EFFICIENCY FOR ACCESS

IKEA Foundation

UKaid
from the British people

DESIGNING AND IMPLEMENTING FIELD TESTING FOR OFF- AND WEAK-GRID REFRIGERATORS

Guidance on refrigerator performance monitoring in the field

JUNE 2022

EFFICIENCY FOR ACCESS COALITION

Efficiency for Access is developing a series of field-testing resources to help practitioners design and implement field testing projects that focus on performance monitoring and measurement of appliances and equipment designed for use in off-grid weak-grid contexts.

We define field testing as the process of collecting, measuring, and analysing a product's data, often but not necessarily used by end-users in real-world settings over an extended period. Successful field testing provides information about the product's performance and user experience and informs on why the product performs the way it does and its impacts on the user's life or livelihood. In addition, the data and intelligence gathered from field testing inform decisions about design, financing, business models and more.

This document complements the January 2022 guide by providing specific design and implementation considerations for refrigerators and resources that can easily be customised based on field testing needs. Although a stand-alone annexe, it should be read together with the appliance agnostic, Practical Guidance for Designing & Implementing Field Testing for Appliances & Productive Use Equipment for a holistic consideration of field testing. The learnings and examples are drawn from the Efficiency for Access team's experience conducting refrigerator field testing in Uganda, Rwanda and India and from industry experts through the Efficiency for Access Off-Grid Refrigerator Technical Working Group. This guide is also published in parallel to a field-testing guide for solar water pumps, which can be accessed here.

CLASP, Co-Secretariat of the Efficiency for Access Coalition, developed this field-testing guide as part of the Low Energy Inclusive Appliances (LEIA) programme, a flagship programme of Efficiency for Access. Efficiency for Access is a global coalition working to promote affordable, high-performing, and inclusive appliances that enable access to clean energy for the world's poorest people. It is a catalyst for change, accelerating the growth of off and weak-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life, and support sustainable development. Current Efficiency for Access Coalition members have programmes and initiatives spanning 54 countries and 26 key technologies. It is co-chaired by UK aid and the IKEA Foundation. This report was authored by Jeremy Tait (Independent Consultant), Riley Macdonald and Makena Ireri, with support from Lisa Kahuthu and Win Njueh of CLASP.

The authors would like to recognise Leo Blyth, William Jamieson (Energy Saving Trust), Elisa Lai (CLASP), the EED Advisory team, Ivan Katic (Danish Technological Institute(DTI)), Judith Evans (Refrigeration Developments and Testing Ltd (RD&T)), Duncan Kerridge (SureChill), Larry Schussler (Sunfrost), Joanna Gentili (Africa Minigrids), Patrick Beks, Randolph van Kasteren (Re/genT) and other members of the Efficiency for Access Off-Grid Refrigerator Technical Working Group for their peer review and input into this report.

clasp IKEA Foundation UKaid from the British people

TABLE OF CONTENTS

Abbreviations and definitions . . . . **iv**

1. Technology scope and objectives **1**

1.1 Refrigerator scope 1

1.2 Refrigerator field testing objectives 2

2. Collecting baseline data for refrigerator field testing **4**

2.1 Template to define the refrigerator under test 4

2.2 Template to define refrigerator condition, situation and usage at start and end of test 4

3. Refrigerator performance testing **5**

3.1 Define technical parameters 5

3.2 Measuring parameters that affect heat load 5

3.3 Refrigerator service delivery testing 6

3.4 Refrigerator energy performance testing 6

4. Design for remote monitoring and testing **6**

5. Further guidance **8**

5.1 Considerations when shipping refrigerators 8

5.2 Other resources 8

6. Annexe **9**

ABBREVIATIONS & DEFINITIONS

Litre	L
Mean kinetic temperature	MKT
Phase change material	PCM
Photovoltaic	PV
Solar direct drive	SDD
Solar home system	SHS
Efficiency for Access	EforA
Autonomy time	The time in hours during which the system (device and any integrated energy storage) maintains the storage temperature within prescribed limits after the power source has been disconnected.
Holdover time	The time in hours during which the appliance maintains the storage temperature within prescribed limits after power source has been disconnected, without use of electrical nor thermal storage capacity.
Latent heat	Energy absorbed or released by a substance during a change in phase that occurs without changing its temperature.
Mean kinetic temperature (MKT)	Calculation of temperature that's slightly higher than the simple average of air temperature readings and more closely reflects the impact of temperature excursions (e.g., if doors are left open).
Phase change material (PCM)	A substance which releases and absorbs energy during phase transition to provide cooling.
Pull-down time	Time that's required to lower a refrigerator compartment from ambient temperature to its desired temperature.
Sensible heat	Heat that can be felt. It is the energy moving from one system to another that changes the temperature rather than changing its physical state (phase).
Temperature excursion	When a temperature reading is outside the recommended range.
Sensible heat	Changes in temperature of a gas or object with no change in phase.

