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Solar Direct Drive refrigerators in Colombia, Kenya and Swaziland

Field Test Results

Final report

Title:
Solar Direct Drive refrigerators in Colombia, Kenya and Swaziland
Field Test Results – Final report

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July 2021
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1. Executive summary

The current report encompasses all remote monitoring activities and results for solar direct drive refrigerators installed in Colombia, Kenya, and the Kingdom of eSwatini (Swaziland) within the SolarChill GEF project. The aim of the monitoring activity was to get an independent, updated, and broad picture of solar direct drive (SDD) refrigerator reliability under real life operating conditions and from different manufacturers. Most of the monitoring was carried out on vaccine refrigerators (SolarChill A) at health clinics but additionally the project has also collected data and experiences from commercial & household (SolarChill B) SDD refrigerators.

Measurement series for 65 vaccine refrigerators within years 2018-2020 have been collected and analysed with focus on energy consumption and temperature behaviour. The presented long-term data for 5 brands shows that SDD technology is generally working very well and mostly (82-96%) within the 2-8°C temperature range as specified by WHO. However, there is a tendency towards too high temperatures for one brand and too low temperatures for another. The latter is more severe as it could spoil the vaccine if local freezing occurs long enough to influence the vaccine temperature.

Analysis of the power consumption reveals that there are big differences between types of SDD units, and in general the daily consumption is far below the available energy from the solar panels. Data and running behaviour indicate that there is potential for improvement for some of the types.

Interviews with the clinics show that most users are generally satisfied, and the refrigerators do their job. As the project was severely delayed it was possible to follow the performance of some of the installations for more than two years. This long-term access has revealed a few severe vulnerabilities for some of the brands, mainly associated with poor thermostat quality and/or fragility of the refrigeration circuit. Such incidents have immediately been reported to the suppliers, but action has not always been swift.

Despite a very big effort with the installation and distribution of the SCB refrigerators and monitoring systems, this part of the project could only collect a limited amount of data compared to what was expected. The data shows some more temperature variation than for the vaccine refrigerators, likely due to the higher cooling load.

The user responses to the questionnaires turned out to be the most valuable data achieved from the SCB activities. The country managers in eSwatini and Kenya have successfully interviewed shop owners and other users of the SCB appliances, and a review of the responses shows that the access to cooling makes a real difference to the users.

The feedback is very positive in general, and the only negative comments are that the units are too small and do not have a freezer compartment. The fact that there is no utility

bill to be paid and that the solar power supply is more stable than the grid is also highlighted. The shop owners report that the sale of goods such as cold milk and juice has improved their business by up to 50% compared to the situation without cooling.

The SolarChill GEF project originally planned to collect data via a single remote monitoring solution (RMS) but for cost reasons ended up with 3-4 different systems, and unintentionally this gave an insight in strong and weak sides for the different RMS. The general experience from the monitoring phase is that after proper set up the operation of the monitoring systems and data transfer is usually very reliable, but installation and connection to the local telecom network can be very demanding and time consuming.

The remote monitoring systems have been very valuable for as a tool for error detection and fault analysis in the cases where refrigerators began to show abnormal behaviour. Some manufacturers have already integrated RMS as standard for same reason.

The project group wish to thank UNEP/GEF for their support to this project.

2. Introduction

The current report is the final field test report from the UNEP-GEF project "SolarChill Development, Testing And Technology Transfer Outreach" (Project number: 4682). The main purpose of the report is to describe the field test programme, its results, and general experiences from the field with SolarChill® technologi. In particular, the report should document the installation and long-term operation of solar powered refrigerators and monitoring systems with the aim to check compliance with WHO requirements and reliability in real use scenarios.

Solar direct drive (SDD) refrigerators have successfully been introduced to the health sector in many countries and have been in use for years, but there has not been a systematic collection of data on their performance under field conditions across different models and climates for a longer period. The project was proposed to provide detailed data so that WHO and the manufacturers could get a detailed insight in the performance and correct any issues that may be registered.

One of the concerns raised by cold chain equipment users and distributors is the limited ability to control the vaccine temperature under all conditions, especially to avoid freezing. If freezing occurs it can have dramatic health care and economic impact if a load of vaccine has to be discarded. It is also important to know if the reliability and energy consumption in practical usage are equivalent to the results acquired by the standardized laboratory test that is used to qualify the appliances for WHO PQS listing. If the actual energy consumption is lower than expected, it may be possible to reduce the PV module size and thus reduce system costs.

Besides cold chain application the project has investigated possible commercial and household application of the same basic technology. Therefore, the refrigerators are classified as

vaccine SDD refrigerators (SolarChill A) and commercial refrigerators (SolarChill B). The results from both types are included in this report.

The primary objective of the entire project was to gather information from field operation of different types of SolarChill refrigerators in three countries: Colombia, Kenya, and the Kingdom of eSwatini. The selection of the three countries and the long-term monitoring should ensure a broad range of operating conditions from hot and humid to temperate and dry environmental conditions. The project consortium hopes the results can be helpful to those who are working with refrigeration in remote areas.

The Danish Technological Institute has been the main responsible partner for the monitoring program under a contract with the overall project manager SKAT Foundation. The project has been funded by GEF (Global Environment Facility) with UNEP as implementing agency.

3. SDD refrigerator types

The GEF project is monitoring 4 different types of vaccine refrigerators and one combined refrigerator/freezer, each one equipped with PV modules as per their WHO PQS system approval.

Table 1 List of brands, models and PV modules used

Brand	Appliance model	Peak power of PV modules used in the project	Nominal array power W_p	Freeze protection*	Temp. zone°C
B Medical	TCW 40	4 x 100 W_p , 12V	400	A	5-43
Haier	HTCD 90(also freezer)	4 x 180 W_p, 24V	720	A	5-43
Zero Appliances	ZLF 30	2 x 270 W_p, 24 V	540	A	5-43
Vestfrost	VLS 024	4 x 90 W_p, 12V	360	A	5-43
Godrej	GVR 50DC	2 x 250 W_p, 24V	500	A	10-43

**) Grade A, user-independent freeze protection (UIFP): when there is no user intervention required to ensure that the vaccines will not be exposed to freezing temperatures whatever the position of the vaccine in the vaccine storage compartment*

There are two fundamentally different refrigerator designs involved in the current study:

1) Chest models where the vaccine compartment is accessed from the top like in a chest freezer and where the thermal storage consists of icepacks or an iceliner surrounding the vaccine chamber. A thermostat controls the compartment temperature. Vaccine freezing is avoided by having some insulation between the ice and the storage volume and in some cases also by local electrical heating elements.
2) Upright models where the vaccine compartment is accessed via a front door and where the thermal storage consists of a water/ice mixture surrounding the vaccine chamber. The refrigeration circuit including evaporator is located at the top. Vaccine freezing is prevented because the lower part of the water/ice tank is never frozen. The regulation acts by natural convection of water at 4°C where it has its maximum density. Only if the ice thickness keeps growing from the top it can cause freezing when it reaches the vaccine compartment.

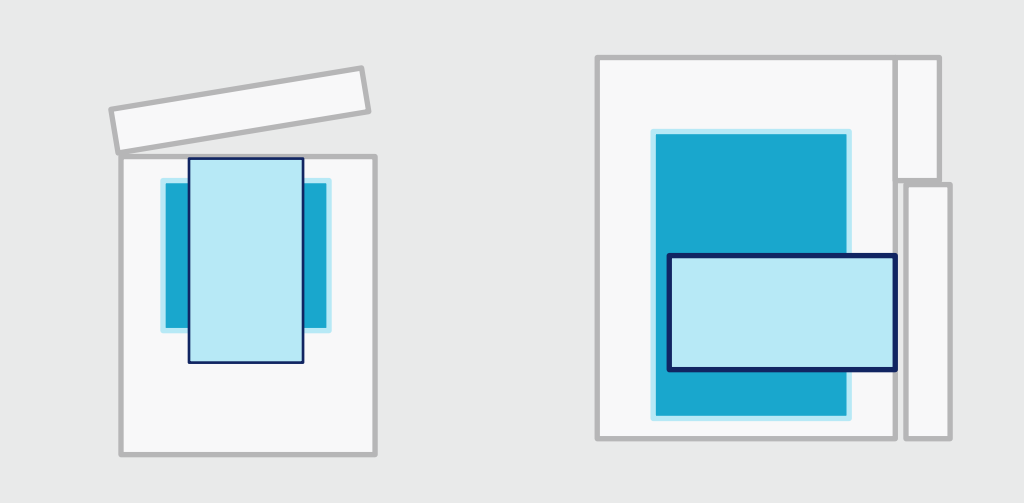


Figure 1 Basic design for chest model (top loaded) and upright model (front loaded). The dark blue volume illustrates the thermal storage and the light blue the vaccine compartment. Zero Appliances and Godrej are the upright models in this field test.

4. Field test programme

In the initial phase of the project, it was decided that the field test programme would be successful if the following objectives could be met.

Objectives for field test of SCA:

- 90% of the data is collected and interviews filled and collected.
- Data analysis has revealed which units has been running successfully through the project and why (or why not).
    - Document successful units:

- Vaccine chamber temperature basically within 2-8 °C). We might use the WHO alarm criteria to indicate out of temperature events: -0.5 °C or less for 1 hour and greater than +8 °C for 10 hours.
- Max 5% of units not functional by end of test (after 1 year)
- The health staff is satisfied with the unit compared to other vaccine cooling methods

For SolarChill B the aim is to get documentation of overall user satisfaction of the product and simple temperature documentation. Success criteria should be:

- 90% of the data is collected and interviews filled and collected.
- Documentation of user friendliness
- Useful and stable cooling capacity (compared to no cooling / unstable / expensive cooling). Product temperature should generally remain in the temperature interval from 1-9 °C.
- Demonstration of commercial benefits (cold drinks sale and/or social benefit e.g. school cafeteria)

Another success criteria is

- Data analysis has revealed which units has been running successfully through the project and why (or why not).
- The data analysis mentioned above can be compared to the user satisfaction.

It is difficult to compare the different SCB models in a field test because they will likely be used in different ways and under different operating conditions in general. The SCB study will therefore be more qualitative than the type A study. However, it would give a good picture of the overall satisfaction and refrigerator performance, which can be used for marketing and further product development. These "soft data" should encompass the questions:

- Does the volume of the tested models correspond to actual needs?
- Is there easy overview and access to the stored goods?
- Are the temperature fluctuations acceptable?
- Is the temperature pull down rate sufficient?
- Is the fridge used the same way every day, or are there peak load periods?
- For commercial use, what is the estimated increase of sales (like cold drinks) compared to the baseline?
- Are there any problems with condensation, mold growth or similar?

These considerations formed the basis for selection of equipment and methodology for the remote monitoring activities presented in the following chapters.

4.1. Methodology

Due to the very nature of off-grid solar power systems, the installations are often done in remote areas with difficult access and away from public electricity grid. At an early stage, the project partners did therefore decide to use GSM based monitoring equipment to ensure regular data transfer without travelling to the sites. This solution is relative expensive but should save substantial time because it is not necessary to download data directly from the data loggers.

The survey showed that there are many brands for temperature data logging, but it was difficult to find universal GSM data loggers at an affordable price. It was therefore decided to use relatively cheap temperature data loggers for most of the installations and supplement with geographically distributed universal data loggers that could include solar irradiance, energy consumption and other details for selected sites.

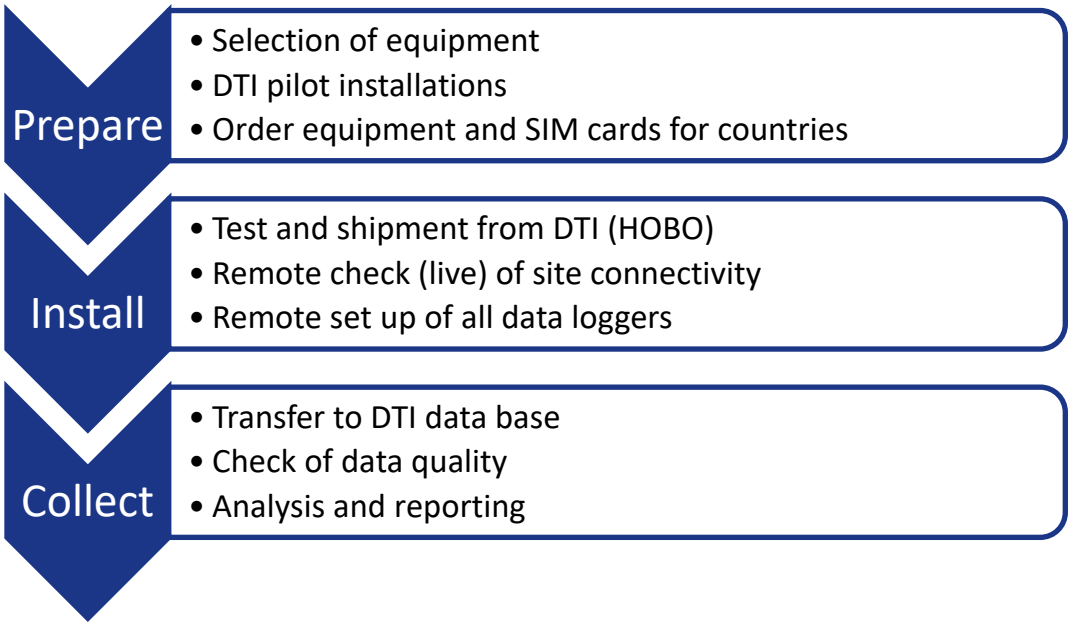
Each country was responsible for selection of suitable installation sites based on a questionnaire including security, access, GSM connectivity etc.

The installation sites are listed in Annex D

Because the project had limited resources for travelling, DTI was not expected to visit the recipient countries for training and installation of the monitoring systems. It was also not possible to install the systems from different factories so instead it was handed over to technical consultants in the countries to receive and install the systems with guidance from distance. Project partner HEAT was conducting the local training and supervision.

Before sending the equipment to the country managers DTI conducted an internal test of the data logger systems and made sure that the mounting of sensors and cabling could be done in practice. The GSM connection download and data transfer procedures were also tested. A set of instructions was subsequently sent and incorporated in the local technical training sessions.

The data should automatically be sent to DTI with regular intervals. The overall process is illustrated here:



The remote monitoring should also be used to identify faulty refrigerators and send this information to the suppliers so they can take action.

5. Selection of monitoring equipment

After a thorough market survey in 2017-18, the following brands were selected for the instrumentation:

1) Onset HOBO3000X for extended monitoring
2) Nexleaf Coldtrace5 for basic (temperature) monitoring
3) Tologg/B Medical for basic monitoring in B Medical brand appliances

All are GSM based data loggers for remote application. The instrumentation was selected so the results could be used for in depth analysis and not just typical temperature. The Nexleaf data logger can only measure 5 temperatures, however, but by distributing the sensors in the refrigerator volume and placing one sensor outside, it is possible to see the behaviour in detail.

The monitored parameters and number of sensors are:

Table 2 Sensors and data loggers

System	Internal Temp.	Ambient Temp.	Hu-midity	Solar Irr.	Open/close	Voltage	Current
HOBO	4	1	1	1	1	1	1
Nexleaf	4	1					
Tologg	1	1			1		

To save data transfer capacity a relatively coarse logging interval was selected for the two data logger types. The ToLogg data logger has a fixed logging rate of 2 minutes.

Table 3 Applied sampling and logging rates

System	Sampling rate	Logging rate	SIM card type
HOBO	30 s	10 min	Local
Nexleaf	10 min	10 min	Global, prepaid
ToLogg	1 s(door)	2 min	Global, prepaid

The HOBO and Nexleaf data loggers were first tested in Denmark/DTI on a temporary refrigerator installation. The power is supplied from a small PV panel on both devices. Usually, the Nexleaf data logger takes DC power directly from the refrigerator supply cable, but this option would involve intrusion in the electrical system, and thus void warranty of the refrigerators and compromised monitoring accuracy. Nexleaf therefore agreed to modify their power supply to PV accordingly. The HOBO logger has PV supply as a standard option.

The Tologg B-Medical logger is supplied by the same factory than the fridge they are mounted on, and supplied by, so here there was no warranty issue regarding power supply.

The high sampling rate of Tologg means that the time when the lid/door is open can be accurately determined. The HOBO logger can only register the number of opening events.

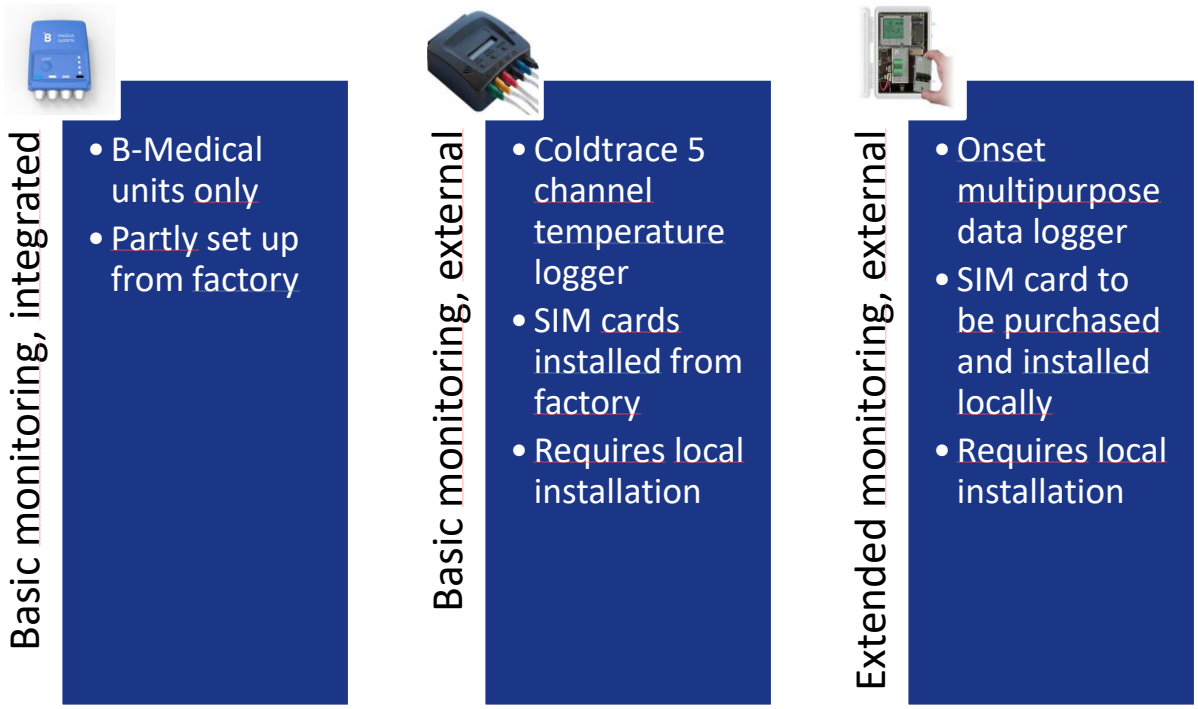


Figure 2 Main characteristics of the remote monitoring systems

5.1. Installation of remote monitoring devices

5.1.1. Onset HOBO data loggers

The HOBO dataloggers were all assembled and tested at DTI before shipment to the recipient countries. The country managers eventually installed the data loggers in the individual refrigerators based on instructions from HEAT and DTI.

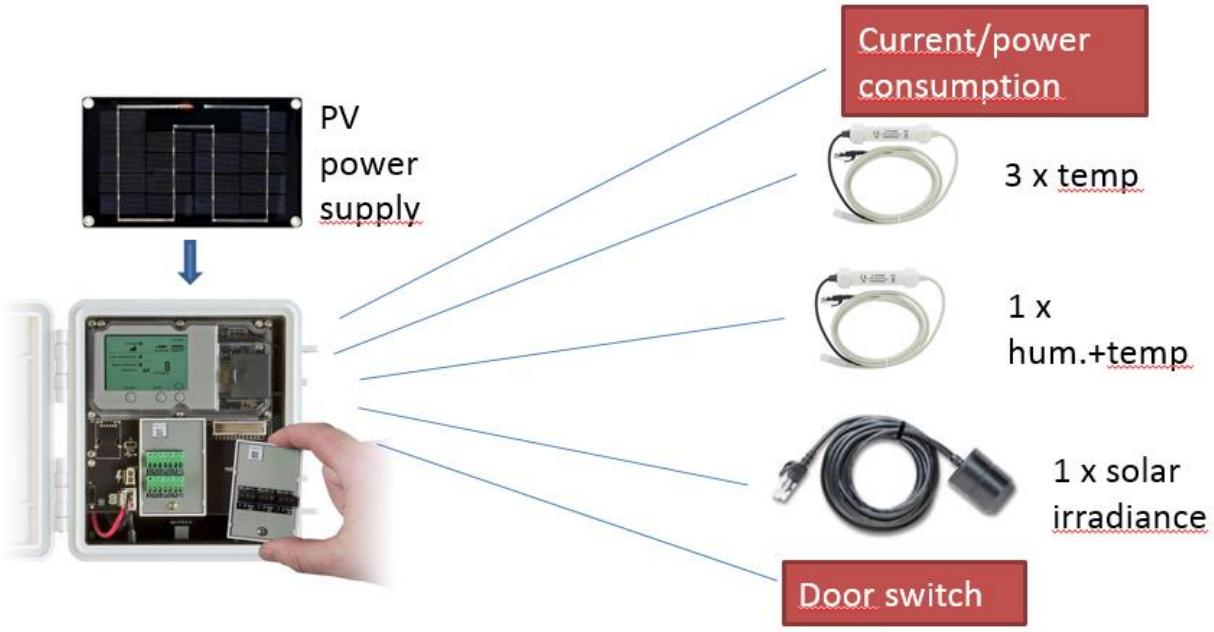


Figure 3 Measurement channels for extended monitoring. Power consumption is calculated from separate current and voltage monitoring.

A serious problem was the cabling through the door opening to the internal sensors. Some of the cables are relatively thick, so DTI removed the outer insulation to minimize the stress on the door gasket and prevent air infiltration. Unfortunately, this caused damage to the cable in some cases so it would have been better with wireless sensors that have recently become available at affordable cost.

Current and voltage measurement is implemented by means of a special cable section with a shunt resistor, voltage divider and MC4 connectors in both ends, so that it can fit to most of the marketed SDD appliances without cutting the power cable.

Figure 4 Plug-in cable section for measurement of current and voltage, so that the power consumption can be calculated.

Figure 5 It was also considered to use this type of DC in-line energy meter but unfortunately it was not compatible with the HOBO data loggers.

Figure 6 Door contact / opening event counter

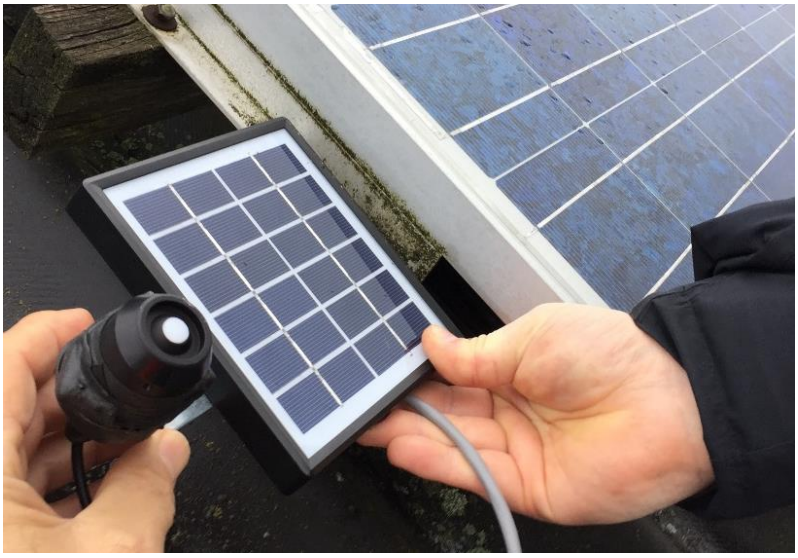


Figure 7 PV 6 V power supply and irradiance sensor. The data logger battery is a 4 V lead acid type.

5.1.2. Nexleaf/Coldtrace 5 data loggers

Main part of the systems are using this type of data logger, specially made for cold chain equipment monitoring. It is intended for multiple refrigerators, so there are 5 temperature channels. In the current project, the sensors are placed like this:

A: Ambient (room) temperature

B: Top of storage compartment

C: Middle of storage compartment

D: Bottom of storage compartment

E: Icepack compartment or evaporator surface (Supposed coldest surface)

Nexleaf use very thin cables that can easily pass the door opening, a main reason for choosing this supplier. However, they seem a bit fragile.

