Requirements for VeraSol Certification of Refrigerators

Draft Version 0.2

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The following document lists proposed requirements for refrigerators[1] to be certified through the VeraSol program. The VeraSol team is seeking stakeholder feedback on the proposed framework and requirements prior to offering certification services for refrigerators.

Eligible refrigerators are those intended for use on, and/or compatible with, off-grid energy systems (e.g., low-voltage DC systems, solar home systems (SHSs), and AC or DC mini-grids). Products should be designed to function safely and effectively within the voltage swings that are common in solar-charged, battery-based distributed energy systems. Most products will be designed for either a nominal 12 V or 24 V DC application (for SHSs or DC mini-grids) or a nominal 110-240 V AC (for AC mini-grids), but other voltages are eligible.

Once finalized, these requirements would apply both to refrigerators included with a VeraSol-certified SHS kit and to those tested for certification as standalone appliances.

- A refrigerator included in an SHS kit would be included on the Spec Sheet for the kit and listed with the SHS kit under the "Solar Energy Kits" section of the VeraSol website: https://data.verasol.org/products/sek. Similarly, a refrigerator that is listed in an SHS kit family, but not included in a fully tested SHS kit, will be included on the Spec Book for the family and listed under the "Solar Energy Kits" section of the website. (See Figure 1.)
- A refrigerator tested as a standalone appliance would be included in the list of tested refrigerators on the VeraSol website: https://data.verasol.org/products/ref
  Certified refrigerators in this list would be distinguished from non-certified appliances with a label on their listing. (See Figure 2.)
- A refrigerator that is included in an SHS kit may also be listed in the list of standalone refrigerators for an additional fee. Similarly, a refrigerator that is already certified as a standalone appliance may also be included in a certified SHS kit, though additional testing may be required. As the company branding the kit and the company branding the refrigerator are commonly two different entities, the listing with the kit and the standalone listing may be presented under two different brand names, subject to the two companies' preferences. Both companies would need to submit documentation for review and sign an agreement as described in the VeraSol Co-branding Policy.[2]

[1] Throughout this document, the term "refrigerators" is used to generally refer to refrigerators, refrigerator-freezer combination units, multi-temperature refrigerators, and freezers.
[2] The scope of the current co-branding policy is limited to co-branding of solar energy kits, but the text will be updated to more clearly cover refrigerators as well.

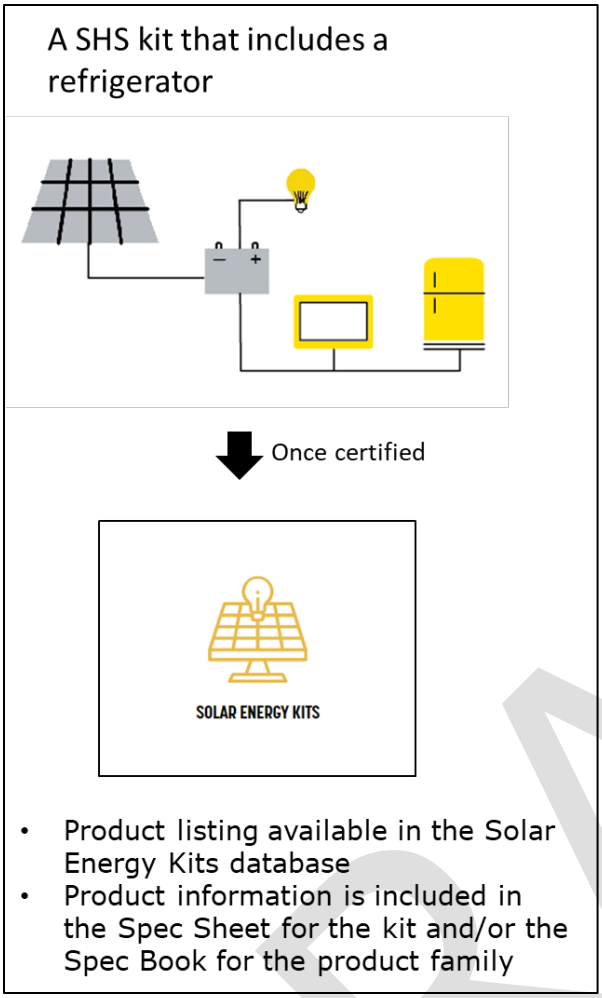

Figure 1. Pathway for a refrigerator included in a VeraSol-certified SHS kit or family of products

