# WHY FRIDGES FAIL PART 2:
## RTM Data for Maintenance

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NEXLEAF ANALYTICS

VILLAGEREACH Starting at the Last Mile

# SUMMARY AND KEY FINDINGS

A cold chain expert and a Ministry of Health (MOH) technician used **Nexleaf Analytics' ColdTrace remote temperature monitoring (RTM)** dashboard data to **remotely** identify every failing fridge in Gaza Province, Mozambique. They then visited or called those 27 clinics with failing fridges, diagnosed and attempted to fix the failures, verified repairs using the ColdTrace dashboard, and documented all of their findings and actions.

This report includes key findings such as **a list of the most common fridge failures, temperature signatures that uniquely identify failures, and spare parts and tools required to address most of the cold chain equipment issues.** The report ends with concrete short-term and long-term recommendations for the MOH and stakeholders.

A major impediment to achieving 95% fridge uptime[1] for the fridges in this assessment was **a lack of necessary tools and spare parts for the local technician**. While next generation equipment will likely address some of the failures identified in this report, improper solar panel and fridge installation and timely maintenance will remain outstanding issues. A follow-up assessment can uncover any common issues early on with next generation equipment that can then be integrated into trainings, planned preventive maintenance, and product design to maximize uptime. RTM can also be used to inform maintenance strategy and provide insight into the long-term field performance of new equipment.

# BACKGROUND

Using a randomized control trial model, **Nexleaf Analytics**, the **Mozambique MOH**, and other partners collaborated to study the performance of vaccine refrigerators and evaluate whether fridge uptime is improved by continuous remote temperature monitoring (RTM) with SMS alerts enabled. (See Appendix I for evaluation details and results up to May 2015).

In August 2014, we began monitoring 83 fridges geographically distributed throughout Province, Mozambique, with Nexleaf's RTM device, ColdTrace. In the ColdTrace intervention group, which actively sent SMS alerts to clinic staff, fridges showed an **88% reduction in freezing**[2] compared to the control group, in which health facility staff used stem thermometers to track fridge temperature twice daily on paper charts. Fridge temperatures in all groups were passively monitored by ColdTrace to, but in the control group, no SMS alerts were sent and staff were not trained in RTM.

Overall, the study showed that fridges frequently failed to maintain the WHO recommended 2°C to 8°C temperature range. Further, while the ColdTrace intervention group achieved higher uptime, even some fridges with RTM alerts enabled did not achieve 95% uptime.

We developed this **follow-up assessment** focused on **repair and maintenance** to:

1) get definitive information on specific reasons for fridge failures;
2) document the diagnoses, tools and spare parts that fix these failures;
3) investigate if and how RTM data can be used to diagnose failing fridges prior to a facility visit and/or remotely enable repairs by calling clinics on the phone to take simple actions.

[1] **fridge uptime** defined as the amount of time the cold chain equipment spends between 2°C to 8°C

[2] **freezing** defined as total duration of freezing excursions under -0.5° C

## ASSESSMENT MODEL

is a cold chain expert who has worked with several leading global bodies in the field of vaccine distribution for over 3 decades. traveled to Mozambique and, along with the MOH technician, viewed 3 months of temperature data from all 83 fridges via the ColdTrace dashboard. Using this data, identified **27 facilities that required maintenance attention**. *(All facilities in this report have been de-identified.)*

This expert and the MOH technician called and/or visited each facility to **diagnose** and attempt to **fix** each problem (given the available tools and spare parts), and to **document** each solution. Data were collected from each site using a survey tool on an iPad. The expert and the technician monitored fridge performance on the dashboard for 72 hours after fixing equipment to make sure they had accurately diagnosed and addressed the cause of failure. Due to a lack of necessary spare parts, they could not address failures such as a flat battery in a solar fridge or a failed compressor.

The expert conducted his field visits from September 24, 2015 until October 14, 2015. All visits, phone calls, and follow-ups documented in this report were completed by the end of November 2015. **After the first few visits, the expert and the MOH technician were able to confidently recognize temperature excursions caused by improperly adjusted thermostats or by flat batteries in solar powered fridges from viewing data on the ColdTrace dashboard alone** (see Figures E and F).

## ASSESSMENT FINDINGS

The cold chain expert and MOH technician diagnosed and addressed fridge failures at a total of **27 facilities** (Table 1), of which 12 sites were visited in person. **Fridge failures in 15 facilities were remotely diagnosed using the ColdTrace dashboard**.