Figure 8 Nexleaf Coldtrace 5 data logger (5 temperature sensors with ultra-flat cable)

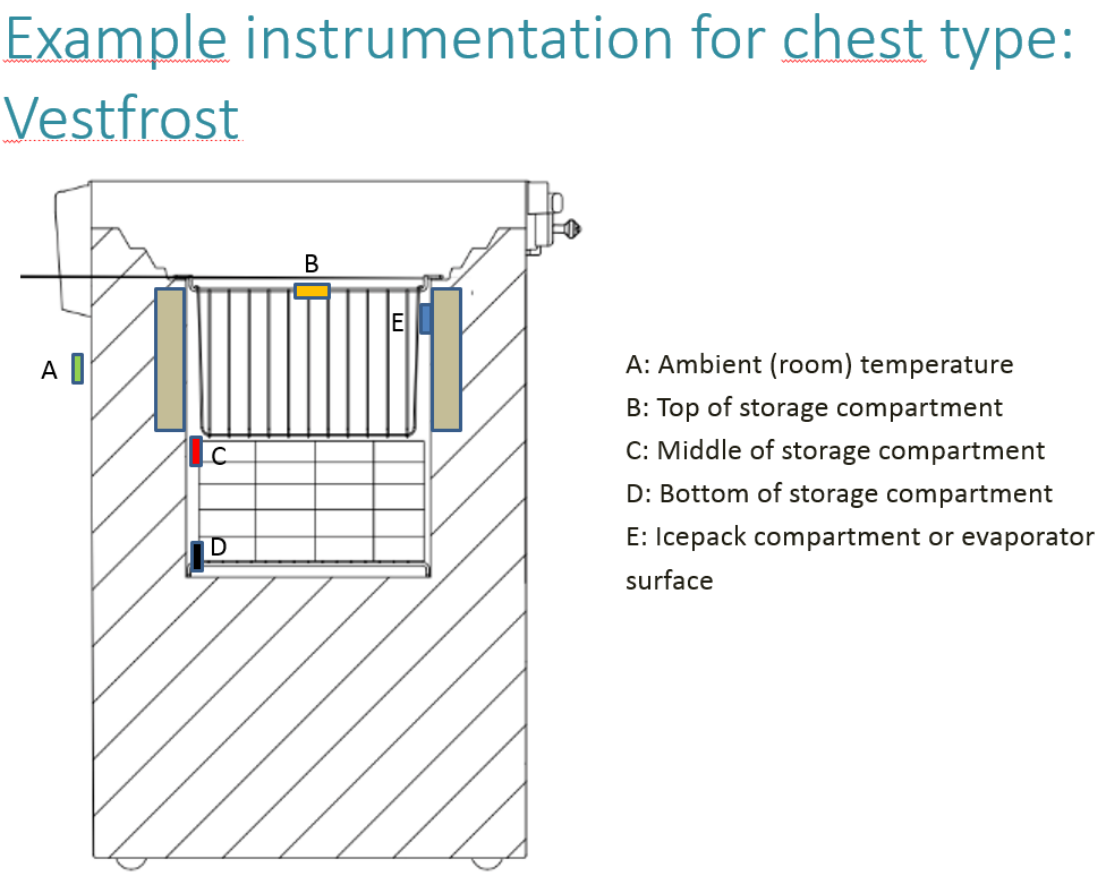


Figure 9 Template for instrumentation with Nexleaf equipment. Sensors are placed so they do not hinder normal use of the refrigerators.

5.1.3. Tologg/B-Medical data logger

This data logger comes with the B Medical devices and is prepared for easy installation on the cabinet. The logger measures door opening (also duration), internal and external temperature.

There is a prepaid international SIM card with 10 years lifetime installed from factory. It is powered by the PV panels running the refrigerator.

Figure 1. Package contents

Complete package contains:

1. Logger TOLOGG-2.3
2. Door sensor
3. Power cable, two possible variants of termination
4. Mounting holder
5. External temperature sensor
6. Internal temperature sensor
7. Dust covers

Figure 10 Integrated B Medical data logger

6. Monitoring sites

The project has purchased a total number of 100 separate dataloggers and 18 integrated loggers in case of B-Medical refrigerators. The data loggers have been sent to the countries mentioned below, but in the end only half of the installations have been able to send valid and regular data most of 2019. Logistic issues, poor connectivity or technical faults are main reasons for this as explained later.

For a complete list of refrigerator installations, see Annex D. The number of RMS in each country and from which data have been received are:

6.1. Colombia

- ☐ 7 Hobo data loggers
- ☐ 2 Nexleaf
- ☐ 12 B-Medical

- ☐ The installed refrigerator types are B-Medical, Vestfrost and Godrej

6.2. Kenya

- ☐ 9 Hobo data loggers
- ☐ 12 Nexleaf
- ☐ The installed refrigerator types are Vestfrost and Zero Appliance

6.3. Swaziland

- ☐ 10 Hobo data loggers
- ☐ 6 Nexleaf
- ☐ 4 B-Medical
- ☐ The installed refrigerator types are B-Medical, Vestfrost, Zero Appliance and Haier

6.4. Other

One Nexleaf data logger was installed on a VLS024 in a clinic in Cameroon as outreach activity, unfortunately the connection was lost. A reference HOBO data logger is installed at DTI with temperature measurement on a VLS024 and a Leff Opteco (SolarChill B).

7. Data transfer and analysis

Data is automatically transferred (when there is connectivity) to the following web portals, run by the respective manufacturers:

www.hobolink.com

www.coldtrace.org

www.vaclog.net

In case of weak or missing signal, the data loggers can store data for substantial time and resume transmission later. At some of the sites, staff must take the data logger to a location with adequate GPS signal in order to upload the data.

HOBO loggers are set up for automatic file transfer to the FTP server at DTI, whereas the other are downloaded manually or via automatic e-mail.

7.1. Field monitoring issues

Field monitoring is notoriously known to be much more prone to errors and problems than laboratory measurements. This project is no exemption. A non-exhaustive list of experienced challenges and problems is given here:

Logistics and communication

The project experienced a whole range of issues when installing the equipment.

- Logistic problems getting the correct loggers to the assigned refrigerators, especially if something had to be changed in last minute. In some cases a device with a wrong serial number was installed in a specific refrigerator and therefore caused some confusion when data did not look as expected in the other end.
- Cumbersome set-up procedure in the field, especially in zones with poor connectivity (mainly using Whatsapp to confirm connection). It takes time to learn how to install and time is limited.
- At many sites the connectivity was so poor that monitoring had to be given up even though a field survey was initially made to ensure that the signal strength was acceptable.
- Working in different time zones causes delay in communication with field staff and in Colombia there are few overlapping work hours with Europe.
- Time delay from installation until the device becomes visible on dashboard (problem for the field staff that could not go on to next site before confirmation was sent from DTI that the device was on line)
- SIM card subscription only possible for short time periods, manual renewal necessary (Colombia). This was a source of much frustration because the local manager had to pay upfront frequently and forward invoices to DTI. In other countries it was no problem to buy a long term prepaid SIM card for data traffic.
- Too expensive to send experts in the field to correct errors, especially in Colombia some locations would take days to reach if possible, at all. One has to accept a high failure rate if there is no way to correct even small technical problems. In many cases the medical staff was unable or unwilling to help because they were afraid to destroy something,
- Impossible or difficult to get in touch. This is mainly the case for remote locations with poor mobile network and if the staff is often out doing services in the field.

Sensor problems

Each type of data logger uses a specific set of sensors, and some of the installation issues are mentioned here.

- Current/voltage sensor plugs not fitting all appliances (had to be tailormade, sometimes wrong polarity) DTI had to ask B-Medical prepare a few refrigerators with plugs matching the sensors.
- Missing color-coding on temperature sensors (Nexleaf). Because the training was based on colour coded cables it caused confusion when a lot of same sensors were delivered with black plugs, so they were indistinguishable.

- Temperature sensors mounted in wrong order. Sometimes the designation for positions A-B-C-D-E and actual mounting was not followed, which made subsequent data analysis very difficult.
- Sensor cables too thick to enter under the refrigerator lid. Some insulation had to be manually removed on the humidity sensor and this resulted in a few damaged cables.
- Data loggers too energy consuming when the signal is weak (Coldtrace). The battery gets exhausted and data are lost. The interrupts could clearly be seen on the remote monitoring system.
- Software errors on data dashboard making download impossible (Vaclog) There have bees some temporary problems during updates and corrections.
- Failure on sensors or sensor groups (HOBO) In a few cases some of the sensors stopped working for unknown reason. Fortunately, there are more internal temperature sensors, so a single failure is not catastrophic.
- Erratic temperature signal on individual sensors (Nexleaf).

Other

- Problems getting legal access to the data (MoH in eSwatini was set up as data owner causing a GDPR issue)
- Theft of the small PV module powering the data loggers
- Manufacturers use different data formats, making data analysis difficult and time consuming

All these problems have resulted in the sad fact that a large part of the monitoring devices or sensors have not been sending the amount of data the project was aiming for. However, due to the initially high number of sites and extended period, there is yet a solid data base for analysis across different brands and climates.

The data are stored at DTI's server but also on the respective monitoring cloud storages for a limited period.

7.2. Evaluation of data loggers

By deploying and using the different monitoring systems over several years the project has gained some experience to be shared here:

HOBO(Onset Corporation). A very robust and versatile type designed for outdoor mounting, but also very expensive. The main advantage is that almost any type of sensor (from Onset) can be applied and that the power consumption is very low. A large battery ensures that it can work for long periods without power. It is a disadvantage that the sensor cables are very thick, so they are difficult to pass through the door sealing. It is also

a drawback that the display does not show actual sensor values so error tracing in the field is difficult if the device is offline.

Coldtrace 5 (Nexleaf): The least expensive, but lower quality. Several units and sensors had technical issues, maybe because the CT5 was newly developed and the project was a sort of test deployment. Coldtrace 5 is made for indoor use, not so robust and has a high energy consumption, especially at sites with low GSM signal (Possibly because it is designed for grid connection and not solar PV) so in many cases the data transfer was interrupted due to low battery state of charge. Only temperature measurements are possible. Main advantage is the extremely thin flat cables, which can easily pass under the door sealing. It is also useful that the display shows the actual temperature values.

Vaclog(Bmed): Only for measurement of temperature (ambient and internal) and door openings. These data loggers worked very stable after set-up, but there were some problems in eSwatini with the network connections, which took a while to solve for the supplier. In Colombia the signal was too weak in a few cases. Because they are integrated from factory there are co cable issues.

8. Monitoring of SolarChill A systems

The data have been analysed per refrigerator model and is presented in anonymized form as letter A-E. As the data sets from the different monitoring systems are not directly comparable, only the centre temperature (common for all platforms) has been evaluated in the temperature statistic across all models and countries.

The data have been collected via the three different software platforms and aggregated with a specially develop tool (Python script) that was originally made by a student at the University of Dresden and later modified by DTI. The tool can sort and analyse the huge amount of data in a more effective way than e.g. Excel can do it.

All devices have not been monitored during same the time period but most of the active monitoring stations have been sending data for at least one year. In some cases, there have been interruptions due to technical issues or insufficient signal strength.

The raw data are available for download from the data logger dashboards found in Annex A.

8.1. Temperature statistics

The most important data analysis consisted in getting a statistical overview of the temperature performance over time for the different brands. The result is shown in the following table where the performance score is depicted monthly. A 100 % score means that all the internal (centre) temperatures have been within the 2-8 °C range in actual month. A lower score means that the temperature has been higher or lower some of the time.

Table 4 Overview of performance for systems with RMS

Gennemsnit af OK	Kolonnemærkater																				
	<01-09-2018	2019											2020								Hovedtotal
Rækkemærkater	okt	nov	jan	feb	mar	apr	maj	jun	jul	aug	okt	nov	jan	feb	mar	maj	jun	jul	aug		
352052080218386						75,5	79,8	62,9	51	54,5	60,4	67,3	68,6	72,8	38,4		80,4	61	36,7		63
352052080218501			100	100	100	100	100	100	100	100	100	100	100	100	100		100	16,9	0,2		90
352052089907518							0	0	0	0	0	0	0	0	0		85,7	100	100		19
356849081517666							71,3	66,4	68,4	68	70,7	59	77	85,4	78,7		64,9	70,2	73,7		71
356849081517914							74,4	72,6	72,7	71,7	75,3	74,8	61,2	50,6	37,4		49,8	49,4	51,5		63
356849081538993			85,1	10,8	60,6	25,7	0	0	0	0	0	64,9	100	100	0		100	100	100		50
356849081540726			63,9	15	62,9	48,7	57,4	87,3	77,6	70,6	74,8	59,3	68	68,9	59,5		73,7	55,3			63
356849081662967			72,8	85,7	87,8	84,1	73,7	70,9	69,5	71,9	84,5	82,6	0	61,2	56,4		39,8	45	49,7		66
356849081664344					98,1	90,9	78,1	63,4	71,1	77	88,8	92,4	98,9	96,8							85
356849081666323			99,8	100	99,4	99,9	100	93,8	99,9	99,8	100	100	99,8	100	100		100	100	100		100
356849081979148			100	100	100	99,8	100	100	100	100	100	100	99,9	100	99,7		99,9	80,1	6,1		94
356849081989006			92,6	83,9	89,3	91,5	81,9	67,5	65,8	68,9	89	91,7	91,9	90	91		62,9	65,2	63,6		80
356849081990160							86,1	71,9	72,8	91,5	98,2	99,1	99,4	99,2	99,3						92
356849081993073			100	100	100	100	100	100	100	100	87,5	0	0	0	0		7,3	10,3	2,9		53
356849082008616			92,7	100	80,7	94,9	96,8	97,9	97,3	99,5	98,8	99,6	98,8	99,1	98,1		95	79,9	17,1		92
356849082009333			100	100	100	100	100	100	100	100	100	100	99,9	100	100		93,5	2,4	5		90
356849082011610			100	100	100	100	100	100	100	100	100	100		100	100		0,4	81,1	38,3		90
356849082011719			100	100	99,9	100	99,9	99,9	99,7	100	100	100	100	99,7	99,9		100	0,8	0		87
356849082016247									94,6	94,6	94,4	91,4	92	86,9	93,4						90
356849082029752							68	69,6	72,8	83,4	81,1		99,3	92,6	91,5		25,8	30,7	17,8		64
356849082030313								94,4	97,5												96
356849082055120			100	100	99,9	99,8	99,9	99,9	100	100	99,9	100	100	99,7	100		84,6	95	100		99
358072045349799			98,3	100	99,9	98,7	98,9	98,6	99,7	99,7		99,9	99,9	99,4	99,8		99,6	99,8	100		100
358072045354740			67,6	80,7	90,8	96,4	99,9														87
COL 1149			100	100	100	100	100	100	100	100	100	100									100
COL 1314			90	66	81	86	89	95	95	94	88	95									89
COL 1719			99	98	100	100	100	100	99	100	96	98									98
COL 2030			100	100	100	100	100	100	100	100	90	93									97
COL 2339			100																		100
COL 2891			100	100	100	100	100	100	100	99	97	98									96
COL 7352			100	100	99	98	100	99	99	100	99	95									98
COL 9051			94	97	94	99	95	85	81	100	90	91									92
COL 9267			63	72	56	57	40	67	79	85	88	79									72
COL 9516			100	99	100	100	100	100	100	100	87	95									98
COL 9862			100	100	100	100	100	100	100	100	97	97									99
COL1	100	100	100	100	100	100	100	100	100	100	100	100									100
COL2			92,5	93,5	92,9	94,3	94,5	94,4	94,9	96,9	96,2	95,3	89,1	85,9	83,8	82,3	90,9	88,7	90		92
COL3					99	100	99	100	100		99	100	97	98	99	99	97	100	100		99
COL4			100		100	100	100	100	100	100		100									100
COL5			0	0	0	0	0	6,7	86,2	93,4	99,8	0	99,2	96,9	99,5	99,5	99	99,8	99,3		61
COL6			99	99,6	100	71,1	100	100	100	100	0	0									68
COL7						81,3	92,9	90,8													88
KEN1		80,7	52,5	44,9	70,7	82,3	52,8	43,7	37,4	47	27,5	37	41,4	43,5	42,2	99	99,5	99,5	98,6		61
KEN2		92,9	96,1	89	83,7	71,9	0	0	2,5	33,8	19,2	2,3	0	0	0	3,7	0	0	0		27
KEN3			99,9	100	100	99,9	99,1	98,7	99,5	99,5	98,8	95,3	100	99,2	99,4	97,6	99,3	99,8	99,6		99
KEN4		85,3	91,8	80	95,2		96	93,8	88,8	82,3	96,4	97,8	99,6	95,7	99,6	99,7	98,5	98	99,2		95
KEN5		99,9	98,1	98,4	81,7	67,8	72,6	79	77	78,6	74,2	70	58,2	49,5	14,9	21,8	36,8	43	20,6		62
KEN6		83,4	92,8	92,9	98,9	98,8	76,3	40,7	45,4	52,4	48,1	51,4	38,4	43,5	39,7	30,8	31,6	34,1	32,8		56
KEN7		45,7	56,3	65,3			66,4	65	64,5	66,3											60
KEN8		100	99,7	99	86,9	85,5	29	0	0	0	0	0									43
KEN9		89,2	100	100	100	100	99,6	99,4	99,3	100	99,3	97,6	100	99	23,2	0	0	0,8	0		70
SWA 0844				100	99	100	100	100	100	100	100	100									100
SWA 1438				100	100	100	100	100	100	100	100	100									100
SWA 5863				100	100	100	100	100	100	100	100	100									100
SWA 8137				100	100	100	100	100	100	100	100	100									100
SWA1										100	100	100	100	99,9	100	100	100	100	100		100
SWA10			98,6	100	100	100						100	100	100	99,9	100	100	100	100		100
SWA2		99,8								99,7	99,5	99,1	40	19,7	50,3	71,1	79,2	87,2	96,5		80
SWA3		100					70	42	61,6	83,9	97,1	99,9	100	100	100	71	53,8	27,9	52,9		81
SWA4		100	100	100	100	100	100	93	100	100	100	100	87,6	88,6	67,4	3,8	0	0	0		75
SWA5		99,5	96,1	98,2	98,2	99,7	99,8	99,5	98,4	99,9	99,4	99,6	99,6	99,6	99,8	100	100	99,9	100		99
SWA6			99,8	99,6	99,9	100	100	100	99,8	99,7	56,1	21,2	0	0	0	0	0	0	0		46
SWA7		100	100	100	100	100	100	100	100	100	99,9	99,9	99,8	99,9	99,9	100	100	100	100		100
SWA8		100	95,1	93,6	88,3	90,6	84,1	77,9	76,3	86,1	86,2	85	80,7	77,8	81,2	72,3	73,1	72,8	68,8		82
SWA9			90,7	97,5	90,6	66,9	68	65,5	63,6	64,7	80	74,2									76
(tom)																					
Hovedtotal	**100**	**92**	**91**	**89**	**92**	**90**	**83**	**81**	**82**	**85**	**83**	**80**	**77**	**78**	**71**	**68**	**69**	**63**	**57**		**80**

Abbreviations used for specific monitoring sites: Kenya=KENxx, Colombia = COLxx, eSwatini=SWAxx

8.1.1. Temperature stability

A simple data point counting of centre temperature readings was carried out for all types of data loggers on all devices:

Table 5 Distribution on measured centre temperature of all data points for each type.

	Type A	Type B	Type C	Type D	Type E
< 0°C	1,2%	0,0%	0,0%	0,0%	0,0%
< 2°C	16,1%	0,5%	8,7%	0,1%	3,8%
OK	82,5%	91,0%	88,6%	84,0%	95,9%
> 8°C	2,4%	8,5%	2,7%	15,9%	0,3%
> 10°C	1,2%	2,4%	0,1%	2,8%	0,2%

In the graphs, only data from the year 2019 are used for comparison reasons.

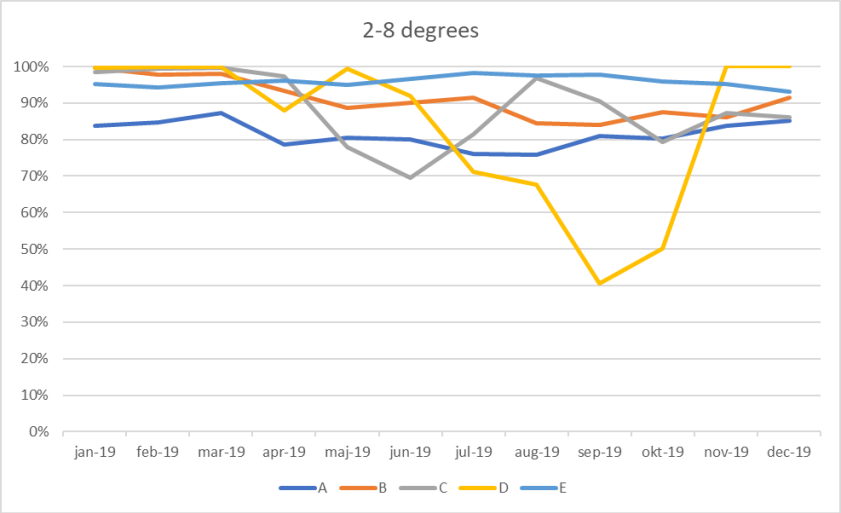
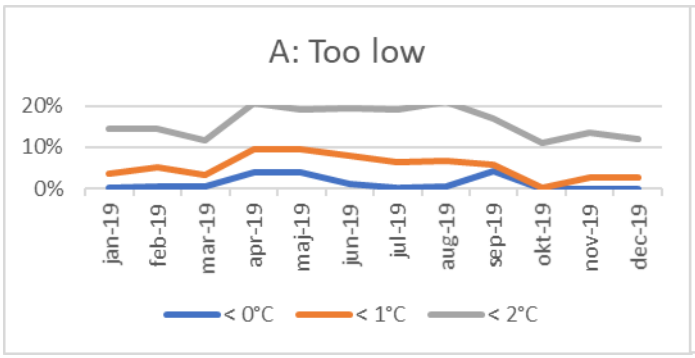
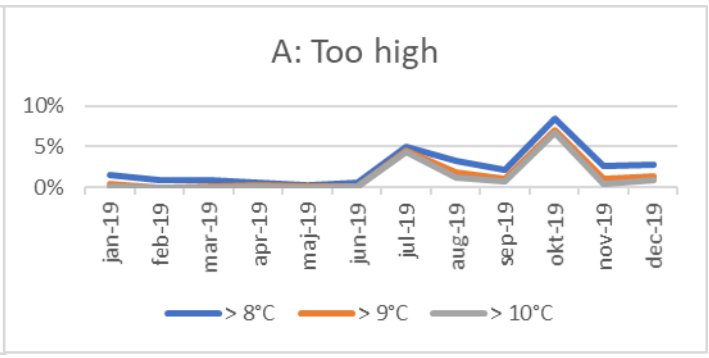
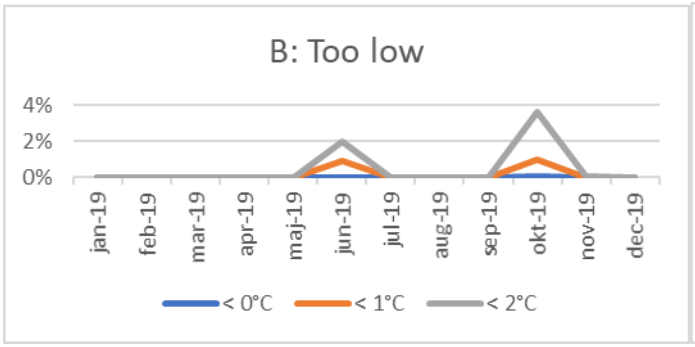


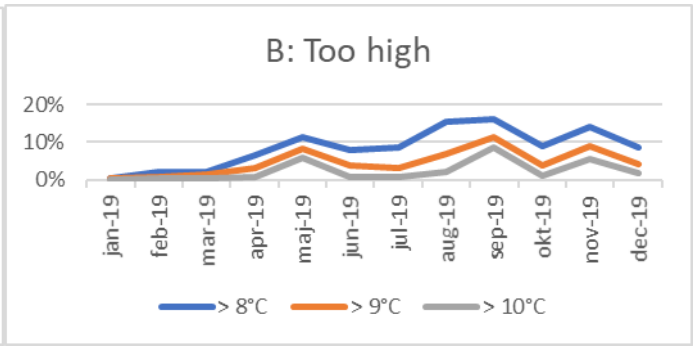
Figure 11 Monthly evolution of centre temperature for all units with remote monitoring