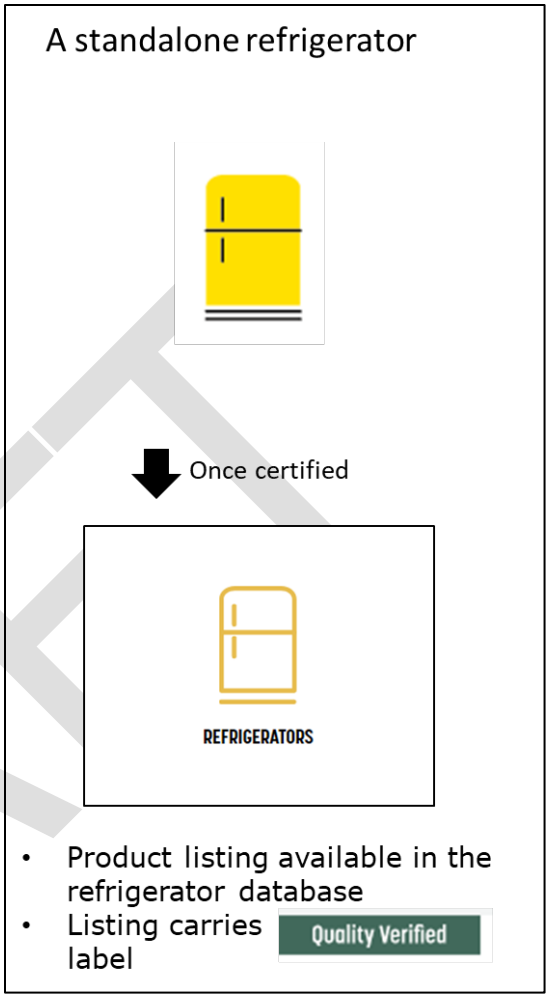

Figure 2. Pathway for a standalone refrigerator to be listed in the VeraSol appliance database

These requirements do not cover solar direct drive refrigerators,[3] though the VeraSol team is considering expanding their scope to include these devices in the future. Additionally, though AC-powered refrigerators may be certified as standalone devices, any refrigerators included with SHS kits must be powered by a DC input. The VeraSol team is also considering expansion to enable to certification of SHS kits with inverters and AC appliances, but currently only supports SHS kits with DC outputs and appliances. Devices with ice-makers and automatic defrosters are also outside the scope of these requirements.

Further, these requirements are strictly for household and commercial refrigerators; vaccine refrigerators and ice-pack freezers will not be eligible for certification through the VeraSol program and should be evaluated through the World Health Organization (WHO) Performance, Quality and Safety (PQS) framework.

[3] A refrigerator powered by a solar electric system with no battery (Source: WHO).

Certification requires testing according to all the following procedures:

- The current version of the Global LEAP Off- and Weak-Grid Refrigerator Test Method.[4] Sample selection for the test shall be coordinated by the VeraSol team. Two samples shall be randomly selected from a stock of at least 20 units. One sample will undergo testing and the other will be reserved as a spare.
- IEC 60335-1
- One of the following: IEC 60335-2-24, or IEC 60335-2-75, or IEC 60335-2-89

For refrigerators to be included with VeraSol-certified SHS kits or SHS kit families, an additional assessment of the instantaneous power when the compressor is operating at under-voltage and over-voltage conditions may be required. The data from these instantaneous power tests and the Global LEAP tests will be shared with the laboratory conducting the SHS kit testing and will be incorporated in the IEC TS 62257-9-5 Energy Service Calculations for that kit. Additional details on this calculation are presented in Annex 3. (Alternatively, if the SHS kit was already certified and is not actively under test, VeraSol may conduct the Energy Service Calculations to add the refrigerator to the kit). Refrigerators included in families but not included in fully tested kits will have run times estimated using the Energy Service Calculations with some adjustments to the assumptions based on the best available data or ratings for the kit(s).

All testing shall be conducted by laboratories accredited to ISO/IEC 17025, and testing to the Global LEAP test methods shall be conducted by a laboratory in the VeraSol network that is approved to test refrigerators. For refrigerators included with SHS kits or SHS kit families, the refrigerator will likely be tested at a different laboratory than the one testing the SHS kit, but data from refrigerator testing will be shared with both VeraSol and the laboratory testing the SHS kit. Prior to testing, companies will work with VeraSol to develop a test plan and sample their product, and will be required to submit documentation and sign a VeraSol testing agreement. Companies will pay the laboratories directly for testing and be responsible for shipping products to the laboratories.

Products that do not meet all requirements following initial testing may undergo full or partial re-testing, or, if the issue(s) can be corrected by changes to the packaging or consumer-facing materials, photographic evidence and a timeline for making the required changes may be accepted. Refrigerators tested as standalone appliances that do not meet all requirements for certification will have one month to correct issues before their data is posted to the VeraSol website. Website listings can be updated to indicate that the refrigerator is "quality verified" once all corrections have been made.

