product would operate in the short-term absence of available power supply when battery power is depleted.

3 Test conditions

3.1 Power supply

Power supply conditions are intended to simulate product connection to off-grid energy systems (e.g. solar home systems or mini-grids). The following power supply conditions are used in this test method:

3.1.1 Normal voltage condition

Input voltage shall be set to the lowest rating plate input voltage (e.g. 12 Vdc in case of an input voltage range from 12-24 Vdc)

3.1.2 Over-voltage condition

Input voltage shall be set to 20% higher than the nominal voltage value

3.1.3 Under-voltage condition

Input voltage shall be set to 10% lower than the nominal voltage value

3.2 Environmental conditions

Environmental conditions are intended to simulate product operation in typical off-grid operating conditions. The following environmental conditions are used in this test method:

Ambient condition	Temperature [°C]	Relative humidity [%]
Low	10 ± 0.5	No requirement
Medium	16 ± 0.5	≤ 75
High	32 ± 0.5	≤ 75
Harsh	43 ± 0.5	≤ 75

4 Recommended test sequence

Testing is recommended to be carried out in the following sequence. Deviations from the sequence for the purpose of reducing testing time are acceptable and should be documented in the test report.

Sequence #	Test	Ambient Temperature and Relative Humidity	Target Temperature Range	Test Load / Test Packages Included
1	Conduct Quality Inspection procedures (5.1)	Not applicable	Not applicable	Not applicable
2	Volume measurement (5.2)	Not applicable	Not applicable	Not applicable
3	Conduct Energy and Performance Testing (5.3)			
3a	Pre-test conditioning with door(s) open (5.4.1)	+32°C / RH ≤75%	Not applicable	No
3b	Pull down test (5.4.2)	+32°C / RH ≤75%	Stabilization < +5.0°C	Yes (test packages)
3c	Steady-state operation test – High ambient / Normal voltage condition (5.4.4)	+32°C / RH ≤75%	Average temperature +5.0°C	No
3d	Over-voltage test (5.4.5)	+32°C/ RH ≤75%	Average temperature +5.0 ± 1.0 °C	No
3e	Under-voltage test (5.4.6)	+32°C/ RH ≤75%	Average temperature +5.0 ± 1.0°C	No
3f	Load processing efficiency of the fresh food compartment (5.4.7)	+32°C/ RH ≤75%	Average temperature +5.0°C	Yes (water bottles)
3g	Autonomy test (5.4.8)	+32°C/ RH ≤75%	Test discontinue when > +12.0°C	No
3h	Steady-state operation test – Medium ambient / Normal voltage condition (5.4.3)	+16°C / RH ≤75%	Average temperature +5°C	No
3i	Steady-state operation test – Harsh ambient / Normal voltage condition (5.4.9)	+43°C/ RH ≤75%	Average temperature between 0 and 5°C	No
3j	For Refrigerator-freezers only: Steady-state operation test – Low ambient / Normal voltage condition (5.4.10)	+10°C / RH ≤75%	Average temperature between 0 and +5°C	No
3k	For Refrigerator-freezers only: Freezing capacity test (5.4.11)	+32°C/ RH ≤75%	Stabilization and measure the time to -6°C/-12°C/-18°C, if achieved	Yes

5 Test procedures

5.1 Quality inspection

1) Take a digital photograph of the product packaging, including all identifying marks.
2) Unpack the product. Using only the manufacturer's installation instructions, set up the system components. Record any problems encountered.
3) Check all samples for defects or damage or any problem which make it difficult or impossible to conduct testing. Record any problems encountered. Record any differences between the samples ordered and those received.
4) Review and photograph all supporting documents (e.g. user manual, warranty card, etc.) that are packaged with the product. Fill out the Quality Inspection Checklist according to Annex A of this procedure.
5) Take the following digital photographs of the product:
    i) A three-quarter view photograph of the appliance with the door open
    ii) All external surfaces of the appliance, the interior layout, and the compressor or cooling system
    iii) A close-up of the product rating plate, other identifying marks, the thermometer and other indicators including lights, the user controls, and any special features or identified weaknesses of the appliance
6) The following aspects are evaluated based on the visual inspection of the product:
    i) General product information
    ii) Quality assessment
        (1) Product marking
        (2) User manual
        (3) User safety
        (4) Design and durability
        (5) Maintenance and repairability
        (6) Environmental impact considerations

5.2 Volume

Determine the volume according to IEC 65552-3: 2015, Annex H for each compartment of the refrigerator.