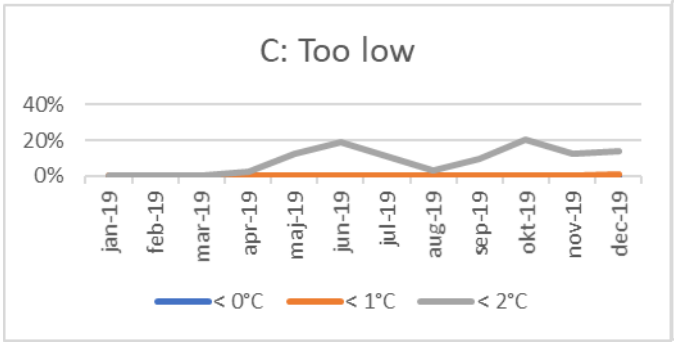
Monthly deviation from the range 2-8 C:

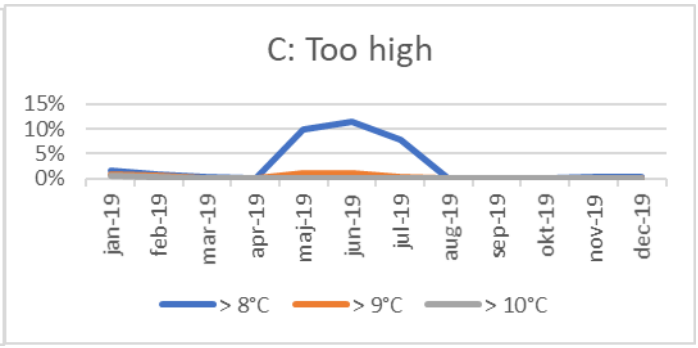


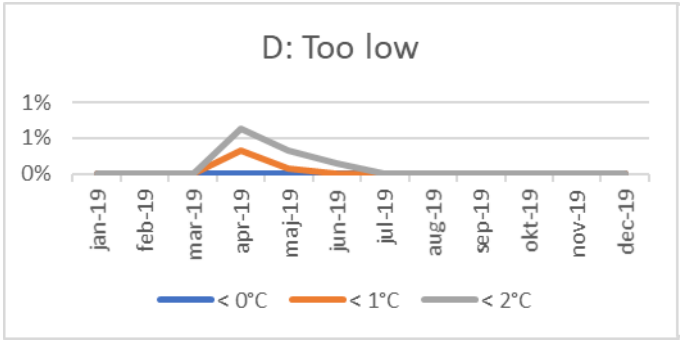


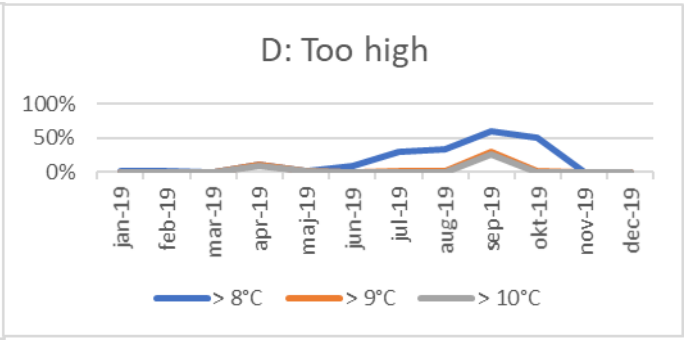












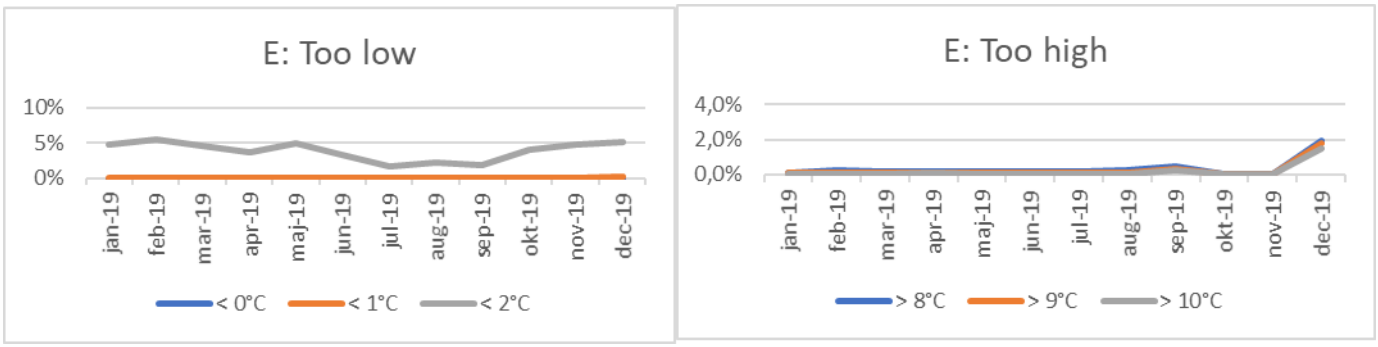


Figure 12 Monthly deviation of centre temperature per refrigerator type.

In general, more than 90% of data points are within the 2-8 degrees range, except for one type that is less stable. The low temperatures should be further investigated and may be caused by imprecise thermostat setting or items disturbing the thermostat sensor. Duration of local freezing is less than one hour and is not likely to cause freezing of vaccine stored in a basket at some distance from the wall. If the vaccine touches the wall for some reason the freezing risk is real, so this must be avoided. The high temperatures are likely associated with door openings, cleaning and intentional or non-intentional power cuts over extended time. Sensor errors or misplaced sensors cannot be ruled out though obviously false records have been discarded.

PQS Lab test Acceptance criteria: To receive a **Grade A** for freeze-protection classification, the appliance's cool-down temperatures:

- Must not drop below 0°C for longer than 1 hour.
- Must not reach -0.5°C for any amount of time.
- Following any excursion below 0°C, within 2 hours the appliance must return to the acceptable temperature range (i.e., consistently between +2°C and +8°C).

Textbox: Freezing protection criteria from WHO PQS specifications

Please notice that the sensors are mounted near the cabinet wall for practical reasons, so they do not disturb normal use of the fridge. Therefore, the measured temperature is slightly colder than the actual vaccine temperature. It must also be noted that sensor accuracy is 0.2-0.5 K depending on type. Small negative temperature measurements are therefore no absolute proof of freezing.

For the sake of comparison, the internal temperature [°C] and current [A] is illustrated for a sample of each type for one week with regular solar irradiance. Different usage patterns resulting in non-comparable door-openings may to a degree influence and blur the picture.

Type A:

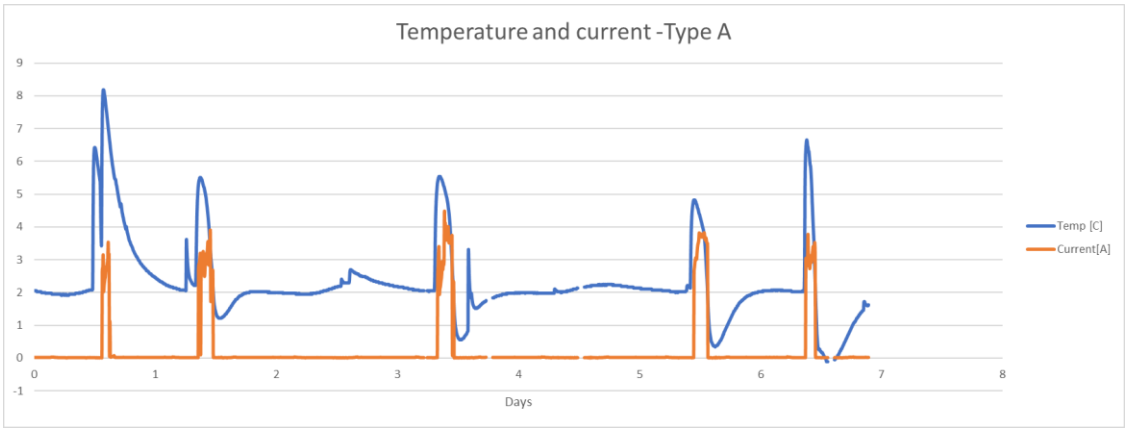


Figure 13 Compressor running 5 of 7 solar days. Temperature spikes are followed by a short dip due to thermal delay after thermostat cut-off.

Type B:

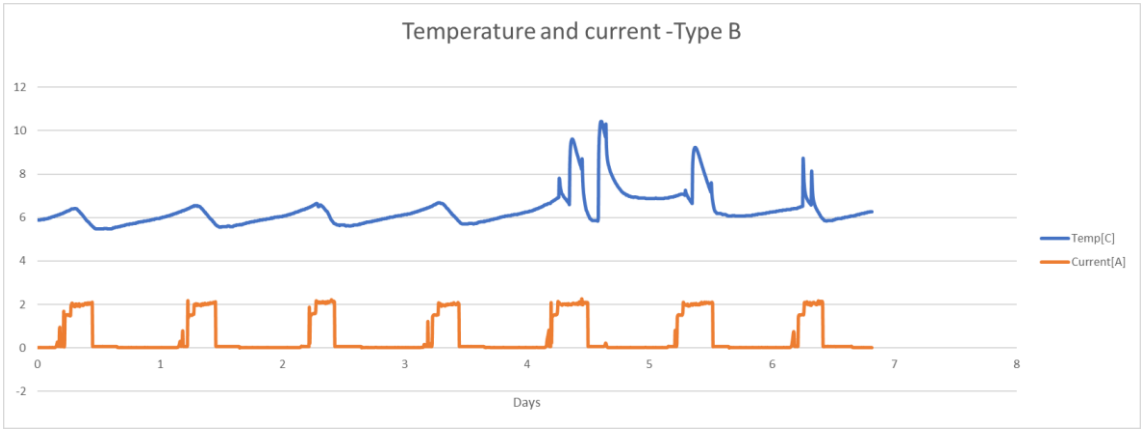


Figure 14 This appliance use almost constant power all days

Type C:

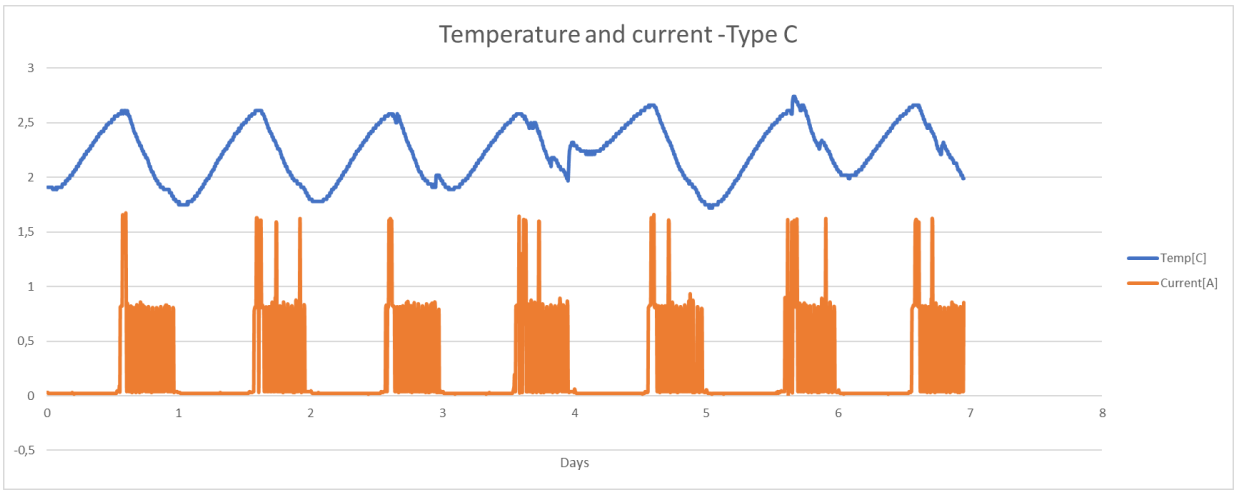


Figure 15 Appliance running many daily on/off cycles. Very stable temperature.

Type D:

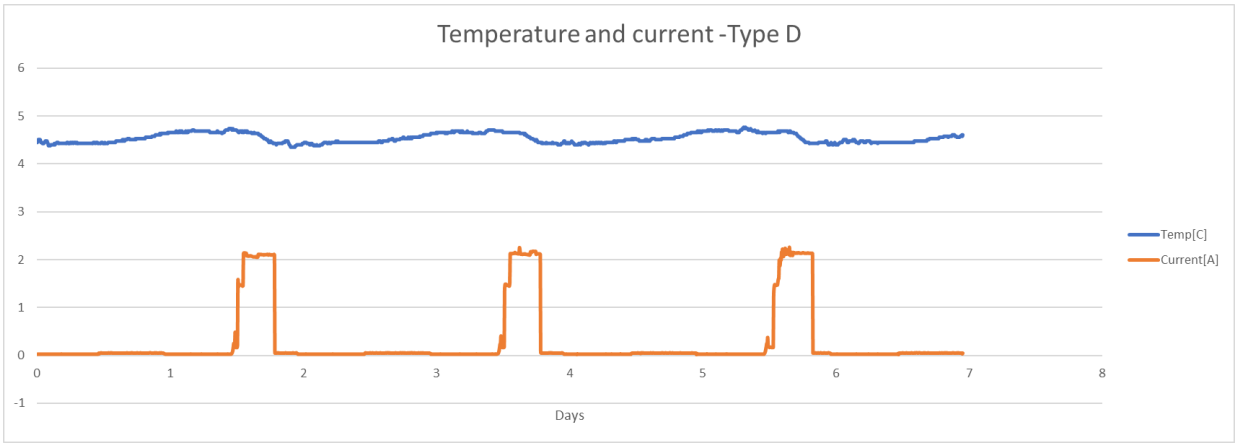


Figure 16 Appliance use power 3 of 7 days. Very stable temperature.

Type E:

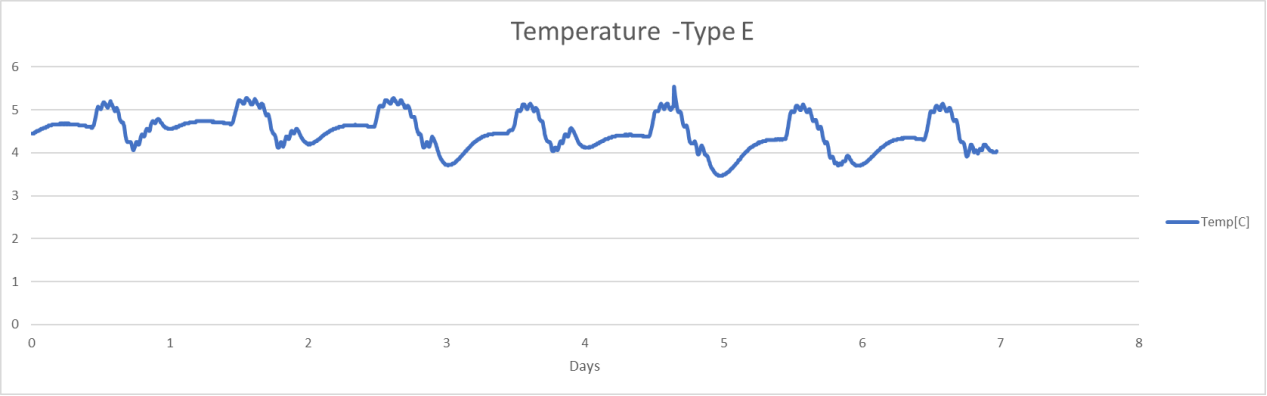


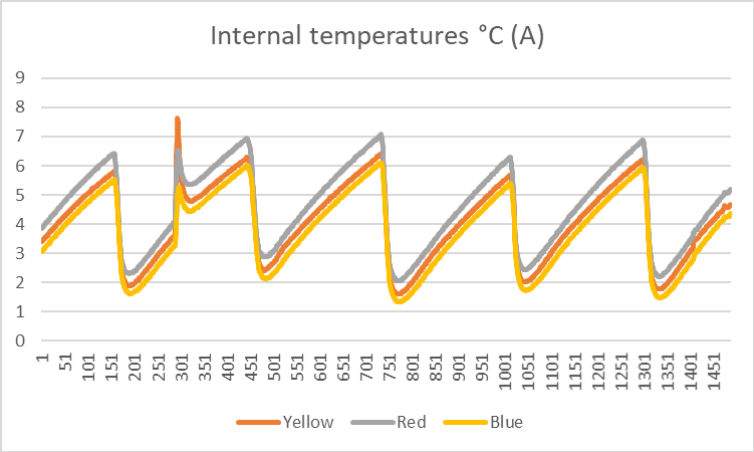
Figure 17 Small temperature fluctuations indicate fine adjustment. Current values not available.

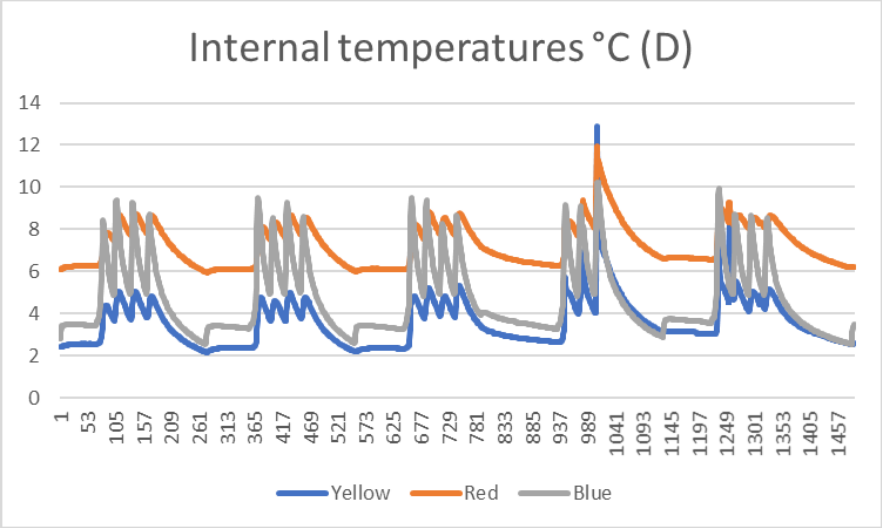
From the profiles above it can be concluded that each brand has its own characteristic design and control strategy, which has a huge influence on power use and temperature stability. Some are running within a very narrow temperature band and with regular daily runtime, while other are operating in a more fluctuating manner.

After installation the refrigerators are generally running as intended and with sufficient PV power available during the entire measurement period. However, a few appliances have failed and some dataloggers lost connection to GSM network.

8.1.2. Temperature distribution

Examples/stratification





8.1.3. Time series for selected stations

The project has collected data for more than a full year of operation from about 55 sites plus additional data for some locations. This means that weather fluctuations have had an impact on the performance of the refrigerators, especially the most critical periods with low irradiance and high ambient temperatures. The time plots show the annual variation of these parameters. Unfortunately, solar data is missing from some stations due to technical problems with the sensors.

The solar irradiance variation for three representative stations in the three countries are shown in the graphs below:

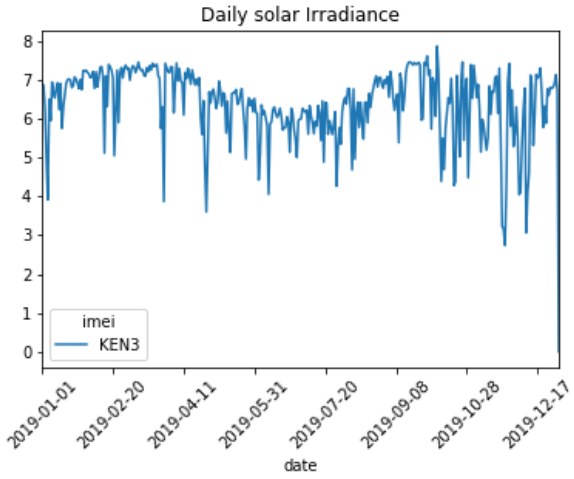


Figure 18 (KEN3) Annual variation of solar irradiance in kWh/m2 day. The data indicates clear sky most of the time and values well above the 3.5 kWh/m2 per day used by WHO PQS test.

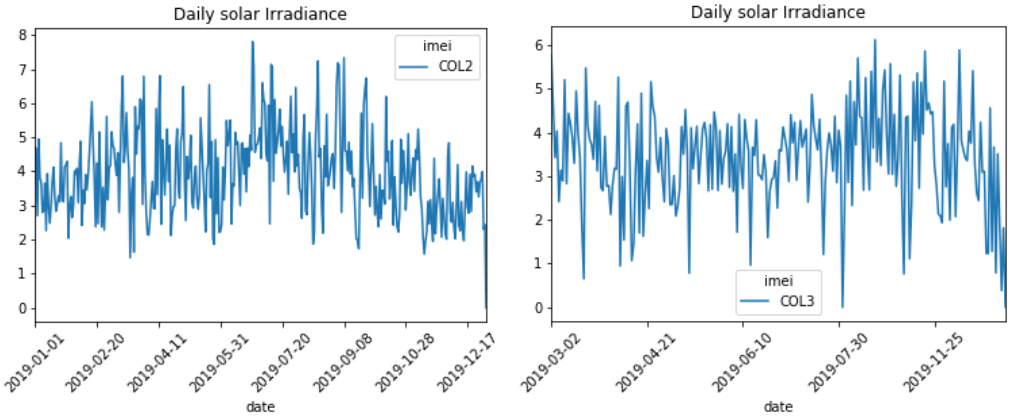


Figure 19 Daily solar energy in kWh/m2 day from COL2 and COL3 exhibits moderate to low values close to WHO PQS design value.

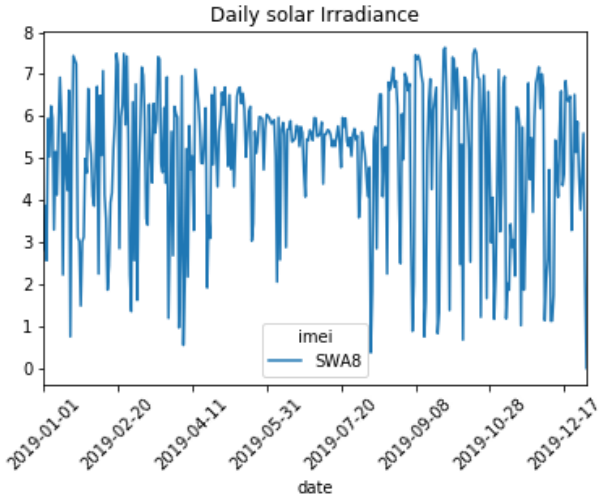


Figure 20 Daily solar energy in kWh/m2 day from SWA8 exhibits a very broad range indicating frequent cloud cover.

An analysis of the internal storage temperature as a function of ambient temperature shows different scatter formations depending on type of fridge and user behaviour. One typical example is shown here:

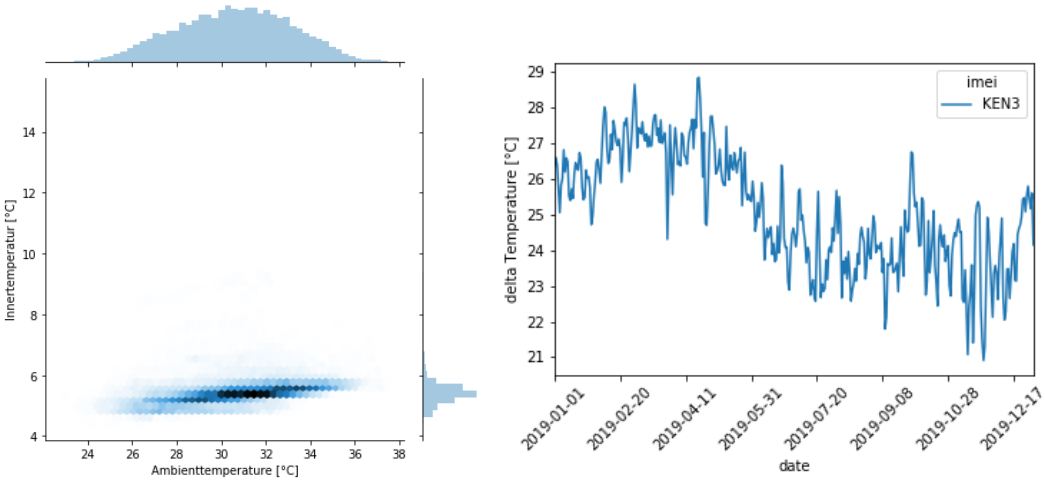


Figure 21 (KEN3)Scatter plot showing distribution of data points. There is a certain positive correlation between ambient temperature and storage temperature. The temperature difference (Tamb-Tint) is shown to the right.