Certified standalone refrigerators and/or refrigerators within a certified kit are subject to market surveillance testing to confirm that they continue meet the VeraSol requirements. Market surveillance tests may be conducted at any time and cover any aspects included in the initial testing. Additionally, certification of both standalone refrigerator and those within a certified kit

[4] Note, products tested in the past two years to prior versions of the Global LEAP Refrigerator Test Methods may be eligible to reference results from some individual tests/evaluations, provided that random sampling procedures were comparable to those described above and the tests were conducted under the same ambient test conditions as specified in the current test methods. For refrigerators included in kits, the additional assessments of instantaneous power may still be required. If prior versions of the Global LEAP Test Methods are referenced, the tests shall have been conducted by a VeraSol-approved test laboratory.

expire after two years. To recertify a refrigerator, manufacturers must sign a renewal agreement with VeraSol and submit documentation, such as photographs, confirming that no changes have been made to the product since the prior testing. If at any point during the two-year certification period changes are made to the refrigerator, companies are required to inform VeraSol of these changes. VeraSol will use this information to determine if full or partial renewal testing according to the Global LEAP Off- and Weak-Grid Refrigerator Test Method will be required to maintain certification.

Table 1. Requirements for VeraSol-certified refrigerators

Category	Metric	Quality Standard
Truth In Advertising	Reporting Requirements for all Refrigerators	Sample shall be marked with the following ratings, both on the sample and on the packaging or other consumer-facing material available prior to purchase: • Name or trademark of the manufacturer or responsible vendor • Uniquely identifiable product name or model number • Intended temperature class/use class. This information must be stated in terms of both temperature and use, for example: Fresh food: 4°C, Beverage/pantry storage: 8°C, Cellar compartment: 12°C, Zero-star freezer: 0°C One-star freezer: -6°C, Two-star freezer: -12°C, Three-star freezer: -18°C Note: The temperature class/use class advertisements will be assessed based on the ability of the refrigerator to maintain the advertised temperature class at an ambient temperature of 43°C. All advertised use classes will be assessed. Testing will be conducted at the standard reference temperatures listed in the examples above; if the advertised temperature is not one of these temperatures, the reference temperature for the temperature class will be used. For example, a product with an advertised temperature of 6°C would be classified as "beverage and pantry" (4°C-8°C) and tested at 8°C. See Table 2 in Annex 1 for details. If a temperature range is advertised, the temperature class of the lowest advertised temperature will be tested. • The volume of each compartment (L) • Daily energy consumption in Wh/day rated at 32°C ambient temperature reported for each applicable use case: refrigerator, refrigerator/freezer, freezer. • Rated voltage or rated voltage range • Nominal battery voltage, if the product is intended to be battery-operated • Nature of supply (AC or DC) • Rated average power in watts (W) or rated average current in amperes (A) reported for each applicable use case: refrigerator, refrigerator/freezer, freezer.

		• Maximum current in amperes (A) • Refrigerant type (chemical name, formula, number) • Total mass of refrigerant (g) If the refrigerator cannot maintain a compartment temperature of ≤4°C at an ambient temperature of 43°C, the phrase "Not intended for long-term storage of temperature-sensitive foods" shall be included on consumer-facing information with the use class rating. Alternative, but comparable phrases may be used. All information shall be presented in a clear, unambiguous manner and have at least the same prominence as other messages on the consumer-facing material with clearly legible font (a minimum of approximately 10 pt font).
	Run time Requirements for Refrigerators **included with SHS kits or SHS kit families** (these requirements do not apply to refrigerators tested for a standalone certification)	The solar run time of a refrigerator included with an SHS kit shall be at least 24 hours. The solar run time is the run time expected in one day of solar charging, including any use or charging of the appliance during the day. As described in IEC TS 62257-9-8, the SHS kit shall present one solar run time profile for all of the included light points on high and any other included appliances, including the refrigerator. The solar run time of the refrigerator in any advertised combination shall be at least 24 hours. Additionally, the SHS kit shall present the full-battery run time of the refrigerator when powered by the kit's battery in the absence of any other loads. If a run time is advertised for the refrigerator or other appliances in the kit, it is assumed to be for solar run time, unless otherwise stated. Solar run time and daily energy service, if advertised, must be based on a solar resource of 5 kWh/m^2. Additional solar run time and energy service values based on alternative values of solar resource may be advertised; the solar resource in kWh/m^2 used to calculate any such alternative values must be clearly indicated. Advertised run times are assumed to be on the following settings, unless otherwise stated in the advertisement: • Refrigerator: Compartment temperature corresponding to the coldest intended use class at an ambient temperature of 32°C. If a freezer is included, the freezer is assumed to be turned on at its coldest setting as well. • Lights: brightest setting • Television: On mode, as specified in IEC TS 62257-9-8 • Radio: On mode, at a volume providing 60 dB at a distance of 1 m from the radio as specified in IEC TS 62257-9-8 • Fan: highest setting • Other appliances: highest setting or charging rate