**Table 1: Most Common Reasons for Fridge Failures**

| Cause of Failure | Number of fridges* |
|---|---|
| Flat Batteries in Solar Fridges | 11 |
| Thermostat Improperly Adjusted | 9 |
| Power Outage | 5 |
| Loose Wiring Connection | 2 |
| Decommissioned Fridge | 2 |
| Failed Compressor | 1 |
| Poor Installation of the Solar Panel | 1 |

*Note: Some fridges had multiple problems.

## Finding 1: Fridges needing thermostat adjustments can be diagnosed and fixed remotely, and fixing improperly adjusted thermostats increased uptime by 30%

9 fridges required **thermostat adjustments** to achieve the correct temperature range; in this category, eight out of the 9 fridges were fixed. One such facility was visited in person, and the expert and technician adjusted the thermostat.

For the other 7, after reviewing temperature graphs on the ColdTrace dashboard and remotely diagnosing a thermostat adjustment problem, the MOH technician **contacted the facilities over the phone** and provided detailed instructions on how to adjust the thermostats.

The technicians then monitored the fridge performance at these facilities for the next 72 hours to make sure the adjustments were done correctly (Figures A and B). **After remote diagnosis and fix of thermostat adjustment, fridge uptime at the 8 facilities was increased by 30%; heat exposure was reduced by 78%, and cold exposure was reduced by 60%** (Figure C).

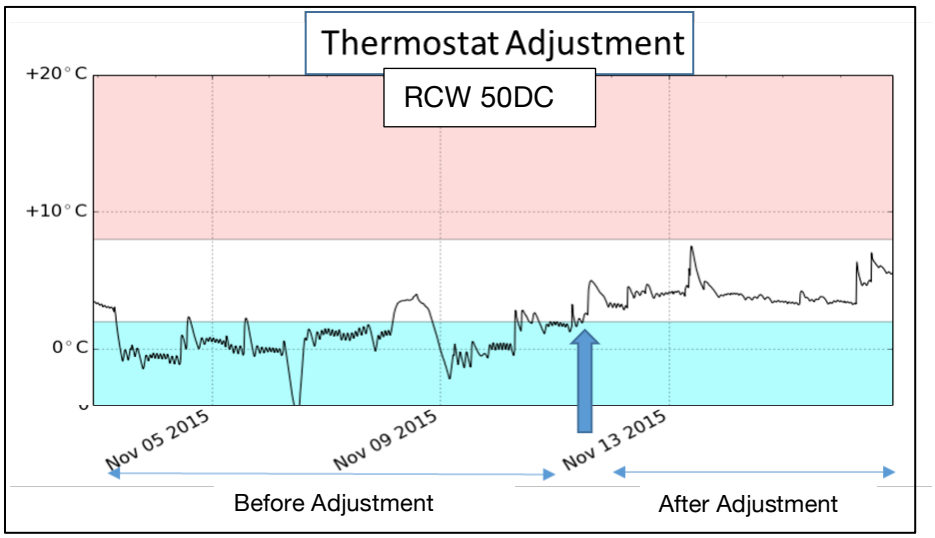



**Figure A:** Screenshot of ColdTrace dashboard showing temperature data from a Dometic RCW 50DC model fridge experiencing cold and freezing excursions before the thermostat adjustment, then performing in range after the adjustment.

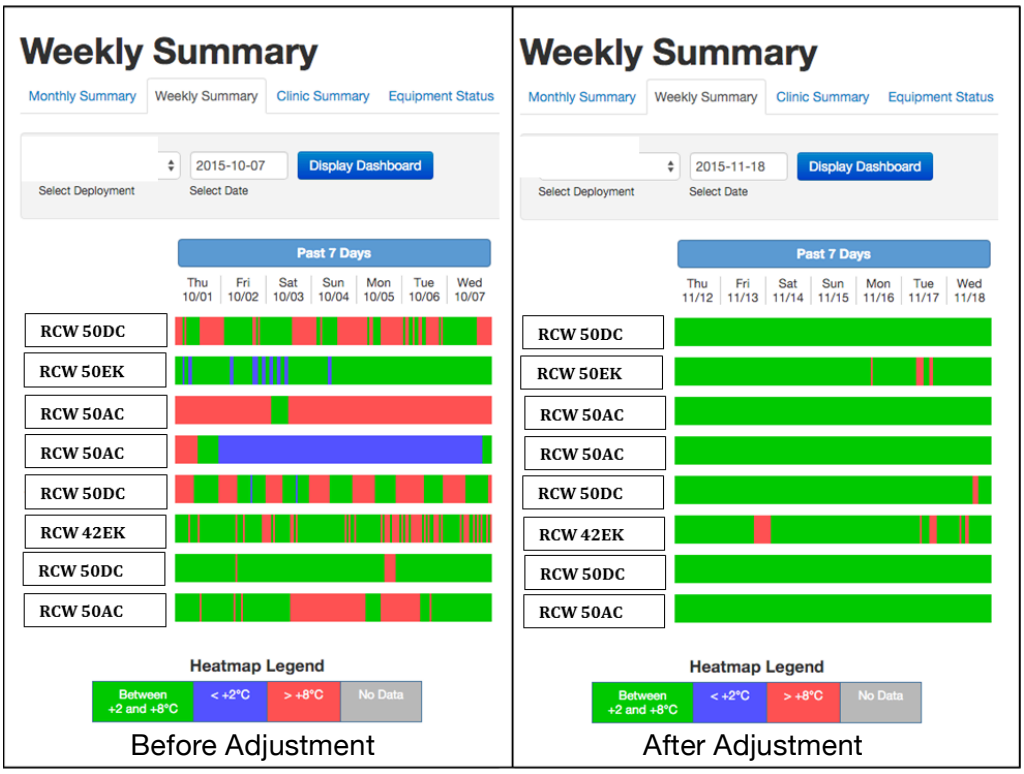



**Figure B:** Screenshot of ColdTrace dashboard weekly summary showing performance of 8 fridges before and after thermostat adjustment.

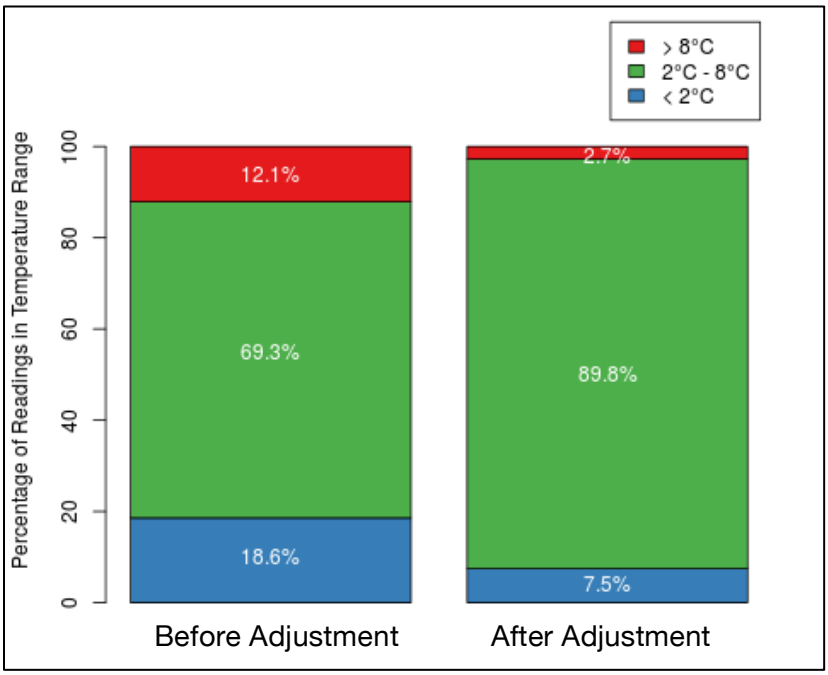



**Figure C:** After remote diagnosis and fix of thermostat adjustment, **fridge uptime at the 8 facilities was increased by 30%.** Heat exposure was reduced by 78%, and cold exposure was reduced by 60%. (n = 8 facilities)

## Finding 2: Fridges with flat batteries could be diagnosed by temperature plots

The technicians identified 11 facilities with Dometic RCW 50DC model solar fridges that had **flat batteries in need of replacement**. These fridges experienced unacceptable frequency and duration of temperature excursions. Unfortunately, due to lack of replacement batteries, the expert and technician could not fix this problem during the assessment. There is an **immediate need** for replacing these batteries and for monitoring fridge performance after replacement.

When diagnosing a RCW 50DC model solar fridge with a flat battery, **a distinctive periodic pattern of temperature excursions appeared on the weekly temperature summary** (Figure D). During the day, the compressor ran using solar power, and the fridge reached the appropriate temperature range. However, overnight the vaccines were exposed to heat excursions because the flat battery failed to store any power to keep the fridge running while the sun was down.

This distinct periodic pattern caused by a flat battery was also seen in daily temperature traces (Figure F). **Alarmingly, the fridge would appear functional to facility personnel checking the temperature during opening and closing of the clinic.**


**Figure D:** Screenshot of the weekly summary visualization on the ColdTrace dashboard showing temperature excursions for several fridges with flat solar batteries. **A distinct periodic pattern of temperature excursions can be observed.**

***Note on cold excursions:** It was previously thought that a flat battery would only cause heat excursions. However, in the case of these fridges, the combination of a flat battery and an improperly adjusted thermostat caused cold excursions, which would occur when the sun was up during the day.

## REMOTE DIAGNOSIS:
### Temperature Data Signatures of 'Thermostat Adjustment Needed' and 'Flat Battery'

Clear patterns in temperature data viewable on the ColdTrace dashboard can be used to remotely diagnose fridge failures due to **thermostat adjustment needed** and **flat battery** (Figures E and F). As facility-level RTM expands, we anticipate that additional temperature data signatures corresponding to other common causes of fridge failure will emerge.

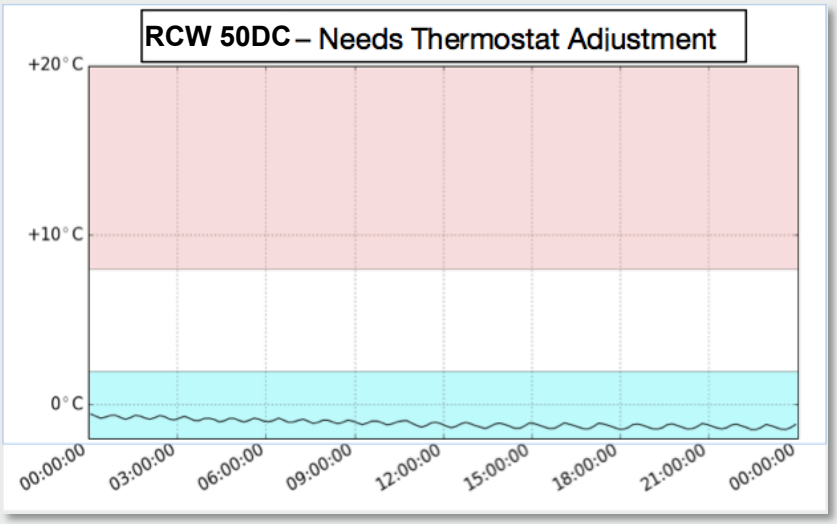



**Figure E:** Screenshot of ColdTrace dashboard showing 24 hours of temperature data from a fridge that **needs thermostat adjustment**. The temperature is consistently out of range.

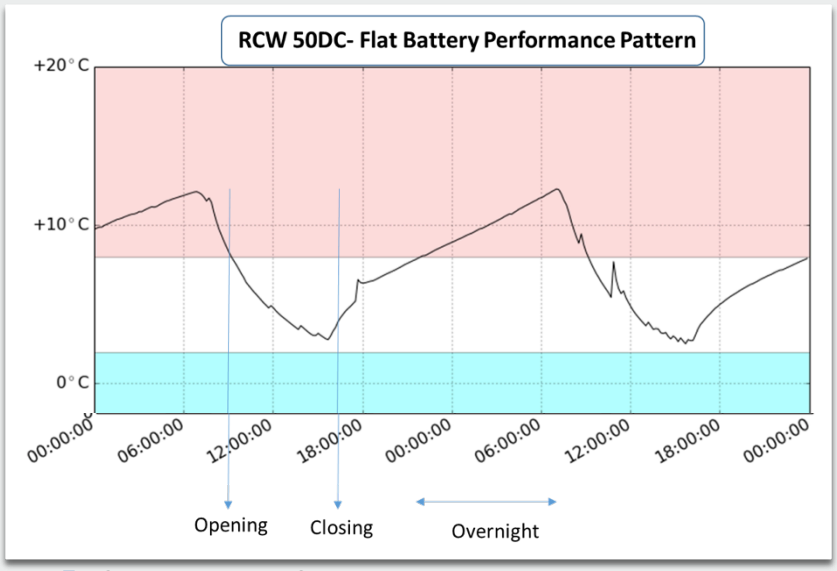



**Figure F:** Screenshot of ColdTrace dashboard showing 48 hours of temperature data from a **solar fridge with flat battery.** At opening and closing time, when facility personnel check the temperature of the fridge, the temperature appears between 2-8° C. However, temperature excursions occur overnight.

## Finding 3: ColdTrace dashboard data enabled local technicians to identify and fix failing fridges

After the expert left Mozambique, the Technology Officer from VillageReach and the MOH technician used the ColdTrace dashboard to identify additional facilities experiencing temperature excursions and address those problems. **After diagnosing and fixing the failing fridges, they continued to use the ColdTrace dashboard to remotely monitor fridge performance**, ensuring an effective fix. If problems continued, escalated alerts from the RTM system prompted the MOH technician to check the temperature data for that fridge.

The Technology Officer from VillageReach explained how he and the MOH technician addressed a problem in a facility using temperature data they viewed on the ColdTrace dashboard (Figure G). The dashboard enabled the technician to confirm the fridge was fixed.

> *"We replaced [Facility A]'s thermostat last Friday and set it to 1 [warmest].* ***On Monday [November 16, 2015] we noticed that fridge was still cold.*** *We went to [Facility A] again on Tuesday and spent all the day there trying to find out the problem. At the end we had to replace the thermal relay…and kept the thermostat set to 1.* ***Now the temperature seems to be good, but we will keep eyes on it****."*

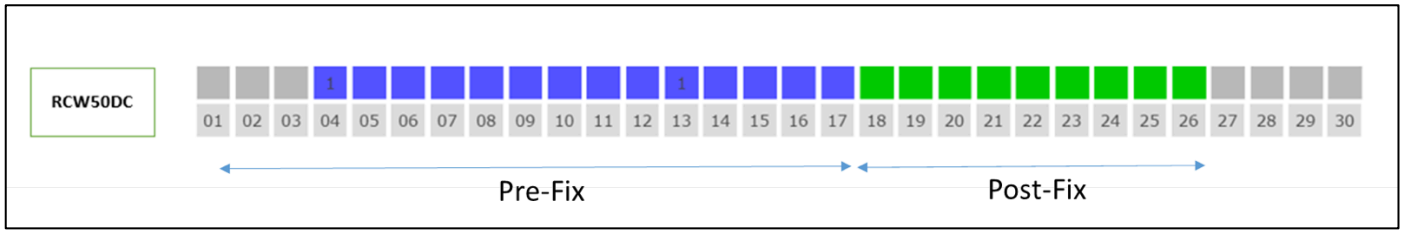



**Figure G:** ColdTrace temperature plot showing temperature excursions from Nov 4-17th, 2015 (blue) pre-fix and proper function (green) post-fix, allowing the MOH technician to ensure fridge failure is addressed properly.

## Finding 4: Other field visit observations

During the 12 field visits conducted for this assessment, the expert documented poor fridge installation, dirty solar panels, and worn gaskets contributing to degraded equipment performance. These types of problems could also recur with next-generation equipment. Details as follows:

**Improper fridge installations:** Poor installation of solar panels, poor wiring, and loose connections were observed in 7 facilities. Some wires were hanging loose under the panels, and for ground-mounted panels, this can cause the wires to be disconnected by animals. Cables should be secured by cable tighteners or run in conduits. Installations can be improved by: a) conducting refresher training for the technicians; and b) supplying the tools and materials needed for proper installation.

**Dirty and incorrectly installed solar panels cause low performance:** In 4 facilities, the expert found the solar panels to be dirty and poorly maintained. Dirty panels can lead to decreased battery charge and thus poor performance. In addition, improper installation techniques were observed, including poor wiring and placement of solar panels in shady areas. Regular trimming of the surrounding trees was also recommended to provide sufficient sun exposure for the solar panels.

**Worn gaskets, a common problem not currently affecting fridge performance:** In 3 facilities, the fridge gaskets were worn off, and the expert recommended replacing the old gaskets when supplies are available. However, the worn gaskets have been temporarily repaired with gaffer tape and do not interfere with the fridge performance at the moment.

**Table 2: Snapshot of Observations from the Field in Gaza, Mozambique**

| | |
|---|---|
| **Average age of the cold box** | 6 years (Range from 4-15 years) |
| **Average year of fridge installation** | 2010 (Range from 2008-2014) |
| **Tools used to fix the issues** | Gaffer tape, multi-meter, screwdriver, spanners |
| **Average distance from the district** | 70 km (range from 30-150 km) |
| **Rural geographic location** | 12 facilities |
| **Staff in charge of the fridge*** | 9 MOH Nurse, 1 General Nurse, 1 Agent Medicina |

*One facility visited had a decommissioned fridge therefore no staff was in charge of that fridge.

# LEARNINGS, RECOMMENDATIONS & NEXT STEPS

A major impediment to achieving 95% uptime for the fridges in this assessment was a lack of necessary tools and spare parts. Below is a summary of how this finding, along with the temperature data signatures and other insights from this assessment, can impact the MOH strategy moving forward:

## Short-term:

- The technician can now remotely diagnose some fridge failures, call facilities on the phone to explain how to fix the thermostat setting, and check fridge data afterwards to ensure successful thermostat adjustment. This will help the MOH to save time, money, and resources.
- The MOH now has the data on facilities with flat batteries that need immediate attention.
- The technician can now promote preventive maintenance actions (such as cleaning solar panels) by calling facilities periodically to help ensure continued reliable operation of fridges.

## Medium-term:

- The technician can prioritize visits to target the worst performing fridges in the district based on ColdTrace data, enabling efficient use of limited human resources and transportation funding.
- The spare parts and tools compiled by the expert listed in Appendices II and III can be procured to improve the technician's capacity.

**APPENDICES II & III REMOVED FROM PUBLIC REPORT**

### Long-term:

- Data on how different equipment models perform can enable the MOH to calculate the average annual cost per fridge model and make evidence-based fridge procurement decisions.
- The failure and repair information gathered in this study can facilitate informed decision-making at the national level around spare parts procurement.
- ColdTrace dashboard data can become a key component of the ongoing maintenance strategy for the country. In addition to enabling targeted maintenance and confirmation of fixes, ColdTrace data can ensure that new fridges are properly installed and functioning properly.

## REPLICABLE MODEL

This assessment model can be replicated in other countries and provinces, and several components of this model can be practiced on a periodic basis by MOH technicians in any district or province that has remote temperature monitoring. Once more, the technicians must have the necessary tools, spare parts, phone resources, and transportation funding to address the problems that RTM data can reveal.

# EVALUATING THE BENEFITS AND COSTS OF REMOTE TEMPERATURE MONITORING: EVIDENCE FROM MOZAMBIQUE

Yavari S, Prosser W, Khanlawia B, Ramanathan N, Coelho A, Bechtel R, Dipuve A, Graham E, and Mvundura M.

## Background

Current protocol for using thermometers twice-a-day to monitor and record vaccine refrigerator temperatures often fails to detect and ensure proper reporting of excursions above or below the recommended 2°C to 8°C range for vaccine storage.

## Hypothesis

By using short-message service (SMS) technology to alert health facility staff about temperature excursions and escalate unresolved issues to supervisors, the **remote temperature monitoring (RTM)** device, ColdTrace, can help facility staff to promptly address problems and better protect vaccine potency.

Although our evaluations remain ongoing, findings communicated here reflect work conducted from August 2014 to April 2015.

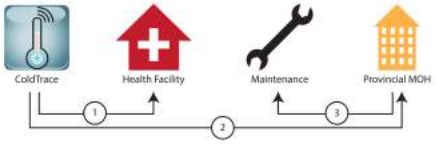
## Evaluation design

Using a randomized control trial design, health facilities were randomized into three groups controlling for the age of the refrigerators and distance of the facility from the provincial Ministry of Health (MOH).

- **Group 1** included 29 health facilities using RTM + SMS alerts (Staff trained on ColdTrace usage).
- **Group 2** included 28 health facilities using 30-day temperature recorders (30DTRs) with visual alerts; staff trained on usage.
- **Group 3** included 26 health facilities with stem thermometers (this is the status quo with twice-a-day temperature readings).

To inform comparisons, continuous temperature and power data were collected and transmitted remotely from all participating health facilities using RTM devices. We also calculated the total cost of ownership (TCO) for the RTM ColdTrace device and collected qualitative data through informal interviews with health facility and MOH staff.

Figure 1: **Role of SMS alerts in Group 1.**




1. ColdTrace SMS alerts are sent to health facility staff when refrigerator temperature is less than 2°C for 30 minutes or more than 8°C for 5 hours.
2. Escalated SMS alerts are sent to supervisors when refrigerator temperature is less than 2°C for 60 minutes or more than 8°C for 10 hours.
3. Technician is informed of faulty refrigerators and visits health facility to address the issues promptly.

## Results

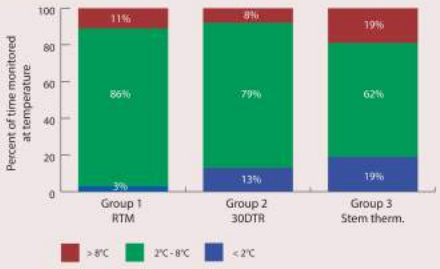
All temperate data presented in these results have been collected by a RTM device placed in each health facility, including at facilities in Groups 2 and 3.

### Key outcomes

**63%-88%**
**Reduction in Cold and Freezing Duration**

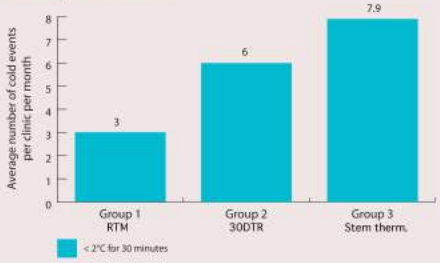
**RTM reduced cold and freezing alarm duration by 63%-88% compared to 30DTR and stem thermometers**

Figure 2: **Fridge uptime achieved in each group.**




Facilities in Group 1 (RTM + SMS) achieved an average uptime of 86%, while those in Group 2 (30DTR) and those in Group 3 (stem thermometers) achieved average uptimes of 79% and 62% respectively.

Figure 3: **Average number of cold events per clinic per month.**



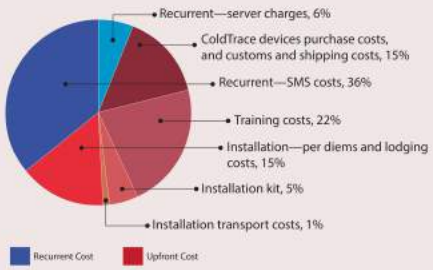

Facilities in Group 1 (RTM + SMS) had 50% fewer cold excursions than those in Group 2 (30DTR) and 62% fewer than those in Group 3 (stem thermometers)($p<0.02$).

Figure 4: **Total monthly duration of cold and freezing alarms (facility average).**


The RTM in Group 1 reduced total duration of cold alarms by 75% compared to Group 2 (30DTR) and by 82% compared to Group 3 (stem thermometers) ($p<0.02$).

The RTM in Group 1 reduced total duration of freezing alarms by 63% compared to Group 2 (30DTR) and by 88% compared to Group 3 (stem thermometers) (Group 3 only $p<0.05$).

Figure 5: **Total cost of ownership of RTM.***




* Costs for RTM annualized over three years; does not include cold chain equipment maintenance and repairs costs.

- Annualized RTM costs per health facility are $US208.
- A health facility serving an annual target population of 250 children stores approximately $226 worth of freeze-sensitive vaccines each month.
- Therefore, for this size of a health facility, the value of vaccines that could be damaged by one freezing incident in a given month is more than the annual costs of RTM.

Figure 6: **Qualitative feedback on the value of RTM + SMS.**

nurse — **"Before I received a SMS alert, I realized the fridge was unplugged accidentally when clinic was being pointed so I corrected the problem."**

technician — **"Before, there was lack of information about fridges. Now, there are some improvements as I get information about any problem that occurs inside the fridge; it facilitates a quicker intervention in equipment, giving us a preliminary diagnosis."**

MOH — **"While on field distribution, we received high temperature alerts due to power outage. We communicated with another colleague in province to load ice packs into the fridge, to request fuel for the generator, and to monitor temperature to prevent loss of vaccines."**

## Conclusion

Lower freezing duration was observed in Group 1 health facilities, this could be because health facility staff and supervisors in Group 1 were informed about temperature excursions through SMS and escalated alerts in real-time and therefore had the opportunity to take prompt actions and inform technicians when needed.