1. Technology scope & objectives

1.1 Refrigerator scope

Refrigerators unlock social and economic benefits for consumers living in off- and weak-grid areas by reducing food waste and enhancing income through new business opportunities. There are various types of refrigerators suitable to operate in energy-constrained conditions. However, compressor-based refrigerators are currently the most popular and viable technology due to the solar market's growth. This guide focuses on compressor-based domestic refrigerators of up to 300 litres (L) designed for household or small business use (e.g., storing fish, milk, or cold beverages). Table 1 provides more details on refrigerator sub-types within the compression-based refrigerator group.

Table 1. Compression refrigerator types.

Refrigerator Type	Definition	Appropriate Power Source
Compression Refrigerators: Operate using compression cycle which requires electricity		
DC household refrigerators and refrigerator-freezers	Designed to be used with a solar energy system and typically feature more efficient design considerations, such as highly efficient compressors and motors, or thicker insulation.	Solar system including PV panel and battery, or generator
SDD refrigerators	Connect directly to a PV panel, and generally include an integrated thermal and/or electric battery to allow for autonomous operation at night or on cloudy days when there is no solar power (Figure 1). SDD technology uses solar energy to freeze water packs or other phase change materials. These ice packs keep the refrigerator cool.	PV panel
Conventional AC refrigerators	Intended for use with a grid power supply, but may be used with a solar system through an inverter. On average, they are less efficient than DC refrigerators, but are currently the most readily available option for most off-grid consumers.	Grid electricity, generator, or solar system with an inverter

Further, this guide focuses on refrigerators in off- or weak-grid settings, either used with a solar home system (SHS), mini-grid, grid connection, generator or solar direct drive (SDD). More information on testing considerations for the power supply can be found in EforA's product-agnostic field testing guide here.

A refrigerator is like a heat pump, meaning the more heat has to be pumped, the more energy it will consume. The compressor creates cold by removing heat from the insulated space. Therefore, it's essential to understand the sources of heat load on a refrigerator if results are to be understood, specifically to make comparisons with other tests. The primary heat loads should be measured or noted in the field test. These include:

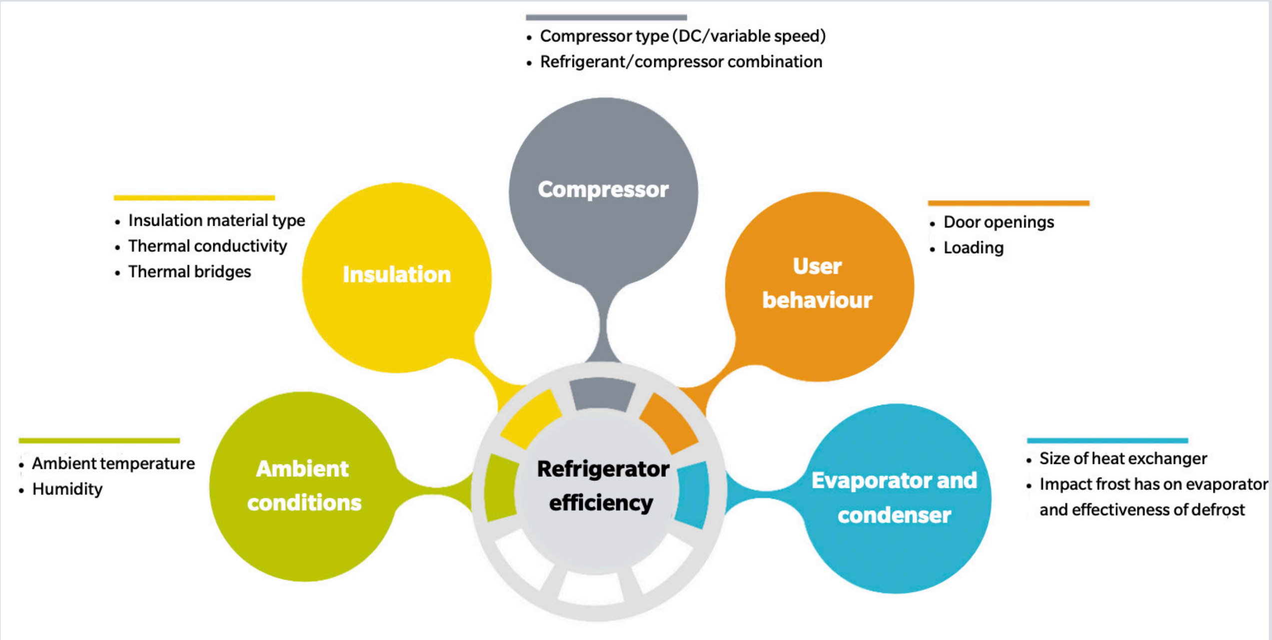
- Heat passing through the insulation from ambient air.
- Additional heat passing through the insulation if the outer surface of the refrigerator is heated.
- Door opening due to waste of already-cooled air and entry of warm air.
- Humidity entering with door openings gives a double hit of 'sensible heat' to cool the water vapour, and then a bigger 'latent heat' as the vapour condenses onto evaporator or fridge walls (plus a third hit on efficiency if it frosts up the evaporator).
- Heat extracted from produce placed in the refrigerated space, especially if ice is being made (ice means sensible heat plus latent heat to be extracted).
- Heat generated by any fan, light or other energy source using component inside the refrigerated space.
- Heat generated by ripening and natural processes in stored fruit and vegetables.