		All advertised run times will be evaluated using an adapted version of the Energy Service Calculations in IEC TS 62257-9-5 and power and energy consumption data from the Global LEAP Refrigerator Test Method and potentially two additional measurements of the instantaneous power when the compressor is operating at under-voltage and over-voltage conditions. See details in Annex 3. Note: lights internal to refrigerators or freezers are considered "accessory" lights and not subject to the requirements for lights in IEC TS 62257-9-8 regardless of luminous flux.
	Performance requirements	• All refrigerators shall maintain a temperature ≤12°C at an ambient temperature of 43°C • All freezers shall maintain a temperature ≤0°C at an ambient temperature of 43°C • Pull-down time: The time required to lower the temperature of the refrigerator to its advertised temperature class shall be less than 9.2 hours (i.e., less than 8 hours with a 15% tolerance) • Refrigerators certified as "standalone" appliances shall meet Minimum Energy Performance Standards as defined in Annex 2.
	All advertisements and specifications (including, but not limited to: temperature ratings, use class, volume, power consumption, and energy consumption)	If reported, accurately specified. Numeric aspects, such as energy consumption, must deviate no more than 15% from advertised ratings (though it is always acceptable if actual performance is better than advertised). If a range is provided, the best rating must be within the 15% tolerance. All advertised features shall be functional. Any description of the product that appears on the packaging, inside the package, and in any other medium (internet, etc.) should be truthful and accurate. No statements should mislead buyers or end users about the features or utility of the product.
Health and Safety	AC-DC Power Supply Safety	Any AC-DC power supply included with a refrigerator carries a recognized consumer electronics safety certification as specified in IEC TS 62257-9-8
	Hazardous Substances	The following chemicals may not be included: lead (except in batteries), mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) or polybrominated diphenyl ethers (PBDEs) Compression-type appliances which use flammable refrigerants shall be marked with a symbol indicating flammability (such as ISO 7010 W021 (2019-07)) and the words "Warning; Risk of fire / Flammable Materials" or a similar explanation 

		Further, the user manual or instructions for compression-type appliances with flammable refrigerants shall include the substance of the following warnings: • WARNING: Keep ventilation openings, in the appliance enclosure or in the built-in structure, clear of obstruction. • WARNING: Do not use mechanical devices or other means to accelerate the defrosting process, other than those recommended by the manufacturer. • WARNING: Do not damage the refrigerant circuit. [This warning is only applicable for appliances with refrigerating circuits which are accessible by the user.] • WARNING: Do not use electrical appliances inside the food storage compartments of the appliance, unless they are of the type recommended by the manufacturer. All foam blowing agents must: • use no Montreal-Protocol-regulated Class I ozone-depleting substances (ODS) as refrigerants; • use no Montreal-Protocol-regulated Class II ozone-depleting substances (ODS) (i.e., HCFCs) as refrigerants, OR have a warranty and clear implementation plan that covers reclamation and safe destruction of Class II ozone-depleting substances
	Safety Evaluation	Meet the requirements of IEC 60335-1 and one of the following: IEC 60335-2-24, IEC 60335-2-75, or IEC 60335-2-89 These tests also cover key aspects of quality and durability.
Quality and Durability	Global LEAP Quality Assessment	Receives a rating of Good or Fair on the packaging, user safety, design and durability, maintenance and repairability and environmental impact considerations sections of the Global LEAP quality assessment
Consumer Information	Warranty	A warranty shall be included with the refrigerator that provides a minimum coverage of at least **two years** on manufacturing defects under normal use and must receive a rating of Good or Fair when evaluated in the Global LEAP quality assessment.
	Date of Manufacture	All products shall be labeled with the date of manufacture or a serial number assuring traceability of date of manufacture (i.e. the date need not be discernible to consumers, only to those who are able to interpret the code). The date of manufacture shall be reported with a precision of at least the month and year. The label may be on the product or the packaging.
	User manual	A user manual covering installation, use and maintenance shall be provided using language and graphics appropriate for the intended market. If the user manual is not in English, an additional English translation shall be provided for assessment. The user manual must receive a rating of Good

		or Fair when evaluated in the Global LEAP quality assessment. If the refrigerator is included with an SHS kit or SHS kit family, the user manual for the kit or refrigerator must also include instructions on how to connect the refrigerator to the kit. If any connections are not made with plug-and-socket connectors, the relevant requirements for these connectors (i.e., screw terminals, spring or lever-actuated terminals, quick disconnect/blade terminals and similar) outlined in IEC TS 62257-9-8 shall be met. The following connectors are not permitted for use with SHS kits: o Alligator (crocodile) clips o Connections made in the field that require soldering or crimping o Screw terminals or binding posts in which the wire is wrapped around the screw and held in place with the screw head or nut, rather than being clamped between two plates or washers. o Twist-on wire connectors (wire nuts) or wires twisted together