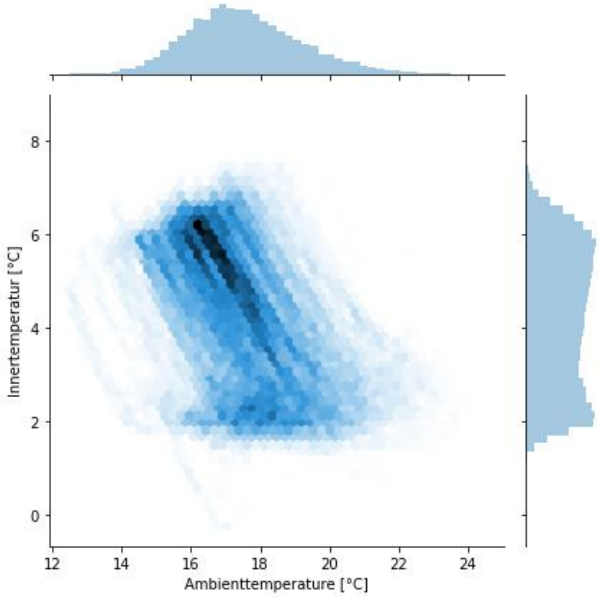


Figure 22 Scatter diagram (COL2) for a site with relatively low ambient temperature. There is no clear correlation between inner and outer temperature.

All the tested refrigerators are approved for maximum 43°C ambient temperature. However, the actual temperature of the sites is mostly in the range 20-35°C. The field test should therefore not be considered as a maximum stress test regarding the ability to maintain sufficiently low temperature under all conditions.

8.2. Power consumption

A main purpose of the project is to measure the energy consumption during normal use in the field.

The power is found from voltage and current measurements on the HOBO data loggers. Due to installations problems many of these measurements are not valid and were discarded before analysis. Unfortunately, this means that some refrigerator models are only represented by only few or with no power consumption data.

Important parameters, which are expected to influence power consumption are insulation standard, ambient temperature, compressor type, door openings etc. The dependency on some of these parameters are shown in this section.

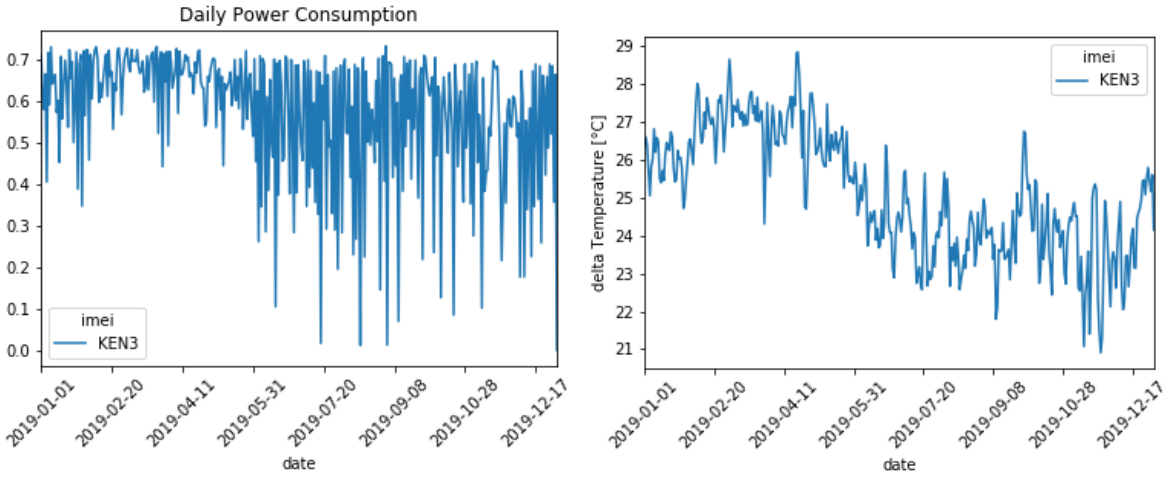


Figure 23 (KEN3) Daily power consumption in kWh/day shows highest value at high temperature differences (February-April) as expected.

The primary parameters that influence energy consumption and inside temperature is ambient temperature and daily number of door openings.

The following graphs for brand(type) A and B show that there is no strong systematic relation between daily number of door openings and daily energy consumption. The most likely reason is that a door opening can imply different actions:

- Checking stock of vaccine
- Taking out cold vaccine
- Inserting cold packs. Cold packs might be warm when introduced into the compartment, resulting in dramatic temperature changes
- Cleaning of cabinet

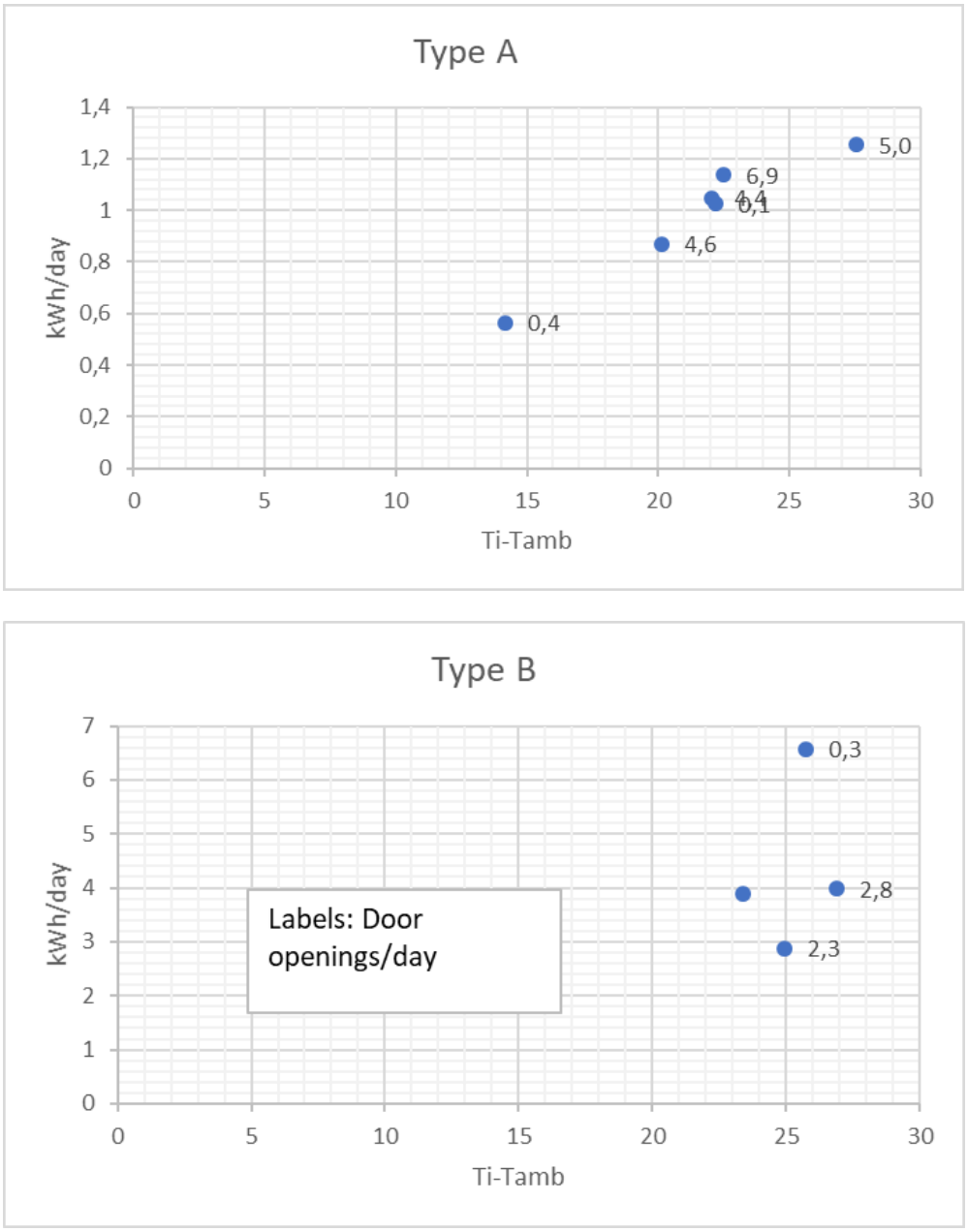


Figure 24 Daily energy consumption as a function of temperature difference ($T_{interior}$-$T_{ambient}$). Only February data are shown for brand(type) A+B. The data labels indicate daily door openings.

For units from brand A there is a clear increase in energy use when ambient temperature increases, no matter how many door openings that are registered. The independence of openings is most likely a consequence of the chest design, where inside cold air is retained in the cabinet when the lid is opened.

For brand B units there is a higher consumption in general. All units are installed at almost same ambient temperature, so the very large differences in energy consumption can only be explained by air exchange when the door is opened and/or by differences in load pattern. In general, cold air will fall out when the door is opened on upright cabinets, which increases energy consumption.

It is surprising to see such a dramatic difference in daily energy consumption, both from brand to brand and for individual installations. However, high or low consumption is not an indicator of quality per se, while vaccine storage temperature certainly is. A stable temperature is best achieved with a design that is robust to climatic conditions and user behaviour.

The energy consumption of each model is determined by several design details:

- Surface area
- Chest or upright type
- Type and thickness of insulation (vacuum panels)
- Optional freezing of icepacks
- One or two compressors
- Electric heater for counteracting freeze risk

The following graph with data from a single unit in Kenya shows how much power is used relatively to the available PV power. The available PV power is calculated from irradiance data and nameplate data for the PV panels. There is a clear maximum limit where no more power can be used, and the compressor is running at full speed. There is also a minimum limit of operation at approximately 50 W. The used fraction is the actual consumption divided by available power.

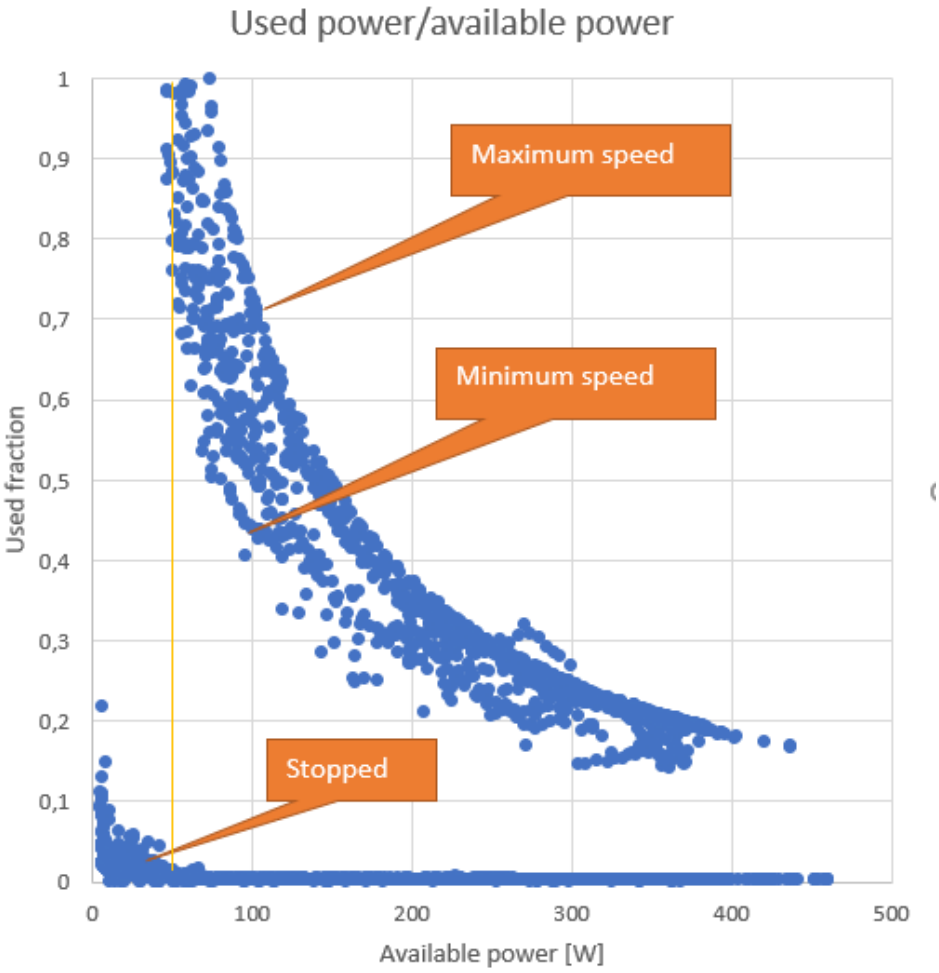


Figure 25 Data for KEN4 showing the fraction of utilized power at different compressor speeds/loads. Maximum available power is calculated to 360 W at 1000 W/m2.

For the stations with valid solar irradiance measurements the available solar power can be estimated by the formula (power in W and irradiance in W/m^2):

*Maximum PV power = Nominal PV power * Irradiance/1000 * 0.9*

The derating factor of 0.9 includes temperature, dirt and cabling losses. Because the maximum power of the PV arrays exceeds the power needed by the compressor, it is only in very cloudy conditions that all power will be consumed by the compressor over a full day.

The available PV power depends on irradiance, so it is useful to see a duration curve for a certain measurement period to get a picture of how much of the time a certain power level is exceeded. Night values are excluded. By comparison with the consumption curve one can see that there is enough power to run the appliance about 80% of the daytime.

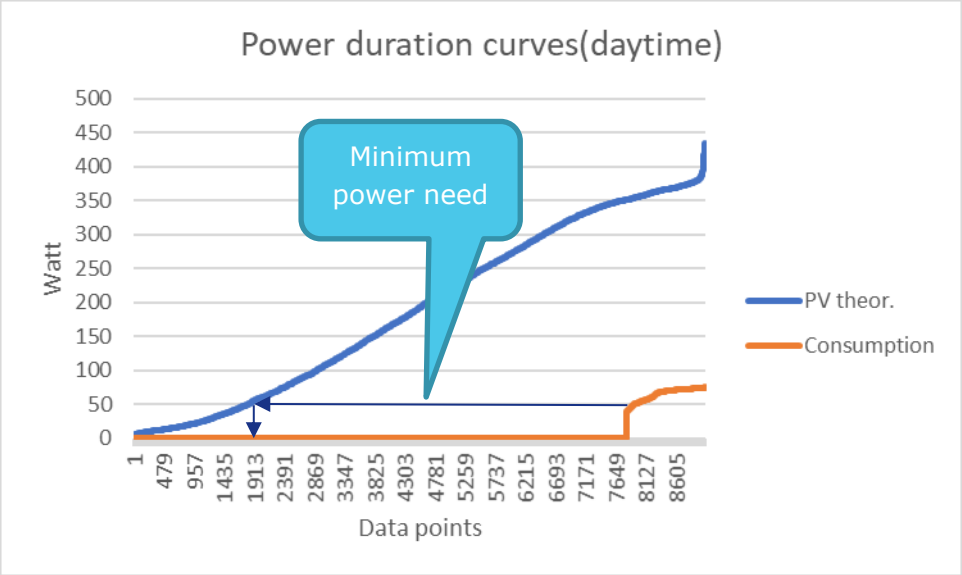


Figure 26 Comparison of duration curves for calculated available power (based on 750 hours of irradiance data) and measured consumed power for KEN4. The area under each curve represents total energy. In this case less than 10% of the available energy is used. Compressor power varies from about 50 to 75 W but is idle far most of the time.

The average values of all energy data and usage parameters are shown in the following table:

Table 6 Daily average energy consumption and door openings

	Type A	Type B	Type C	Type D	Type E
kWh/day	0,98	5,28	1,86	2,55	N/A
Used solar fraction	0,06	0,19	0,08	N/A	N/A
Daily door openings	2,82	3,57	2,24	N/A	N/A
Delta T	21,11	24,34	18,81	18,34	N/A

The data indicate that the PV arrays are heavily oversized. However, there could be times of the year with less irradiance and higher ambient temperature (Delta T), or installations with shading or heavy soiling of the panels. This can justify some oversizing of the PV power supply to ensure that the compressor can also start up on partly cloudy days. The typical start power is 50 W, which can be delivered from a 500 W PV array at 100 W/m^2 i.e. cloudy conditions. The panel dimensioning is based on a laboratory test with an insolation of 3.5 kWh/m^2 per day as specified by WHO (at 43°C for the types tested). For the locations in the current project, the typical daily insolation is higher than this and ambient temperature is well below 43°C. Energy scarcity is thus no issue at all.

8.3. Relative humidity

The HOBO data loggers are equipped with at combined temperature and RH sensor placed in the centre of the compartment.

Examination of the results shows that in almost all the installations the relative humidity was in the range 90-100% all the time, which is a natural level given the warm and humid surroundings of most of the refrigerators.

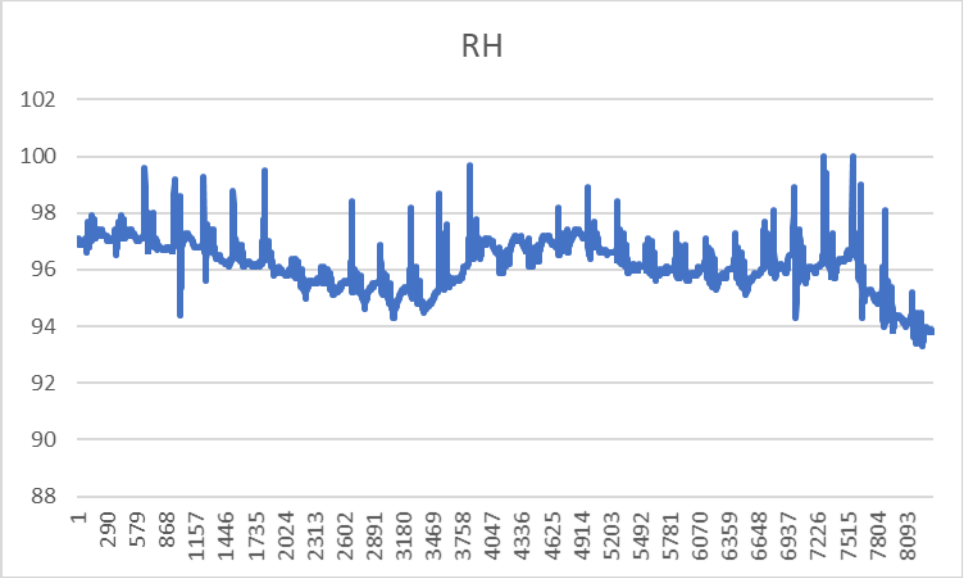


Figure 27 Typical monthly measurement result for RH%. In many cases the value is constant = 100% indicating that sensor is saturated.

The measurements confirm that the RH level is very high, no matter the type of refrigerator, and that condensation on cold surfaces takes place. (Water inside the appliances has been reported by users)

8.4. User behaviour

The influence of usage on the thermal performance can be extracted from the monitoring sites with a functional door opening sensor. Frequent door opening indicates heavy use of the equipment and higher temperature fluctuation can be expected. It turns out that the average daily number of door openings varies from 1-10 but do not have any clear influence on the temperature performance. It is most likely because the thermal mass of the goods taken in and out is very low compared to the mass of the thermal storage.

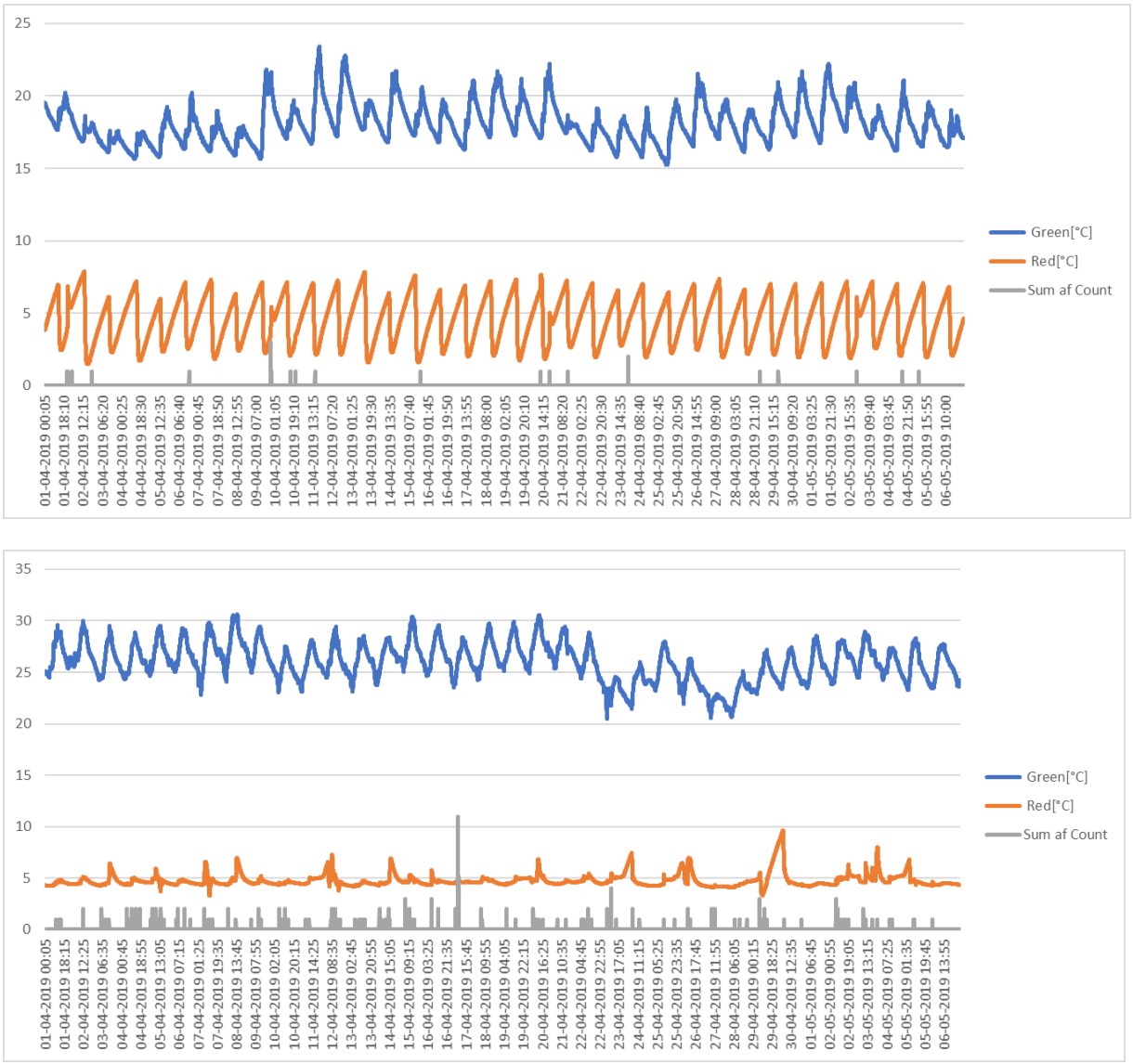


Figure 28 Type A at two different locations with low and high number of door openings (Grey bars show daily openings). The temperature (red/center) is more stable for the latter, where the ambient temperature(green) is also higher. The reason is most likely that in this case there is always a mix of ice and water, whereby low temperatures are prevented.

8.5. User questionnaire for SCA

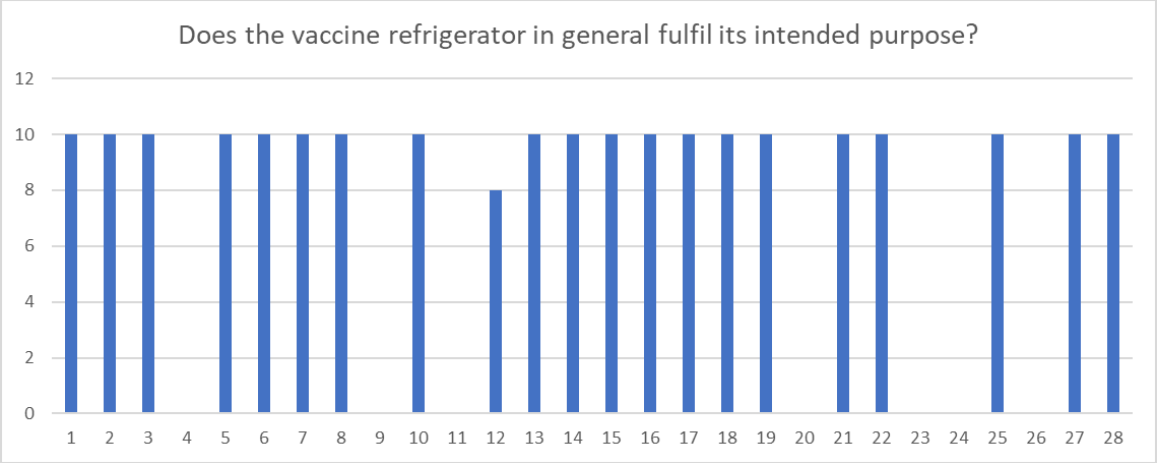
A systematic way to collect data is by a user questionnaire that was designed in a way to make it simple to convert ratings to an Excel sheet for statistical analysis. The full questionnaire templates can be found in Annex C.