5.3 Test setup

5.3.1 Product configuration

a) Remove any accessories, loose trays, bins or containers that have no dedicated position or essential function during normal use, as specified in the instructions

b) Remove any thermal storage devices (e.g. ice-bricks or similar) that are removable without the use of a tool, irrespective of any instructions in the product manual

c) Configure the product using the power cable included in the product package, as follows:

i) If a DC cable is provided with the product, use the DC cable and a suitable DC power supply for testing

ii) If only an AC/DC converter is provided with the product, use the AC/DC converter and a suitable AC power supply for testing

iii) The type of power cable and power supply used shall be documented in the test report

5.3.2 Test equipment

a) Set up laboratory equipment in accordance with Annex A of IEC 62552-1:2015: Test room and instrumentation. The requirement measurement uncertainty of the inrush current measurement should be better then ± 5%.

b) The appliance needs to be placed in the climate room with a rear clearance / distance of 100mm.

c) Prepare test load packages for the Freezing capacity test (5.4.3) in accordance with Annex B.

5.3.3 Data collection

a) Record internal compartment temperature data (in degrees Celsius, to a resolution of 0.1°C) and instantaneous power consumption (in Watts, to a resolution of 0.1W) and accumulated energy consumption over the relevant test period (in Watt-hours, to a resolution of 0.1Wh) for the duration of each test run, at equal measuring intervals not greater than 1 minute, in accordance of IEC 62552-1:2015.

b) Record the following data for each test run (as applicable):

i) number of cooling system duty cycles and a graphical display of on/off cycles

ii) the ambient temperature and humidity of the test room

iii) the settings of any user-adjustable temperature control devices and any other user-adjustable controls, dampers, etc.

iv) a diagram showing locations of the temperature sensors in all compartments as applicable;

c) For purposes of this test method, stabilization is determined based on IEC 62552-3:2015.

5.4 Energy and Performance testing

5.4.1 Pre-test conditioning

a) Prior to the start of testing, the refrigerator shall be installed in a test room and with instrumentation as specified in IEC 62552-1:2015, Annex A.

b) Prior to the start of testing, the refrigerator shall be prepared and set up in accordance with IEC 62552-1:2015, Annex B.

c) Prior to the start of testing, the refrigerator shall have air temperature sensors installed at the positions specified in IEC 62552-1:2015, Annex D.

5.4.2 Pull-down test

a) The test measures the time required to cool test loads in the fresh food compartment to a desired temperature (+10°C) at the ambient condition of 32°C.

b) Load the appliance with 0.5kg test load packages and M-packages as described in the cooling capacity test from IEC 62552-2: 2015. The total load of the packages corresponds with 4.5kg/100 liter fresh food compartment volume.

c) With the test chamber ambient temperature set to +32°C, leave the door/lid open and soak for at least 6 hours.

d) Ensure that proper measurement equipment (with “inrush current option”) is selected to measure the inrush peak current of the compressor during the start of the test, which is when the appliance is connected to the mains supply.

e) Close the door/lid, connect the power supply and inrush current measurement equipment and switch on the appliance at its coldest thermostat setting(s). Measure the inrush current and begin recording elapsed time.

f) Monitor the temperature within the fresh food compartment at one minute intervals. Discontinue testing at the moment when the average M-package temperature reaches +10°C. Stability shall be determined in accordance with IEC 62552-3:2015, Annex B.

g) Record the elapsed time and accumulated energy.