As highlighted in Figure 1, the main factors affecting refrigerator performance are (in order of relative importance):

- The **ambient conditions,** including humidity and ambient temperature. Ambient temperature directly impacts efficiency and consumption for two main reasons:
    - The biggest heat load on a typical household refrigerator is heat entering through the insulation, which is proportional to ambient temperature and can be higher as it is on the surface of the refrigerator.
    - The efficiency of the cooling unit goes down as ambient temperature increases. A simple rule of thumb is that if the ambient temperature goes up by 5°C, then the consumption of a refrigerator will increase by 10% or so and a freezer by 15% or more. Hence, it is essential to measure the air temperature.

- **Insulation** is critical to improved autonomy and energy efficiency. Factors that affect improved insulation include thicker insulation, the use of insulation material with lower thermal conductivity, and reducing thermal bridges across insulation.[1]
- The **compressor** is the main electrical component and consumer of energy in the refrigerator. It includes a motor and pump to move the refrigerant through the system. Selecting a compressor with the best efficiency for the range of conditions in a specific application should be prioritised.[2]
- **User behaviour**, including the number, timing and duration of door openings and how the user loads the refrigerator:
  - Opening doors at the warmest and most humid times of day have a higher impact. While door openings are less influential for chest-style appliances (lid/hatch on top) since air exchange is lower, they are crucial for vertical appliances since cold air flows out and is replaced by warm and humid air. Therefore, it is essential to know if the door is frequently opened or left open for long periods. User training is vital to ensure good practice and minimise consumption. However, for most situations, heat gain through insulation and from loaded produce is more important than that from door openings.
  - The food load (amount, location, and food type) can significantly affect a refrigerator's performance. Refrigerators work best when at least 1/3 to 1/2 full, and items should be placed strategically within the compartment to ensure proper airflow.
- The **evaporator** should be considered in high-humidity areas where frost is likely. Evaporators in chilled compartments may get frosted if under-sized or temperature controls are set too low. More frost means less available space, lower efficiency, and less effective cooling. Considerations for a well-designed evaporator include a less impacted design by frost and can mechanically remove frost (e.g., a plate evaporator).[3] Users may need advice on when and how to do this (e.g., attacking frost with a knife means punctured pipework and a failed refrigerator).
- The **condenser** needs free air circulation (usually at the rear of the fridge) so that it can shed heat easily and work more efficiently into the atmosphere. If the condenser is pressed against a surface or located in an enclosure with poor air circulation, its ability to shed heat is hampered, and the refrigerator may not work at all (i.e., bring down internal temperature).

Figure 1: Key factors affecting the efficiency and performance of an off-grid refrigerator.