List of questions:

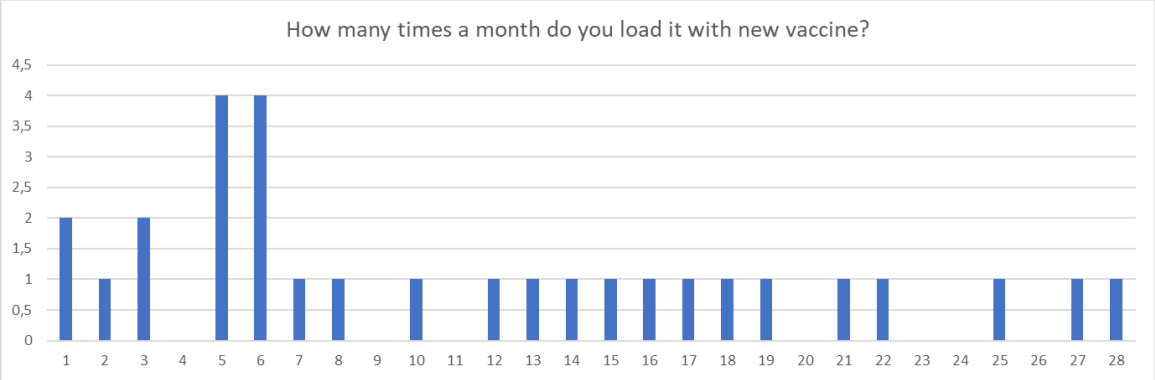
1. Does the vaccine refrigerator in general fulfil its intended purpose?
2. How many times per day do you open the door/lid?
3. Average time (minutes) per opening
4. How many times a month do you load it with new vaccine?
5. How many times did you have technical problems with the unit (pls describe all types of problems you experienced)
6. Is the storage capacity too low?
7. Are you using the unit for icepack freezing too (yes/no)
8. If cooling water-packs where are they stored?
9. Is cleaning/daily maintenance easy?
10. Is the unit free of condensation?
11. Is the storage temperature regulation OK?
12. Was any vaccine damaged due to wrong storage temperature?
13. Did you follow the manufacturers maintenance guide in all aspects?
14. Any other comments or recommendations to manufacturer?

The project contacted 28 installations in Colombia:

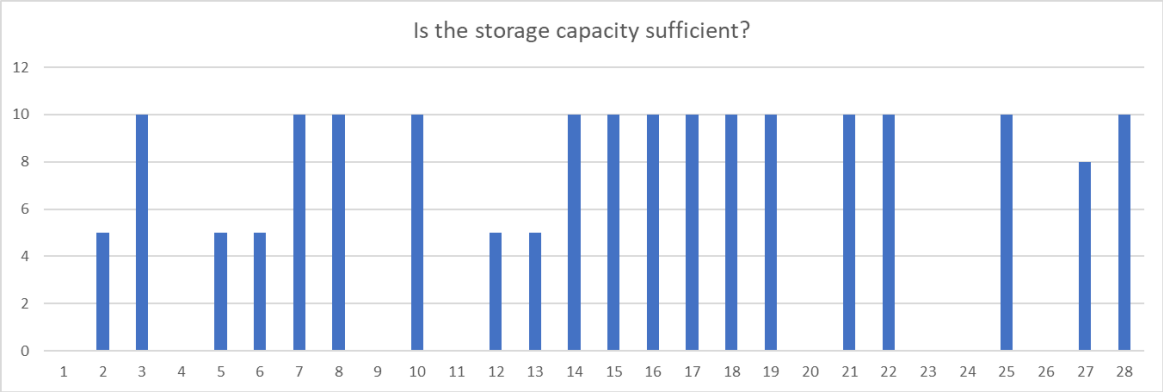
The average score for each of the questions is given below. In qualitative questions 10 is the maximum score expressing full satisfaction and 0 is total dissatisfaction. Some of the most important results are shown in the following graphs.



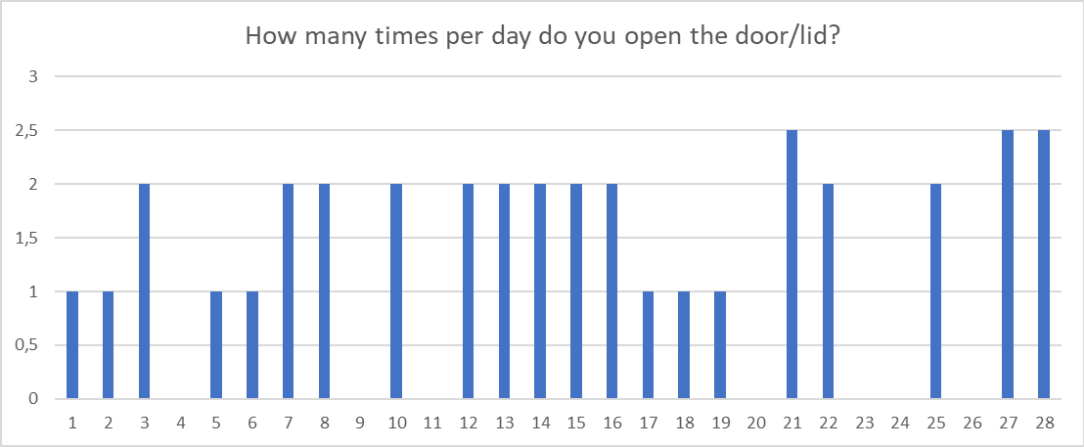
Almost full satisfaction shows that the presence of the refrigerators make a real difference.



Except for a few clinics the cabinets are rarely loaded with new vaccine. This may be due to the remote location(logistics) or due to low turnover.



Most respondents find the storage capacity sufficient, but if there is intensive use like no. 5 and 6 the answers indicate that volume should preferably have been bigger.



The openings are another indicator on how intensely the units are used. Openings are rare in all cases and there is no clear correlation to the other answers. A low number of openings means that there is very little impact on the energy consumption.

All answers/ratings are found in the following table:

Table 7 User feed-back from clinics in Colombia

No:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Does the vaccine refrigerator in general fulfil its intended purpose?	10	10	10	0	10	10	10	10		10	0	8	10	10	10
How many times per day do you open the door/lid?	1	1	2		1	1	2	2		2		2	2	2	2
Average time (minutes) per opening	5	1	1		5	5	3	3		1		2	5	6	5
How many times a month do you load it with new vaccine?	2	1	2		4	4	1	1		1		1	1	1	1
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)	0	0	0		0	0	0	0		0		0	0	0	0
Is the storage capacity too low?	0	5	10		5	5	10	10		10		5	5	10	10
Easy access and overview of stored items?	10	10	10		10	10	10	10		10		10	10	10	10
Are you using the unit for icepack freezing too (yes/no)	yes	Yes	Yes		Yes	Yes	10	10		No		Yes		No	No
Is cleaning/daily maintenance easy?	10	10	10		10	10	10	10		10		10	10	10	10
Is the unit free of condensation?	10	10	10		10	10	10	10		10		10	10	10	10
Is the storage temperature regulation OK?	10	10	10	0	10	10	10	10		10		10	10	10	10
Was any vaccine damaged due to wrong storage temperature?	No	No	No		No	No	No	No		No		No	No	No	No
Did you follow the manufacturers maintenance guide in all aspects?	Yes	Yes	Yes		Yes	Yes	Yes	Yes		Yes		Yes	Yes	Yes	Yes
Any other comments or recommendations to manufacturer?	No.	rage for	Satisfied		No		Satisfied	atisfied.		Satisfied					Satisfied

16	17	18	19	20	21	22	23	24	25	26	27	28
10	10	10	10	0	10	10	0	0	10	0	10	10
2	1	1	1		2,5	2			2		2,5	2,5
5	5	5	5		3,5	1			2		1	3,5
1	1	1	1		1	1			1		1	1
0	0	0	0		0	0			0		0	0
10	10	10	10		10	10			10		8	10
10	10	10	10		10	10			10		10	10
No	No	No	Yes						Yes		Yes	Yes
10	10	10	10		10	10			10		10	10
10	10	10	10		10	10			10		10	10
10	10	10	10		10	10			10		10	10
NO	No	No	No		No	No			No		No	No
Yes	Yes	Yes	Yes		Yes	Yes			Yes		Yes	Yes
atisfied	Satisfied	Satisfied	Satisfied								Satisfied	

Some additional comments from individual respondents in Colombia shows the challenges operating a SDD installation in remote areas:

#4: The temperature regulation system is not working, so the fridge is out of service.
#9: The compressor doesn't work. For this reason, the unit is out of service.
#11: The Unit is out of service due to lack of vaccination staff
#12: In cloudy days, the ice packs get melted because of the lack of electrical feeding capacity by the solar panels.
#20: The fridge worked in normal conditions for one year. After that, it was put out of service due to failure of temperature electronic controller. At the end, the compressor did not start.
#23: The solar panels were stolen.
#24: The fridge is out of temperature operating range. Sometimes too cold, sometimes too hot. Failure associated to temperature sensor or temperature electronic controller.

As an overall conclusion on the interviews made in Colombia users are satisfied, but they mention some important issues that need attention.

8.6. Failures and problems

An important task in the project has been to document how reliable SDD refrigerators are in practical use, either reported via remote monitoring or via user feedback. The following technical problems have been encountered for individual refrigerators:

- KEN2: Leak of refrigerant
- KEN8: Leak of refrigerant
- COL6: Electrical disconnect, internal or external
- Additional errors reported:
    - Pool of water every day inside the refrigeration chamber
    - Leak of refrigerant
    - Freezing temperatures in vaccine compartment
    - Moisture and condensation
    - Freezing of top insulation, so the lid could not open

The leakage problem concerns a specific type and is most like a result of weak internal factory check before shipment.

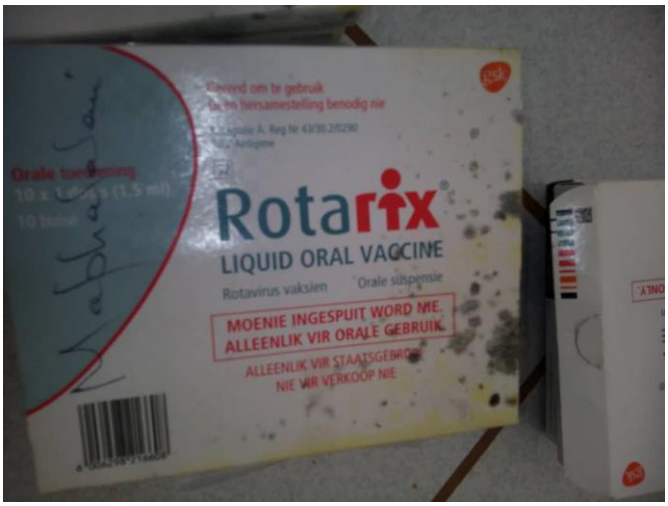


Figure 29 Mould growth on cartridge due to condensation/high humidity. One user reported that high humidity and condensation results in mould growth and spoiled cartridges. It is inevitable to have condensation due to large temperature differences and very humid ambient air that is immediately condensing on the walls when the cabinet is opened.

The manufacturer was contacted and replied that the walls should be wiped regularly with a dry cloth to prevent excessive build-up of condensation on the walls.

At most of the monitored sites the internal relative humidity value is close to 100% all the time, only for very dry sites it differs.

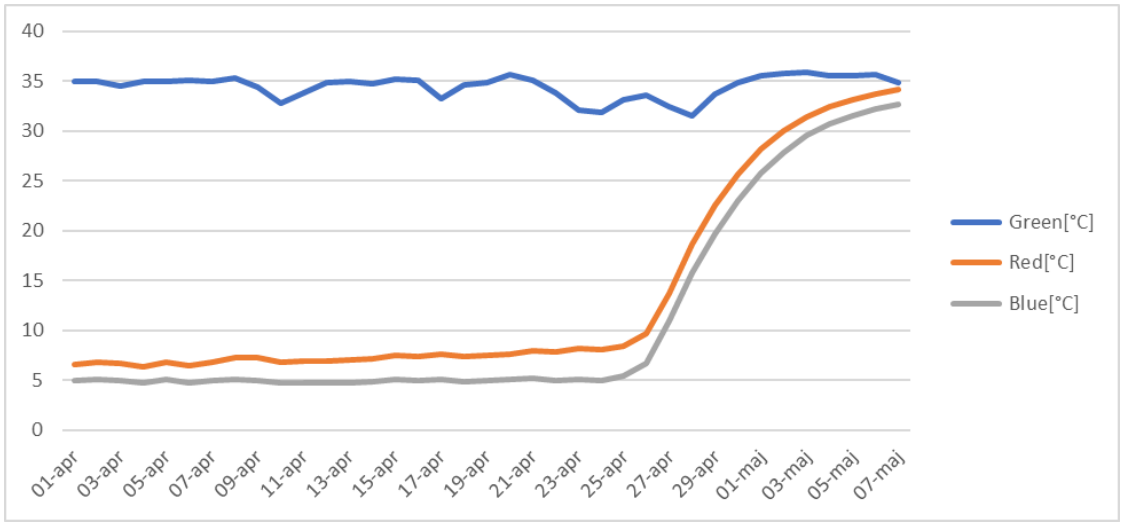


Figure 30 Appliance failure and sudden temperature rise. The example shows that daily attention is important.

8.7. Summary of SCA results

Measurement series within years 2018-2020 have been collected and analysed with focus on energy consumption and temperature behaviour. The project has been challenged by many practical issues concerning data collection and installation, but nevertheless the presented long-term data shows that SDD technology is generally working very well and mostly (82-96%) within the 2-8°C temperature range as specified by WHO. However, there is a tendency towards too high temperatures for type B and too low temperatures for type A. The latter is more severe as it could spoil the vaccine if local freezing occurs long enough to influence the vaccine temperature. On sites with this problem the staff have been asked to adjust the thermostat. The observed duration of local freezing occurrences is less than an hour and the manufacturer has taken action to solve this issue.

Analysis of the power consumption reveals that there are large differences between types of SDD units and in general the consumption is far below the available energy from the solar panels. Data and running behaviour indicate that there is potential for improvement for some of the types. However, the reported field data should be interpreted with caution as each installation and use pattern is unique. Furthermore, field data are not so easy to error check as data from laboratory measurements are.

Interviews with the clinics show that most users are generally satisfied, and the refrigerators do their job. As the project was severely delayed it was possible to follow the performance of some of the installations for more than two years. This long-term access has revealed some severe vulnerabilities for some of the brands, mainly associated with poor thermostat quality and/or fragility of the refrigeration circuit. Such incidents have immediately been reported to the suppliers, but action has not always been swift.

9. Monitoring of SolarChill B systems

After a market survey and consultancy with potential manufacturers, the following systems were used in the last phase of monitoring in the project. All are chest type refrigerators.

1) Modified VLS054 from Vestfrostsolutions
2) Leff Quingdao type SDDR-145
3) Palfridge type LC221

Besides the types above a few prototypes were tested in Colombia directly by the local manufacturers.

Table 8 Original list of SCB installations prepared for monitoring

	Site	Application	Fridge type
	Name	Use	Model
COL_B1			Leff
COL_B2			Leff
COL_B3			Leff
COL_B4			Leff
COL_B5			Leff
COL_B6			Prototype
COL_B7			Prototype
COL_B8			Prototype
COL_B9			Vestfrost
COL_B10			Vestfrost
COL_B11			Vestfrost
COL_B12			Vestfrost
COL_B13			Vestfrost
COL_B14			Vestfrost
COL_B15			Vestfrost
SWA_B1	Nkwene grocery	Shop	Palfridge
SWA_B2	Nokhutula grocery	Shop	Vestfrost
SWA_B3	Bindzani grocery	Shop	Vestfrost
SWA_B4	Lushini grocery	Shop	Palfridge
SWA_B5	Nhlane grocery	Shop	Palfridge
KEN_B1	Nanyuuki		Leff
KEN_B2	Kakuma	Ref.Camp	Leff
KEN_B3	Makueni	Ref.Camp	Leff
KEN_B4	Makueni		Leff
KEN_B5	Nazareth		Leff
KEN_B6	Nairobi		Vestfrost
KEN_B7	Kakuma	Ref.Camp	Vestfrost
KEN_B8	Kakuma	Ref.Camp	Vestfrost

Information from web sites about the different refrigerator types:

PRODUCT

VLS 054 SDD GREEN LINE

SOLAR DIRECT DRIVEN REFRIGERATOR

New integrated ice bank technology with increased thermal energy storage provides self controlling and reliable temperatures in the area of +2°C to +8°C rated according to highest climate zone within ambient temperature area from +5°C to +43°C.

Solar panels are connected plug & play directly to the appliances.

SPECIFICATIONS

Gross volume, litres (cu. ft.)	108 (3.81)
Net volume, litres (cu. ft.)	55.5 (1.95)
Temperature range (43°C AMB)	+2° to +8°C
Autonomy, hours	72.4
Hold-over time, hours	78.2
Refrigerant	R600a
WHO PQS code	E003/041
Freeze protection, grade	A
Climate class	T
Min. solar radiation, kWh/m2/day	3.5
Voltage, V Dc	12

FEATURES

Storage baskets, no	1
Temperature control	Automatic
Lock + keys	YES
Plug and Play solar kit	YES

DIMENSIONS

Height, mm (inches)	850 (33.46)
Width, mm (inches)	720 (28.34)
Depth, mm (inches)	600 (23.62)
Gross weight, kg (lbs)	85 (187.39)
Net weight, kg (lbs)	65 (143.30)

LOADING QUANTITIES

Qty. per 20' / 40' container	44 / 92
Qty. per truck (EU standard)	106

Figure 31 Data for Vestfrostsolutions VLS054. Gross volume 108 l

Figure 32 SDD refrigerator,Qingdao LEFF International Trading Co., Ltd.-Qingdao LEFF International Trading Co., Ltd. (opteco.cn) 145 l volume

Figure 33 Palfridge model LC221 with 192 l volume

The PV power supply system for the SCP refrigerators differs from manufacturer to manufacturer:

Table 9 SCB models and power supply systems.

	Gross volume	PV type	Nominal PV power
VLS	108	Crystalline silicon 4 x 90W	360 Wp 3.3 W/l
Leff	145	Crystalline silicon 180W 35V, 2 pcs	360 Wp 2.5 W/l
Palfridge	192	Amorphous silicon 4 x Schott Solar 100 W (?)	400 Wp(?) 2.1 W/l

Figure 34 Installation of thin film (Amorphous modules). This module type has less power loss at elevated temperature than the crystalline types.

The power to volume ratio ranges from 2.1 to 3.3 watt/litre. The module size for Palfridge is estimated from installation photos and data sheets.

9.1. Instrumentation for SolarChill B

A fast and simple monitoring approach was used for SolarChill B due to the late deployment and limited time for monitoring within the project period. It was found most effective to send small single-use temperature loggers directly to the country managers who could install them without risk of installation faults or problems with reading of remote monitoring (GSM) loggers. The single channel temperature loggers are of the type EasyLog. Data are downloaded manually though a USB connector.

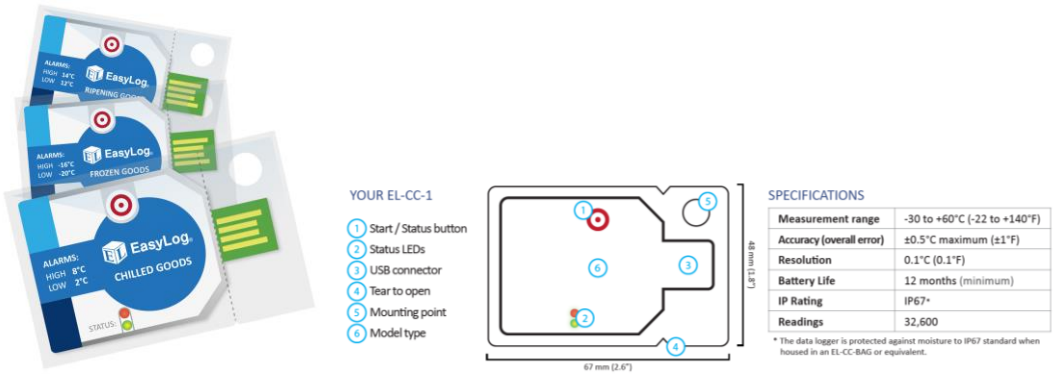


Figure 35 Single channel data loggers.

The battery can last for a year once logging has started. After download, the data is sent to DTI for analysis.

The dataloggers were installed by local staff with one in the basket and one outside for ambient temperature recording.

9.2. Monitoring results for SolarChill B

The SolarChill B refrigerators for food and beverages have been installed in several shops and clinics in the recipient countries and have only been instrumented with simple temperature loggers. As a supplement interviews were used to collect user experience and feedback to the manufacturers. The main results are listed in the following section.

9.3. User questionnaires for SCB

A systematic way to collect data is by a user questionnaire that was design in a way to make it simple to convert ratings to an Excel sheet for statistical analysis. Though intensions were good the reality was that the questionnaires were filled out in hand and later scanned, so many data had to be re-entered.

List of questions:

1. Does the refrigerator in general fulfil its intended purpose? 0= not at all. 10 = perfectly well
2. How many times a week do you load it with new items? Please also notice kind of products.
3. How many times did you have technical problems with the unit (pls describe all types of problems you experienced)
4. Is the storage capacity too low? 0= much too small, 10 = large enough
5. Easy access and overview of stored items? 0=bad, 10=perfect

6. Is cleaning/daily maintenance easy? 0=very difficult,10= very easy
7. Is the unit free of condensation? 0= heavy problems, soaked 10= no free water
8. Is the storage temperature regulation OK? 10= perfect
9. Were any goods damaged due to wrong storage temperature Y/N
10. Do you use the fridge the same way every day, or are there peak load periods?
11. What is the commercial benefit by using a fridge for your business?
12. How many % is your business improved?
13. Did you start selling new products due to the new cooling opportunity? Which?
14. Would you recommend this product to others?
15. Any other comments or recommendations to manufacturer?

Summary of 19 interviews:

1. Almost all users report a score of 8-10. A single has a score of 5 with no explanation, maybe when comparing with a plug-in refrigerator.
2. There is a high variation in the number of weekly reloading ranging from less than one to seven. Without a quantity and product description it is difficult to assess the energy needs implied but it shows that the use patterns are quite different.
3. All respondents have reported zero, so no failures.
4. Again, there is a high variation from 3-10 reflecting the use patterns and sales volumes. Most answers are in the medium range so we may conclude the cabinets should be at least 50% bigger for full satisfaction.
5. Answers from 5-10 indicate that access is not perfect due to the chest design, but some users seem to be quite satisfied. Maybe these units are not too much loaded and therefore it is easy to check and find the goods.
6. Cleaning is reported as very easy and all has given a rating of 10. The regular and smooth inner surfaces are easier to clean than a fridge with shelves and holders.
7. There are differences to this question with answers from 5-10 and comments about water at the bottom of the cabinet. Drainage of condensate seem to be an issue if the user should not wipe up excess water every day.
8. The temperature is reported as OK by many but a singe 4 and some 5 ratings show that not all users are satisfied with the temperature, which is generally too high. A shop owner comment that some buyers prefer very cold milk and the fridge cannot deliver that.
9. No goods have been damaged at any of the sites.
10. Most users have the same daily needs but a few report they have peak sales. E.g. after people return from church.
11. The shops report they can sell new products after they have got access to cooling, in particular milk, yoghurt and soft drinks.
12. Commercial sales have increased with up to 100% for some of the sites but typically 30-40% in average.
13. All respondents would recommend this technology to others
14. Most comments are about the limited size and lack of a freezer section.