5.4.3 Steady-state operation test – Medium ambient / Normal voltage conditions

a) The test determines the temperature performance and reference energy consumption at +4°C and +5°C fresh food temperature at 16°C ambient temperature.

b) Set the test chamber ambient temperature to 16°C

c) Stabilization is determined based on IEC 62552-3:2015.

a) Follow the procedure described in IEC 62552-3:2015 taking into account a target temperature of +5°C. For this test, several tests using different temperature control settings are conducted to obtain values of energy consumption measurement and multiples values for interpolation calculation to estimate the energy consumption for a point where all compartments are at exactly +5 °C. Reference IEC 62552: 2015, part 3, Annex I (Worked examples of energy consumption calculations), section I.3.2.2 (Single compartment example) for detailed calculation methodology.

b) Use the same method above, estimate the energy consumption at +4°C using interpolation or extrapolation. The objective of this interpolation is to achieve more comparable results using the fresh food temperature definition of IEC 62552: 2015.

5.4.4 Steady-state operation test – High ambient/ Normal voltage conditions

a) The test determines the temperature performance and reference energy consumption at +4°C and +5°C fresh food temperature at 32°C ambient temperature.

a) Set the test chamber ambient temperature to 32°C

b) Follow the procedure described in IEC 62552-3:2015 taking into account a reference temperature of +5°C

c) Determine the energy consumption at +5°C using interpolation

d) Estimate the energy consumption at +4°C using interpolation or extrapolation

5.4.5 Over-voltage test

a) The test verifies whether the product is able to perform and function normally at high input voltage operation.

b) Set the compartment temperature to +5 ± 2°C and keep the test chamber temperature at 32°C.

c) Increase the power supply voltage to 20% higher than the nominal voltage.

d) Record internal compartment temperatures, instantaneous power consumption, and accumulated energy over a period of at least 4 hours.

5.4.6 Under-voltage test

a) The test verifies whether the product is able to perform and function normally at low input voltage operation.

a) Set the compartment temperature to +5 ± 2°C and keep the test chamber temperature at 32°C

b) Decrease the power supply voltage to 10% lower than the nominal voltage.

c) Record internal compartment temperatures, instantaneous power consumption, and accumulated energy over a period of at least 4 hours.

5.4.7 Load processing efficiency of the fresh food compartment

a) The purpose of this test is to quantify the incremental energy impact of user behavior such as door openings and cooling warm food and drinks.

b) Keep the test chamber ambient temperature to 32 °C, stabilize the 500ml PET bottles with a water content [x] corresponding with 12 grams per litres fresh food volume and apply the nominal voltage

c) Follow the procedure described in IEC 62552-3:2015, Annex G, taking into account a reference temperature of +5°C ± 2°C

d) Once specified conditions are met, the door of the largest unfrozen compartment is opened for a specified time and the water bottles placed in their specified positions. A recommended time

for door opening and for door closing is 2,5 s, leaving 55 s to load, as described in IEC 62552-3:2015, Annex G.

a) Determine the additional energy caused by the loading of the bottles $\Delta E_{\text{additional test}}$

b) Determine the daily energy consumption of cooling [x] grams of water per day.

$$E_{load\ processing} = E_{high\ ambient+5°C} + \Delta E_{additional\ test}$$

5.4.8 Autonomy test

a) The test determines product autonomy – the ability to keep a sealed fresh food compartment cool without input of power. The test measures the time of fresh food compartment temperature rise from +5 to +12°C when the refrigerator is disconnected from power supply and at

b) Keep the test chamber ambient temperature to 32 °C, remove the bottles of the load processing test and allow the appliance to operate normally for 2 hours with an average temperature of +5°C or lower.

c) Switch off the power supply to the appliance. Begin recording elapsed time.

d) Monitor the temperature within the fresh food compartment at one minute intervals. Discontinue testing at the moment when the warmest internal temperature measurement in the fresh food compartment exceeds an average temperature of +12°C.

e) Record the elapsed time from +5 to +12°C.