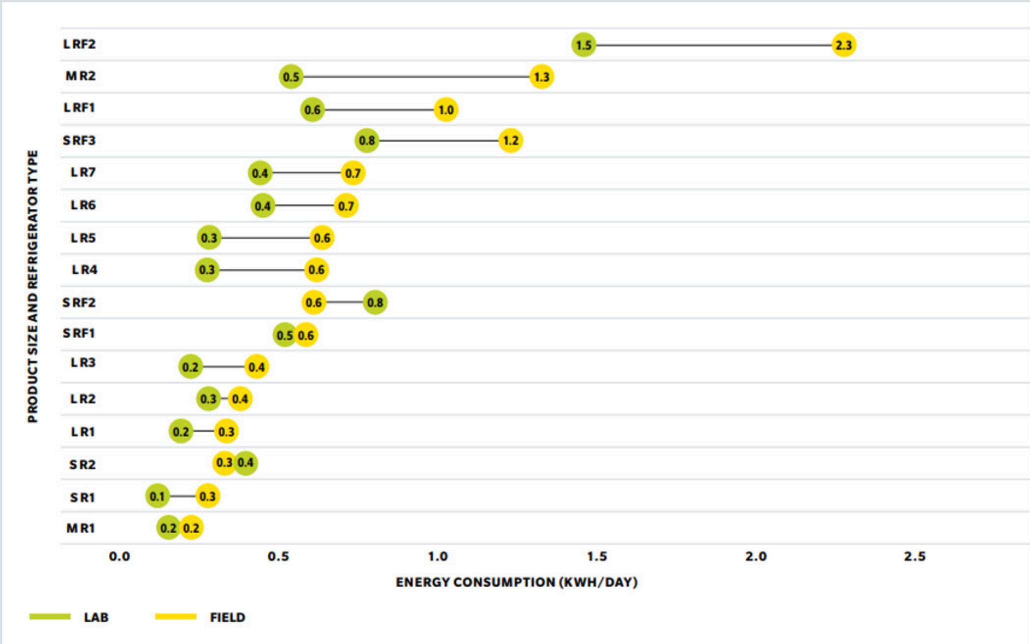


1.2 Refrigerator field testing objectives

A refrigerator's performances vary depending on environmental conditions and user behaviour. While laboratory testing generates comparable and consistent performance data, the results can differ from performance measured during testing with real users. For example, in 2018, Efficiency for Access installed 36 refrigerators in small retail shops in rural Uganda for field testing. The data showed that the daily energy consumption differed considerably from lab-tested measurements (Figure 2), with 88% of tested refrigerators consuming more energy in the field than in the lab. In addition, the medium and large refrigerators consumed on average 124% and 80% more energy, respectively, in the field compared to lab testing. This variance in energy was largely due to use cases and user behaviour.[4] This highlights a need for programmes, companies and others to perform field testing on refrigerators to get a realistic measure of performance that allows for optimal power system sizing and planning.

1. Efficiency for Access Coalition, Off-Grid Refrigeration Technology Roadmap, 2019.
2. The United Nations Environment Programme, The Potential to Improve the Energy Efficiency of Refrigeration, Air Conditioning, and Heat Pumps, 2019.
3. Efficiency for Access Coalition, Off-Grid Refrigeration Technology Roadmap, 2019.
4. Efficiency for Access Coalition, Appliance Data Trends Report, 2021.

Figure 2: Differences in energy consumption between lab vs field testing.



Before initiating field testing, it is essential to establish the project's objectives and research questions that you want to answer. Examples of potential research questions are highlighted in Table 2.

Table 2: Potential research questions for refrigerator field testing.

Research Aim	Example Questions
To understand refrigerator performance in varied real use	What is the average ambient, maximum and minimum temperatures reached? What is the time of these peaks in a given location? How is the refrigerator's autonomous performance? How do door openings affect energy consumption? How do ambient conditions affect energy consumption?
To discover performance limitations not identified during laboratory tests	How does the performance vary with amount and type of food or storage items? How does power supply quality impact refrigerator performance?
To determine what design features and technical specifications potentially need to change	How does thicker insulation affect energy consumption and autonomy?
To monitor how performance varies with seasonality or over time	What is the average daily energy consumption? Is the average daily energy consumption the same on weekdays and weekends? How do months/seasons influence the energy consumption?
To investigate field performance of certain ancillary or associated equipment	What is the real amount of energy drawn from the power supply (e.g. solar system)? What's the refrigerator's effect on other loads?
To determine 'real' appliance usage patterns by measuring/observing user behaviour	Is the consumer using the refrigerator for food or beverage storage? Is the consumer using the refrigerator for household or commercial use? Does the consumer turn their refrigerator off at night?
To determine what design features and technical specifications might potentially need to change	Given the understanding of the consumer what may need to change to optimally match the fridge to its use case? Examples include controls, storage organisation, door opening, dimensions, capacity.
To evaluate adequacy of packaging for shipping (protecting the appliance in transit)	Do products or components arrive with damage?
To evaluate end user comprehension of product documentation, e.g., installation instructions, user manuals, trouble shooting and repairs, warning labels, etc.	How well do refrigerator distributors or consumers understand the instructions for installation and operation? Does this influence usage and performance?