Annex 1: Temperature Classes and Use Classes

Testing will be conducted at the standard reference temperatures described in the Global LEAP test methods. The range of acceptable advertised temperatures associated with each use class is presented in Table 2. If the advertised temperature is not a standard reference temperature, the reference temperature for the associated use class will be used for assessment.

Table 2. Use classes and associated temperatures

Use Class*	Reference testing temperature	Range of acceptable advertised temperatures
Cellar compartment	12°C	9°C – 12°C
Beverage and pantry	8°C	4°C – 8°C
Fresh food	4°C	1°C – 4°C
Zero-star freezer	0°C	-5°C – 0°C
One-star freezer	-6°C	-11°C – -6°C
Two-star freezer	-12°C	-17°C – -12°C
Three-star freezer	-18°C	≤ -18°C
*Alternative, but comparable phrases may be used to describe the use class		

Annex 2: Minimum Energy Performance Standards (MEPS) for Standalone Refrigerators

The minimum energy performance standards (MEPS) outlined below are derived from the requirements proposed in the Model Regulation Guidelines for Energy-Efficient and Climate-friendly Commercial Refrigeration Equipment published by United for Efficiency (U4E), though an additional allowance has been added to increase the suggested minimum energy. This adjustment was made after reviewing several years of test data from off-grid refrigerators. The allowance may be adjusted in the future as efficiency in the sector increases.

To comply with the MEPS, the Annual Energy Consumption (AEC), as calculated in Equation 1, shall be less than or equal to Maximum Annual Energy Consumption (AECmax), as calculated per Table 3.

Equation 1. $\mathrm{AEC} = \mathrm{EC}_{32} \times (365/1000)$ in kWh per year

where EC_{32} is the measured energy consumption in Wh per 24 hours at an ambient temperature of 32°C, rounded to nearest integer.

Table 3. Maximum Annual Energy Consumption (AECmax) adjusted by Volume

Reference Temperature	Product Category	AECmax (kWh/year)
32°C	Refrigerators	$0.220\times AV+137+A_R$
	Refrigerator-Freezers	$0.288\times AV+210+A_{RF}$
	Freezers	$0.268\times AV+247+A_F$

where:

A_R is an allowance for refrigerators with a value of 66 kWh/year
A_{RF} is an allowance for refrigerator-freezers with a value of 225 kWh/year
A_F is an allowance for freezers with a value of 133 kWh/year, and

AV is Adjusted Volume, as calculated per Equations 2 and 3.

Equation 2. $\text{Adjusted Volume (AV)} = \sum_{i=1}^{n}(V_i \times K_i)$

where V_i is the volume in compartment i, and K_i is the volume adjustment factor, as calculated per Equation 3 and rounded to two decimal places.

Equation 3. $K_i = \frac{32°\text{C} - T_i}{32°\text{C} - T_2}$

where T_2 is the temperature of a fresh-food compartment (4°C), and T_i is the temperature of the individual compartment concerned.

Annex 3: Proposed changes to Energy Service Calculations of IEC TS 62257-9-5 to assess run time of refrigerators included in SHS kits

This section describes changes to incorporate refrigerators into the energy service calculations defined in IEC TS 62257-9-5:2018, Annex GG. These calculations will only apply to refrigerators included with SHS kits and are needed to estimate the run time of the refrigerator when powered by the SHS kit and when powered in conjunction with any other loads (such as lights, radios, TVs and fans).

The energy service calculations are typically calculated as part of the testing of an SHS kit according to IEC TS 62257-9-8 and use a spreadsheet to estimate the solar run time and full-battery run time of any appliance or combination of appliances powered by the kit. Calculating the run time of appliances in combination with a refrigerator is complicated by the need to ensure the refrigerator has sufficient energy reserved to stay powered for 24 hours/day, by the fact that the refrigerator power cycles throughout the day, and by the often non-linear relationship between refrigerator power and voltage. The following section describes the changes required to the energy service calculations and associated spreadsheet to incorporate refrigerators.

The revisions are based on the following general principles:

- The run time for a refrigerator is defined as the time that it is actively maintaining its internal temperature. Depending on the design of the refrigerator, the cooling system (e.g. refrigeration compressor or thermoelectric cooling element) will not necessarily be operating for the entire duration of the run time. The run time does not include "holdover time" as defined in WHO/PQS/E003/RF04.4, that is, the time after the power supply is disconnected during which the refrigerator maintains an acceptable temperature.