5.4.9 Steady-state operation test – Harsh ambient / Normal voltage conditions

a) The test determines whether the product's fresh food compartment temperature is able to control between 0 and +5°C at the harsh ambient condition of 43°C.

b) With the test chamber ambient temperature set to +43°C, verify that that all measured internal temperatures in the fresh food compartment have stabilized at an average temperature between 0 and +5°C. Stability shall be determined in accordance with IEC 62552-3:2015, Annex B.

c) Record internal compartment temperatures, instantaneous power consumption, and accumulated energy over 24 hours in accordance with IEC 62552-3: 2015.

5.4.10 For refrigerator-freezers only: Steady-state operation test – Low ambient / Normal voltage conditions

a) With the test chamber ambient temperature set to +10°C, verify that that all measured internal temperatures in the fresh food compartment have stabilized at an average temperature between 0 and +5°C. Stability shall be determined in accordance with IEC 62552-3:2015, Annex B.

b) Record internal compartment temperatures, instantaneous power consumption, and accumulated energy over 24 hours in accordance with IEC 62552-3: 2015.

5.4.11 For refrigerator-freezers only: Freezing capacity test

a) The test determines freezing performance of refrigerator-freezer combination units by measuring the time of required to reduce the freezing compartment temperature to -6°C and -12°C, -18°C target temperatures at the ambient condition of 32°C.

b) Test load packages shall be prepared in accordance with IEC 62552-1 Annex C.

c) With the test chamber ambient temperature set to +32°C, test load packages into the freezer compartment in accordance with the loading instructions in IEC 62552-2:2015, Section 8.4.3. When the compartment is too small to accommodate 2.0 kg of light load or for a compartment with an internal temperature measured above 0°C (during test 5.4.4), one 0.5kg package shall be loaded. Close the door/lid. Begin recording elapsed time.

d) Monitor the temperature within the freezer compartment at one minute intervals. Discontinue testing at the moment when the warmest internal temperature measurement in the freezer compartment has stabilized or achieve a temperature colder than -18°C.

e) Record the elapsed time from 32°C to -6, -12 and -18°C in case these temperatures are achieved.

Annex A: Quality inspection checklist

Use the checklist below to document observations and results of quality inspection.

General Product Information

Sample model	
Legal manufacturer or reseller	
Product Type/Description	
Country of Origin	
Conformity assessment rating	
Serial number	
Height [cm]	
Width [cm]	
Depth [cm]	
Weight [kg]	
Power supply type [AC or DC]	
Rated voltage range [V]	
Rated power range [W]	
Rated current [I]	
Rated frequency (if product is AC)	
Volume fresh food compartment [litres]	
Volume freezer compartment [litres]	
Climate class declared	
Temperature zone rating fresh food compartment	
Temperature zone rating freezer compartment	
Refrigerant	
Total Mass of Refrigerant	
Compressor type [-]	

Product Photos

Picture of the sample with the door(s) closed	
Picture of the refrigerator with the door(s) open	
Left side picture	
Back side picture	
Right side picture	
Picture of the rating plate	
Picture of control mechanism	
Warmest setting possible fresh food	
Coldest setting possible fresh food	
Picture of compressor compartment	
Picture of condenser	
Picture of sample damage (*if applicable*)	

Quality Assessment

In this section, the quality assessment is rated based on poor, fair, and good based on the following criteria.

No.	Aspect	Poor	Fair	Good
1	Quality related evaluation	Substantially worse compared to general products (conventional and off grid) present on the market	Corresponding to general products present on the market	Substantially better compared to general products present on the market
2	Risk of human accidents	High	Low	No risk
3	Risk of appliance damage	High	Low	No risk
4	Risk of decreased appliance lifetime	High	Low	No risk
5	Risk of inferior performance	High	Low	No risk
6	Key information (user manual)	Missing	Limited available	Present

Product Marking[1]