9.3.1. Kenya

Table 10 SCB user feedback from Kenya

Date of interview	08-01-2021		08-01-2021		08-01-2021	
Country	Kenya		Kenya		Kenya	
Location	Mikindani		Busia		Kangemi	
Interviewer	Norah Okello	Pawame Customer Care	Norah Okello	Pawame Customer Care	Norah Okello	Pawame Customer Care
Date of installation of the unit	05-07-2020		07-09-2020		13-12-2019	
Refrigerator type	VestFrost		Vestfrost		VestFrost	
Name and position of user	Christian Health Association Of Kenya	254739 26 36 90	Mediatrix Adhiambo	254745889702	Josphat Murunga	254726520775
	Rating/Value	Comments	Rating/Value	Comments	Rating/Value	Comments
Does the refrigerator, in general, fulfil its intended purpose?	9	Very useful	10	Very useful	10	Very useful
How many times a week do you load it with new items? Please also write down what kind of products.	Twice	Soda Water and Milk	Everyday	Two crates of soda and Milk	Everyday	Milk, vegetable, meat
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)	No	No technical issue observed	No	She has never experienced any	No	He has never experienced any
Is the storage capacity too low?	5	The fridge capacity is small	No	The storage serves its purpose	Yes	The fridge is a bit small
Easy access and overview of stored items?	5		10		10	
Is cleaning/daily maintenance easy?	10	They wash it at least 3 times in a month	10	she cleans it every day before loading it	10	He washes it at least two times a week before loading it
Is the unit free of condensation?	10	No concerns	10		5	Most of the time he finds water on the base
Is the storage temperature regulation OK?	5	It's not cold enough	10		10	
Were any goods damaged due to wrong storage temperature	No	No concerns	No		No	
Do you use the fridge the same way every day, or are there peak load periods?	Yes	There are peak load periods which happens two times in a month	Yes	She uses it every day	Yes	He uses it every day
What is the commercial benefit by using a fridge for your business?	50%	It serves a good purpose, but their major concern is not having a locker unit where they can close it when they are not around, by this they incur losses because they cannot fast track their goods.	98%	Very few outlets in the region have cold beverages, the fridge has multiplied her number of customers	100%	He uses it for personal use
How many % is your business improved?						
Did you start selling new products due to the new cooling opportunity? Which?	Yes	Milk	No	she is planning to start selling, after evaluating the effectiveness of if	No	Uses it for personal uses
Would you recommend this product to others?	10	It is highly recommended	10	Highly recommended	10	Highly recommended it serves the(common mwananchi)i.e ordinary people
Any other comments or recommendations to the manufacturer?	Yes	-Storage capacity to be a bit bigger	Yes	The solar idea was very thoughtful, cheap and easy to use.she is a happy customer	Yes	-Storage capacity to be a bit bigger
		-To have a lock mechanism /access where they can monitor their goods(Security purpose)				-The fridge is a bit heavy if it can be a bit lighter.
						-If they can improvise to generate

9.3.2. eSwatini

Table 11 SCB user feedback from eSwatini (without comments)

Date of interview	21-09-2020	29-09-2020	25-09-2020	22-09-2020	25-09-2020
Country	SWA	SWA	SWA	SWA	SWA
Location	Bhojane supermarket	Bindzani grocery	Ebenezer grocery	Ekuphumeleni grocery	Tfultika grocery
Interviewer	Clifford Damini	Patricia Maniba	Patricia Maniba	Clifford Damini	Patricia Maniba
Date of installation of unit					
Refrigerator type	Palfridge	Vestfrost	Vestfrost	Vestfrost	Palfridge
Name and position of user	Mnqobi shopkeeper	Nomsa /assistant	Thembe Nyoni/ownwer	Tandeka Rich	
	Rating/value	Rating/value	Rating/value	Rating/value	Rating/value
Does the refrigerator in general fulfil its intended purpose? 0= not at all. 10 = perfectly well	10	10	8	8	8
How many times a week do you load it with new items? Please also notice kind of products.	3	1	0,5	7	2
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)	0	0	0	0	0
Is the storage capacity too low? 0= much too small, 10 = large enough	4	5	5	7	8
Easy access and overview of stored items? 0=bad, 10=perfect	5	6	7	10	10
Is cleaning/daily maintenance easy? 0=very difficult,10= very easy	10	10	10	10	10
Is the unit free of condensation? 0= heavy problems, soaked 10= no free water	6	10	10	6	10
Is the storage temperature regulation OK? 10= perfect		10	7	9	7
Were any goods damaged due to wrong storage temperature Y/N	No	No	No	No	No
Do you use the fridge the same way every day, or are there peak load periods?	Yes	Yes	Yes	Yes	Yes
What is the commercial benefit by using a fridge for your business?					
How many % is your business improved?	30	25	20	40	25
Did you start selling new products due to the new cooling opportunity? Which?	No	No	Yes	No	Yes
Would you recommend this product to others?	Yes	Yes	Yes	Yes	Yes
Any other comments or recommendations to manufacturer?	Yes	Yes	Yes	Yes	Yes

...continued

21-09-2020	21-09-2020	21-09-2020	22-09-2020	28-09-2020	28-09-2020	29-09-2020	29-09-2020
SWA	SWA	SWA	SWA	SWA	SWA	SWA	SWA
Avukile Emayeba General	Emazomba Grocery	Ndoma Grocery	Lubhedze Grocery	Lushini Grocery	Nhlane Grocery	Mkhandvo Grocery	
Clifford Damini	Clifford Damini	Patricia Mamba	Clifford Damini	Patricia Mamba	Patricia Mamba	Patricia Mamba	Patricia Mamba
Vestfrost	Palfridge	Palfridge	Palfridge	Palfridge	Palfridge	Palfridge	Vestfrost
Florence Sibiya/shop owner	Samuel Ngozo	Employee	Owner	Mfendolo Mkhomane	Ayanda Masoko	Owner	Owner
Rating/value	Rating/value	Rating/value	Rating/value	Rating/value	Rating/value	Rating/value	Rating/value
10	10	10	10	10	10	10	10
1	3	1	2	3	1	4	1
0	0	0	0	0	0	0	0
3	5	8	7	5	5	8	10
7	8	8	8	10	10	10	10
10	10	10	10	10	10	10	10
7	10	7	7	10	5	10	10
10	7	8	8	5	4	10	8
No	No	No	Yes	Yes	No	No	No
	Yes	Yes	Yes	Yes	Yes	No	No
		Yes	Yes	Yes	Yes	Yes	
10	5	20	30	20	20	15	10
Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes		Yes	Yes	Bibber model with deep freezer	Yes

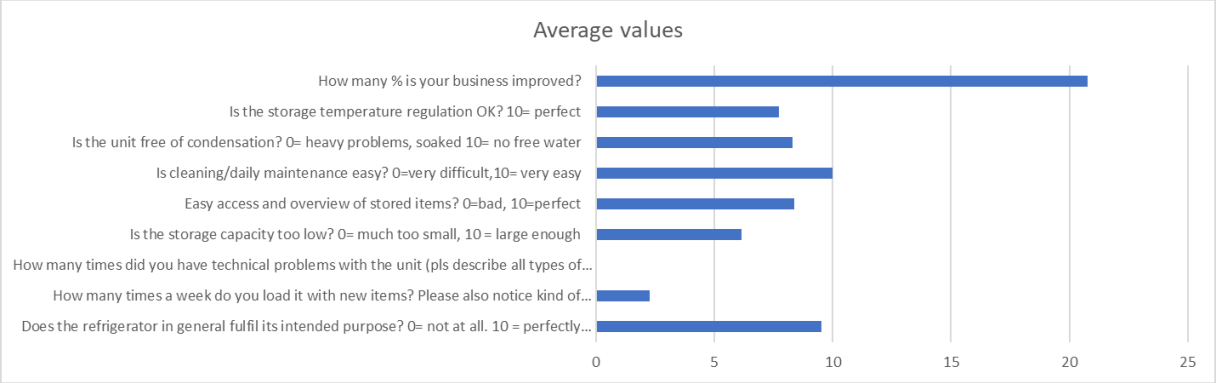


Table 12 List of comments

Does the refrigerator in general fulfil its intended purpose? 0= not at all. 10 = perfectly well			Need freezer compartment	Less cool on hot days	No freezer	Works perfectly well	Works perfectly well	Perfectly	Perfectly well				
How many times a week do you load it with new items? Please also notice kind of products.	Refilling of stock. Soft drinks, dairy products.	Ice, cold drinks		Soft drinks only	Soft drinks	Soft drings and juice	Soft drinks, dairy, juice	Drinks,milk	Soft drinks and dairy products	Soft drinks, Polony	Soft drinks and milk	Soft drinks,emasi(sour milk),milk	Soft drinks, ice pops
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)													
Is the storage capacity too low? 0= much too small, 10 = large enough	Need more space		Too small, need at least bigger capacity	Not big enough	If the capacity can be increased	Is too small	Storage capacity is small	If they can get one with bigger space	small		A bigger refrigerator could be useful	Need bigger capacity	It is not a busy area
Easy access and overview of stored items? 0=bad, 10=perfect	If it was vertical and see through glass	As some goods are stored under otther types of goods	A vertical transparent refrigerator is recommended	Easy to access, picking and reloading		Easy to pick items	Easy in loading and removing	Easy access	Easy to remove and reload				
Is cleaning/daily maintenance easy? 0=very difficult,10= very easy	Easy to clean			Easy to clean		Easy to wash	Easy to clean		Easy to clean				
Is the unit free of condensation? 0= heavy problems, soaked 10= no free water	Sometimes after cutting off it condenses			Condenses usually when it is hot		It condenses when it is hot	No condensation	If it is too hot it condensed	If it is too hot it condensed	No condensation	Everyday in the morning you find water		
Is the storage temperature regulation OK? 10= perfect			Hot days		When temperature is high	Temperature is ok	Sometime true temperature differs	When temperatures are high	Not bad	Sometimes it is not cold	The place is very hot		
Were any goods damaged due to wrong storage temperature Y/N									Long time ago some frozen chicken was damaged	Polony on hot conditions			
Do you use the fridge the same way every day, or are there peak load periods?	It works the same even during peak periods	Same way	Mid day	Same every day	Mid day	Peak periods when it is hot		Midday	Same way			Peak time in weekends	More used during month ends
What is the commercial benefit by using a fridge for your business?	It helps a lot in the reduction of power usage	More customers are visiting the shop, meaning there is a commercial benefit	There are benefits because there are drinks	More sales of soft drinks	There is a huge benefit	We benefit by selling refrigerated products	Canned soft drinks and youghurt	There is a commercial benefit	There is a commercial benefit	The money we used for gas refrigerator is saved	More frequenting customers	Sales benefit	Increased sales
How many % is your business improved?	Og course there is a financial difference					Slight improvement							
Did you start selling new products due to the new cooling opportunity? Which?			Soft drinks	But more soft drinks	The soft drinks-before there was none	Soft drinks and juice	Canned soft drinks and youghurt	Milt+soft drinks	Did not sell soft drinks before		Soft drinks and milk	Milk and sour milk	Soft drinks
Would you recommend this product to others?	Of course I would recommend it to others			Works perfect and no costs		It is user frindly			Used at no cost				
Any other comments or recommendations to manufacturer?	1.Must produce a vertical model with glass front. 2. Must improve stprage capacity	A bigger size of the refrigerator will do the job perfectly.	If the fridge could be bigger and have a freezer compartment	Must try to make it vertican with front glass	Features for deep freezer included	Try to mke it more colder	Bigger storage capacity and quick frosting	Convert to deep freezer	Would wich it had bigger capacity	Bibber refrigerator with freezer compartment	Bigger make with deep freezer		If the fridge can have a deep freezer compartment

9.3.3. Colombia

(none received)

9.4. Data evaluation

Only a few useful data have been received, which is presented here.

Time series from Kenya/Kangemi shows a very fine temperature curve with moderate day/night oscillations and some higher peaks. The warm peaks are likely due to opening and reloading action. The minimum temperature is well above the freeze limit and the temperature level remains constant over the whole monitoring period.

The fridge (VLS054) is used for vegetables, milk and meat according to the user interview. Daily input/output is not recorded. Condensation water has to be wiped from the bottom every day.

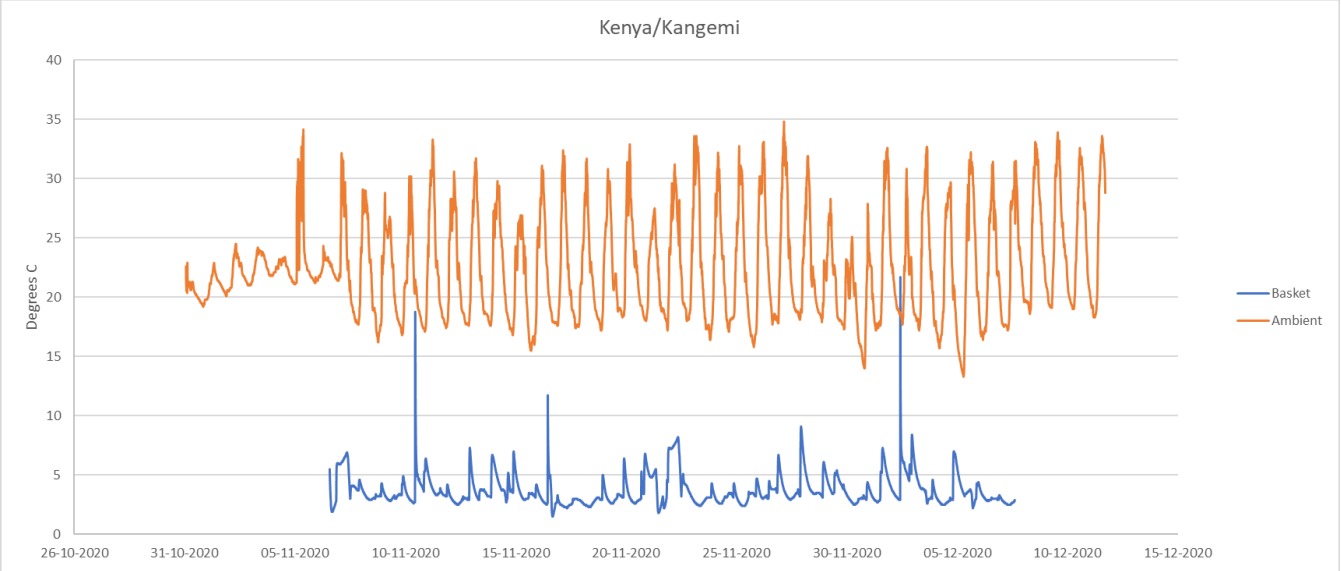


Figure 36 Internal temperature for Kenya- Kangemi site. Moderate oscillations.

Another set of data from Kenya/Kisumu exhibits somewhat higher fluctuations and a generally higher temperature level. The first 4 days the temperature is pulled down (and the iceliner freezing) but then it looks like the device is disconnected for some reason or the datalogger has been misplaced. After a while it turns back to normal but at a quite high average temperature of 10 °C so maybe the ice storage is not adequately frozen. Ambient temperature recording was not received for the same time period, but it is at same level as former site.

The appliance is a VLS054 and user is Margaret Bodo (No interview).

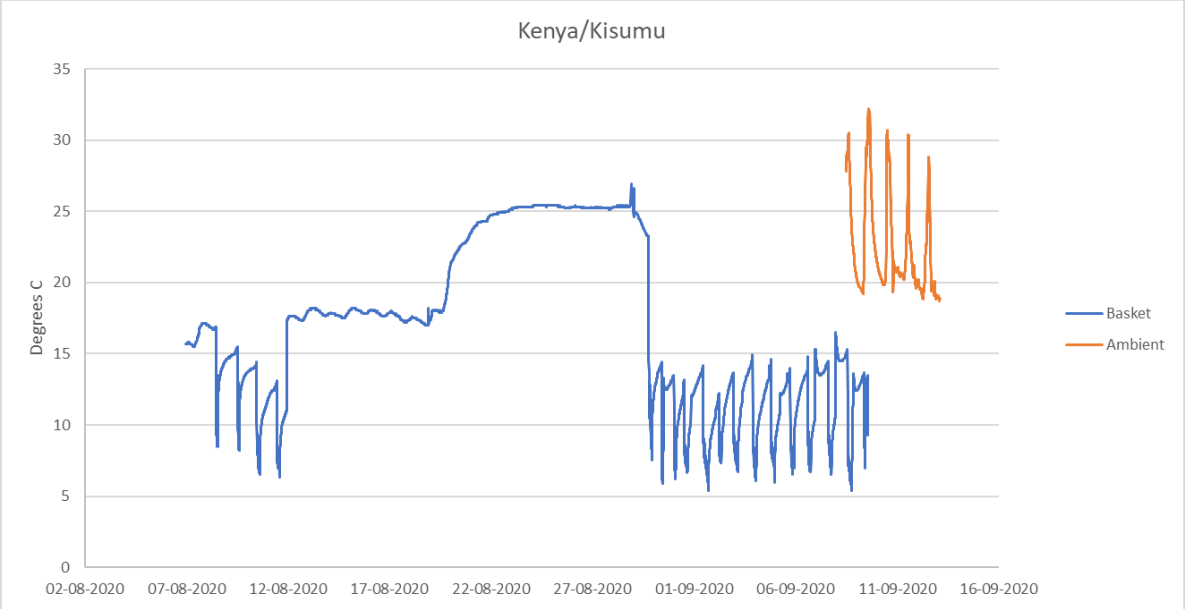


Figure 37 Internal temperature for Kenya- Kisumu site. The appliance har probably been off for a while. Daily oscillations are rather high.

10. Summary of SCB results

Despite a very big effort with the installation and distribution of the SCB refrigerators and monitoring systems, this part of the project could only collect a limited amount of data compared to what was expected.

The reasons are numerous, but mostly they have to do with the practical issues when distributing and installing such systems in remote areas with very limited communication options and lack of technically qualified partners.

Though more than 50 sets of low-cost temperature data loggers have been sent to the representatives in the recipient countries DTI did only receive useful data from two sites in Kenya and none from the other countries. By end of the project there were no resources and no time left for field travels and follow-up so the report had to be finished with the scarce data available.

Even with all data collected, it would have been difficult to evaluate the success just on basis of temperature readings because the refrigerators are used in different ways (load and climate).

The user responses to the questionnaires has turned out to be the most valuable data achieved from the SCB activities. The country managers in eSwatini and Kenya have successfully interviewed shop owners and other users of the SCB appliances, and a review of the responses shows that the access to cooling makes a real difference to the users.

The feedback is very positive in general, and the only negative comments are that the units are too small and do not have a freezer compartment. The fact that there is no utility bill to be paid and that the solar power supply is more stable than the grid is also highlighted.

The shop owners agree that the sale of goods such as cold milk and juice has improved their business by up to 50% compared to the situation without cooling.

11. Lessons learned

In the current project the term "remote monitoring" should be understood very literarily as most of the installation sites are located far from cities and normal electricity supply and other infrastructure. The selection of equipment was made with this in mind, i.e. with focus on autonomous and reliable operation. Some of the problems that were encountered and could be mitigated in a proper remote monitoring system are:

- Communication about technical details is difficult on distance and misunderstandings happen! Avoid too complex sensor installation unless it can be done by a skilled responsible.
- The project used three different solutions, which made it very complex to collect and compare data. Use a single reliable equipment supplier if possible.
- Signal failures. Use failsafe sensors where polarity cannot be swapped incidentally
- In some cases, it was impossible to get connection even though the signal was checked beforehand with a cell phone. Therefore, some of the monitoring kits were useless as remote monitoring stations. (They might still be used for local read-out). Check GSM connectivity with the real equipment if the signal is not strong!
- It is often difficult to find technically skilled persons in remote areas, so reliability and simplicity of the equipment is a must.
- Do not underestimate time and effort to get remote monitoring devices installed and registered. Problems with correct matching of equipment with SIM card numbers and GDPR issues were unexpected obstacles. If remote monitoring and live access is not a must, simple stand-alone data loggers are much faster to get up running.

At the beginning of the project there were few useful and affordable systems in the market, but today more and more GSM or internet-based data logging equipment is available at modest cost and some cabinet manufactures have already integrated such monitoring. The author hope that this report can be helpful to other remote monitoring programmes.

12. ANNEX A Instrumentation

Onset/HOBO data loggers

The HOBO dataloggers were all assembled and tested at DTI before shipment to the recipient countries. The country managers eventually installed the data loggers in the individual refrigerators based on instructions from HEAT and DTI.

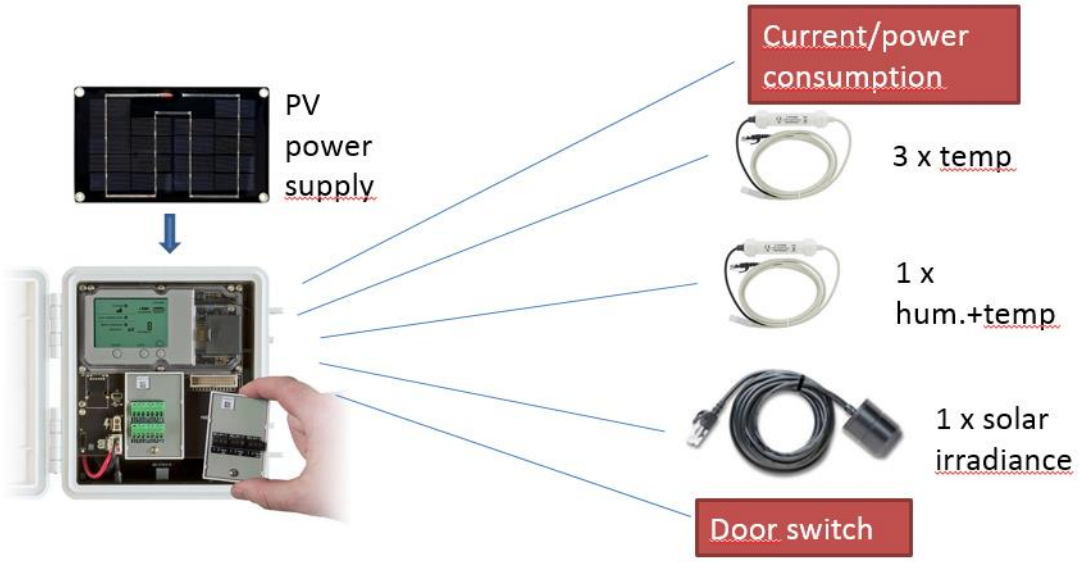


Figure 38 Measurement channels for extended monitoring. Power consumption is found from separate current and voltage monitoring.

A serious problem was the cabling through the door opening to the internal sensors. Some of the cables are very thick, so DTI removed the outer insulation in order to minimize the stress on the door gasket and prevent air infiltration.

Current and voltage measurement is implemented by means of a special cable section with shunt resistor and MC4 connectors in both ends, so that it can fit to most of the marketed SDD appliances.

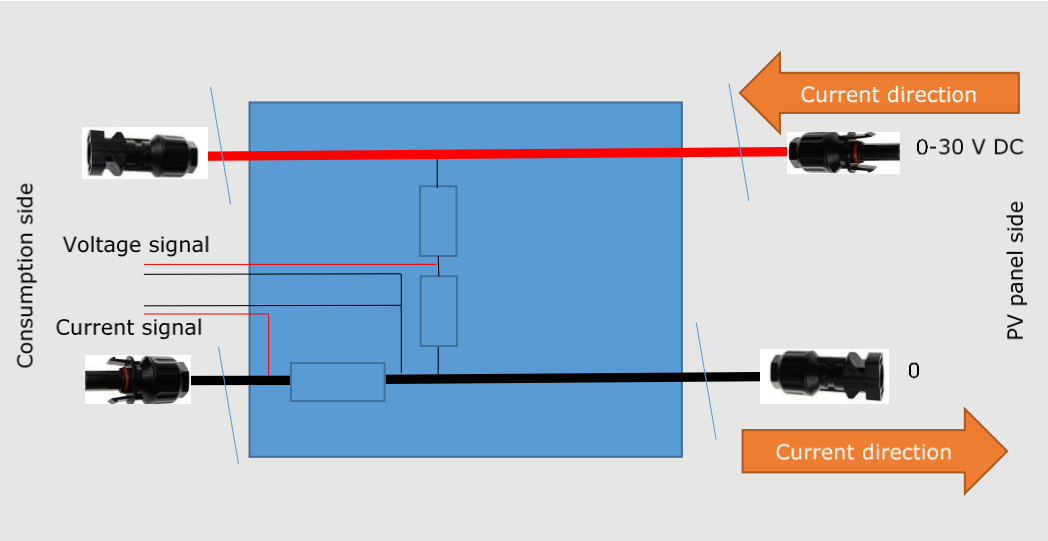


Figure 39 Plug-in cable section for measurement of current and voltage, so that the power consumption can be calculated.

Sensor accuracy:

- Voltage: ±0.6 mV ±0.2% of reading
- RH: 0.1% RH
- Temperature: ±0.2°C from 0° to 50°C
- Irradiance: ±10 W/m2 or ±5%, whichever is greater in sunlight

Nexleaf/Coldtrace 5 data loggers

Main part of the systems are using this type of data logger, specially made for cold chain equipment monitoring. It is intended for multiple refrigerators, so there are 5 temperature channels. In the current project, the sensors are placed like this:

A: Ambient (room) temperature

B: Top of storage compartment

C: Middle of storage compartment

D: Bottom of storage compartment

E: Icepack compartment or evaporator surface (Supposed coldest surface)

Nexleaf use very thin cables that can easily pass the door opening, a main reason for choosing this supplier. However, they are a bit delicate.