- A refrigerator is not useful if it does not operate continuously. Therefore, the existing approach to run time evaluation in IEC TS 62257-9-5 and -9-8, in which the run time is compared to the manufacturer's advertised value, is not appropriate. Instead, sufficient energy is allocated to refrigerators to allow them to operate for the full required duration. Any remaining energy is then allocated to the other appliances.

The following assumptions are made:

- A refrigerator consists of a single constant-power load that cycles on and off. This power will be measured in the appliance power consumption test; the specific procedure is to be determined. (An actual refrigerator has several loads, some intermittent and some continuous, and the compressor power varies with temperature.) The duty cycle is determined by dividing the measured 24-hour average power by the measured power.
- The relationship between voltage and power (i.e., the efficiency of the refrigerator at different input voltages) is modeled using one or three measurements – the daily energy at the nominal voltage, and potentially two measurements of instantaneous power at under-voltage and over-voltage conditions. (This procedure is being developed based on an ongoing analysis of test data, and the related calculations are not included in the tables below.)
- The above parameters (power, duty cycle) are constant throughout the day. (In reality, there may be a diurnal cycle, due to changes both in ambient temperature and in usage.) In future versions of the energy service calculations, this may be adjusted to better model the relationship between the battery-to-port efficiency and the variable power during the cycle.
- The required solar run time for refrigerators is 24 hours. This is a minimum requirement and does not provide any safeguard for geographic variations in solar resource, losses due to suboptimal installation, and variations in ambient temperature and use patterns. Because the ESC is designed to provide an average estimate of run times, using a minimum requirement of 24 hours could mean that on some days or in some climates, the refrigerator will not be powered for a full 24 hours. This lack of reliability is likely acceptable for non-critical, non-perishable items, which constitutes the majority of the current off-grid refrigerator market.
- There is no required minimum full-battery run time for refrigerators; however, the kit is required to advertise a full-battery run time for the refrigerator, and this run time will be evaluated using the ESC.

The following table shows the modifications to the **full-battery run time** energy service calculations (GG.4.1.5) to include refrigerators.

Note: The symbols used in these formulas are defined in the indicated numbered steps in IEC TS 62257-9-5. In some cases, an additional n *has been added to the subscript; this has been done only when the value of* n *is referenced in the formula.*

Spreadsheet location ('Sample # (FB)' sheet)	**Procedure step (GG.4.1.5 unless otherwise noted)**	**Changes for refrigerators**	**Changes to non-refrigerator appliances**
A243:G270, O94:O127	d)	The ESC assumes a "standby loss" duration of 15 hours. The standby loss refers to the self-consumption of the product; that is, the power consumption when no appliances are used. This energy must be subtracted from the available battery energy. Since refrigerators can have run times of more than 15 hours, the standby loss duration of 15 hours is inadequate. Therefore, the procedure is modified to determine a different standby energy quantity E_{sb} for each combination and for each individual refrigerator.	The standby loss duration calculated as described is used for all appliances in a combination containing a refrigerator. There are no changes to the calculations for combinations that do not include refrigerators or for individual non-refrigerator appliances.
O56:O60	t) 4)	For refrigerators, the target run time t_{t} is multiplied by the duty cycle. $t_{\text{t}} = t_{\text{r}} \cdot D$	No change
N19:N23	v)	The formula for energy demand (E_{ar}) is modified by multiplying the power by the duty cycle. $E_{\text{ar}} = \frac{P_{\text{a}} \cdot D \cdot t_{\text{r}}}{\eta_{b\text{-a}}}$	No change
O8:O41	y)	For refrigerators, the PV energy is simply allocated to each refrigerator in the order that they are entered in the spreadsheet. (It is considered more useful to have one fully functioning refrigerator than two refrigerators that cannot operate for the full day.)	Refrigerators are excluded from the summation and from the total energy E_{b}. $E_{\text{a}} = \left(E_{\text{b}} - \sum_{\substack{\text{refrs} \\ j}} E_{\text{a},j} \right) \cdot \frac{E_{\text{ar}}}{\sum_{\substack{\text{nonrefrs} \\ i}} E_{\text{ar},i}}$

		$E_{\mathrm{a},n} = \min\left(E_{\mathrm{ar},n}, E_{\mathrm{b}} - \sum_{\substack{\mathrm{refrs} \\ j=1}}^{n-1} E_{\mathrm{a},j}\right)$	
P19:P23, P105:P109	z)	As before, the formula is modified by multiplying the power by the duty cycle. $t_{\mathrm{a}} = \frac{E_{\mathrm{a}} \cdot \eta_{\mathrm{b\text{-}a}}}{P_{\mathrm{a}} \cdot D}$	No change.