Appliance marked with rated voltage of rated voltage range	[yes/no]
Appliance marked with the nature of supply unless the rated frequency is present	[yes/no]
Appliance marked with rated power in Watts or rated current in Amperes	[yes/no]
Appliance marked with the name, trade mark or identification mark of the manufacturer or responsible vendor	[yes/no]
Appliance marked with the number according to degree of protection against ingress of water, other than IPX0	[yes/no]
Appliances which can be mains and battery operated marked with the battery voltage	[yes/no]
Appliances which can be battery operated marked with the type of battery, distinguishing between rechargeable and non-rechargeable batteries, if necessary, unless the type is irrelevant for the operation of the appliance.	[yes/no]
Appliance marked with caution “RISK OF FIRE” (only applicable for flammable refrigerants)	[yes/no]
Remarks	
Score	**[Poor / Fair / Good]**

Assessment of User Manual

Operation manual included		[yes/no]
Language	Instruction in English	[yes/no]
	Other language(s) used	[list all languages]
Instructions on Installation	Unpacking	[yes/no]
	Door removal, leveling, and alignment	[yes/no]

[1] Referencing requirements in IEC 60335-1 and IEC 60335-2-24

	Handle installation and removal	[yes/no]
	Location Requirements	[yes/no]
	Electrical Requirements	[yes/no]
	Additional requirements for compression type of refrigerators using flammable refrigerants according IEC 60335-2-24, 7.12	[yes/no]
Instruction on Product Use	Instructions on using the controls	[yes/no]
	Switching on procedure	[yes/no]
	Cooling down time	[yes/no]
	Use of temperature controller	[yes/no]
	Indication lights and other displays	[yes/no]
	Connection to power source	[yes/no]
	Compatibility with solar systems	[yes/no]
Diagnostic / repair procedures		[yes/no]
Disposal / recovery / recycle procedure		[yes/no]
Remarks		
Score		**[Poor / Fair / Good]**

User safety assessment

Internal lighting switches on when the door is open	[yes/no]
Outside finishing sharp edges[2]	[yes/no]
Power switch accessible to the user without tools	[yes/no]
Power switch protected from accidental changes in position	[yes/no]
Grounding	[yes/no]

[2] IEC 60335-1, 22.14: Appliances shall have no ragged or sharp edges, other then those necessary for the function of the appliance that could create a hazard for the user in normal use or during user maintenance

Pull relief quality main supply plug	[yes/no]
General cable finishing	[yes/no]
Electrical scheme present on the cabinet	[yes/no]
Remarks	
Score	**[Poor / Fair / Good]**

Assessment of design and durability

Door	Robustness of door hinge	
	Robustness of door handle	
	Door sealing quality	
Door Score		**[Poor / Fair / Good]**
Cooling System	Refrigerant tubes decently mounted	
	Mounting quality of the compressor	
Cooling System Score		**[Poor / Fair / Good]**
Refrigerator Housing	Robustness of refrigerator housing	
	Robustness of wheels	
	Internal lighting switches on when the door is open	
Refrigerator Housing Score		**[Poor / Fair / Good]**
General Design and Durability Remarks		

Assessment of Serviceability and Maintenance

Maintenance and cleaning instructions	Cleaning the cabinet	
	Cleaning the condenser	
	Defrosting the evaporator	
	Changing the internal lighting[3]	
	Recommendation for service frequency	
	Diagnostic / repair procedures	
	Spare parts list	
	Preventive maintenance checks	

[3] Remark IEC 60335-2-24, 7.12

Serviceability evaluation	Replacing the door lock	
	Replacing compressor	
	Replacing the condenser, condenser fan, and evaporator fan	
Remarks		
Score		**[Poor / Fair / Good]**

Environmental impact considerations

Refrigerator designed for safe and easy disassembly and disposal i.e. could a trained professional with limited set of tool disassemble the product?	
Thermal insulation blowing agent complies with Montreal Protocol requirements	
Lead (except in batteries), mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated biphenyl ethers (PBDE) present	
Remarks	
Score	**[Poor / Fair / Good]**