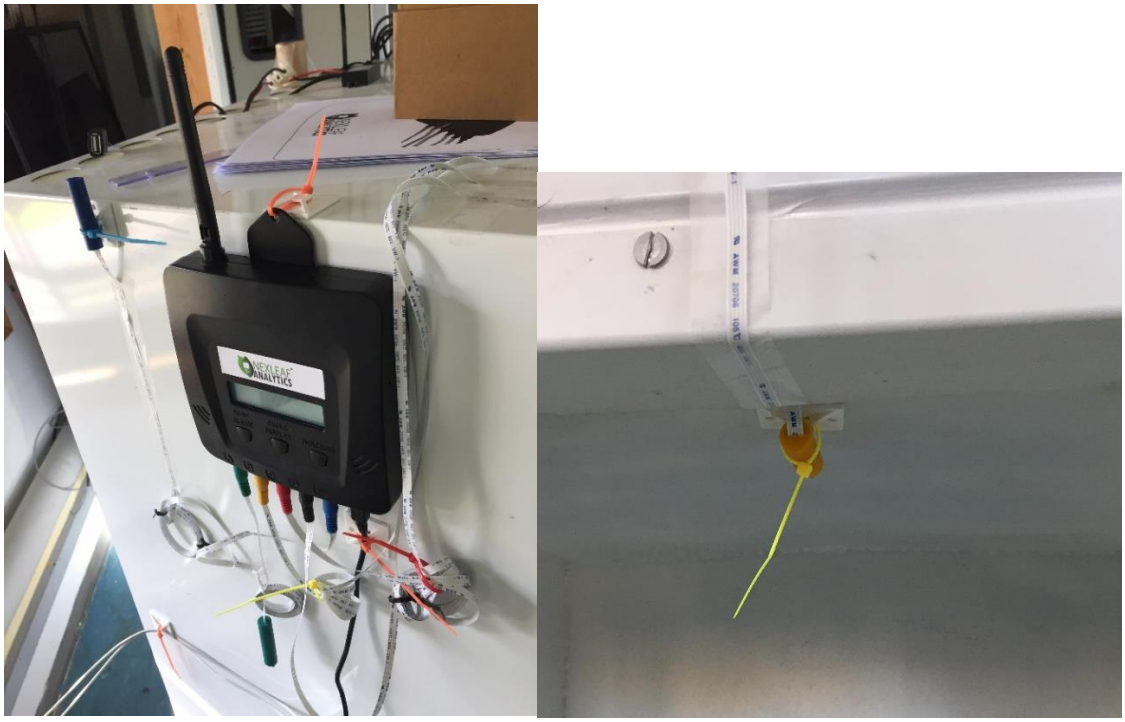
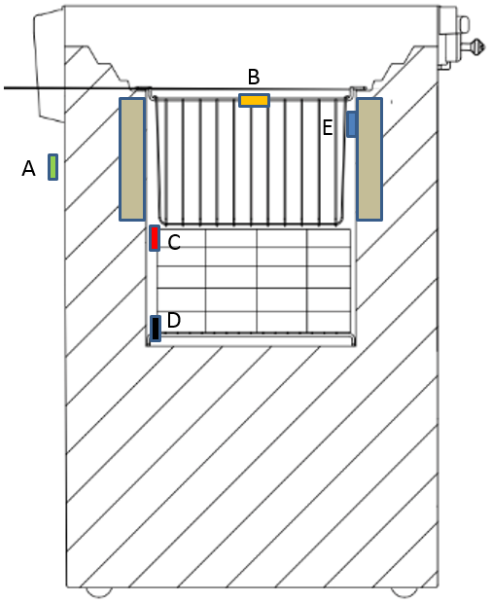


Figure 40 Nexleaf Coldtrace 5 data logger (5 temperature sensors with ultra-flat cable)

Example instrumentation for chest type: Vestfrost



A: Ambient (room) temperature
B: Top of storage compartment
C: Middle of storage compartment
D: Bottom of storage compartment
E: Icepack compartment or evaporator surface

Figure 41 Template for instrumentation with Nexleaf equipment

Sensor accuracy:

- Temperature: ±0.5 C°

Tologg/B-Medical data logger

This data logger comes with the B Medical devices and is prepared for easy installation on the cabinet. The logger measures door opening (also duration), internal and external temperature.

Figure 1. Package contents

Complete package contains:

1. Logger TOLOGG-2.3
2. Door sensor
3. Power cable, two possible variants of termination
4. Mounting holder
5. External temperature sensor
6. Internal temperature sensor
7. Dust covers

Figure 42 Integrated B Medical data logger

Sensor accuracy:

- Temperature: ±0.4 C°

Data transfer and analysis

Data is automatically transferred (when there is connectivity) to the following web portals, run by the respective manufacturers:

www.hobolink.com

A user guide for the dashboard as well as a link to the HOBO RX3000 data logger can be found on this web portal. It is free to register as a user if you have the serial numbers of the data loggers and SIM cards.

Contact person: Stokholm Carsten, Metric Industrial DK <cs@metric.dk>

www.coldtrace.org

There is a link to the CT5 data logger manual and a dashboard link under "Resources".
Contact person: Martin Lukac <martin@nexleaf.org>

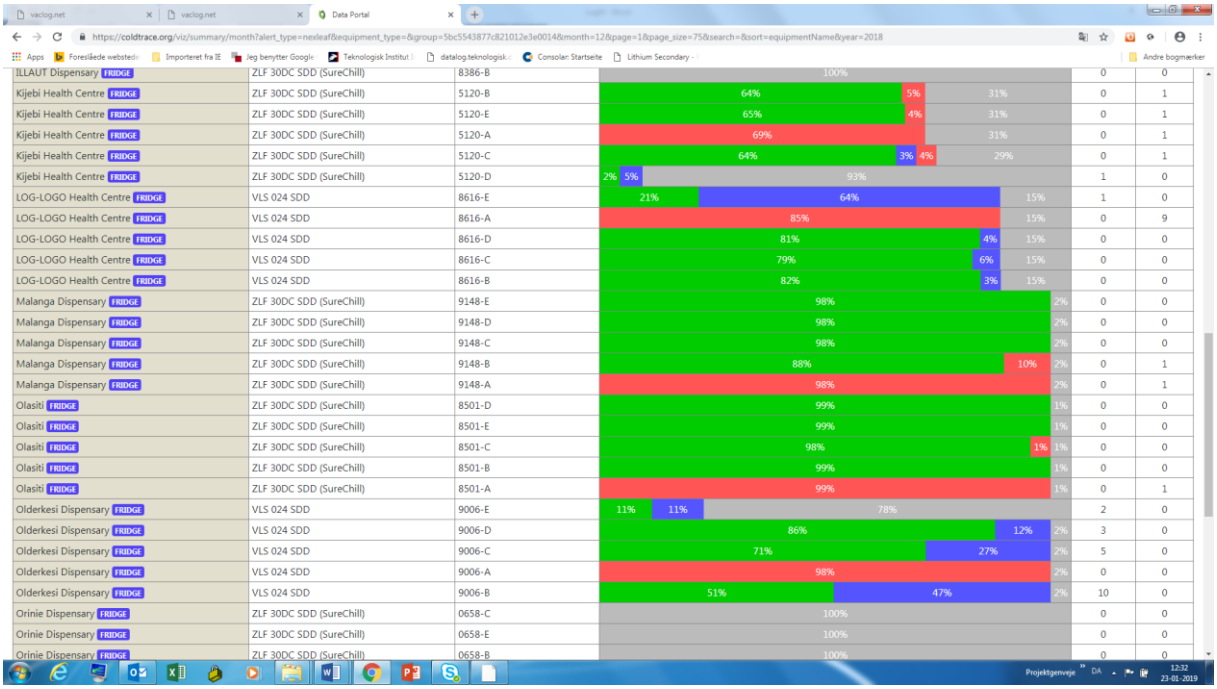
www.vaclog.net

A video guide is available on the site.
Contact person: Enes Hodzic <Enes.Hodzic@bmedicalsystems.com>

In case of weak or missing signal, the data loggers can store data for substantial time and resume transmission later. At some of the sites, staff has to take the data logger to a location with adequate GPS signal in order to upload the data.

HOBO loggers are set up for automatic file transfer to the FTP server at DTI, whereas the other are downloaded manually.

Example of dashboard for remote monitoring:



ILLAUT Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	8386-B	100%	0	0
Kijebi Health Centre FRIDGE	ZLF 30DC SDD (SureChill)	5120-B	64% 5% 31%	0	1
Kijebi Health Centre FRIDGE	ZLF 30DC SDD (SureChill)	5120-E	65% 4% 31%	0	1
Kijebi Health Centre FRIDGE	ZLF 30DC SDD (SureChill)	5120-A	69% 31%	0	1
Kijebi Health Centre FRIDGE	ZLF 30DC SDD (SureChill)	5120-C	64% 3% 4% 29%	0	1
Kijebi Health Centre FRIDGE	ZLF 30DC SDD (SureChill)	5120-D	2% 5% 93%	1	0
LOG-LOGO Health Centre FRIDGE	VLS 024 SDD	8616-E	21% 64% 15%	1	0
LOG-LOGO Health Centre FRIDGE	VLS 024 SDD	8616-A	85% 15%	0	9
LOG-LOGO Health Centre FRIDGE	VLS 024 SDD	8616-D	81% 4% 15%	0	0
LOG-LOGO Health Centre FRIDGE	VLS 024 SDD	8616-C	79% 6% 15%	0	0
LOG-LOGO Health Centre FRIDGE	VLS 024 SDD	8616-B	82% 3% 15%	0	0
Malanga Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	9148-E	98% 2%	0	0
Malanga Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	9148-D	98% 2%	0	0
Malanga Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	9148-C	98% 2%	0	0
Malanga Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	9148-B	88% 10% 2%	0	1
Malanga Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	9148-A	98% 2%	0	1
Olasiti FRIDGE	ZLF 30DC SDD (SureChill)	8501-D	99% 1%	0	0
Olasiti FRIDGE	ZLF 30DC SDD (SureChill)	8501-E	99% 1%	0	0
Olasiti FRIDGE	ZLF 30DC SDD (SureChill)	8501-C	98% 1% 1%	0	0
Olasiti FRIDGE	ZLF 30DC SDD (SureChill)	8501-B	99% 1%	0	0
Olasiti FRIDGE	ZLF 30DC SDD (SureChill)	8501-A	99% 1%	0	1
Olderkesi Dispensary FRIDGE	VLS 024 SDD	9006-E	11% 11% 78%	2	0
Olderkesi Dispensary FRIDGE	VLS 024 SDD	9006-D	86% 12% 2%	3	0
Olderkesi Dispensary FRIDGE	VLS 024 SDD	9006-C	71% 27% 2%	5	0
Olderkesi Dispensary FRIDGE	VLS 024 SDD	9006-A	98% 2%	0	0
Olderkesi Dispensary FRIDGE	VLS 024 SDD	9006-B	51% 47% 2%	10	0
Orinie Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	0658-C	100%	0	0
Orinie Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	0658-E	100%	0	0
Orinie Dispensary FRIDGE	ZLF 30DC SDD (SureChill)	0658-B	100%	0	0

Figure 43 Screen dump of Coldtrace (Nexleaf) temperature data. Green colour indicate that the temperature is within 2-8 °C range.

EL-CC-1 Range

Cold Chain Data Logging Solutions

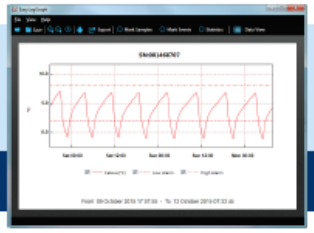
EasyLog

- 3 data loggers for monitoring Chilled Goods, Frozen Goods and Ripening Goods.
- No set-up required. One button press-to-start logging.
- Pre-configured with appropriate sample rates and alarm thresholds for each application.
- Reusable with 12+ months battery life.
- Various export options including PDF, Microsoft Excel and JPEG.

Each of the three Cold Chain loggers comes pre-configured for use in your particular application – simply press the button to start logging. During a logging session, pressing the button will light up the status LEDs to give a quick indication as to whether the temperature has exceeded an alarm condition at any point. Once your session has been completed, tear open the IP67-rated plastic wallet to reveal the USB connector and plug it in to your PC. Use the free EasyLog CC software for Windows to download and graph the data, and then prime your logger for its next use.

EasyLog CC Software

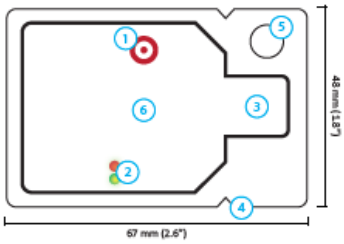
The simple-to-use software allows you to view the data graphically, in a table or export it in various formats for use in further reporting.



Download the latest version of the software free of charge from www.easylogcc.com

YOUR EL-CC-1

1. Start / Status button
2. Status LEDs
3. USB connector
4. Tear to open
5. Mounting point
6. Model type



SPECIFICATIONS

Measurement range	-30 to +60°C (-22 to +140°F)
Accuracy (overall error)	±0.5°C maximum (±1°F)
Resolution	0.1°C (0.1°F)
Battery Life	12 months (minimum)
IP Rating	IP67*
Readings	32,600

* The data logger is protected against moisture to IP67 standard when housed in an EL-CC-BAG or equivalent.

MODEL SPECIFIC

	Chilled Goods	Frozen Goods	Ripening Goods
High Alarm Level	8°C	-16°C	14°C
Low Alarm Level	2°C	-20°C	12°C
Logging Interval	10 minutes (220 days)	10 minutes (220 days)	10 minutes (220 days)
Part Number	EL-CC-1-001	EL-CC-1-002	EL-CC-1-003

This unit can be quickly customised for use in multiple markets. If you have a specific monitoring application, that requires different sample rates or alarm thresholds, call us today.

ACCESSORIES

EL-CC-BAG: Pack of 5 waterproof bags for data logger during use.

EasyLog

www.lascarelectronics.com

LASCAR electronics

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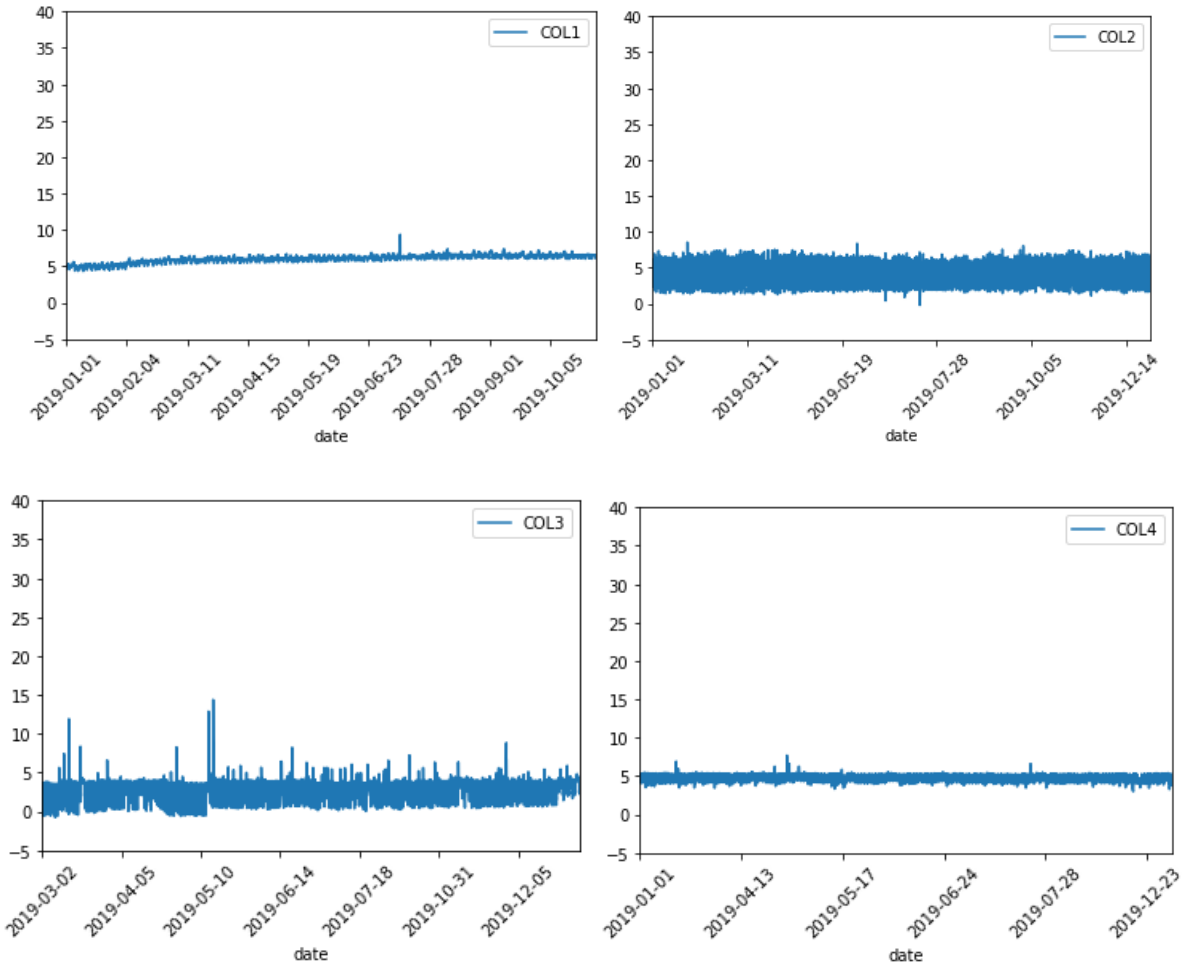
13. ANNEX B Time series

All HOBO data collected in 2019 (Average storage temperature in °C)



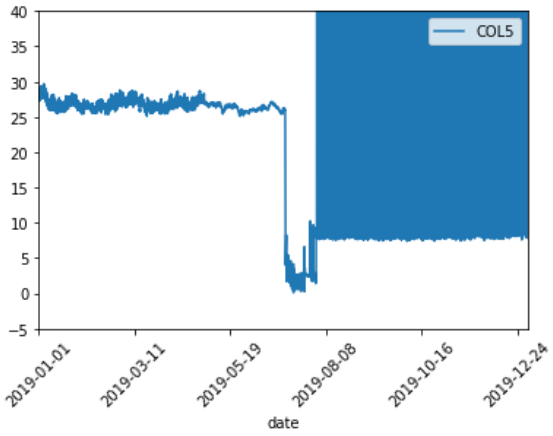


Figure 1 COL5 Litoral San Juan Only running since midsummer. High fluctuations are sensor faults.

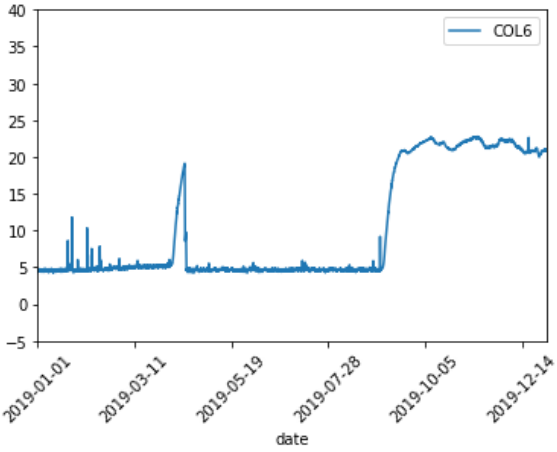
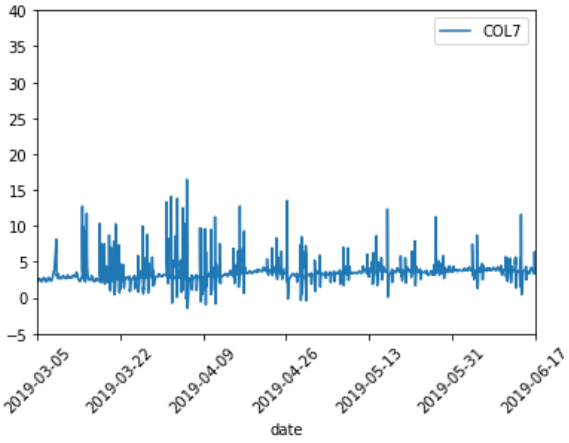


Figure 2 COL6 Cordoba: Out of service for unknown reason since late summer 2019



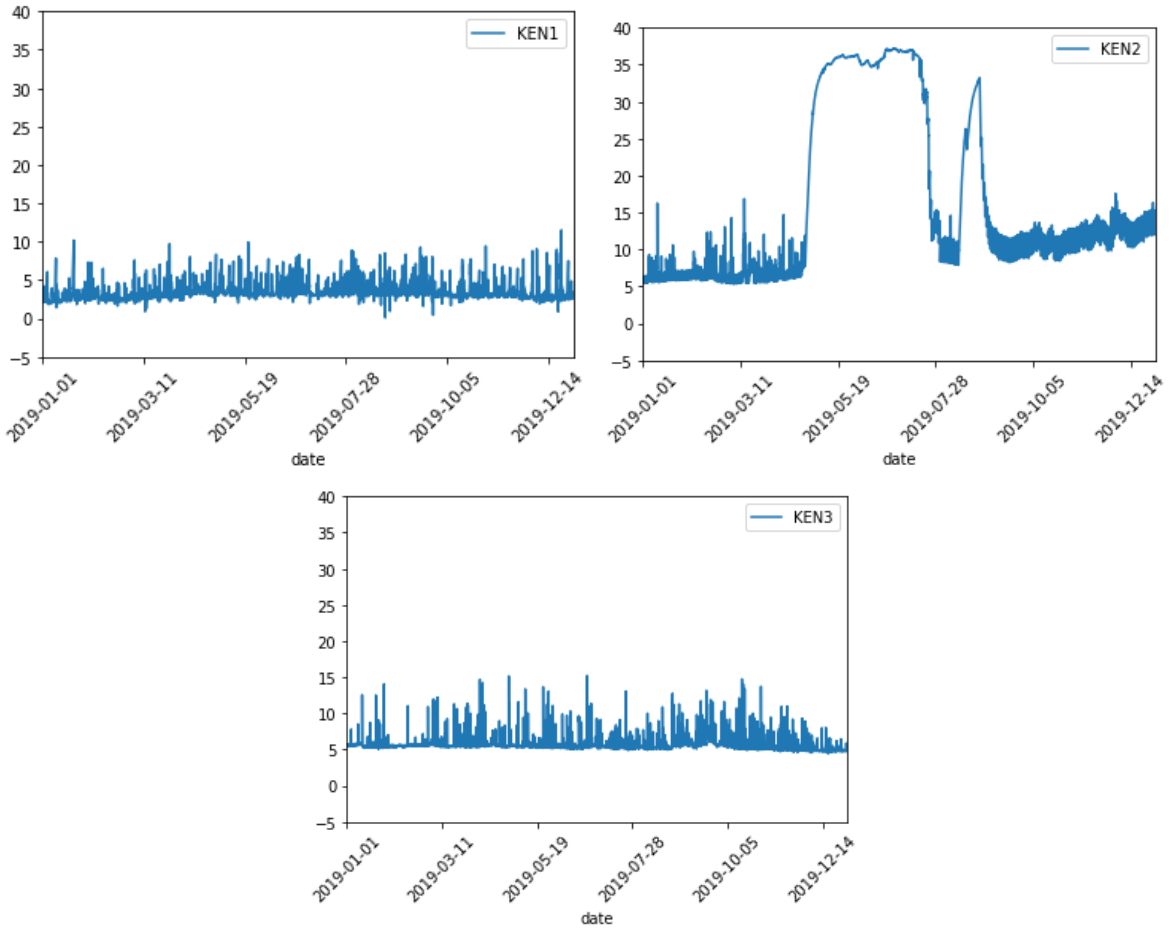


Figure 3 KEN2 shows technical fault, partly repaired. Temperature increasing, probably a leak.