The following table shows the modifications to the **solar run time** energy service calculations (GG.4.2.4) to include refrigerators.

Spreadsheet location ('Sample # (SD)' sheet)	**Procedure step (GG.4.2.4 unless otherwise noted)**	**Changes for refrigerators**	**Changes to non-refrigerator appliances**
A270:G284	c), GG.4.1.5 d)	The standby loss calculation is modified as described in the FBRT table.	
R19:S23, Q162:Q166	r)	Instead of using the day and night use fractions, the day run time for refrigerators is fixed at 7 h and the night run time is the remaining total duration. $t_{\mathrm{r,day}} = 7\ \mathrm{h}$ $t_{\mathrm{r,night}} = \max(0, \text{total run time} - 7\ \mathrm{h})$ The formulas for day and night energy demand are modified by multiplying the power by the duty cycle. $E_{\mathrm{ar,day}} = \frac{P_{\mathrm{a,day}} \cdot D \cdot t_{\mathrm{r,day}}}{\eta_{\mathrm{b\text{-}a,day}}}$ $E_{\mathrm{ar,night}} = \frac{P_{\mathrm{a,night}} \cdot D \cdot t_{\mathrm{r,night}}}{\eta_{\mathrm{b\text{-}a,night}}}$	No change
T8:T41, Y8:Y41	u), aa)	For refrigerators, the PV energy is simply allocated to each refrigerator in the order that they are	Refrigerators are excluded from the summation and from the total energy E_{PV}.

		entered in the spreadsheet. (It is considered more useful to have one fully functioning refrigerator than two refrigerators that cannot operate for the full day.) PV energy is first allocated to refrigerator 1 for daytime use, then for night use, then to refrigerator 2 for daytime use, refrigerator 2 for night use, and so on. The total energy allocated to refrigerators for night use is limited so that enough PV energy remains for the standby loss. For refrigerator *n*: $$E_{\text{a,day*},n} = \min\left(E_{\text{ar,day},n}, E_{\text{PV}} - \sum_{\substack{\text{refrs} \\ j=1}}^{n-1}\left(E_{\text{a,day*},j} + E_{\text{a,night*},j}\right)\right)$$ $$E_{\text{a,day*},n} = \min\left(E_{\text{ar,day},n}, E_{PV} - \sum_{\substack{\text{refrs} \\ j=1}}^{n-1}\left(E_{\text{a,day*},j} + E_{\text{a,night*},j}\right)\right)$$ $$E_{\text{a,night*},n} = \min\left(E_{\text{ar,night},n}, \max\left(0, E_{PV} - E_{\text{sb}} - \sum_{\substack{\text{refrs} \\ j=1}}^{n-1}\left(E_{\text{a,day*},j} + E_{\text{a,night*},j}\right) - E_{\text{a,day*},n}\right)\right)$$ The purpose of the $\max(0, \ldots)$ in this formula is to prevent a negative value of run time in the case where the standby energy is greater than the	$$E_{\text{a,day*}} = \max\left(0, E_{\text{PV}} - \sum_{\substack{\text{refrs} \\ j}} E_{\text{a,day*},j}\right) \cdot \frac{E_{\text{ar,day}}}{\sum_{\substack{\text{nonrefrs} \\ i}} E_{\text{ar},i}}$$

		remaining PV energy. This can occur because the standby duration is fixed.	
U19:U22	v)	As before, the formula is modified by multiplying the power by the duty cycle. $$t_{\text{a,op,day*}} = \min\left(7\text{ h}, \frac{E_{\text{a,day,*}} \cdot \eta_{\text{b-a,day}}}{P_{\text{a,day}} \cdot D}\right)$$	No change.
V8:V41	w)	For refrigerators, $t_{\text{a,op,day}}$ is always equal to $t_{\text{a,op,day*}}$. That is, the daytime duration of operation of a refrigerator will never be reduced in order to plug in other appliances.	The number of refrigerators is subtracted from $N_{\text{p,day}}$, and refrigerators are excluded from the summation. $$t_{a,op,day} = \min\left(1, \frac{7\text{ h} \times \left(N_{\text{p,day}} - N_{\text{refr}}\right)}{\sum_{\text{nonrefrs}} t_{\text{a,op,day*}}}\right)$$
X19:X22	z)	$E_{\text{a,day}}$ is always the same as $E_{\text{a,day*}}$ (since the refrigerator daytime run time is never reduced to plug in other appliances, the refrigerator energy demand will also never be reduced). *Note: this has the same effect as modifying the original formula to include the duty cycle. However, since the formula must be inconsistent in either case, the simpler calculation is preferred.*	No change.
Z8:Z41	bb), cc)	As before, energy is allocated to refrigerators in order; the total energy is limited to the battery capacity less the standby loss. $$E_{\text{a,night},n} = \min\left(E_{\text{a,night*},n}, \frac{E_{\text{FBRT}}}{\eta_{\text{bcc}} \cdot \eta_{\text{b}}} - E_{\text{sb}} - \sum_{\substack{\text{refrs} \\ j=1}}^{n-1} E_{\text{a,night},j}\right)$$	The refrigerator energy is subtracted from the FBRT energy in the calculation of $E_{\text{a,night,total}}$. $$E_{\text{a,night,total}} = \max\left(0, \min\left(\sum_{\substack{\text{nonrefr} \\ i}} E_{\text{a,night*}} + \sum_{\substack{\text{refr} \\ j}} E_{\text{a,night}}, \frac{E_{\text{FBRT}}}{\eta_{\text{bcc}} \cdot \eta_{\text{b}}} - \sum_{\substack{\text{refr} \\ j}} E_{\text{a,night}}\right) - E_{\text{sb}}\right)$$ In addition, it is possible for $E_{\text{a,night,total}}$ to be negative if daytime refrigerator use consumes all the available PV energy; this