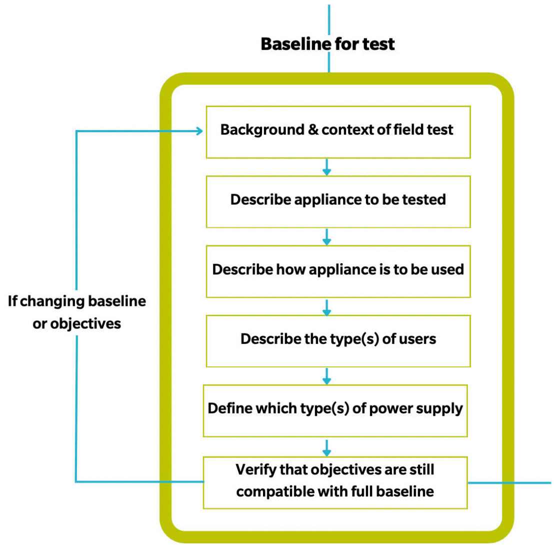
2. Collecting baseline data for refrigerator field testing

Collecting baseline data is the second critical step in refrigerator field testing. It helps clarify the equipment to be tested (power, capacity, type of controls, etc.). These details also serve as the primary input for selecting appropriate monitoring equipment to use in field testing projects.

2.1 Template to define the refrigerator under test

Table 3 in the Annexe section can be used to capture details of the refrigerator under test. The list is not exhaustive and not all parts are relevant for all tests. As well as completing a data table, take photos of the appliance (front, rear, sides, three-quarter view with the door open, rating plate, compressor, packaging, internal light, user controls, special features).

Figure 3: Steps for collecting baseline data.



2.2 Template to define refrigerator condition, situation, and usage at start and end of test

Table 4 provides considerations regarding the set up and condition of the refrigerator in its test location as the test begins.

Table 4: Definition of the condition of the refrigerator in its test location.

Consideration	Notes about the refrigerator and its set up
Description of the location of the appliance and what is located around it	
Photographs of the appliance in its test location	
What electricity supply connections are in place? (include photographs)	
What are the control settings?	
What sensors are in place? (include photographs)	
Check for adequate free air circulation to condenser	
Check appliance is complete and was not damaged in transit	
What cable lengths, thickness, and types are used for provision of power? What connectors are used? (for assessing sources of power loss that should be considered)	
Check the condition of door seals and whether seal is made when closed (use a strip of paper to probe for gaps between seal and door frame or check that strip is gripped)	
At or near the end of the test period, run through the above checks again to note what changes or damage (if any) has occurred. At the end of the test, check for any change to other electrical loads on the system; has power available to appliance under test been affected?	

3. Refrigerator performance testing

3.1 Define technical parameters

Table 5 outlines the most critical factors that may affect refrigerator performance, including heat load, service delivery, and energy performance. Some of these metrics can be measured through lab testing according to the [Global LEAP Off-Grid Refrigerator Test Method], field testing, or a user survey. Some parameters may be under the user's control, while others are associated with the environment in which it is used. In field testing, these factors cannot necessarily be controlled, but if identified in advance, they can be measured or noted during the test to understand the results correctly. If an essential factor is not assessed, the results could be hard to interpret or even useless, especially if they are not as expected. While some metrics in Table 5 (e.g., ambient temperature, door openings, and relative humidity) are controlled and measured in the lab, they do not necessarily represent real-world conditions that field testing can capture.

Table 5: Technical parameters that can be measured in the lab, field, or through user surveys.