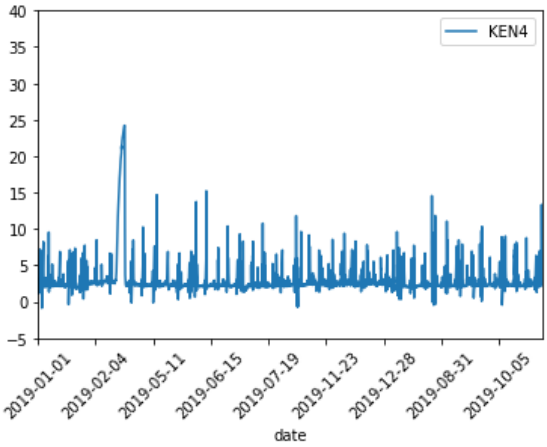
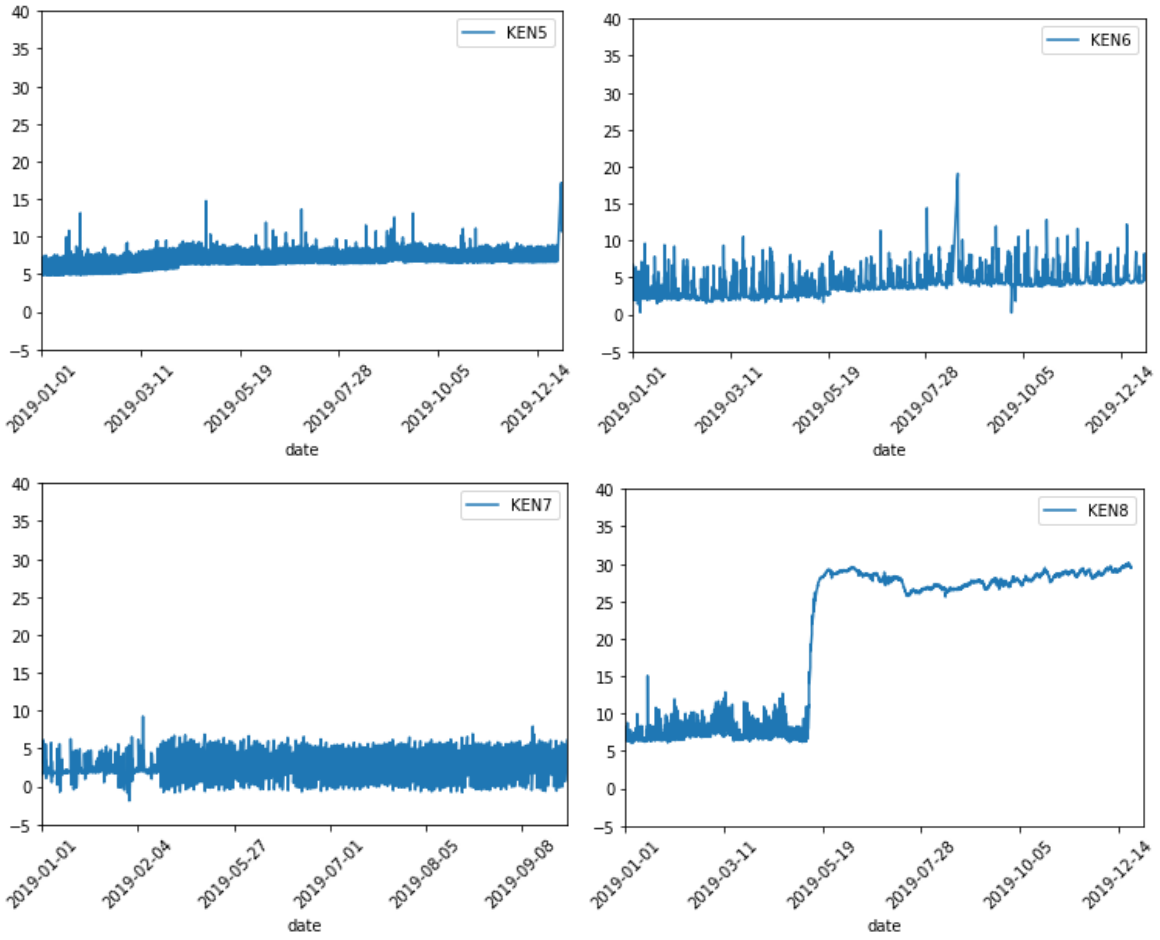
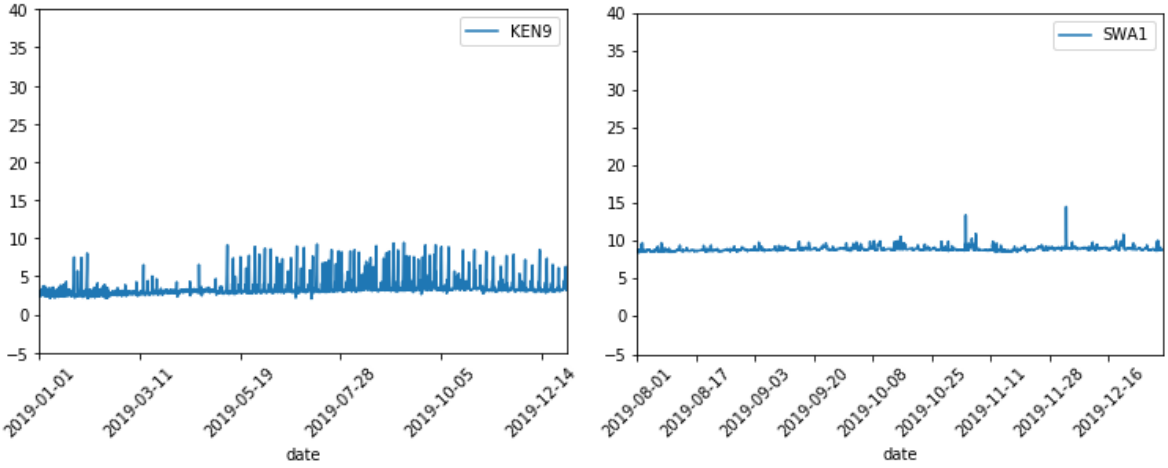
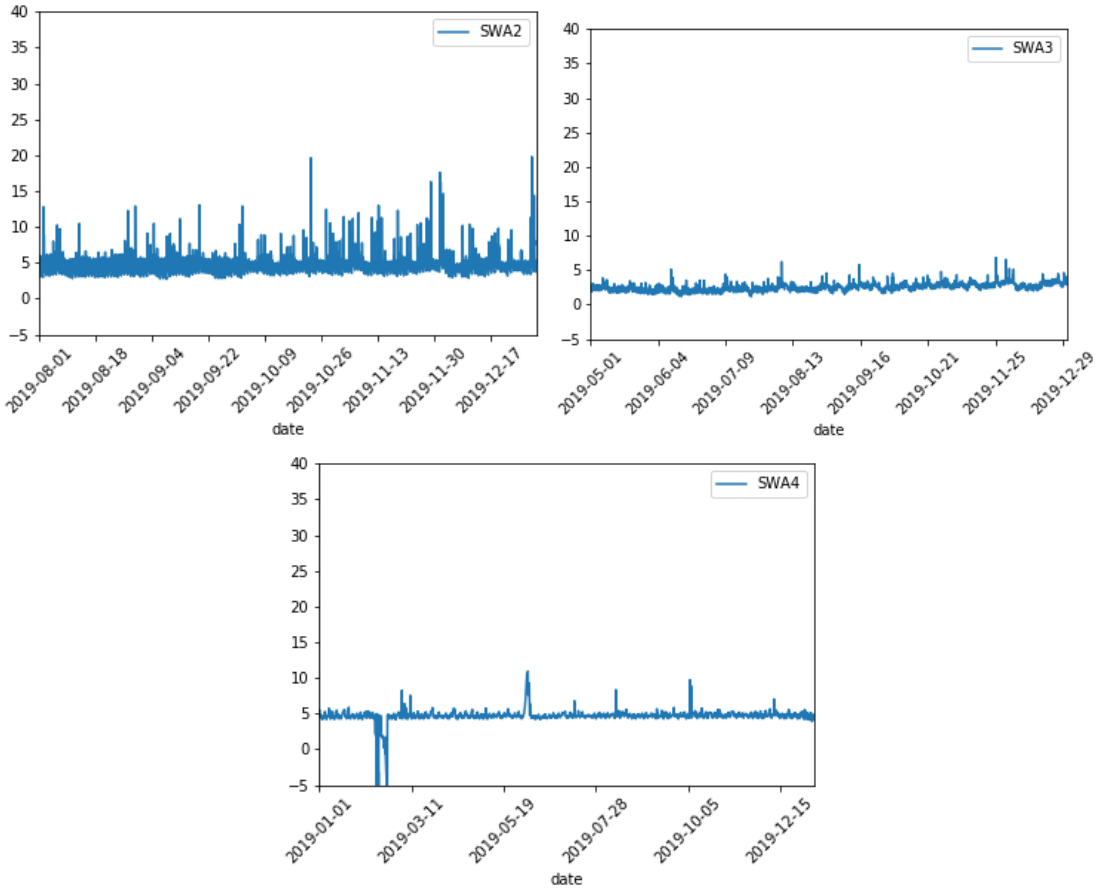


Figure 4 KEN4 has some high spikes, like due to many door openings

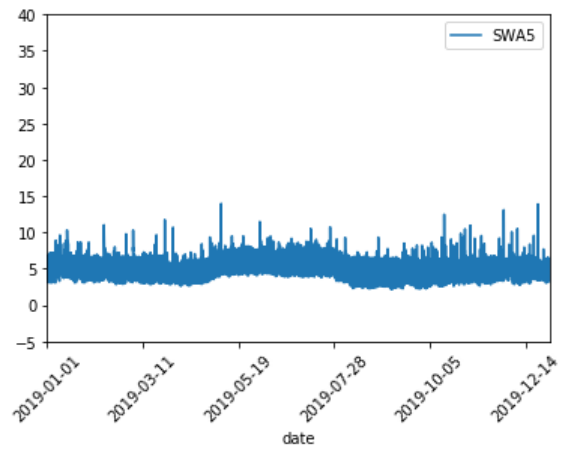


Figur 5 KEN 8 stopped due to technical fault. Not repaired, out of service.





Figur 6 SWA4 has a negative temperature dip, most likely a sensor fault as it comes back on track


SWA5
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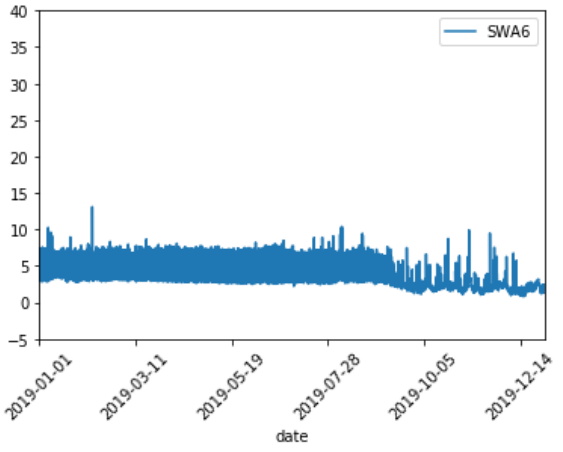
2019-12-14
date


SWA6
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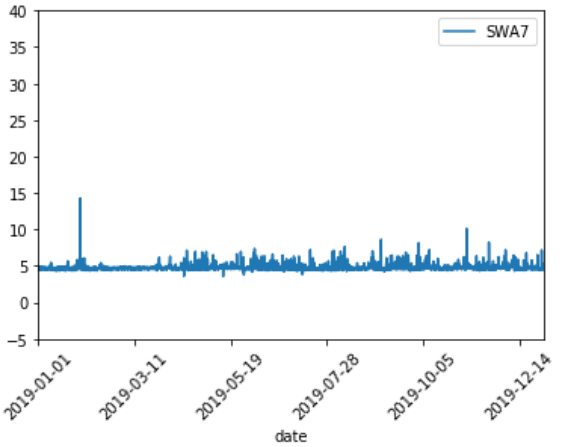
2019-03-11
2019-05-19
2019-07-28
2019-10-05
2019-12-14
date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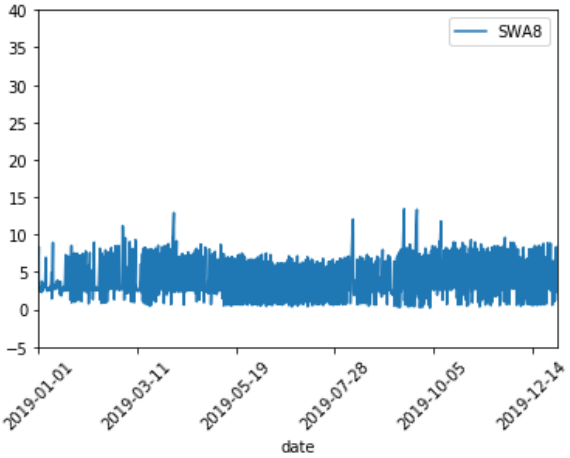
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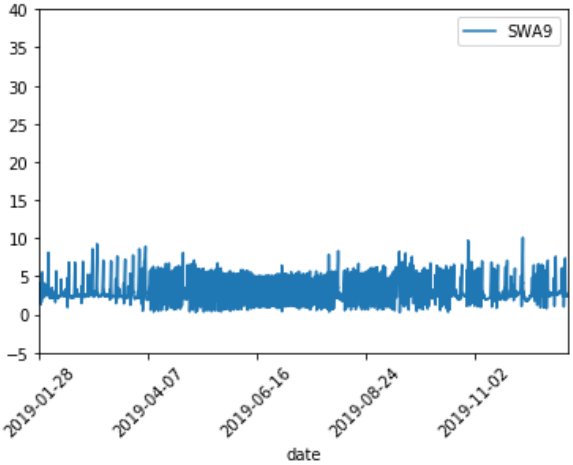
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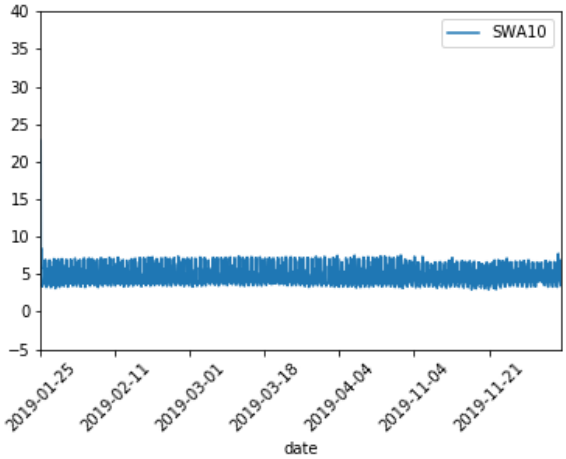
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2019-04-04
2019-11-04
2019-11-21
date

14. ANNEX C Questionnaires

Template for SCA user interview (phone or personal)

Date of interview	YYYY-MM-DD	
Country	COL/KEN/SWA	
Location	Site no + name	
Interviewer		
Date of installation of unit	YYYY-MM-DD	
Refrigerator type + serial no		
Name and position of interviewed user		
	Rating/value	Comments
Does the vaccine refrigerator in general fulfil its intended purpose? 0= not at all 10 = perfectly well		
How many times per day do you open the door/lid?		
Average time (minutes) per opening		
How many times a month do you load it with new vaccine?		
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)		
Is the storage capacity too low? 0= much too small, 10 = large enough		
Easy access and overview of stored items? 0=bad, 10=perfect		
Are you using the unit for ice-pack freezing too (yes/no)		
If cooling water-packs where are they stored? ▪ A: Bottom ▪ B: In basket		
Is cleaning/daily maintenance easy? 0=very difficult,10= very easy		
Is the unit free of condensation? 0= heavy problems, soaked 10= no free water		

Is the storage temperature regulation OK? 10= perfect		
Was any vaccine damaged due to wrong storage temperature Y/N		
Did you follow the manufacturers maintenance guide in all aspects?		
Any other comments or recommendations to manufacturer?		

Template for SCB user interview (phone or personal)

Date of interview		
Country		
Location		
Interviewer		
Date of installation of unit		
Refrigerator type		
Name and position of user		
	Rating/value	Comments
Does the refrigerator in general fulfil its intended purpose? 0= not at all 10 = perfectly well		
How many times a week do you load it with new items? Please also notice kind of products.		
How many times did you have technical problems with the unit (pls describe all types of problems you experienced)		
Is the storage capacity too low? 0= much too small, 10 = large enough		
Easy access and overview of stored items? 0=bad, 10=perfect		
Is cleaning/daily maintenance easy? 0=very difficult,10= very easy		

Is the unit free of condensation? 0= heavy problems, soaked 10= no free water		
Is the storage temperature regulation OK? 10= perfect		
Were any goods damaged due to wrong storage temperature Y/N		
Do you use the fridge the same way every day, or are there peak load periods?		
What is the commercial benefit by using a fridge for your business? How many % is your business improved?		
Did you start selling new products due to the new cooling opportunity? Which?		
Would you recommend this product to others?		
Any other comments or recommendations to manufacturer?		

Summary of comments from eSwatini:

GEF SolarChill Project Equipment
Feedback Interviews
21-29 September 2020

Name of shop	Unit type	Data logger	COMMENTS
Emazomba	TFF	Both available	Capacity too small, owner would like to increase quantities and varieties of product. User happy with the performance of the unit.
Bhojane	TFF	Both available	Capacity too small. Would like to have an upright bottle cooler with a glass door that uses solar.
Emalangeni	Vestfrost	None available	Capacity too small and would like the fridge to be cooler.
SBS/ Mpuluzi	TFF	Both available	Unit to be moved to another grocery shop. Owner of the shop passed on and the family is at loggerheads regarding the estate. The owner of the shop had two wives.
Lubhedze	TFF	Outside available	Capacity too small.
Ekuphumuleni	Vestfrost	Outside available	Condenses when it is too hot
Induna	TFF	None available	Condenses when it is too hot
Ebbenezer	Vestfrost	None available	Would want a freezer type.
Thandabantu	TFF	None available	Solar panels were stolen and replaced during the site feedback visits. The store operator available never made use of the unit therefore could not be interviewed.
Emahandeni	TFF	None available	Capacity too small.
Nkwene	TFF	Both available	Capacity too small.
Nokuthula	Vestfrost	None	Would like to have a freezer unit.
Bindzani	Vestfrost	None	Capacity too small
Lushini	TFF	Outside available	Would want a freezer type.
Nhlane	TFF	Both available	Capacity too small and would like to have a freezer type unit.

General comments: MCIT officers explained why the capacity of the units was small. All grocery store operators were happy with the performance of the nits and mentioned that there were potential benefits associated with the presence of the units. Units have enabled them to sell products that they did not before.

15. Annex D List of installations with RMS

Colombia:

ID	Latitude	Longitude	Unit
1	-0,88	-70,98	B-Medical TCW40 SDD
2	-1	-74,02	B-Medical TCW40 SDD
3	10,08	-73,15	Godrej Appliances GVR50DC
4	7,96	-74,05	Vestfrost VLS024 SDD Greenline
5	8,56	-74,26	Godrej Appliances GVR50DC
6	1,63	-74,56	B-Medical TCW40 SDD
7	1,34	-74,85	Vestfrost VLS024 SDD Greenline
8	1,57	-75,87	Vestfrost VLS024 SDD Greenline
9	2,8	-76,48	B-Medical TCW40 SDD
10	2,57	-77,89	B-Medical TCW40 SDD
11	1,82	-76,78	Vestfrost VLS024 SDD Greenline
12	10,46	-73,26	Vestfrost VLS024 SDD Greenline
13	10,42	-73,59	B-Medical TCW40 SDD
14	8,66	-76,17	B-Medical TCW40 SDD
15	7,74	-76,41	Godrej Appliances GVR50DC
16	5,52	-76,97	B-Medical TCW40 SDD
17	4,26	-77,36	B-Medical TCW40 SDD
18	4,26	-77,36	Vestfrost VLS024 SDD Greenline
19	1,86	-69,01	B-Medical TCW40 SDD
20	2,72	-67,56	Godrej Appliances GVR50DC
21	2,72	-67,56	B-Medical TCW40 SDD
22	12,2	-72,15	Vestfrost VLS024 SDD Greenline
23	11,93	-71,28	B-Medical TCW40 SDD
24	12,22	-71,48	B-Medical TCW40 SDD
25	12,35	-71,31	Godrej Appliances GVR50DC
26	12,2	-72,15	Vestfrost VLS024 SDD Greenline
27	10,53	-74,2	Vestfrost VLS024 SDD Greenline
28	10,19	-74,92	Vestfrost VLS024 SDD Greenline
29	2,48	-78,11	B-Medical TCW40 SDD
30	2,04	-78,66	Vestfrost VLS024 SDD Greenline
31	1,7	-78,25	Vestfrost VLS024 SDD Greenline
32	0,96	-76,41	Vestfrost VLS024 SDD Greenline
33	-0,19	-74,78	B-Medical TCW40 SDD
34	0,02	-71,01	Godrej Appliances GVR50DC
35	0,02	-71,01	B-Medical TCW40 SDD
36	0,62	-69,21	B-Medical TCW40 SDD
37	6,18	-68,35	Vestfrost VLS024 SDD Greenline

eSwatini:

ID	Site	Latitude	Longitude	Unit
1	Mbabane	31,143	-26,333	TCW 40
2	Piggs peak	31,249	-25,958	TCW 40
3	Ekufikeni	31,091	-26,025	HTCD 90
4	Maphalaleni	31,122	-26,066	ZLF 30
5	Sithobela	31,596	-26,882	HTCD 90
6	Siteki	31,950	-26,454	TCW 40
7	Mambane	31,906	-26,446	HTCD 90
8	Bhahwini	31,242	-26,752	ZLF 30
9	Gebeni	31,347	-26,637	ZLF 30
10	Ncabaneni	31,130	-26,619	ZLF 30
11	Mankayane	31,063	-26,671	HTCD 90
12	Bulunga	31,550	-26,617	ZLF 30
13	Zondwako	31,310	-26,250	ZLF 30
14	King Sobhuza II	31,362	-26,495	TCW 40
15	Nsalitje	31,650	-27,283	ZLF 30
16	Hlatikhulu	31,324	-26,974	HTCD 90
17	Nhlangano	31,208	-27,121	TCW 40
18	Gege	31,016	-26,968	ZLF 30
19	New Haven	31,491	-27,051	ZLF 30
20	Mfishane	31,366	-26,575	ZLF 30
21	Sigcineni	31,303	-26,725	ZLF 30
22	Ntjanini	31,561	-27,076	ZLF 30
23	Nhlangunjani	30,879	-27,037	ZLF 30
24	Nhletjeni	31,393	-27,043	ZLF 30
25	Moti	31,423	-26,704	Vestfrost
26	Hluti	31,560	-27,203	Vestfrost
27	Phunga	31,483	-26,797	Vestfrost
28	Dwalile	30,796	-26,661	ZLF 30
29	Sigombeni	31,329	-26,361	Vestfrost
30	Mahlangatsha	31,077	-26,822	Vestfrost
31	Mpuluzi	30,876	-26,445	Vestfrost
32	Musi	30,912	-26,723	Vestfrost
33	Mkhitsini	31,414	-26,632	Vestfrost
34	Lushikishini	30,871	-26,799	Vestfrost
35	Malandzela	31,292	-26,129	Vestfrost
36	Ndvwabangeni	31,580	-25,866	Vestfrost
37	Ekuphileni	31,375	-26,239	Vestfrost
38	Ndzevane	31,953	-26,948	Vestfrost
39	Vuvulane	31,879	-26,075	Vestfrost
40	Lubulini	31,903	-27,021	Vestfrost

Kenya:

No	Latitude	Longitude	Fridge Type
1			ZLF 30DC
2	-1,0786562	35,8538387	VLS024
3	-0,8315092	35,9645605	VLS024
4			ZLF 30DC
5			ZLF 30DC
6	-1,0786562	35,8538387	VLS024
7	-1,0786562	35,8538387	VLS 024
8			VLS 024
9			ZLF 30DC
10	-0,7002107	34,9545157	ZLF 30DC
11	-0,4373655	34,1621208	VLS024
12	-0,5660066	34,1621023	ZLF 30DC
13	-0,689396	34,1485274	ZLF 30DC
14	0,3335767	34,487342	VLS 024
15	0,4683481	35,9501518	VLS024
16	0,6075519	34,9599122	VLS 024
17	-3,2556	36,0178	ZLF 30DC
18	3,1023721	35,4742461	VLS 024
19	3,5501707	35,8310643	VLS 024
20	-3,1247	35,7357	ZLF 30DC
21	4,205345	34,3424702	VLS 024
22	1,9805	37,9116	VLS 024
23	1,8341	37,454	ZLF 30DC
24	2,6496	36,9326	VLS 024
25	1,8483441	37,0050293	ZLF 30DC
26	1,7776921	37,2010052	VLS024
27	-0,1743219	37,8612262	ZLF 30DC
28			ZLF 30DC
29			VLS024
30	-1,4517887	38,2290315	VLS024
31			VLS024
32	-3,353723	40,017878	ZLF 30DC
33	-3,2468	39,7931	ZLF 30DC
34	-2,2715208	40,010189	VLS024
35	-2,2715208	40,010189	VLS024
36	-1,1801206	39,8324239	ZLF 30DC