			requires the value of $E_{\text{a,night,total}}$ to be limited to non-negative values. In the calculation of $E_{\text{a,night}}$ refrigerators are excluded from the summation. In addition, the value of $E_{\text{a,night}}$ is set to zero if $E_{\text{a,night*}}$ is zero (to avoid division by zero).
P64:P68	l) 4)	For refrigerators, the target run time t_{t} (for both day and night) is multiplied by the duty cycle. $t_{\text{t}} = t_{\text{r}} \cdot D$	No change
Q162:Q166, R162:R166 *	r) (individual use)	The day run time for refrigerators is fixed at 7 h. $t_{\text{r,day}} = 7$ h For individual use, it is not necessary to calculate $t_{\text{r,night}}$ or $E_{\text{ar,night}}$.	No change.
Q162:Q166	r) (individual use)	the daytime energy demand formula is modified by multiplying the power by the duty cycle. $E_{\text{ar,day}} = \frac{P_{\text{a,day}} \cdot D \cdot t_{\text{r,day}}}{\eta_{\text{b-a,day}}}$	
S162:S166 *	ll)	Rather than allocating the energy proportionally, the nighttime energy is simply the PV energy or the energy required for 7 h of operation, whichever is less. $E_{\text{a,day*}} = \min\left(E_{\text{PV}}, E_{\text{ar,day}}\right)$	
T162:T166	v) (individual use)	As before, the formula is modified by multiplying the power by the duty cycle. $t_{\text{a,op,day*}} = \min\left(7\text{ h}, \frac{E_{\text{a,day,*}} \cdot \eta_{\text{b-a,day}}}{P_{\text{a,day}} \cdot D}\right)$	No change.
V162:V166	z) (individual use)	$E_{\text{a,day}}$ is always the same as $E_{\text{a,day*}}$ (since the refrigerator daytime run time is never reduced to plug in other appliances, the refrigerator energy demand will also never be reduced). *Note: this has the same effect as modifying the original formula to include the duty cycle. However, since the formula must be inconsistent in either case, the simpler calculation is preferred.*	No change.

W151:W184	nn) (individual use)	The formula for $E_{\text{a,night}*}$ can be algebraically simplified to $$E_{\text{a,night}*} = E_{\text{PV}} - E_{\text{a,day}}$$ That is, the nighttime energy consumption (not considering the battery capacity or standby loss) is just the remaining PV energy subtracting daytime use. This formula can be used for all individual appliance run times. With this change, $E_{\text{ar,night}}$ is no longer required for refrigerators.
X151:X184	oo)	The formula in the spreadsheet has been modified to reference the correct standby energy value, but there is no change to the definition of the calculation. In addition, it is possible in some circumstances for the formula to return a negative result; in this case it is set to zero.
* The changes marked with * are equivalent to the original calculation method with the daytime use percentage set to 100%.		

About VeraSol

An evolution of Lighting Global Quality Assurance, the VeraSol program supports high-performing, durable off-grid products that expand access to modern energy services. VeraSol builds upon the strong foundation for quality assurance laid by the World Bank Group and expands its services to encompass off-grid appliances, productive use equipment, and component-based solar home systems. Like Lighting Global Quality Assurance, the VeraSol program is managed by CLASP in collaboration with the Schatz Energy Research Center at Humboldt State University. Foundational support is provided by the World Bank Group's Lighting Global program, UKaid, IKEA Foundation, Good Energies Foundation, and others.

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