Category	Parameters	Data Source		
		Lab testing with Global LEAP test method	Field testing	User survey
Heat load	Ambient air temperature		x	
	Outside surface temperature of refrigerator		x	
	Door openings		x	x
	Relative humidity		x	
	Load (refrigerator compartment contents)		x	x
Service delivery	Pull-down time	x	x	
	Average temperature of compartment	x	x	
	Average temperature of load in compartment	x	x	
	Autonomy	x	x	
Energy Performance	Minimum-maximum voltage input	x	x	
	Minimum-maximum current input	x	x	
	Minimum-maximum power input (calculated using voltage and current)	x	x	
	Volume of unfrozen and/or frozen food compartment	x		
	Instantaneous power	x	x	
	Total energy consumption (calculated using voltage and current over a given period of time)	x	x	
	Over-under voltage resilience	x		

3.2 Measuring parameters that affect heat load

The parameters below should be measured to fully assess the heat loading for a refrigerator in the field test. However, relative importance will vary by situation and budget, and not all are necessarily needed. Types and sources of temperature and humidity sensors are shown in Table 6.[5]

1. **Ambient air temperature and relative humidity near the outside of the appliance** can be measured in a place indicative of the general air in the room around the appliance. Ideally, place a thermocouple within 2 metres of the refrigerator and as close as possible to the height of the refrigerator. If on a wall, place it 30 cm away from room corners or the ceiling and in a position with air circulation. One measurement point is generally adequate. Don't place the sensor above or near the condenser which dumps the heat from the refrigerator (usually at the back of the cabinet) or near other sources of heat unless this is indicative of the general air in the room near the refrigerator.

2. **Outside surface temperature of the refrigerator**: Site a thermocouple on the outer surface of the refrigerator cabinet, particularly on any significant part of the surface that gets direct sunshine. It will enable the calculation of heat transmission through the insulation.

3. **Door openings**: Magnetic switch, reed switch, light sensors or, on horizontal lids, tilt sensors can detect when a door is open or closed and send data on the count of openings per day, duration open and time of day to be stored locally or via Wi-Fi.[6] If a measurement is not possible, obtain an interview record of rough usage and number of openings.

5. Temperature devices approved by UNICEF for vaccine refrigerator monitoring are identified at this web site: https://supply.unicef.org/all-materials/cold-chain-equipment/temperature-monitoring-devices.html?p=1.
6. Example sensor: https://monnit.blob.core.windows.net/content/documents/datasheets/ALTA/ADS-008-Open-Closed-Sensor-Data-Sheet.pdf.

4. **Heat load from stored produce** is particularly relevant for high throughput retail. If the quantity of food or drink being loaded per day can be estimated, the heat load can be calculated using the specific heat capacity of the produce, the mass and the temperature drop achieved (likely to be the difference between ambient temperature and achieved storage temperature). This could be estimated from sales records, sampling of usage rates or survey questions. In some situations, the user could be asked to tap a 'counter button' by the fridge for each soda bottle loaded (for example), which could be wired to the data logger.

3.3 Refrigerator service delivery testing

The service delivery of a refrigerator can be measured by the ability to cool to the desired storage temperature. This can be evaluated by measuring the temperature in the refrigerated space (either the air temperature or the temperature of produce items). When analysing refrigerator temperatures, especially for temperature-sensitive products such as medicines, the most useful proxy for the storage temperature experienced by the product is called the 'mean kinetic temperature' (MKT), expressed in degrees Celsius.[7] The MKT calculates as slightly higher than the simple average of air temperature readings and more closely reflects the impact of temperature excursions (e.g., if doors are left open). Some temperature loggers can automatically output the MKT.

Suggestion: Consider if it is useful and possible to detect if the appliance is deliberately switched off by the user (to save power, as opposed to when power input is simply not available).

Suggestion: If temperature of stored foodstuff is the main concern, reduce recording of transient spikes in air temperature whenever the door is opened by tucking the thermocouple into a hole drilled in (for example) a small nylon block. The temperature spikes are not representative of what happens to stored produce.

Suggestion: For refrigerators used in retail or food service applications, consider if it would be helpful to measure the time taken to cool a known quantity of produce (e.g., time taken to cool 20 drinks, in cans, from ambient temperature to storage temperature, all loaded together into an empty and pre-chilled fridge). For example, this is best done in a lab, perhaps according to the load processing test Annex in IEC 62552, but a simulation may be instructive in a field setting.

It may also be key to measure the time required to lower a refrigerator compartment from ambient temperature to its desired temperature, or the pull-down time, which can be heavily impacted by ambient temperature. Note that the pull-down time for SDD refrigerators can be much longer than for other refrigerator types due to the thermal battery.

Depending on the use case, it may be important to measure the temperature performance when power is unavailable, i.e., the autonomy or holdover performance. For example, disconnecting the refrigerator from its power source and measuring the time it takes to rise to a given temperature (e.g., the time it takes the fridge to rise from 4ºC to 8ºC with no external power) can evaluate this. The monitoring system must have an independent power source for this to be effective.

3.4 Refrigerator energy performance testing

Energy consumption can be calculated using two key metrics: voltage and current. A power meter that automatically integrates energy consumption is also an option. Please note that while separate voltage and current data streams can be helpful to understand more details of performance, they are not mandatory if using a power meter. See Annex II in EforA's product agnostic field testing guide for more information on evaluating these metrics.

- **Current draw (Amps)** includes measuring instantaneous start-up/surge currents when the unit is switched on. Knowing the power at intervals of a few seconds can deduce the compressor cycling pattern (on / off or variable speed operation). However, this high-frequency data sampling is impractical for most field tests since the peak current is likely to be recognisable when recorded in a more extended data series at a much lower sampling frequency.
- **Voltage** at refrigerator input.

4. Design for remote monitoring and data logging

Table 6 provides an overview of sensors recommended for field testing of refrigerators, including their accuracy and measurement resolution.

The location of temperature sensors is crucial to understanding what is happening inside the refrigerator but should not inconvenience users. There are several essential things to note when installing the sensors. These are:

- Sensors should represent the mean temperature of the cooled space as experienced by the user. Therefore, they should be located ideally near the centre or upper part of the cooled space, perhaps under a shelf.
- Keep sensors at least 15 cm away from the evaporator (cooling plate) and any air circulation fan, as this would not represent the cooled space's mean temperature.

7. Calculation of MKT involves conversion to degrees Kelvin, enthalpy of the air, the gas constant (shc) and natural logarithms. Free Excel spreadsheet function downloads are available that carry it out on the temperature data stream. One example explanation is: https://www.temperaturemonitoringuae.com/how-to-calculate-mean-kinetic-temperature-mkt-in-excel/.

- Preferably, use two sensors to understand performance better and continue monitoring if one sensor fails. For example, one could be placed near the top and the other just under halfway down the cooled space.
- Either or both evaporating and condensing temperatures are 'nice to haves' for refrigeration engineers to calculate circuit efficiency. For example, one sensor could be on the evaporator plate or close by in the cooled air stream, another on the condenser outside.

Figure 4: Sensor placement on a refrigerator.

Table 6: Overview list of sensors and placement guidance for field testing of refrigerators.

Equipment	Measurement	Minimum Instrument Accuracy	Measurement Resolution	Number and placement of equipment.
Voltage sensor	Voltage drawn (Volts)	± 5%	0.1 V	One sensor wired as close as possible to the appliance power input
Current sensor	Current drawn (Amperes)	± 5%	0.1 A	One sensor on the power input cable. This could be at the distribution board or closer to the appliance
Power meter	Energy consumption (Wh)	± 5%	0.1 Wh (at equal measuring intervals)	One energy meter with voltage measurement as close as possible to the appliance power input. Note: if using a power meter, voltage and current may be measured using this device instead.
Ambient temperature sensor	Ambient dry bulb temperature (°C)	± 1.0°C	0.1°C	One sensor in a location with good air circulation and shielded from direct sunlight and sources of heat. The height of the ambient temperature sensors should be at ± 10 centimetres from the height of the appliance under test.
Ambient humidity sensor	Ambient relative humidity (%)	± 5%	1%	One sensor on the outer wall of the appliance or nearby, at a height similar to that of the appliance
Storage compartment temperature sensor(s)	Internal dry bulb temperature (°C)	[8] ± 1.0	0.1°C (at equal measuring intervals not exceeding 1 hour)	Ideally two sensors evenly spaced across the compartment or one close to central. Sensors could be placed just below a shelf, but a few centimetres m away from the shelf if the shelf itself is refrigerated, such as the base of an ice compartment surface.
Other temperature sensors	Evaporating temperature and/or condensing temperature	± 1.0	0.1°C (at equal measuring intervals not exceeding 1 hour)	Only needed if refrigerator circuit performance diagnostics is important. Evaporating temperature measured on the cooling plate inside the storage volume; condensing temperature measured outside on the condenser (or outlet of compressor).
Door opening sensor	Number and duration of door openings	N/A	N/A	One magnet/contact sensor placed at the unit's door, or a light sensor inside. See also bullet 3 in section 5.2.

8. Source: AHRI Standard 1250 (I-P) - 2014 Standard for Performance Rating of Walk-in Coolers and Freezers

5. Further guidance

5.1 Considerations when shipping refrigerators

Efficiency for Access' product-agnostic field testing guide includes general guidance on considerations for shipping appliances. Additional factors specific to refrigerators include that refrigerants (and other chemicals) are subject to national safety regulations and shipping companies' rules. The rules vary according to which refrigerant is present, refrigerants quantity and sometimes, the overall quantity in the whole shipment (if there are several appliances).

Regulations are often aimed at commercial and industrial cooling equipment rather than small household-style refrigerators containing only 50 grams or so of hydrocarbon as a refrigerant, but this must be confirmed. In addition, special regulations may apply if the appliance is being shipped by air which is significantly more stringent for flammable refrigerants than by surface freight.

Some suppliers of refrigerators that contain hydrocarbon refrigerants that EforA contacted confirmed they don't encounter problems with imports into Africa. There are shipping agents with good experience with such appliances. However, problems can arise due to a lack of knowledge or due to the policies of the shipping agent. Check the 'Dangerous Goods' information pages of candidate freight forwarders to indicate their experience with such products.

For further guidance:

- The Efficiency for Access Guide to Shipping Appliances has a short section on refrigerators on page 12.

The Efficiency for Access Guide to Shipping Appliances links to the United Nations Economic Commission for Europe (UNECE) Recommendations on the Transport of Dangerous Goods - Model Regulations Volume I, Nineteenth revised edition (2015). The guide gives further information about UNECE 'special provisions' in Chapter 3.3. It identifies category UN 3358 called 'REFRIGERATING MACHINES containing flammable, non-toxic, liquefied gas', which are in Division 2.1 and subject to special provision 291, with packing instructions of designation P003 and special packing provision PP32. Volume II of that document includes what packing to 'P003' means. Division 2.2 is the classification for non-flammable, non-toxic gases; flammable gases such as those in hydrocarbon-based refrigerators are in Division 2.1.

- The GIZ Proklima Guidelines for The Safe Use of Hydrocarbon Refrigerants is a handbook for engineers, technicians, trainers and policymakers for climate-friendly cooling, which has shipping information in section 4.6, page 98. According to IATA rules, this guide suggests refrigerators containing less than 100g of hydrocarbon can be air-freighted.

5.2 Other resources

- Learning Paper: The Challenges of Field-Testing Off-Grid Refrigerators, Energy 4 Impact /CLASP/IMC Worldwide, January 2019. Available from: https://efficiencyforaccess.org/publications/learning-paper-the-challenges-of-testing-off-grid-refrigerators

- Solar Direct Drive refrigerators in Colombia, Kenya and Swaziland, Field Test Results Q1-2019, Field Test Report #3, Danish Technological Institute for the SolarChill project, June 2019. Available from: https://www.solarchill.org/english/resources/.

6. Annexe

Table 3: Template to define the refrigerator under test.

Appliance name and model number:
Manufacturer or reseller:
Refrigerator type (e.g., multi-temperature refrigerator freezer, combination unit, etc.):
Product description:
Country of origin:
Unique serial number of the appliance:
Outer dimensions: Height (cm):
Width (cm):
Depth (cm):
Weight (kg):
Power supply type (AC or DC, SDD, etc):
Rated voltage range (V):
Rated power range (W):
Rated current (A):
Rated frequency if product is AC (50Hz, 60Hz):
Rated volume unfrozen food compartment (litres):
Rated volume freezer compartment or ice compartment (litres):
Climate class declared (tropical, sub-tropical, temperate):
Rated temperature range for the unfrozen food compartment:
Rated temperature range for the frozen food compartment and/or ice compartment:
Refrigeration system type (vapour compression; absorption; Peltier (solid state cooling):
Refrigerant type (R290, R600a, R134a, etc.):
Refrigerant mass in the refrigerator circuit (grams):
Insulating foam material:
Thickness of insulation (indicative):
Insulating foam blowing agent:
Compressor model:
Is there an internal air circulation fan? (yes/no):
Special features of the appliance that are relevant to the planned test:
Other details from the rating plate: