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Seventh Quest Regular Trial Shipment

Bananas from Ecuador to the Netherlands

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Report 763

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Colophon

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Abstract

The "Quest regular" system has been developed to reduce power consumption of reefer containers. The Quest Regular concept and corresponding CCPC software was tested in a real-life shipment of bananas from Ecuador to the Netherlands in December 2006. The goal of the trial shipment was to test the software and compare the power usage, temperature distribution and product quality of 7 test containers to 3 reference containers. The reference containers were shipped simultaneously at original settings. Three different sets of settings were used for the test containers, Quest1, Quest2 and Quest3. One of the test containers was equipped with a scroll compressor: Quest1-scroll. Shipment from Ecuador was chosen to be able to test on a relatively long voyage.

Including the pull down phase, mean savings over the whole trip are 40% for Quest1, 54% for Quest1-scroll, 45% for Quest2 and 48% for Quest3. Power savings during cycling are approximately 50% to 70%, depending on ambient temperature.

The supply and return air fluctuations in the Quest containers are dampened in the carton temperature data. The largest recorded carton temperature fluctuation has an amplitude of 0.25°C.

As in the previous banana trial, a few units give alarm code 64 (discharge temperature over limit). We advise Carrier to double check if this is a CCPC software effect.

During Quest Regular Mode, the minimum supply temperature mostly does not reach supply setting for the scroll unit and the Quest3 settings. The Quest1 and Quest2 test containers did reach the minimum supply temperature. The adaptation of the field software, after comparable issues in the previous shipments, apparently improved performance, but did not fully prevent the issue to come up again.

The carton temperatures in the Quest containers are warmer then those of the reference containers, with a larger bandwidth. The Quest3 and Quest1-scroll containers are further from setpoint then the Quest1 and Quest2 containers. This is already the case after pull down, so probably caused by produce specifics or stowage. The Quest1 and Quest2 containers are 0.5°C further from the setpoint, while the bandwidth was 0.9°C and 0.3°C larger.

The Quest regime seems not to have change quality output compared to normal regime, except possible slightly faster ripening of the bananas in the warmest cartons.

Acknowledgements

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We also thank Carrier Transicold for providing the necessary CCPC software for the trial and the unit data-files that were made from the unit downloads. We especially would like to thank Mr. Griffin, Mr. Dudley, Mr. McIntosh and Mr. Rogers.

Quality inspections at arrival was supported by MMS. We would like to thank Mr. Pailes for sharing their data files and findings with us, part of which were used for this report.

We are indebted to our A&F colleagues Mr. van den Boogaard, Mr. Boerrigter, Mr. van Soest, and Mrs. Otma for their help during the organisation of the trial and its preparations as well as the product quality assessments.

Finally, our thanks go to Fruta Del Pacifico and Belfruco, whose fruit was transported and who made quality inspection possible after transport.

Contents

1 Introduction

The "Quest regular" system has been developed to reduce power consumption of reefer containers. As a follow-up of the real-life Quest trial with mangoes, apples, mandarins, bananas, melons and pineapples it has been tested for long shipments of bananas, pineapples and mangoes in December 2006. In order to exactly determine the amount of power reduction, a comparison was made with three standard controlled reefer containers. All ten 40ft. containers were loaded with bananas from the same origin and transported on the same vessels (Maersk Rosario and Jeppesen Maersk). The shipment was from Ecuador (Guayaquil) to the Netherlands (Rotterdam). The transport time was 20 days to Rotterdam.

Seven test containers were equipped with and controlled by the "Quest Regular" software, also referred to as CCPC (Compressor-Cycle Perishable Cooling). The containers MAEU5830158 (test11) and MWCU6801403 (test12) were controlled according to CCPC settings set 1; the containers MWCU6532963 (test21) and MWCU6781441 (test22) according to CCPC settings set 2, which was relatively warm compared to settings set 1; and the containers GESU9059750 (test31) and MWCU6755653 (test32) according to CCPC settings set 3, which was relatively cold compared to settings set 1. The containers CRLU5184302 (ref 1) and MWCU6711932 (ref2) served as reference containers. Also, two reefer container equipped with scroll compressors were used in this test. MWCU6881883 was installed with the "Quest Regular" software (test14) with settings set 1 and MWCU6883253 (ref4) served as reference. During the shipment power consumption of all containers was measured using externally added kWh-meters. The temperature distribution was measured using 18 sensors per container and logging the actual temperature every 30 minutes. Eighteen atmosphere samplers were placed in eight of the ten containers. Fruit samples for quality evaluation (12 cartons per container) were taken from 6 pallets in all containers (see scheme and location of the temperature sensors). All test cartons contained a temperature sensor (Tiny Tag) to be able to compare the temperature distributions of the containers. With these readings it would be possible to determine correlations between local temperatures and quality development of the fruits. After arrival at the warehouse of Belfruco in Antwerp, the bananas were transported in a climate controlled van to A&F in Wageningen. At A&F a first inspection of the quality was performed. Subsequently the bananas were ripened during 6-7 days and evaluated again. The quality evaluation was extended by a 3 days' shelf life simulation of the test samples using the experimental facilities of A&F.

A precise quality evaluation was necessary as the Quest Regular mode operation allows the supply air to have a low value during specific interval times. This value is lower than the value that is commonly considered a chilling temperature. The idea behind this is that chilling will be avoided by cycling, as the supplied air is only on this low level for short periods. Product temperature and internal metabolic processes do not follow these quick changes of the temperature settings i.e. chilling will not occur. This hypothesis was tested successfully for several commodities before. The energy saving method is only of value when product i.e. banana quality is not harmed by it.

2 Material and methods

2.1 Product

The banana variety was Cavendish. The bananas originated from different Fair Trade growers from the El Oro province in Ecuador. The fruit was exported by Fruta Del Pacifico. The initial temperature of the bananas was around 25°C.

Figure 1 Cavendish banana

Figure 2 Cavendish banana open

2.2 Packaging and stowage

The bananas were packed in cardboard boxes, inside plastic bags. The bags were mostly banavac, vacuum sucked plastic bags containing all bananas in a carton. Some cartons were filled with clusters in polybags, packed separately in small bags. The carton size was 400x500 mm, stacked 9 cartons high (6 on a layer). In total 10 containers with 1080 cartons were packed, placed on 20 pallets. The pallets used, were wooden industrial pallets size 1200x1000 mm. 20 pallets were fitted in the container cross stacked (see also Figure 5).

Note that in ref1 one of the pallets (left hand side at the door end) was only 5 layers high.

2.3 Unit settings

Eight of the containers used were fitted with Carrier Thinline refrigeration units, two with Eliteline units (i.e. with scroll compressor). The CCPC software (version 9590 for recip and version 9555 for scroll), was installed on all units using a Microlink 3 card or a Microlink 2/3 adapter. The reference containers were running in normal mode with settings as usual for Cavendish Banana. For these, the CCPC software was only used to enable additional data logging. The Thinline reference units were fitted with the previous version of the CCPC software, to enable extra data logging while not automatically starting CCPC mode. The Quest containers were running in CCPC mode.

The reference container settings were:

◊ Supply setpoint	13.3 °C = 55.9 F
◊ Fan setting	High
◊ Vent setting	30 m^3/hr

The CCPC settings are shown in the following table:

Table 2 CCPC settings fro test containers

	Settings set Quest1	Settings set Quest2[a]	Settings set Quest3
Supply setpoint	11.8 °C = 53.2 F	12.8 °C = 55.0 F	10.8 °C = 51.4 F
Return Air Pulldown Low Limit	14.3 °C = 57.7 F	14.8 °C = 58.6 F	14.3 °C = 57.7 F
Return Air Low Limit	14.3 °C = 57.7 F	14.8 °C = 58.6 F	14.3 °C = 57.7 F
Return Air High Limit	14.8 °C = 58.6 F	15.3 °C = 59.5 F	14.8 °C = 58.6 F
Fan setting	Alternating	Alternating	Alternating
Vent setting	30 m^3/hr	30 m^3/hr	30 m^3/hr

Defrost interval was set to automatic and Humidity, Dehumidification and Bulb Mode were all set to OFF for all containers. The in Range Limit (Code 30) was set to 0.5°C.

2.4 Voyage schedule

On December 6th and 7th the containers were loaded with bananas. Subsequently, the containers were taken to the harbour of Guayaquil. The setup is shown in Table 3.

Table 3 Container setup

Container nr	Setup mode	Stuffing date	Commodity	Grower
MAEU 583 015 8	CCPC 1 (test11)	7/12/2006	Banana	Grupo Agricola Prieto
CRLU 518 430 2	NORMAL (ref1)	6/12/2006	Banana	Grupo Agricola Prieto
MWCU 653 296 3	CCPC 2 (test21)	6/12/2006	Banana	Grupo Agricola Prieto
GESU 905 975 0	CCPC 3 (test31)	7/12/2006	Banana	HDA La Playa
MWCU 680 140 3	CCPC 1 (test12)	7/12/2006	Banana	Grupo Agricola Prieto
MWCU 671 193 2	NORMAL (ref2)	7/12/2006	Banana	Grupo Agricola Prieto
MWCU 678 144 1	CCPC 2 (test22)	7/12/2006	Banana	Grupo Agricola Prieto
MWCU 675 565 3	CCPC 3 (test32)	7/12/2006	Banana	Grupo Agricola Prieto
MWCU 688 188 3	CCPC 1 (test14)	6/12/2006	Banana	HDA La Playa
MWCU 688 325 3	NORMAL (ref4)	6/12/2006	Banana	HDA La Playa

All containers were loaded to the vessel (Maersk Rosario) on December 11th.

[a] *The return air limits for unit test22 were mistakably set to 14.3, 14.7 and 15.2°C instead of 14.8, 14.8 and 15.3°C.*

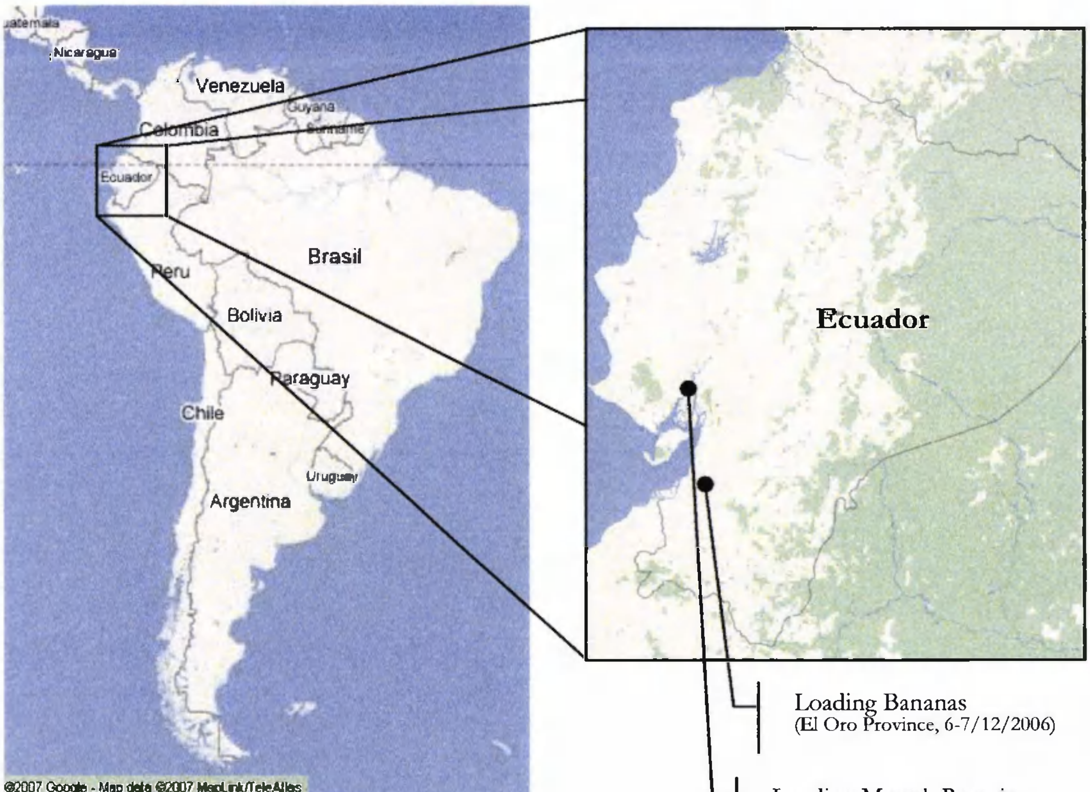

Figure 3 Map of loading and departure locations [1]

Figure 4 Map of the vessels route (left Maersk Rosario[b], right Jeppesen Maersk) [2]

The containers arrived in Rotterdam (The Netherlands) on December 30th and were transported to Antwerp (by truck) on January 2nd. Figure 22 and Figure 23 in the appendix depict the mean temperature and relative humidity in December for such a trip.

2.5 Unit and climate measurements

External kWh meters were attached to all units. The CCPC software installed on the containers included additional data logging, storing elaborate unit information every hour. Temperatures were measured by 4 USDA probes (if available) and 18 Tiny tags inside the containers.

[b] *Guayaquil to Balboa*

Additional ethylene sensors were placed in each container. In order to measure the temperature reaction of the fruit to the software system the Tiny Tags data loggers were placed next to the fruit to the sidewall of each carton. Data recording had been pre-set for every 30 minutes. The instruments were placed in 6 pallets at the bottom and ¾ in height.

Figure 5 shows the stowage plan of the pallets in the containers. The yellow marked pallets were fitted with temperature, relative humidity and gas decomposition sensors. These are also the pallets from which samples for shelf live testing were taken. The green marked pallets were used as alternative in some cases.

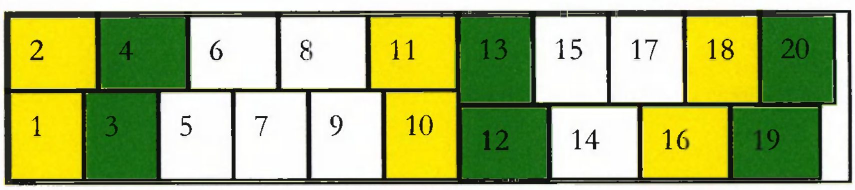

Figure 5 Container layout

2.6 Quality measurements

Banana pallets contained 9 layers of cartons. From each container 12 cartons were taken as sample cartons. These cartons were mostly located on:

- Pallet 1, layers 1 and 8
- Pallet 2, layers 1 and 8
- Pallet 10, layers 1 and 8
- Pallet 11, layers 1 and 8
- Pallet 16, layers 1 and 8
- Pallet 18, layers 1 and 8

In some cases, layers 9, 10 or 11 were used.

All samples were taken on January 2nd 2007. The sample cartons were transported to AFSG in Wageningen in a climate controlled van (14.0°C). Upon arrival at the test facilities of AFSG, a first quality inspection of the bananas was carried out. Each carton was given a code for the banana colour (Figure 6) and for "dullness" (Table 4). In each carton in three fingers "under peel damage" (discolouration under the upper peel layer, Table 4) and pulp quality was judged.

Table 4 Scale of "under peel damage"

Score	Under peel damage
0	No discolouration
1	Slight discolouration
2	Clear discolouration
3	Severe discolouration

The bananas were stored there at 14.0°C until January 5th. Subsequently, all samples were exposed to a ripening protocol of AFSG. On January 12th the bananas were stored at 18°C/75% relative humidity (RH) as a simulation of shelf life.

Quality evaluations took place on January 12th and 15th, after the 3 days' shelf life simulation. Quality indicators were:

- Colour (scale 2 – 7, figure 1), at day 0 and 3, score per cluster
- The degree of "dullness": a greyish haze on the banana (scale 1 – 6) at day 0 and 3 (score per cluster, Table 5).

Table 5 "Dullness" scale.

Score	% of dull surface
0	0
1	1 – 5
2	6 – 10
3	11 – 25
4	26 – 50
5	51 – 75
6	> 75

- Blackening of the peel (# of clusters with black spots) at day 3
- Sugarspots according to a scale 0 – 7; score per cluster (Table 6).

Table 6 Sugar spots scale.

Score	# sugar spots per finger
0	0
1	1 – 10
2	11 – 20
3	21 – 30
4	31 – 40
5	41 – 50
6	51 – 60
7	> 60

Also the packing code on the cartons was noted, in order to know the date and time of packing and loading.

Figure 6 Colour of banana, scale 2 – 7: 2 = green, 7 is yellow with sugarspots. In case of clusters with green parts and sugar spots as well, colour score is 5 as a maximum, and sugar spots is scored as shown in table 5.

3 Temperatures

Figure 7 to Figure 13 show the Tiny Tag data for the coolest and warmest cartons, as well as the mean temperature of all cartons. This gives an overview of all carton temperature readings, which are shown in Figure 24 to Figure 37 in the appendix. The closing of the container doors is defined as t=0, because pull down was part of the testing protocol. Note that these are different actual time instances for the various containers. To get a good impression of the spatial distributions of the carton temperatures and how these change in time, see the movies on the accompanying cd.

3.1 Temperature readings at the start of the trip

The initial temperature readings of the cartons in the test and reference containers lie around 25°C.

3.2 Temperature readings during pull down

Pull down was executed in CCPC mode for all test containers. Containers ref1, test21, test14 and ref4 start to pull down on December 6th, the rest started on December 7th. The number of days for the return air to reach the high return air limit and the pull down limit are shown in Table 7. (The test containers start to cycle at reaching this pull down limit.) Containers ref1 and test11 take a long time to pull down the return air temperature, other containers show relatively comparable values. Also, the mean, minimal and maximum carton temperatures are shown for the time instance that the pull down limit is reached.

Table 7 Pull down times and carton temperatures at Tpdlim (t)

Container	Thlim (°C)	Tpdlim (°C)	Time to Thlim (days)	Time to Tpdlim (days)	Min carton T (°C)	Max carton T (°C)	Mean carton T (°C)
Ref1[c]	14.8	14.3	4.2	16.9	*13.5*	*13.9*	*13.7*
Ref2	14.8	14.3	2.2	3.6	13.9	17.1	15.1
Ref4 (scroll)	14.8	14.3	1.5	2.1	13.5	17.7	15.2
Test11	14.8	14.3	5	5	13.2	17.6	14.9
Test12	14.8	14.3	1.8	1.9	14.2	18.9	16.0
Test14 (scroll)	14.8	14.3	1.3	1.3	13.5	22.2	18.1
Test21	15.3	14.8	2.2	2.3	13.1	16.2	14.5
Test22	15.2	14.3	1.6	2	13.5	17.7	15.1
Test31	14.8	14.3	2.1	2.1	13.4	21.9	17.2
Test32	14.8	14.3	2.3	2.3	13.7	19.9	16.0

[c] *For ref1 only the (unit-side) pallets 1 and 2 out of the 6 test pallets were retrieved at arrival, therefore the carton temperatures shown are not comparable to those of the other containers and thus printed in red italics.*

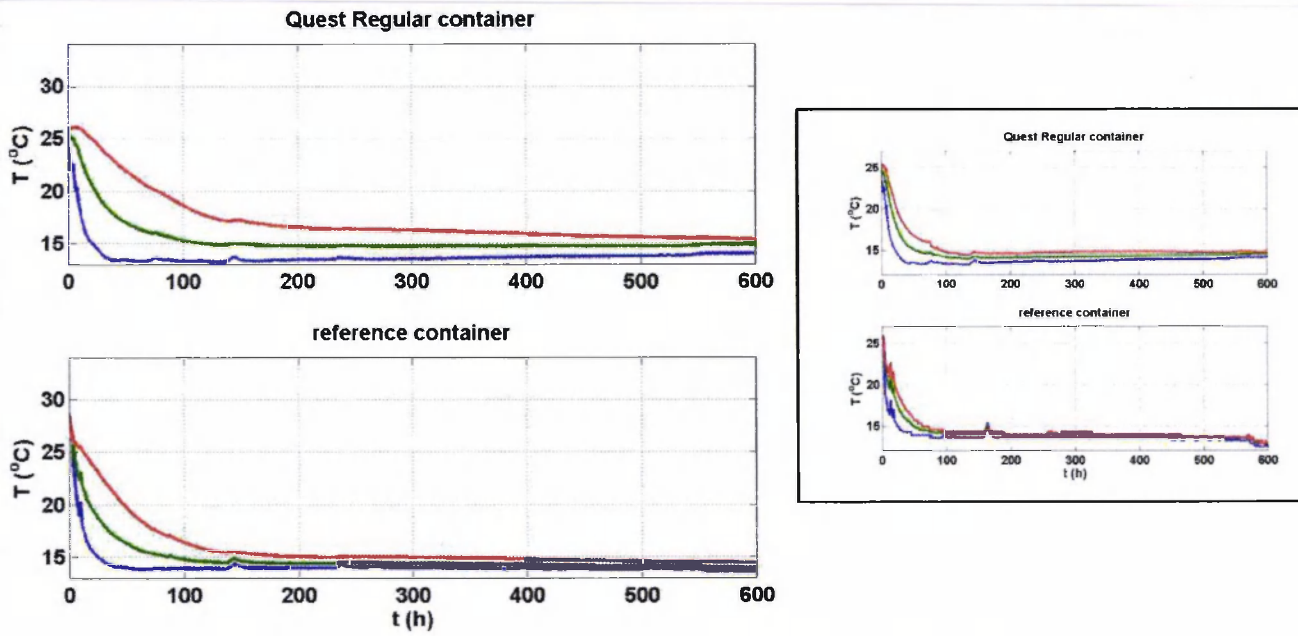

Figure 7 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test11 and ref2 (inlay test11 and ref1)

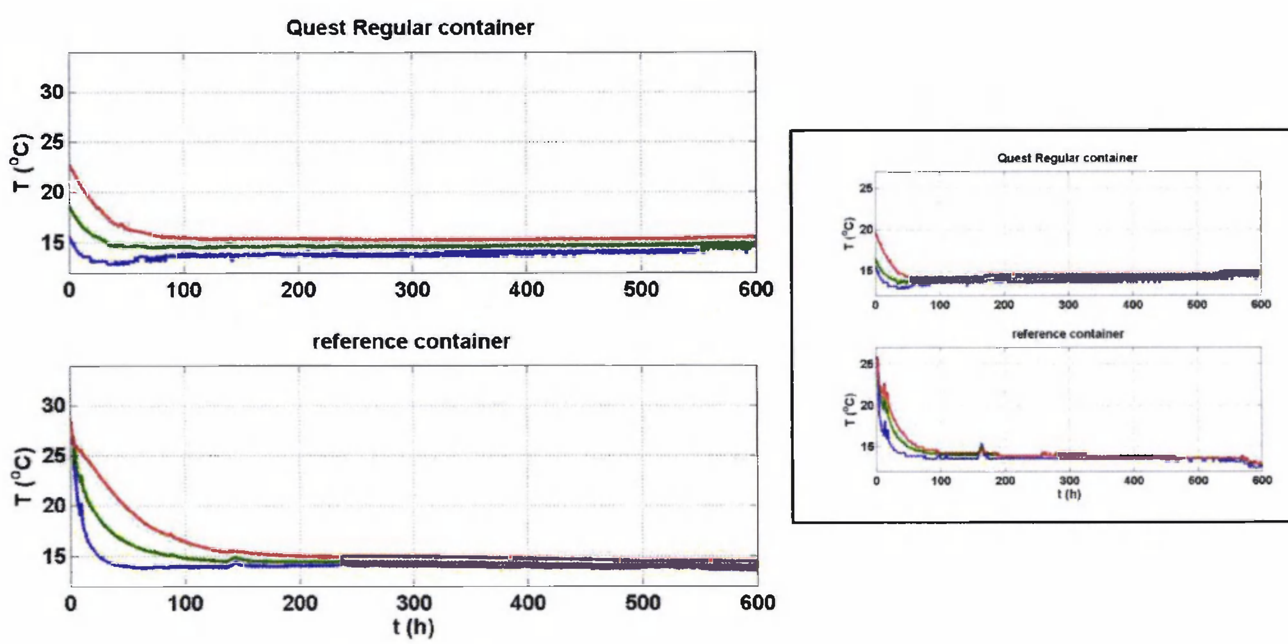

Figure 8 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test21 and ref2 (inlay test21 and ref1)

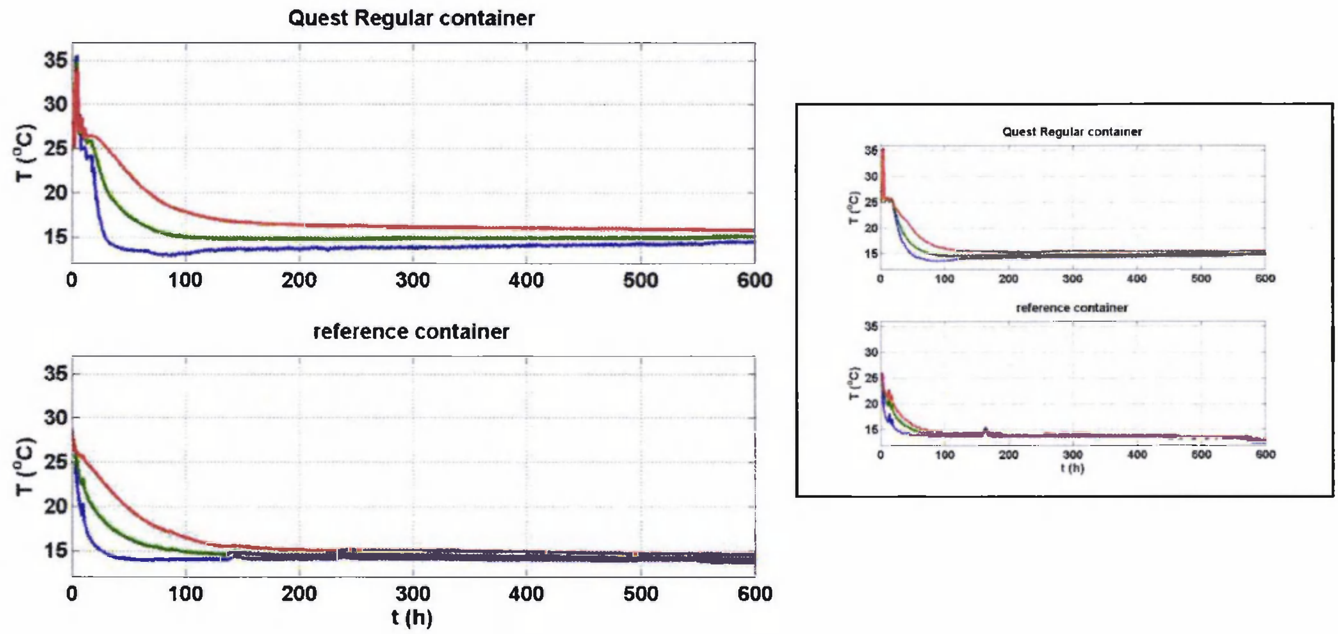

Figure 9 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test31 and ref2 (inlay test31 and ref1)

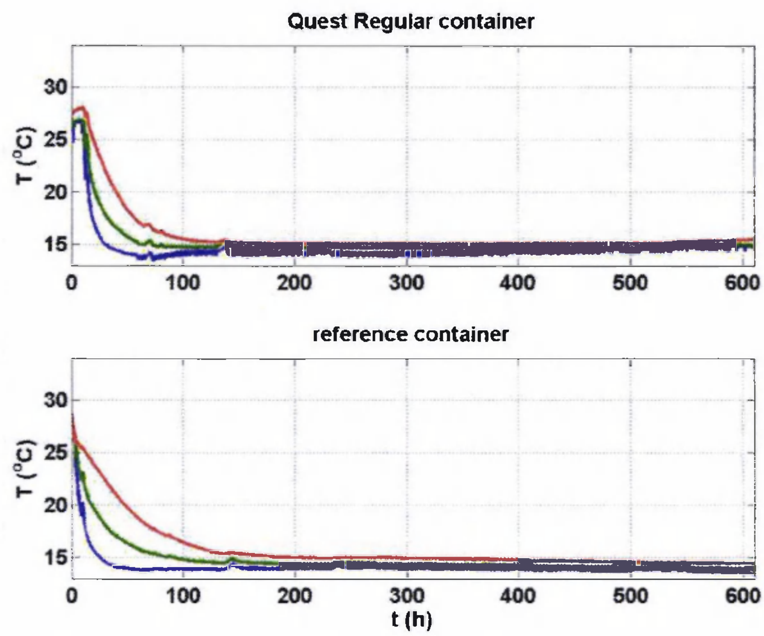

Figure 10 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test12 and ref2

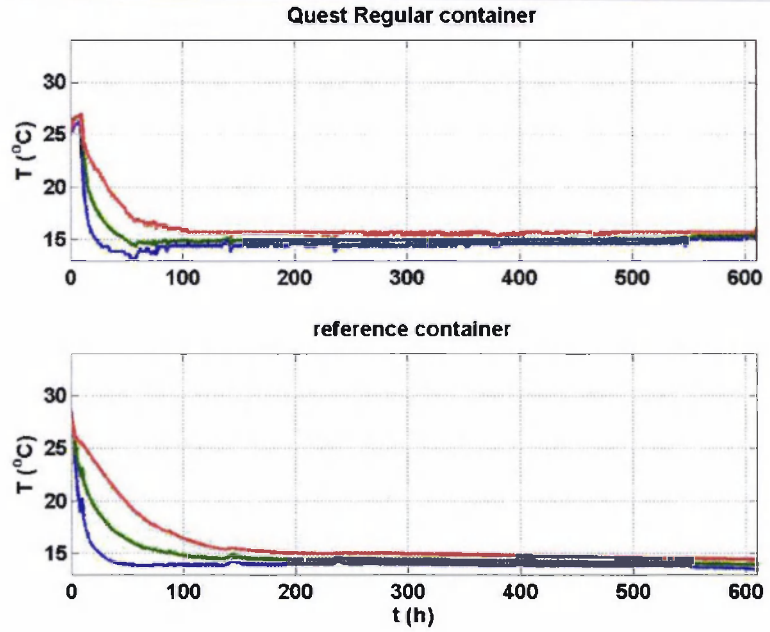

Figure 11 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test22 and ref2

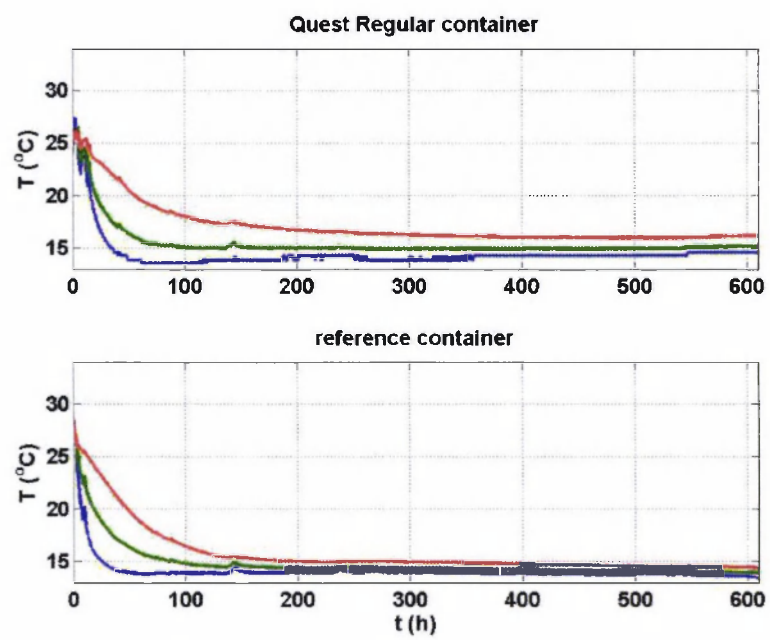

Figure 12 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test32 and ref2

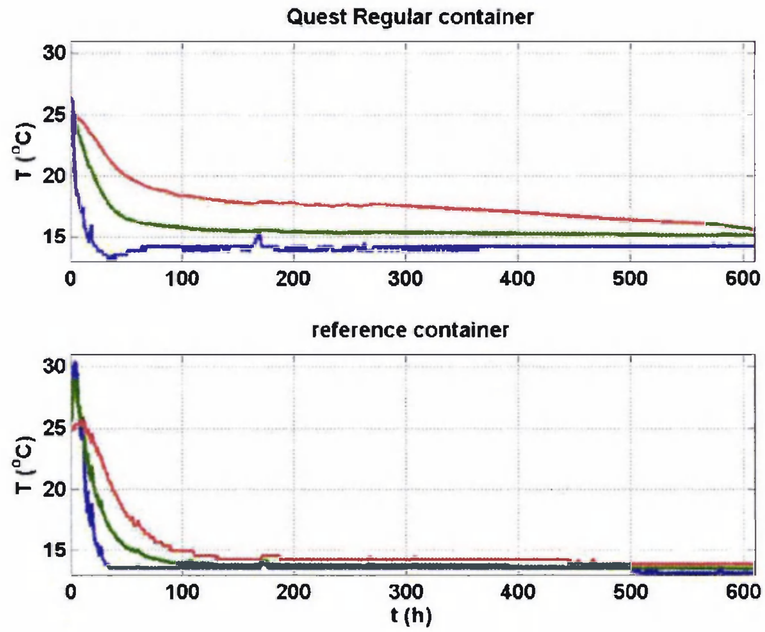

Figure 13 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-), for test14 and ref4

The mean carton temperatures of test14 and test31 are relatively warm at the time instance that the pull down limit is reached. The maximum carton temperature for these are also on the warm side. Test32 also has a relatively warm maximum carton temperature at that time. These are also the units that reach the pull down limit almost immediately after reaching the high return air limit. The carton temperatures of the Thinline test containers with Quest1 (i.e. default) and Quest2 settings[d] are comparable to those of ref2 and ref4.

Note that in ref1 one of the pallets (left hand side at the door end) was only 5 layers high. This might have disturbed the airflow and therefore the temperature distribution in the container. Also, note that test22 had an erroneous Tpdlim setting, 0.4 °C lower then the intended Tllim value.

3.3 Temperatures at the start of the selected Quest Regular period

The starting time for comparison of temperatures for the Quest Regular period is 2½ days after closing of the doors, (December 9th until January 1st, t=60 – 600 h). Most test containers have then reached the bound to start cycling. Quest containers test11, test14 and test31 start off about 1°C warmer than the reference containers (see Table 8 and Figure 24 to Figure 37 and Figure 48 to Figure 54 in the appendix).

[d] *Test12 temperatures in the table seem somewhat high, but note that time to reach pull down limit is also short. When comparing the graphs, pull down of Test12 is comparable to that of the references.*

Table 8 Mean carton temperatures at start of selected QR period

Container	Mean carton T (°C)
Ref1[e]	*14.6*
Ref2	15.7
Ref4 (scroll)	15.0
Test11	16.5
Test12	15.0
Test14 (scroll)	16.2
Test21	14.7
Test22	14.6
Test31	16.5
Test32	15.8

3.4 Supply air temperatures during Quest Regular Mode

During Quest Regular Mode, the Eliteline (scroll) unit and the units with the cool settings (test31 and test32) mainly do not reach the minimum supply temperature of its supply setting, but stop at about 12.4, 11.3 and 11.8°C instead of 11.8, 10.8 and 10.8°C respectively (see Figure 38 to Figure 47 in the appendix). These are also the units with short cooling periods of 5 to 8 minutes. The average supply temperature error during cooling lies between 1 and 2 °C for these units (see Figure 87 to Figure 94 in the appendix).

The units with the default and warm settings (test11, test12, test21 and test22) do reach the appropriate supply temperatures of 10.8 and 11.8°C. For these units the average supply temperature error during cooling lies between 0.5 and 1°C. Their cooling periods are somewhat longer 10 to 20 minutes.

Adaptation of the field software, after the previous banana trial shipment, apparently improved the supply temperature control, but not enough to accommodate the supply temperature setting of more then 2.5°C below the Low Return Air Limit or the cooling periods shorter then 10 minutes.

3.5 Temperature readings during Quest Regular Mode

The supply and return air fluctuation of the Quest containers are dampened in the carton temperature data (measured with a 30 min period). The fluctuations are hardly visible in containers test11, test14 and test32. Containers test12, test21, test22 and test31 show fluctuations up to an amplitude of 0.25°C. An example is shown in Figure 14.

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[e] *For ref1 only the (unit-side) pallets 1 and 2 out of the 6 test pallets were retrieved at arrival, therefore the carton temperatures shown are not comparable to those of the other containers and thus printed in red italics.*

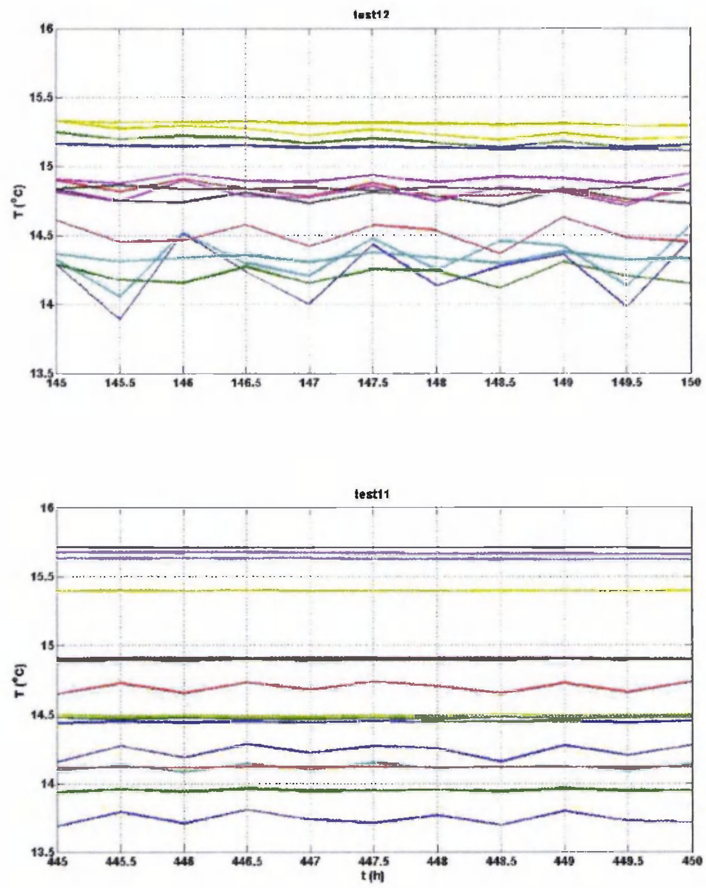

Figure 14 Example of the carton temperature fluctuations in a Quest container

As Table 9 shows, not all product temperature sensors were retrieved from all the containers. For all but one container this is no issue. For unit CRLU5184302 (ref1) only 4 instruments were retrieved, which means we cannot use it as a reference container for temperature distribution inside the container. Therefore, the data from ref1 will not be used in the analysis. Only ref2 and ref4 are used as reference containers.

Table 9 Product temperature sensors retrieved

Container nr	# sensors	Container nr	# Sensors
MAEU 583 015 8 (test11)	16	MWCU 671 193 2 (ref2)	14
CRLU 518 430 2 (ref1)	4	MWCU 678 144 1 (test22)	13
MWCU 653 296 3 (test21)	14	MWCU 675 565 3 (test32)	13
GESU 905 975 0 (test31)	16	MWCU 688 188 3 (test14)	16
MWCU 680 140 3 (test12)	14	MWCU 688 325 3 (ref4)	12

The temperature data for the Quest Regular period (December 9th until January 1st, t=60 – 600 h) from the temperature sensors have been summarized in Table 10 through Table 14. The tables contain information on the temperatures of the coolest and warmest cartons as well as the mean temperature of all cartons in a container combined.

First of all, the deviation from the given setpoint is important (see column 3 of Table 10 and Table 13). The mean carton temperature of the Quest1 (recip) containers is 14.8°C. The mean carton temperature of the Quest2 containers is 14.8°C. The mean carton temperature of the Quest3 containers is 15.0°C. The mean carton temperature of the reference container (ref2) is 14.3°C (the temperature from the cooler spots in ref 1 was on average 13.8°C). Thus, the Quest1 and Quest2 containers are 0.5°C further from the setpoint of 13.3°C than the reference container. The Quest3 containers are 1.2°C further from the setpoint.
For the Quest1-scroll container the mean carton temperature is 15.4°C. The mean carton temperature for the reference container (ref4) is 13.7°C. Thus the Quest1-scroll container is 1.7°C further from the setpoint of 13.3°C than the reference container.

Table 10 The mean of the minimum, mean and maximum carton temperature readings

Container	mean min carton T (°C)	mean mean carton T (°C)	mean max carton T (°C)
Test11	13.6	14.8	16.4
Test21	13.9	14.6	15.3
Test31	13.7	14.9	16.3
Ref1	*13.5*	*13.8*	*13.9*
Test12	14.3	14.8	15.2
Test22	14.5	14.9	15.6
Test32	14.0	15.0	16.5
Ref2	13.9	14.3	14.9
Test14	14.1	15.4	17.2
Ref4	13.4	13.7	14.2

Secondly, the maximum bandwidth of the carton temperatures is considered[f] (see column 2 and 4 of Table 11 and Table 13). Looking at the lowest and highest temperatures measured in the cartons, the maximum temperature difference between the coolest and warmest cartons is 5.7°C in the Quest1 (recip) containers, 3.1°C in the Quest2 containers, 7.0°C in the Quest3 containers and 5.2°C in the reference container. Thus, in the most extreme situation, the Quest2 containers have a 2.1°C smaller maximum temperature bandwidth than the reference container and the Quest1 and Quest3 respectively a 0.5°C and 1.8°C larger maximum temperature bandwidth.

[f] *Note that for this trial pull down was included. We have chosen to include the part of the data where carton temperatures are still decreasing, although cycling has already started for most of the containers. Therefore, bandwidths recorded in this report are naturally larger then in the report of the previous banana trial.*

The maximum temperature difference between the coolest and warmest cartons in the Quest1-scroll cartons is 5.6°C, for the reference container it is 3.9°C. In the most extreme situation the Quest1-scroll container has a 1.7°C larger maximum temperature bandwidth.

Table 11 The ranges of the minimum, mean and maximum carton temperature readings (from December 9th to January 1st for banana)

Container	min carton T (°C)	mean carton T (°C)	max carton T (°C)
Test11	13.1 to 14.1	14.7 to 16.4	15.3 to 21.1
Test21	13.1 to 14.5	14.4 to 14.9	15.2 to 16.0
Test31	12.8 to 14.4	14.6 to 16.5	15.6 to 20.7
Ref1	*12.4 to 15.3*	*12.7 to 14.9*	*12.8 to 14.3*
Test12	13.4 to 14.9	14.5 to 15.4	15.1 to 16.8
Test22	13.5 to 15.3	14.3 to 15.5	15.3 to 16.7
Test32	13.5 to 14.5	14.8 to 15.8	15.9 to 19.5
Ref2	13.4 to 14.4	13.9 to 15.7	14.3 to 18.6
Test14	13.8 to 15.3	15.1 to 16.2	15.5 to 19.4
Ref4	13.1 to 16.0	13.4 to 15.0	13.8 to 17.0

Thirdly, the mean bandwidth of the carton temperatures is considered (see column 2 and 4 of Table 10 and Table 14). Looking at the mean of the carton temperatures in time, the temperature difference between the coolest and warmest cartons is 1.9°C in the Quest 1 containers, 1.3°C in the Quest 2 containers, 2.6°C in the Quest 3 containers and 1.0°C in the reference container. Thus, on average, the Quest 1 containers have a 0.9°C, the Quest 2 containers a 0.3°C and the Quest 3 container a 1.6°C larger temperature bandwidth than the reference container.
The mean temperature difference between the coolest and warmest cartons in the Quest 4 container is 3.1°C and for the reference container 0.8°C. So the Quest 4 container has a 2.3°C larger temperature bandwidth than the reference container.

Table 12 The deviations from setpoint for the minimum, mean and maximum carton temperature readings

Container	dev min carton T (°C)	dev mean carton T (°C)	dev max carton T (°C)
Test11	-0.2 to 0.8	1.4 to 3.1	2.0 to 7.8
Test21	-0.2 to 1.2	1.1 to 1.6	1.9 to 2.7
Test31	-0.5 to 1.1	1.3 to 3.2	2.3 to 7.4
Ref1	*-0.9 to 2.0*	*-0.6 to 1.6*	*-0.5 to 1.0*
Test12	0.1 to 1.6	1.2 to 2.1	1.8 to 3.5
Test22	0.2 to 2.0	1.0 to 2.2	2.0 to 3.4
Test32	0.2 to 1.2	1.5 to 2.5	2.6 to 6.2
Ref2	0.1 to 1.1	0.6 to 2.4	1 to 5.3
Test14	0.5 to 1.0	1.8 to 2.9	2.2 to 6.1
Ref4	-0.2 to 2.7	0.1 to 1.7	0.5 to 3.7

Fourthly, the deviation of the coolest carton from the given setpoint is important (see column 2 of Table 13 and Table 14). The coolest cartons of the Quest1 (recip) containers are 0.7°C, the Quest2 containers 0.9°C and the Quest3 containers 0.6°C above setpoint. The coolest cartons of the reference container are 0.6°C above setpoint. Thus, the coolest cartons of the Quest1 containers are 0.1 °C, the Quest2 containers 0.3°C and the Quest3 containers 0.0°C further from the setpoint than the reference container.
The coolest carton of the Quest1-scroll container is 0.8°C above setpoint and those from the reference container 0.1°C above setpoint. So the coolest carton of the Quest1-scroll container is 0.7°C further from the setpoint than the reference container.

Table 13 The deviations from setpoint for the mean of the minimum, mean and maximum carton temperature readings

Container	dev mean min carton T (°C)	dev mean mean carton T (°C)	dev mean max carton T (°C)
Test11	0.3	1.5	3.1
Test21	0.6	1.3	2.0
Test31	0.4	1.6	3.0
Ref1	*0.2*	*0.5*	*0.6*
Test12	1.0	1.5	1.9
Test22	1.2	1.6	2.3
Test32	0.7	1.7	3.2
Ref2	0.6	1.0	1.6
Test14	0.8	2.1	3.9
Ref4	0.1	0.4	0.9

Finally, the deviation of the warmest cartons from the given setpoint is important (see column 4 of Table 13 and Table 14). The warmest cartons of the Quest1 (recip) containers are 2.5°C, the Quest2 containers 2.2°C and the Quest3 containers 3.1°C above setpoint. The warmest cartons of the reference container are 1.6°C above setpoint. Thus, the warmest cartons of the Quest1 containers are 0.9°C, the Quest2 containers 0.6°C and the Quest3 containers 1.5°C further from the setpoint than the reference containers.
The warmest carton of the Quest1-scroll container is 3.9°C above setpoint and those from the reference container 0.9°C above setpoint. So the warmest carton of the Quest1-scroll container is 3.0°C further from the setpoint than the reference container.

In Table 26 and Table 27 in the appendix, the ambient temperature measured with IButton loggers on the outside of the units are shown. All containers had a lower mean ambient temperature than the ref2 container. Test14 has a lower mean temperature then the ref4 container. The largest difference of 2.0°C in mean ambient temperature is between ref2 container and test22. This means that the ambient temperature did not cause the warmer carton temperatures in the Quest containers.

Table 14 The difference in deviation from setpoint for the Quest container compared to the reference container, for the coolest, mean and warmest carton

	ΔT coolest carton (°C)	ΔT mean carton (°C)	ΔT warmest carton (°C)
Test11 & ref1	*-0.1*	*-1.0*	*-0.8*
Test21 & ref1	*-0.4*	*-0.8*	*-0.6*
Test31 & ref1	*-0.2*	*-1.1*	*-1.5*
Test11 & ref2	0.3	-0.5	-1.5
Test21 & ref2	0.0	-0.3	-0.4
Test31 & ref2	0.2	-0.6	-1.4
Test12 & ref2	-0.4	-0.5	-0.3
Test22 & ref2	-0.6	-0.6	-0.7
Test32 & ref2	-0.1	-0.7	-1.6
Test14 & ref4	-0.7	-1.7	-3.0

Overall, carton temperatures in the Quest containers are on the warm side, but with a satisfactory bandwidth. The Quest3 containers, with the coolest settings, are further from setpoint then the Quest1 and Quest2 containers. This is already the case after pull down, so probably caused by produce specifics or stowage. The Quest1 and Quest2 containers are 0.5°C are further from the setpoint, while the bandwidth is 0.9°C and 0.3°C larger then the reference container. The Quest3 containers are 0.7°C further from setpoint and have a 1.6°C larger bandwidth. The coolest cartons for Quest1, Quest2 and Quest3 are respectively 0.1°C, 0.3°C and 0.0°C further from the setpoint. The warmest cartons are respectively 0.9°C, 0.6°C and 1.5°C further from the setpoint. The Quest1-scroll container is 1.7°C further from setpoint than the reference container with a 2.3°C larger bandwidth. The coolest carton for Quest1-scroll is 0.7°C from setpoint. The warmest carton is 3.0°C further from setpoint. This is already the case after pull down, so probably caused by produce specifics or stowage.

USDA readings during the trip are shown in Figure 38 to Figure 44 in the appendix. As very few probes were available, a comparison would be unreliable.

3.6 Discharge temperature alarm

Three out of seven test units give alarm code 64 (discharge temperature over limit) during the trip, see Table 24 and Table 25. this alarm also came up ion the previous banana trial. Since it is also present for unit ref2 and only for part of the test units it does not have to be a CCPC software effect, still since it keeps appearing we advise Carrier to double check this issue.

3.7 Temperatures at the end of the trip

Figure 55 through Figure 61 in the appendix show a snapshot of the carton temperatures near the end of the trip. In accordance with the above they show that carton temperatures of the Quest containers are warmer than those of the reference containers. Also, they give an indication of the temperature distributions over the various locations inside the containers.

4 Power Consumption

Power consumption data were read from the kWh meters by Maersk employees once/twice a day during the sea voyage. Time and energy data were taken from the kWh meters, see Figure 15. Time axis is such that t = 0 starts at December 5th 2006 16:00.

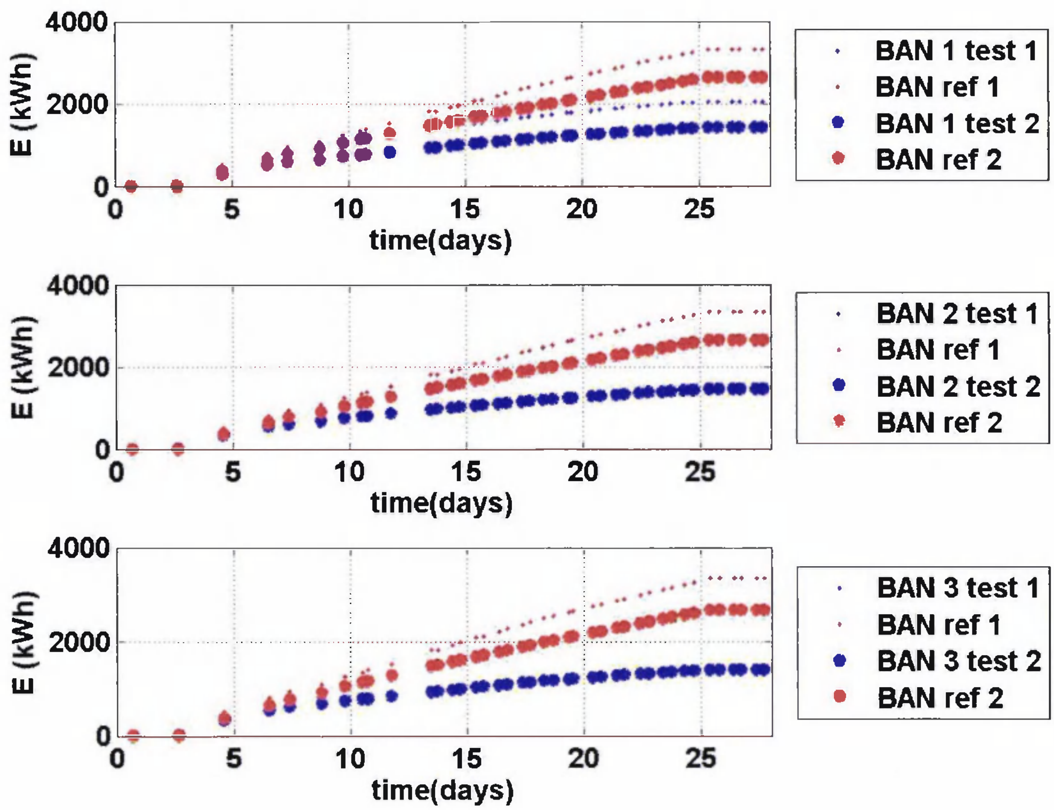

Figure 15 Energy readings as a function of time for the three container sets

On board the Jeppesen, some of the reefers were running with a water cooled condenser, while others had air or combined water and air cooling of the condenser, see Table 15. This can also affects the power consumption of the reefers. Containers in this trial showed a 1 kW higher power consumption for air cooled instead of water cooled condensers. All banana containers were stored in the cargo hold.

Table 15 Type of condenser cooling of the reefers and ventilation setting at unloading

Container	Condenser cooling	Ventilation setting at arrival in Antwerp (m^3/h)	Mean Power (kW)
Ref 1	air cooled condenser	30	5.9
Test11	air cooled condenser	30	3.8
Test21	air+water cooled condenser	30	2.6
Test31	air+water cooled condenser	30	2.6
Ref2	water cooled condenser	35	4.9
Test12	water cooled condenser	50	2.7
Test22	water cooled condenser	15	2.7
Test32	water cooled condenser	30	2.5
Ref4 (scroll)	water cooled condenser	15	4.2
Test14 (scroll)	water cooled condenser	30	1.9

The reference containers (ref1 and ref2) used 3323 and 2646 kWh in 561 and 544 hour, a mean power usage of 5.9 and 4.9 kW. Note that ref1's condenser was air cooled, while ref2's was water cooled.

The reference container with scroll compressor (ref4) used 2409 kWh in 574 hour, a mean power usage of 4.2 kW.

The Quest1-scroll container (test14) used 1104 kWh in 568 h, a mean power usage of 1.9 kW, which is 54% less compared to the reference container. Note that ref4 had a relatively small ventilation opening at unloading and thus might have had a smaller heat load.

The Quest1 containers (recip: test11 and test12, default settings) used 2056 and 1427 kWh in 543 and 537 h, a mean power usage of 3.8 and 2.7 kW, which is 36 and 45% less compared to the reference containers. Note that ref1's and test11's condensers were air cooled, while ref2's and test12's were water cooled. Also, test12 had a relatively large ventilation opening at unloading and thus might have had a higher heat load.

The Quest2 containers (test21 and test22, warmer settings) used 1492 and 1447 kWh in 568 and 541 h, a mean power usage of 2.6 and 2.7 kW, which is 56 and 45% less compared to the reference containers. Note that the 56% saving is unreliable, since ref1's condenser was air cooled while test21's condenser was air and water cooled. Both ref2's and test22's condenser were water cooled. Also, test22 had a relatively small ventilation opening at unloading and thus might have had a smaller heat load.

The Quest3 containers (test31 and test32, cooler settings) used 1394 and 1384 kWh in 539 and 544 h, a mean power usage of 2.6 and 2.5 kW, which is 56 and 48% less compared to the reference containers. Note that the 56% saving is unreliable, since ref1's condenser was air cooled while test31's condenser was air and water cooled. Both ref2's and test32's condenser were water cooled.

Taking into account the differences in condenser cooling, we estimate mean savings to be

- for Quest1 to be 40% (could be higher due to different vent setting and not reaching setpoint),
- for Quest1-scroll to be 54% (could be higher due to not reaching setpoint),
- for Quest2 to be 45% (could be smaller due to difference in vent setting) and
- for Quest3 to be 48% (could be higher due to not reaching setpoint).

This includes the pull down phase during which the unit is not cycling yet.
The power consumption and savings per day are shown in Figure 16 through Figure 19. Power savings during cycling are approximately 50% and rise up to 70% when ambient temperature becomes cooler.

The power savings are largely due to the periods that the compressor is turned off during cycling, the length of which can be seen in Figure 79 through Figure 83 in the appendix. (For comparison, also the active hours and defrost time of the units are shown.)

- Compressor off time intervals for test11 last approximately 25 - 100 minutes, about 1.5 - 14 times as long as the compressor-on time intervals. For test12 this is 20 – 200 mins and 1 – 20 times as long. For test14 (scroll) this is 10 - 200 minutes, and 1 - 25 times as long.
- Compressor off time intervals for test21 last approximately 30 - 200 minutes, about 1.7 - 17 times as long as the compressor-on time intervals. For test22 this is 30 - 200 minutes, and 1.5 - 17 times as long.
- Compressor off time intervals for test31 last approximately 10 - 200 minutes, about 1 - 40 times as long as the compressor-on time intervals. For test32 this is 10 - 300 minutes, and 1 - 60 times as long.

The compressor off periods become shorter when ambient temperature is higher. Compressor on times than become slightly longer. Other factors of influence are the reduced fan speed during compressor-off time intervals and the somewhat reduced amount of ventilation during low fan speed/compressor off periods. Defrost is not relevant since temperatures are high and therefore, defrost is not activated. Only the ref1 unit shows some deice energy consumption, at the end of the trip it consumes 6 times 0.6 kWh.

None of the banana containers have dehumidification energy readings. The reference containers show some short heating activity, when ambient temperature lies below setpoint at the end of the trip, see Table 24 and Table 25 in the appendix.

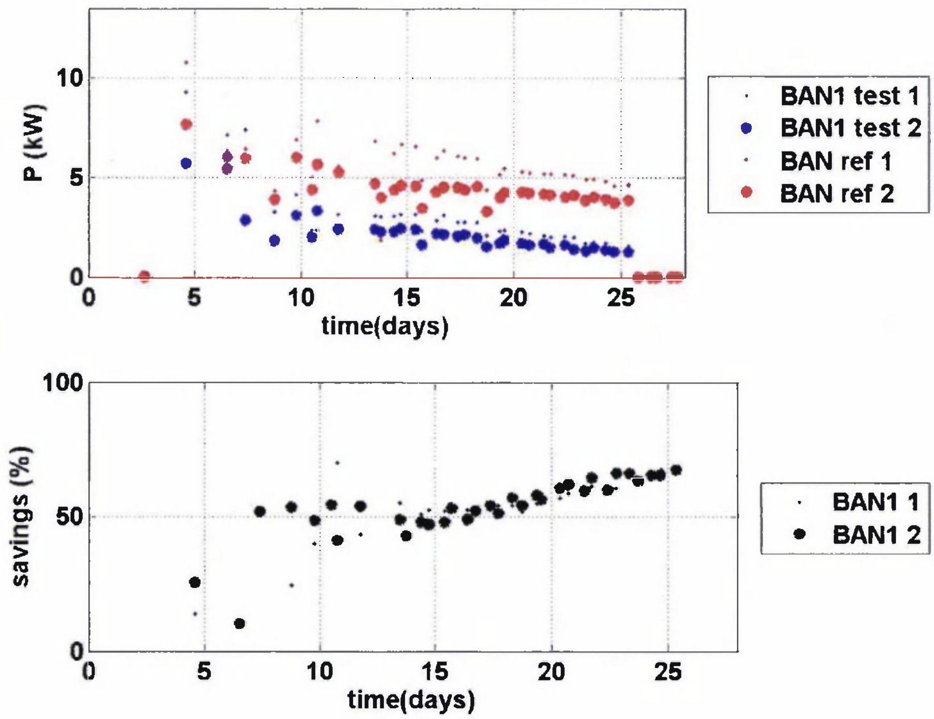

Figure 16 Power and savings as a function of time for container sets Quest1 (recip)

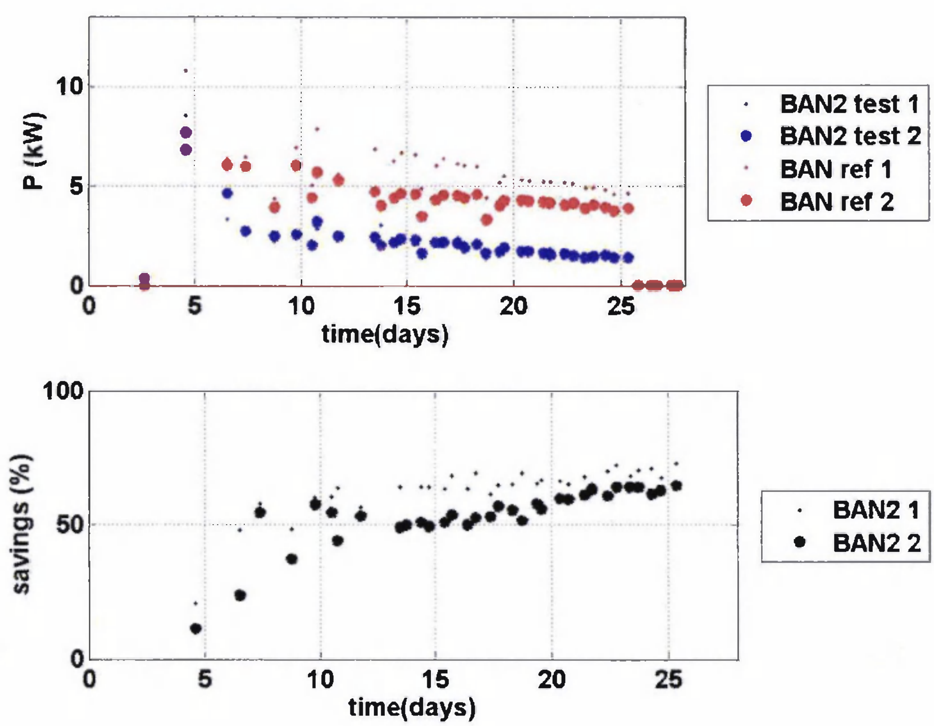

Figure 17 Power and savings as a function of time for container sets Quest2

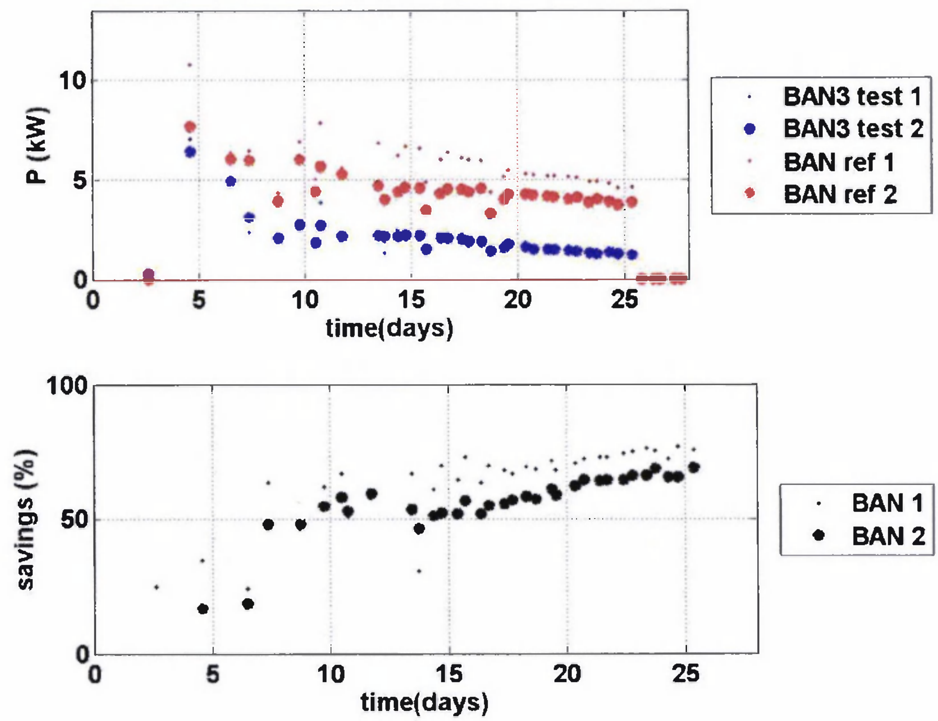

Figure 18 Power and savings as a function of time for container sets Quest3

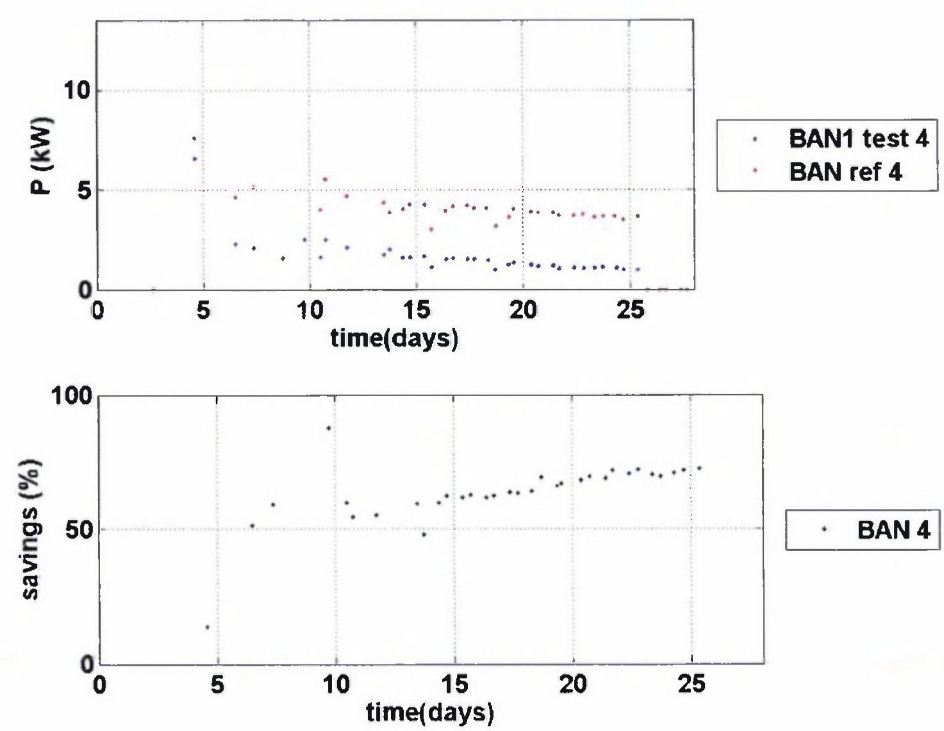

Figure 19 Power and savings as a function of time for the scroll compressor container set

5 Evaluation of fruit quality

5.1 Quality at arrival

At arrival the bananas were green (colour 2 – 2.5). In 12 cartons under peel damage > 1 (scale 0 – 3) was found. 4 out of these 12 cartons were filled with clusters packed in polybags (see also 5.3). Under peel damage seems not to be due to the temperature, because the lowest measured temperature in the cartons with the highest damage was variable (12.8 – 15.9°C), see Table 16.

Table 16 Temperatures of cartons with under peel damage

Container	Packing	Mean T [°C]	Lowest T [°C]	T < 13°C hours	T < 13°C Mean [°C]	T < 14°C hours	T < 14°C Mean [°C]	Under peel damage [0 – 3]
Test 1-1	polybags	14.1	13.4	0	-	408	13.7	2.0
Test 1-1	polybags	15.2	14.3	0	-	0	-	2.0
Test 2-1	polybags	14.6	13.8	0	-	1.5	13.8	1.7
Test 3-2	banavac	16.6	15.7	0	-	0	-	1.7
Test 1-1	banavac	15.2	14.3	0	-	0	-	1.3
Test 1-2	banavac	15.1	14.1	0	-	0	-	1.3
Test 1-2	banavac	15.6	14.8	0	-	0	-	1.3
Test 1-2	banavac	15.9	15.0	0	-	0	-	1.3
Test 1-4	banavac	14.8	13.9	0	-	6	13.9	1.3
Test 2-1	polybags	14.2	12.8	6	12.8	177	13.6	1.3
Test 3-2	banavac	15.5	14.6	0	-	0	-	1.3
Test 3-2	banavac	17.1	15.9	0	-	0	-	1.3

No dullness was found. Pulp quality was good (Figure 20).

Figure 20 Pulp

5.2 Packing date and packing method

The ten containers were loaded in a time range of two days. The packing date can be deduced from a 8 digit code, stamped on each carton. The bananas were grown by different farms, from two co-operations. The "oldest" bananas were packed on 6 December and the "youngest" bananas on 7 December. In total 111 cartons with known position and temperature data were retrieved. These 111 cartons originated from 39 grower/packing date combinations (see Figure 21).

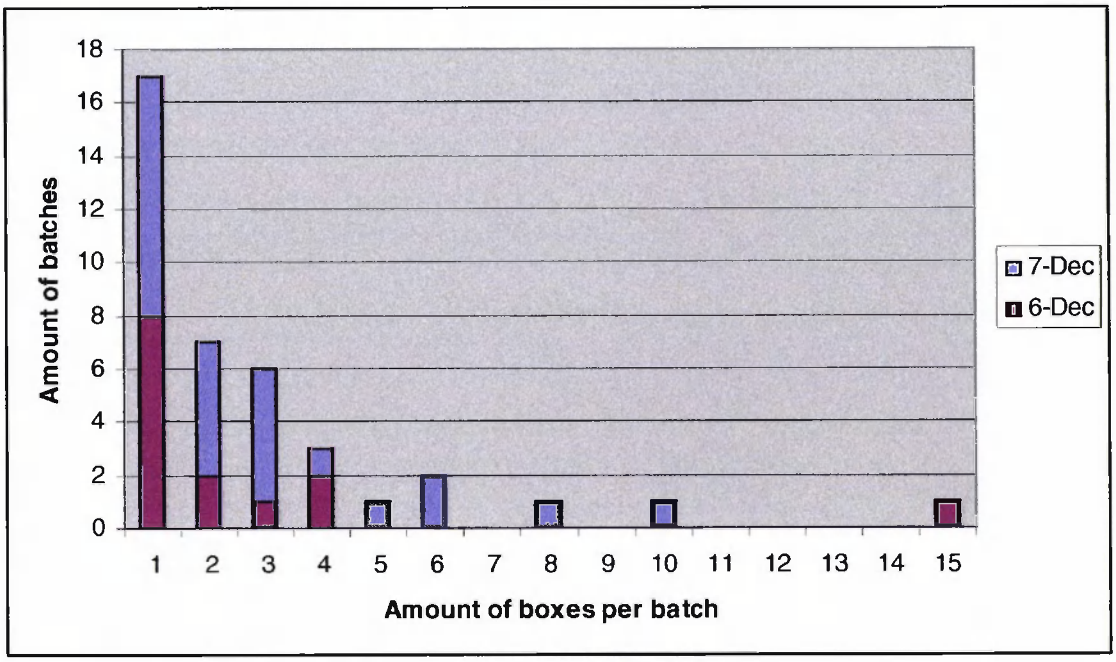

Figure 21 Batches of bananas.

5.3 Effect of packaging

Most of the cartons were filled with bananas packed in "banavac", 14 out of 116 cartons contained individually packed clusters, in polybags.

In the 12 highest dullness scores after 3 days of shelf life is shown. Table 17 shows that 8 out of 14 cartons with bananas in polybags were amongst the 12 cartons with the highest dullness score. At the moment of unpacking (start of shelf life) the bananas packed in banavac felt wet, the ones in polybags felt very dry. Amongst the cases with high dullness scores were also cartons with a minimum temperature of more than 15°C. Therefore it is likely that dullness was not due to too low temperatures, but to moisture loss, caused by the method of packing.) Dullness caused by moisture loss was seen before in earlier experiments (original Quest project).

Table 17 Cartons with highest dullness score after 3 days of shelf life.

Container	Packing	Mean T [°C]	Lowest T [°C]	T < 13°C hours	T < 13°C Mean [°C]	T < 14°C hours	T < 14°C Mean [°C]	Dull [0 – 6]
Test 2-1	polybag	14.4	13.5	0	-	35	13.7	3.7
Test 3-1	polybag	15.7	14.6	0	-	0	-	3.5
Test 1-1	polybag	14.8	13.9	0	-	20	13.9	3.4
Test 3-1	polybag	14.3	13.1	0	-	493	13.7	2.4
Test 2-1	banavac	15.6	15.2	0	-	0	-	2.3
Test 3-2	banavac	14.4	13.5	0	-	233	13.7	2.2
Test 2-1	polybag	14.6	13.8	0	-	2	13.8	1.9
Test 3-1	polybag	14.2	12.8	18	12.9	411	13.6	1.8
Test 1-4	banavac	17.3	15.8	0	-	0	-	1.8
Test 3-1	polybag	16.6	15.3	0	-	0	-	1.6
Test 1-1	polybag	15.3	14.3	0	-	0	-	1.6
Test 1-4	banavac	16.9	15.6	0	-	0	-	1.6

5.4 Average temperature and quality

Because the cartons for quality evaluation were from 39 different batches, it was not possible to examine the correlation between temperature and quality from all 10 containers. Therefore quality aspects were compared of bananas from ten cartons with the highest average temperature (from different containers) and ten cartons with the lowest average temperature (from different containers (Table 18).

Table 18 Effect of average temperature on quality aspects. The data are from bananas located at spots with the 10 lowest - and the 10 highest average temperatures. Analysis of variance (ANOVA) showed a significant effect ("sign") or no significant effect ("nosign").

	Average temperature [°C]	Under peel damage [0 – 3]	Colour day 0 [2 – 7]	Colour day 3 [2 – 7]	Dullness day 0 [0 – 6]	Dullness day 3 [0 – 6]	Sugar spots day 3 [0 – 7]
T low	14.0	0.7	3.9	4.7	0.1	0.5	0.2
T high	17.0	0.8	4.1	5.3	0.2	0.6	1.8
ANOVA	Sign	nosign	nosign	nosign	nosign	nosign	sign

Table 18 shows that there is a significant difference of 3°C between the 10 coldest and the 10 warmest spots. A significant effect of this difference was only found at the amount of sugar spots at day 3 of shelf life: bananas from the warmest spots had more sugar spots than bananas from the coldest spots. However, some average temperature cartons showed a much larger number of sugar spots.

5.5 Effect of locations in containers

Because the cartons for quality evaluation were from 39 different batches, it was not possible to compare the containers. In 3 containers the effect of the location within the container was examined, because in these containers most evaluated cartons had the same packing code (per container).

5.5.1 Container Reference 1

From this container 10 out of 12 evaluated cartons had the same packing code. Temperature in the cartons were 14.1 – 15.6°C. The evaluated cartons were located on layers 1, 2, 6, 7, 8 and 10. Table 19 shows the results of the analysis of variance.

Table 19 Effect of the layer on quality aspects of bananas from container Reference 2 that showed a significant effect by analysis of variance (ANOVA). The data are from bananas located at low layers (4 cartons at layers 1 or 2) and high layers (6 cartons located on layers 6, 7, 8 or 10).

Layer	Average temperature [°C]	Under peel damage [0 – 3]	Colour day 0 [2 – 7]
Low	14.3	0.7	3.7
High	15.0	0.2	4.2

The temperature difference between the layers was very small; significant effects on under peel damage and colour after ripening were small. Although under peel damage in the lower layers was significant, hardly any dullness was found after ripening and after 3 days of shelf life. The significant effects were not relevant. No effect was found due to the position of the pallets.

5.5.2 Container Test 1-1

All 12 evaluated cartons from this container had the same packing code, however 4 out of 12 were packed in polybags. The temperature in the remaining 8 cartons varied: 14.5 – 16.8°C. In one carton (14.6°C) dullness scored 0.9 on day 3, in two other cartons at the same temperature no dullness was found. Average temperature in layers 1 and 8 were 14.6°C and 16.1°C. In the carton on layer 1 of a pallet in the middle of the container (14.6°C) dullness on day 3 of shelf life was 0.9 (scale 0 – 6), dullness in the other cartons were < 0.2. Most sugar spots were found in two cartons from pallets at the door side of the containers at layer 8 (16.1 and 16.8°C).

5.5.3 Container Test 1-4

From this container 15 out of 16 evaluated cartons had the same packing code. The temperature in the cartons was variable: 14.2 – 17.7°C. No relevant significant effects of the location in the container were found. At higher temperatures bananas were a little more yellow than at lower temperatures (Table 20); however this was not more than a slight trend.

Table 20 Effect of pallet location and layer on average temperature and colour on day 3 of shelf life from container Test 1-4. Results with different characters showed a significant effect by analysis of variance (ANOVA).

Pallet location	Layer	Average temperature [°C]	Colour day 3 [0 – 6]
Near cool unit	1	14.5 a	4.6 a
	8	15.9 ab	4.8 ab
Middle	1	14.6 a	4.8 ab
	8	15.8 b	4.4 a
Near doors	1	15.3 ab	4.6 a
	8	17.3 c	5.2 b

5.6 Ethylene measurements

All ethylene concentrations were negligible (< 0.1 ppm).

6 Conclusions

6.1 Power savings

Table 21 shows the mean savings for the various quest settings, taking into account the differences in condenser cooling.

Table 21 Approximate power savings

Settings	Approximate savings (%)	Remark
Quest1-sroll (default)	54	> 54%? difference in vent setting & did not reach setpoint
Quest 1 (default)	40	> 40%? difference in vent setting
Quest 2 (warm)	45	< 45%? difference in vent setting
Quest 3 (cold)	48	> 48%? did not reach setpoint

This includes the pull down phase during which the unit is not cycling yet. Power savings during cycling are approximately 50% and rise up to 70% when ambient temperature becomes cooler.

6.2 Temperatures

The supply and return air fluctuations in the Quest containers are dampened in the carton temperature data. Many cartons show no fluctuating temperatures at all. The largest recorded carton temperature fluctuations has an amplitude of 0.25°C.

During Quest Regular Mode, the minimum supply temperature mostly does not reach supply setting for the scroll unit and the Quest3 settings. The Quest1 and Quest2 test containers did reach the minimum supply temperature. Adaptation of the field software, after the previous banana trial shipment, apparently improved the supply temperature control. However, it does not yet accommodate the supply temperature setting of more then 2.5°C below the Low Return Air Limit nor the cooling periods shorter then 10 minutes.

Table 22 shows the performance of the various Quest containers, compared to the reference containers. It shows the differences in deviation from the setpoint, for the mean carton temperature in a Quest versus a reference container. Also, the differences in bandwidth are shown. The last two columns show the deviations from the setpoint for the coolest and warmest cartons in the containers. A negative number means that the Quest container is further from the setpoint then the reference or has a larger bandwidth.
Overall, carton temperatures in the Quest container are warmer then those of the reference containers, with a larger bandwidth. The Quest3 and Quest1-scroll containers are further from setpoint then the Quest1 and Quest2 containers. This is already the case after pull down, so probably caused by produce specifics or stowage.

Table 22 Performance of the various Quest containers versus the reference containers

	Mean closeness to setpoint (°C)	Size bandwidth (°C)	Coolest carton closeness to setpoint (°C)	Warmest carton closeness to setpoint (°C)
Test1 & ref 2	-0.5	-0.9	-0.1	-0.9
Test2 & ref 2	-0.5	-0.3	-0.3	-0.6
Test3 & ref 2	-0.7	-1.6	0	-1.5
Test4 & ref 4	-1.7	-2.3	-0.7	-3.0

As in the previous banana trial, a few test units give alarm code 64 (discharge temperature over limit) during the trip, as well as ref2. We advise Carrier to double check if this is a CCPC software effect.

6.3 Product quality

The 116 test cartons originated from 39 different batches and were packed in two different kinds of bags: clusters separate in polybags or in one banavac. This makes quality comparison cumbersome.

Bananas packed in polybags showed high on dullness. Bananas in these small bags felt much dryer then those in banavacs. Dullness is probably caused by moisture loss instead of being a chilling indicator. Quality inspection at arrival did not show differences due to packing times or containers. Bananas packed in polybags showed more under peel damage at arrival.

No relation could be found between the average carton temperature (approximately 14.0 to 17.0°C) and the product quality indicators: rot, under peel damage, colour and dullness. This indicates that there was no chilling injury. The warmest cartons showed more sugar spots then the coolest cartons. However, some average temperature cartons showed a very large number of sugar spots. Therefore origin seemed of more influence then carton temperature.

The Quest regime seems not to have change quality output compared to normal regime, except perhaps slightly faster ripening in the warmest cartons.

References

[1] http://www.googlemaps.com/

[2] http://www.maersksealand.com/

[3] http://www.cdc.noaa.gov/cgi-bin/GrADS.pl

Appendix I: Ambient conditions between Ecuador and the Netherlands

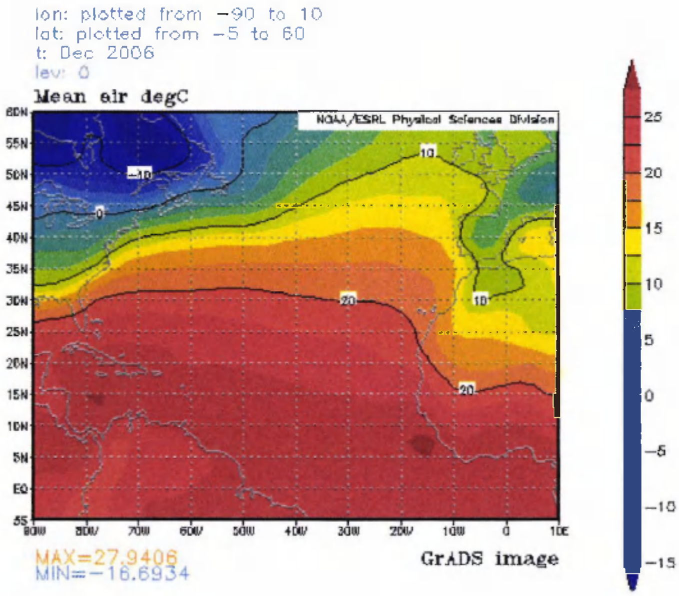

Figure 22 Mean December temperature between Ecuador and the Netherlands [3]

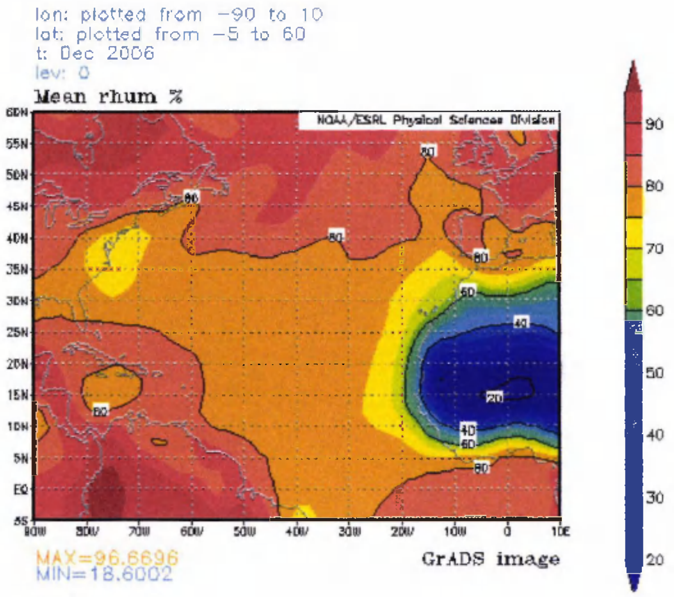

Figure 23 Mean December relative humidity between Ecuador and the Netherlands [3]

Appendix II: Unloading and dcx file information

Table 23 Unloading and dcx temperature information

Container	Vent Position at unloading (CMH)	pallets missing at unloading	usda	ret	sup	superror
Test11	30	0	usda4 23 -> 15-> 26 degC	14.2/14.5/14.9, ok	11.6/ 13->14 / 14.6, min 0.2 deg C cooler then defined	neg 0.5 / av 0.5 / pos 8 Kmin
Ref1	30	4	None	15.0->12.5	13.3, end of trip 12.5	
Test21	30	0	None	14.8 / 15.0/15.3	12.7/ 14.5/ 15.8 to 15.2: o.k.	neg 1 -> 0 / av. 0.5 / pos 25 -> 5 -> 10 -> 5 Kmins
Test31	30	0	None	14.3/14.5/14.8: ok	10.9 to 12.1 mostly 11.3 / 13.0 to 14.3 mostly 14.0 / 15.5 to 14.5, mostly 14.8:does not reach setpoint for most of the trip, 15.5, when return is 14.8?	neg peaks to 4 / av 1 / pos 25 -> 5 Kmin
Test12	50	0	None	14.3/14.5/14.8: ok	11.6-> 11.8 / 14.0 -> 14.5 / 15.5 -> 15.2 -> 14.8: Tsupsp reached, why high max?	neg 1-> 0 / av 1 / pos 15 -> 5 Kmin
Ref2	35	0	Usda1 and 4, 14 deg C	14.5-> 13.7	13.3	
Test22	15	0	usda1, 20 to 18 deg C, usda2 13.8 to 15.2 deg C	day 5, cool to 14.3, then 14.7 to 15.2: o.k.	12.7/ 15.0 / 16.1: reaches Tsupsp, why maximum so high?	neg 0.6 -> 0.2, av 0.4 / pos 8 Kmin
Test32	30	0	None	14.3/14.5/14.8: ok	10.7->12.0, 11.8 mostly / 14->14.5 / 15.4, does only reach Tsupsp around start of cycling, then climbs up	neg 25 Kmin / av 1.5 Kmin / pos 0
Test14	30	0	None	14.3/14.5/14.8 : ok	12.4 (11.6 to 12.6 at start) / 14.5 / 15.9 to 15.2 to 15.0: does not reach Tsupsp for most of trip	neg 1 to 0 / av 1 / pos 26 to 5 Kmin
Ref4	15	1	None	13.8 to 13.4 deg C	13.3 deg C	neg 25 to 1/ av 0 / pos 25 to 1

Table 24 DCX information, containers test11, ref1, test21 and test31

Container	Alarms from dcx files	cool limit max (Kmin)	clm trigger	deice	heat	dehum	cool period	non-cool period
Test11	None	40/20	no	no	no	no	27 -> 7	40 -> 25 -> 60 -> 100
Ref1	None	nvt	nvt	after day 25, 6* 0.6 kWh	0.05 regularly, after day 18 0.1, after day 25 0.5 kWh	no		defrosts 7* 20 mins after day 25
Test21	None	day 4: 140, 80, 20	no	no	no	no	30 -> 12 mins	50-> 30 -> 60 -> 200 mins
Test31	dec 11-14 2* AL20 control fuse, dec 07 1* Battery pack failure	20	no	no	no	no	10 -> 5 mins	10 -> 30 -> 45 -> 200 mins

Table 25 DCX information, containers test12, ref2, test22, test32, test14 and ref4

Container	Alarms from dcx files	cool limit max (Kmin)	clm trigger	deice	heat	dehum	cool period	non-cool period
Test12	dec 08-09 15*AL64 Discharge T over limit	40/20	no	no	no	no	20 -> 10 mins	20->60 -> 200 mins
Ref2	dec 08 - jan 02 9* AL64, dec 05 1* AL20	nvt	nvt	no	3 peaks after day 24: 0.05, 0.15, 0.15	no		
Test22	dec 08 - 23 48* AL64	310 peak, then 3 peaks of 80	yes, day 5	no	no	no	20 -> 12 mins	30 -> 60 mins, after day 25: 900 and 200 mins
Test32	dec 05 - 09 9* AL64	20	no	no	no	no	10 to 5 mins	10 to 40 mins after day 25: 100-300 mins
Test14	None	20	no	no	no	no	10 to 8 mins	10 to 25 to 45 to 130 to 200 mins
Ref4	none	no	no	no	peak 0.05 at day 25	no		20 mins at day 25

Appendix III: Carton temperatures

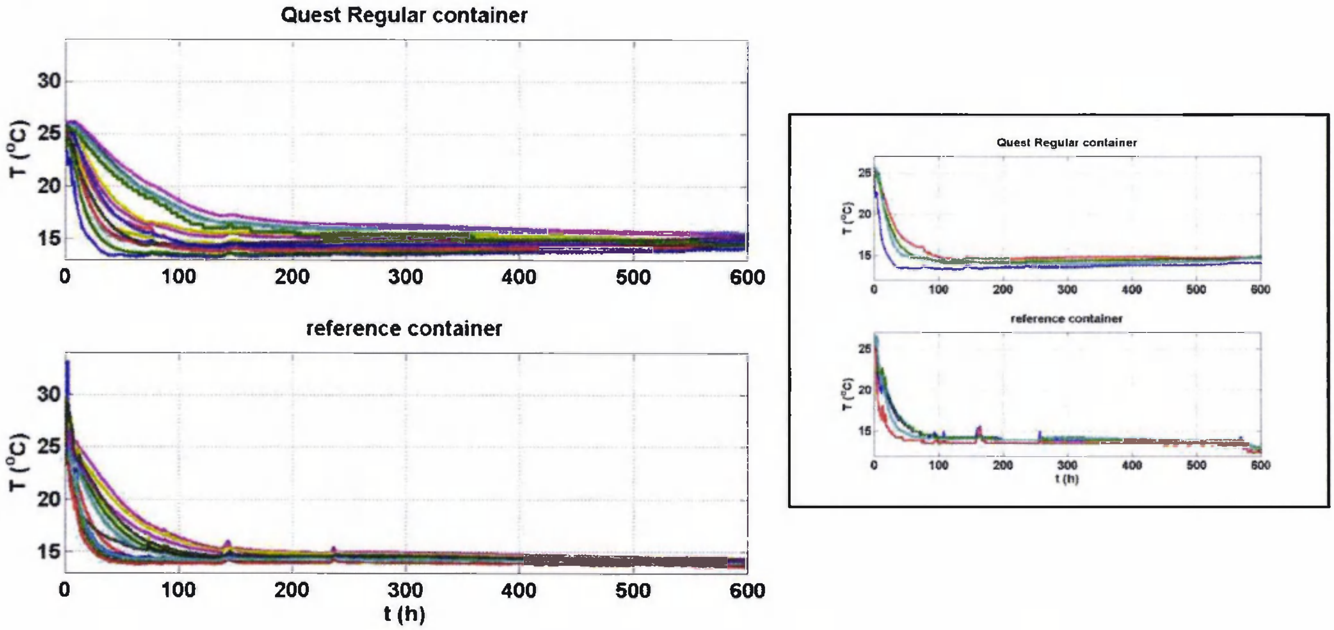

Figure 24 Temperature readings of Tiny Tags in cartons, all data, for test11 and ref2 (Inlay all data test11 and ref1)

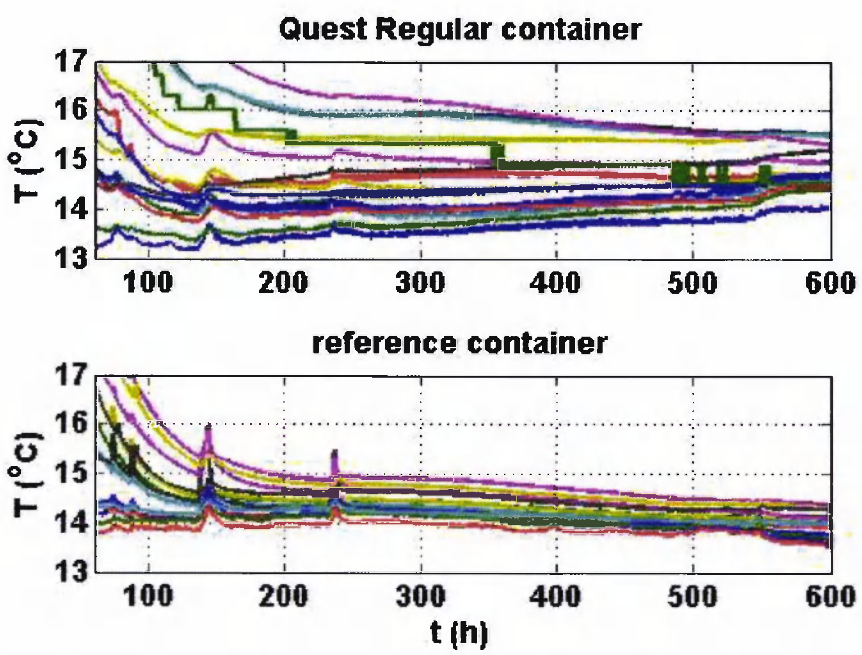

Figure 25 Temperature readings of Tiny Tags in cartons, zoom in, for test11 and ref2

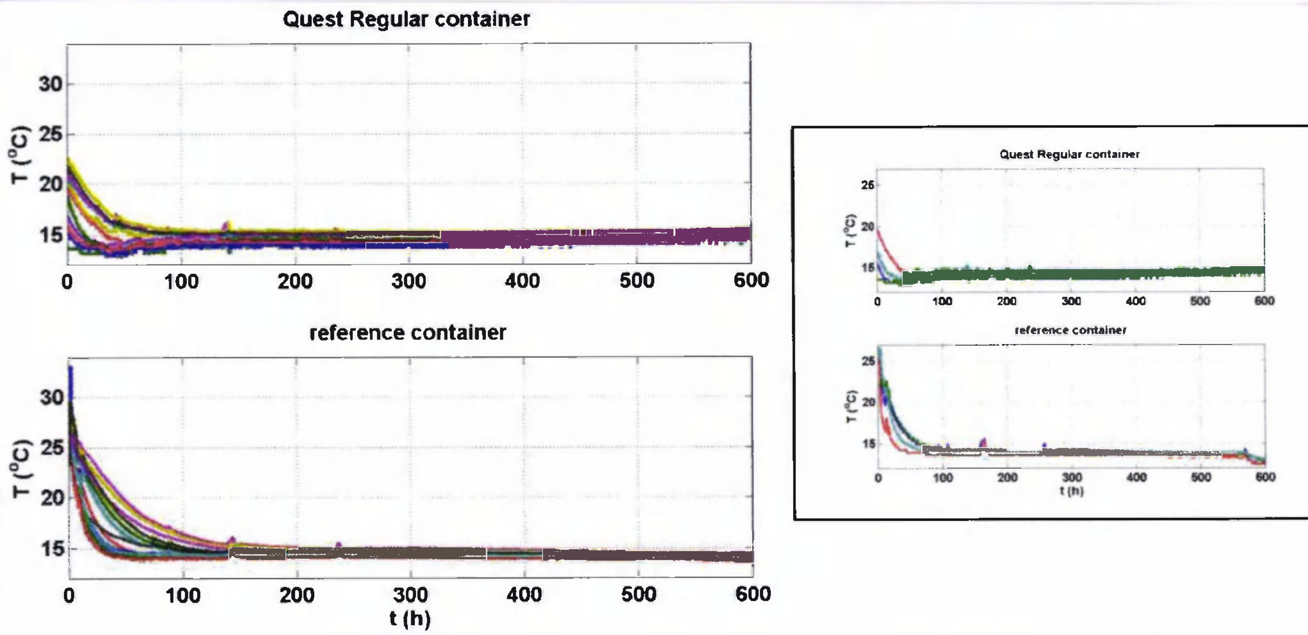

Figure 26 Temperature readings of Tiny Tags in cartons, all data, for test21 and ref2 (Inlay all data test21 and ref1)

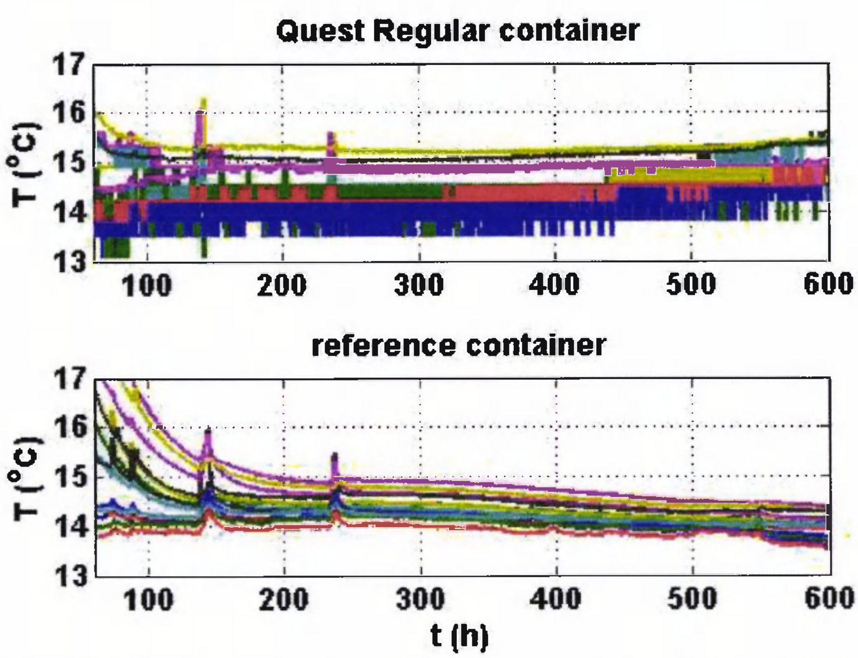

Figure 27 Temperature readings of Tiny Tags in cartons, zoom in, for test21 and ref2

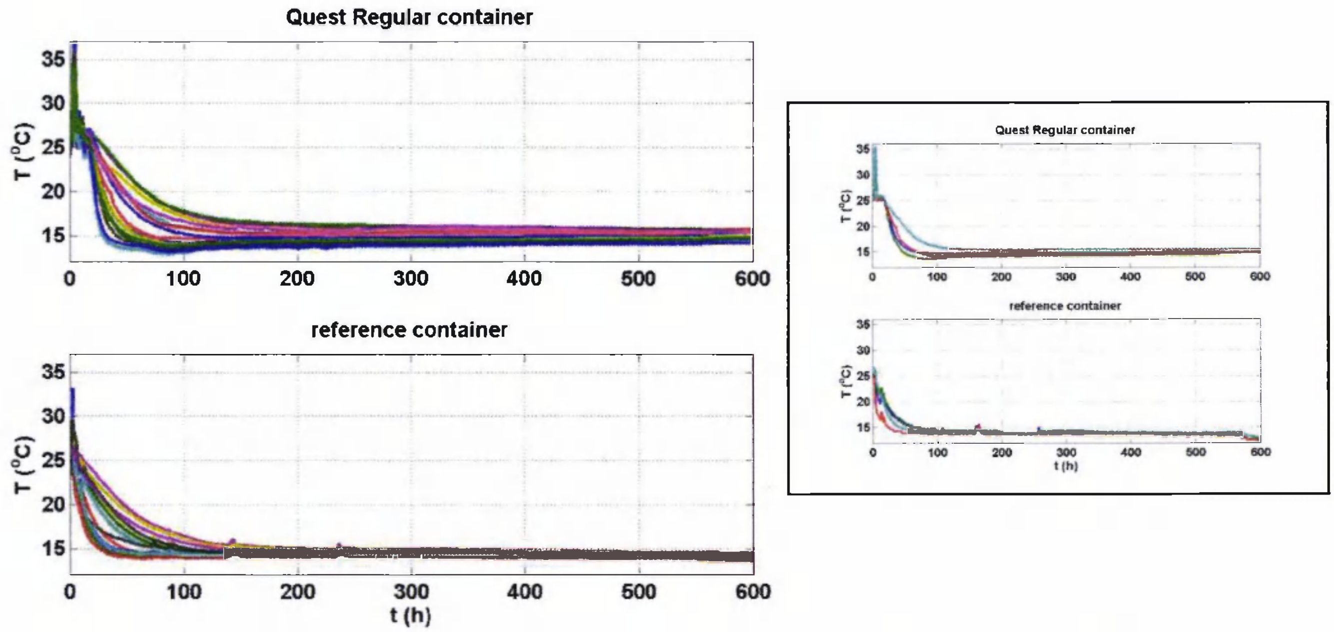

Figure 28 Temperature readings of Tiny Tags in cartons, all data, for test31 and ref2 (Inlay all data test31 and ref1)

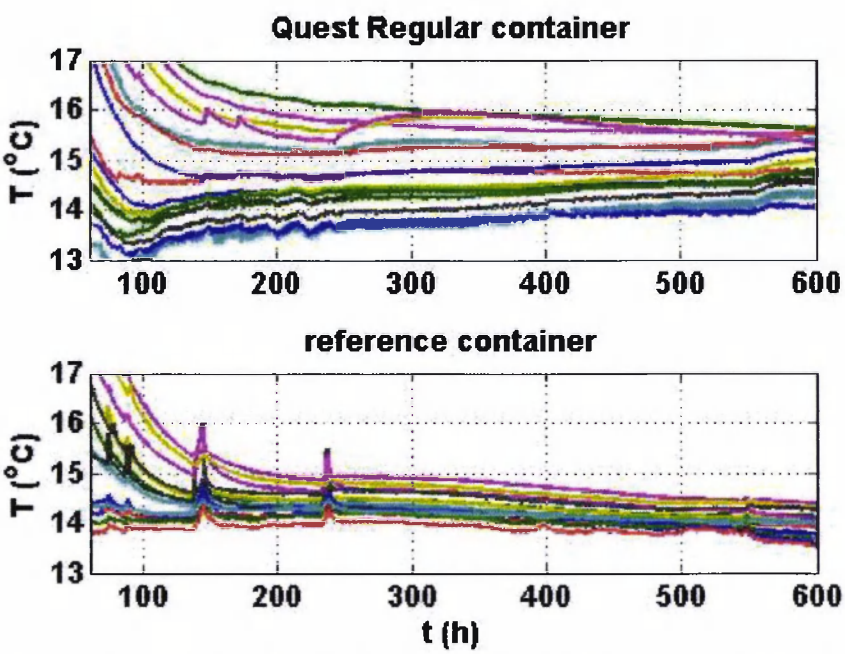

Figure 29 Temperature readings of Tiny Tags in cartons, zoom in, for test31 and ref2

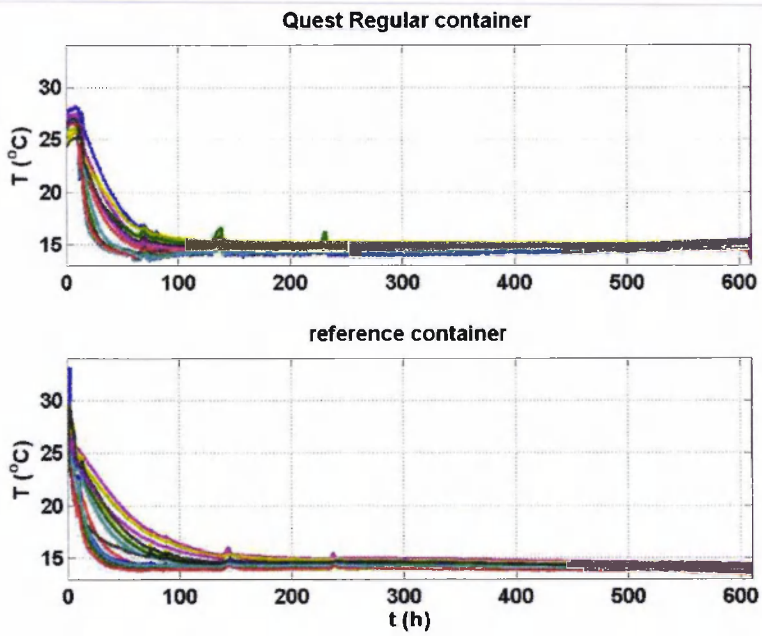

Figure 30 Temperature readings of Tiny Tags in cartons, all data, for test12 and ref2

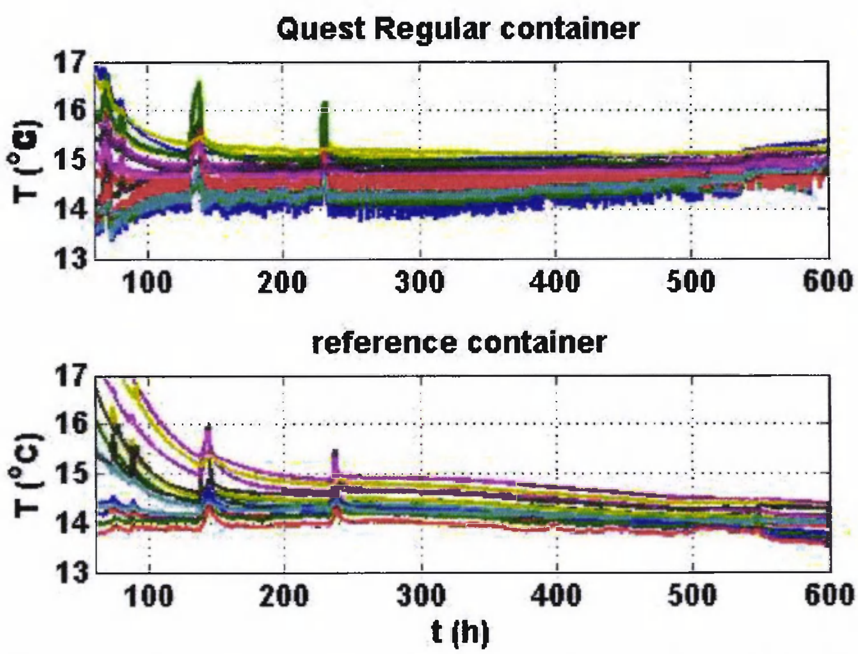

Figure 31 Temperature readings of Tiny Tags in cartons, zoom in, for test12 and ref2

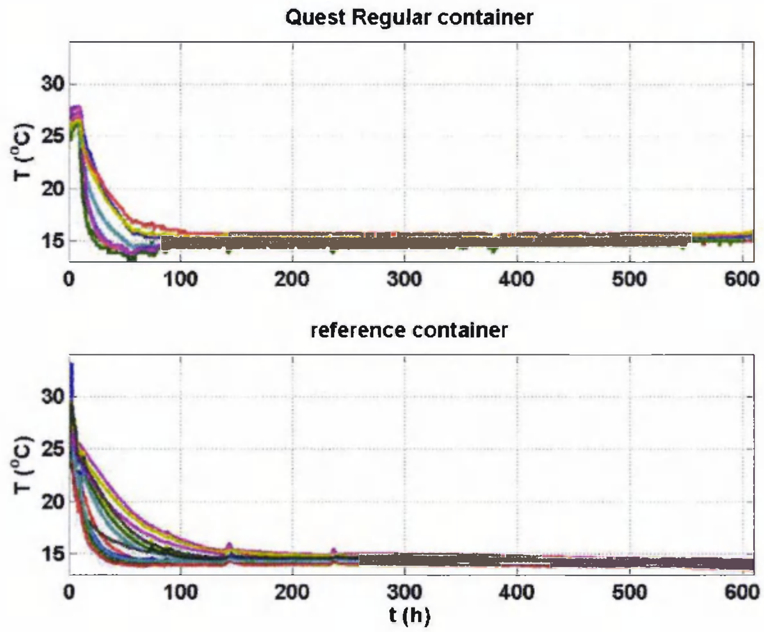

Figure 32 Temperature readings of Tiny Tags in cartons, all data, for test22 and ref2

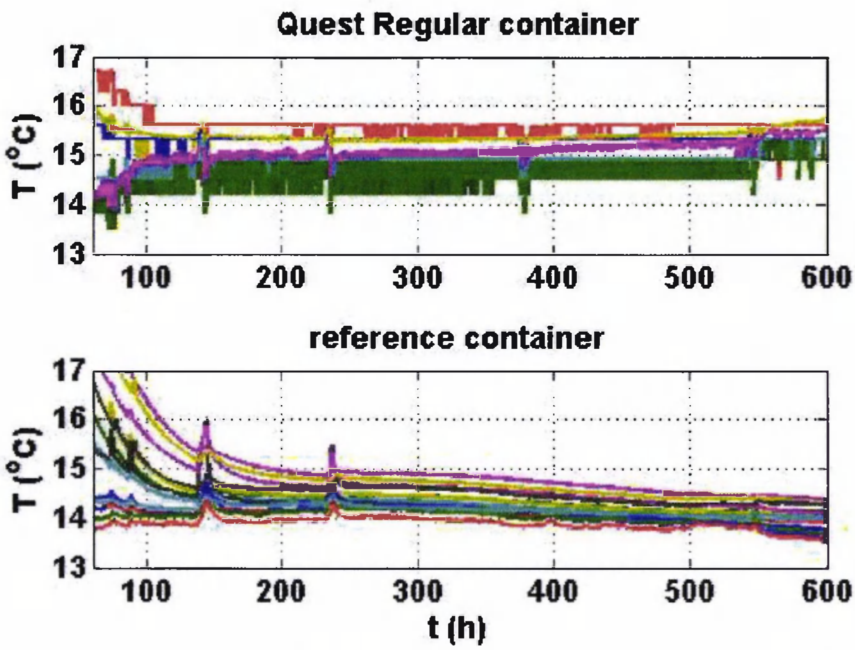

Figure 33 Temperature readings of Tiny Tags in cartons, zoom in, for test22 and ref2

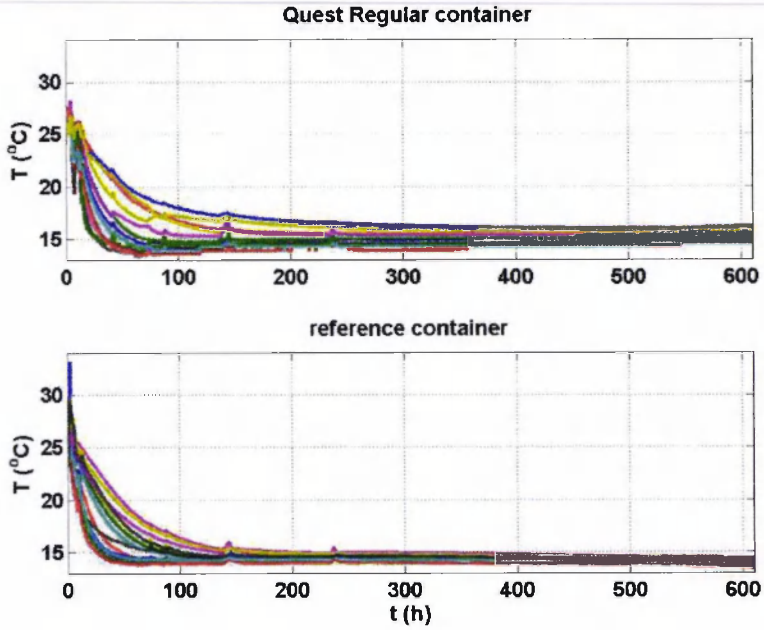

Figure 34 Temperature readings of Tiny Tags in cartons, all data, for test32 and ref2

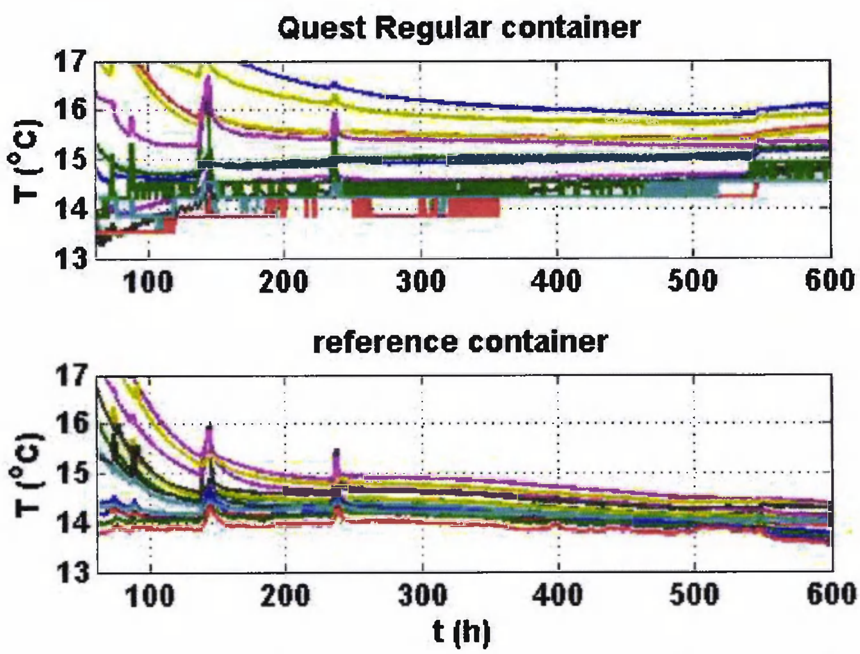

Figure 35 Temperature readings of Tiny Tags in cartons, zoom in, for test32 and ref2

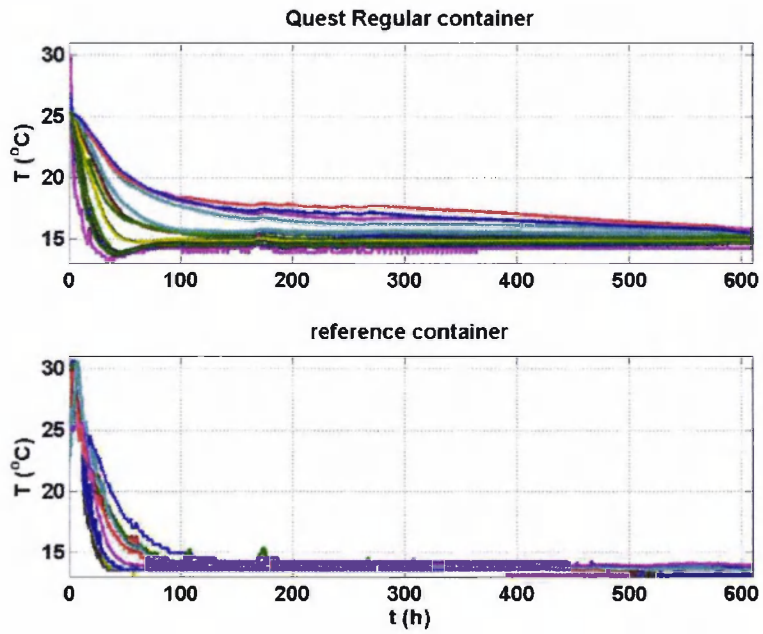

Figure 36 Temperature readings of Tiny Tags in cartons, all data, for test14 and ref4

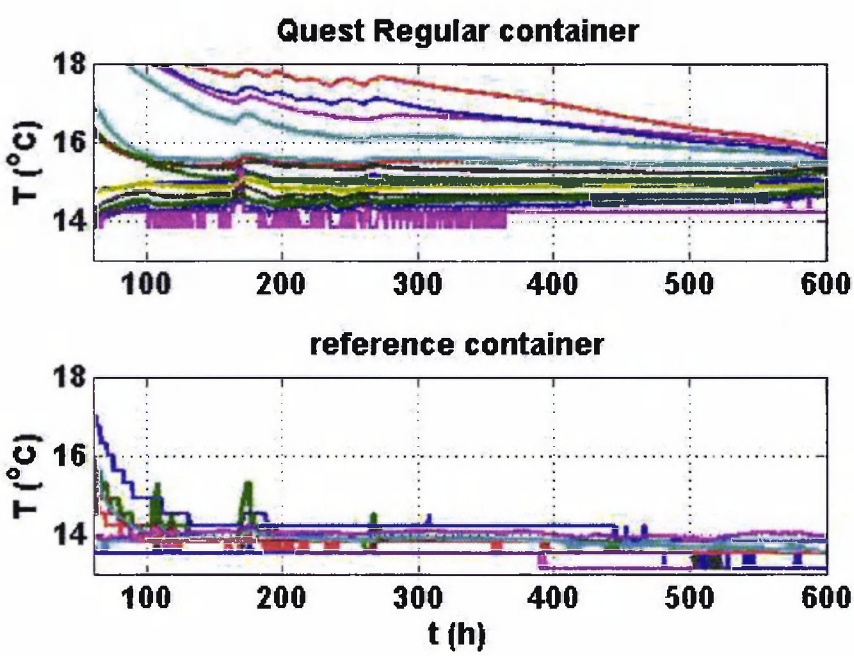

Figure 37 Temperature readings of Tiny Tags in cartons, zoom in, for test14 and ref4

Appendix IV: Unit temperature readings as a function of time

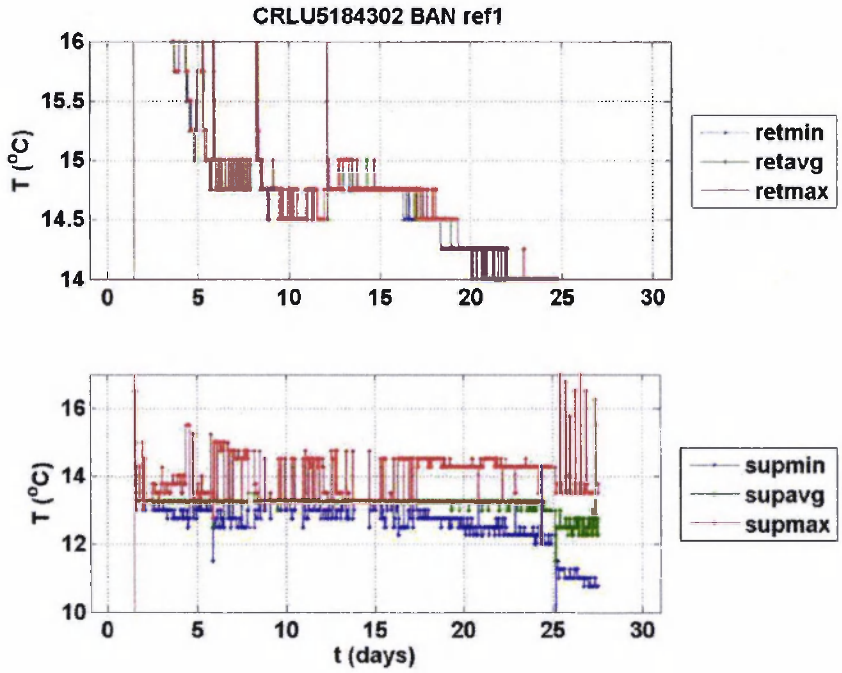

Figure 38 Temperature readings from the unit for the ref1 container.

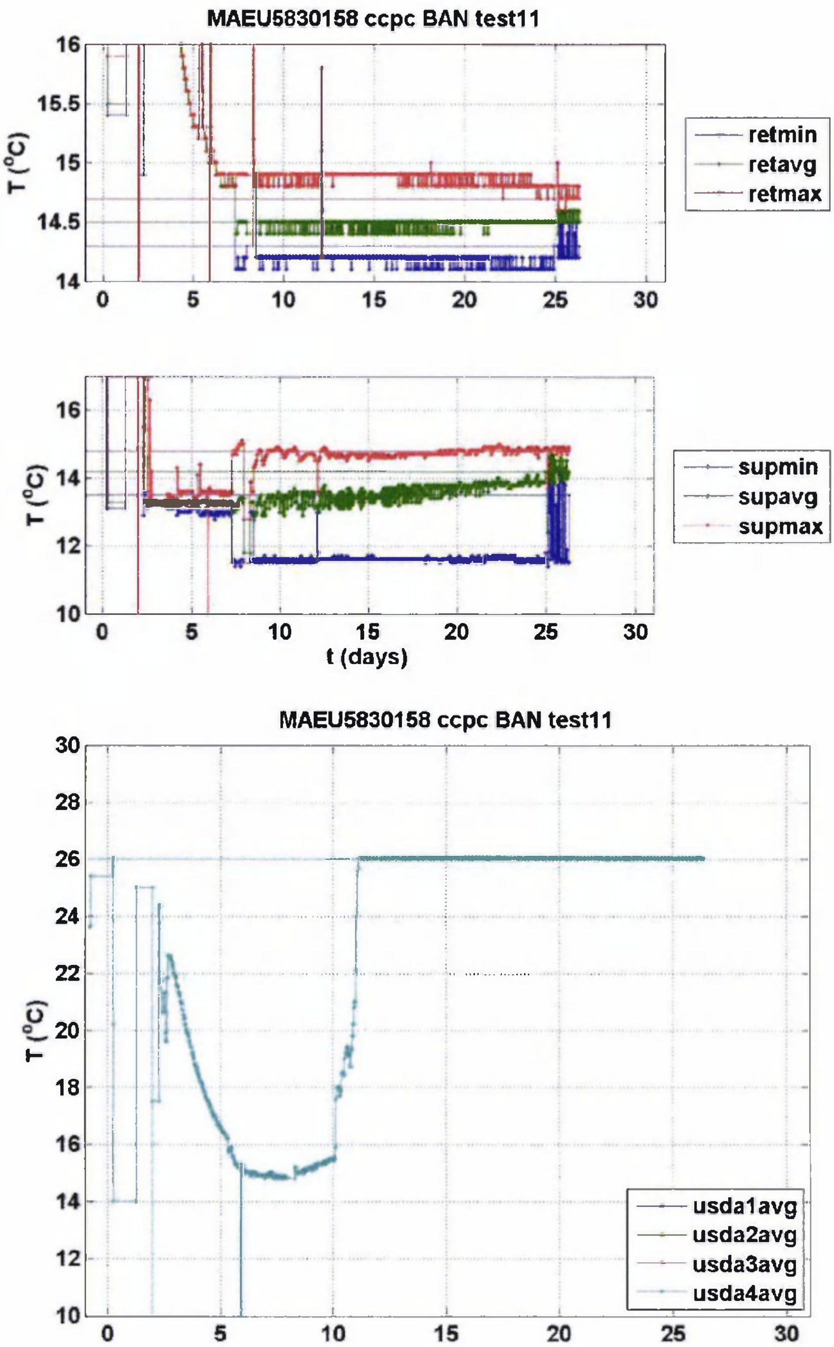

Figure 39 Temperature readings from the unit for the test11 container

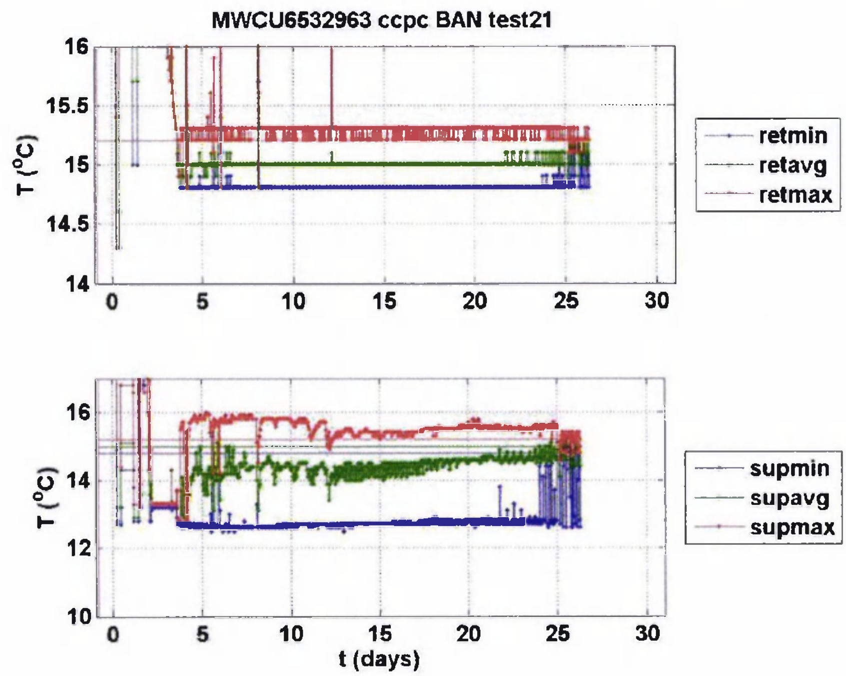

Figure 40 Temperature readings from the unit for the test21 container.

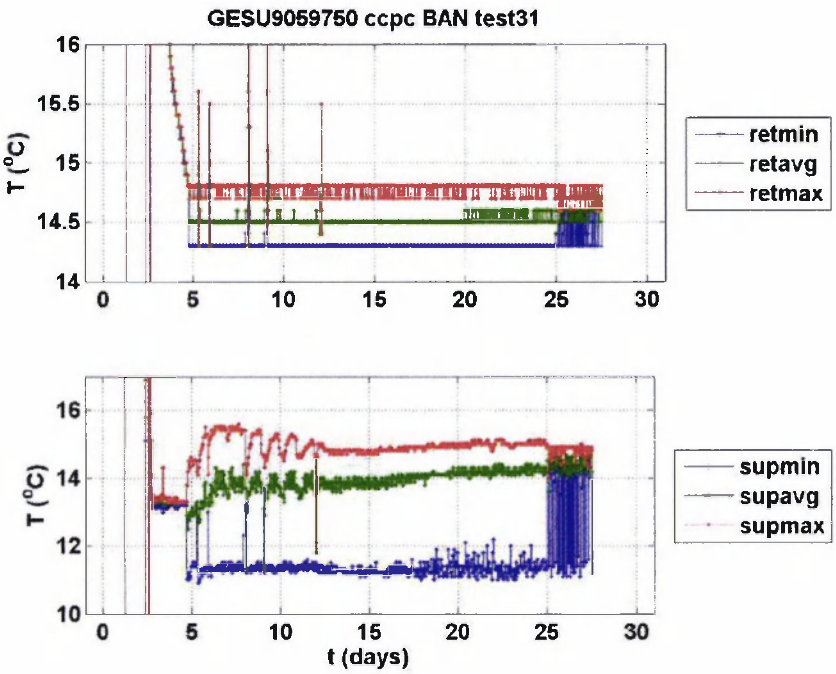

Figure 41 Temperature readings from the unit for the test31 container.

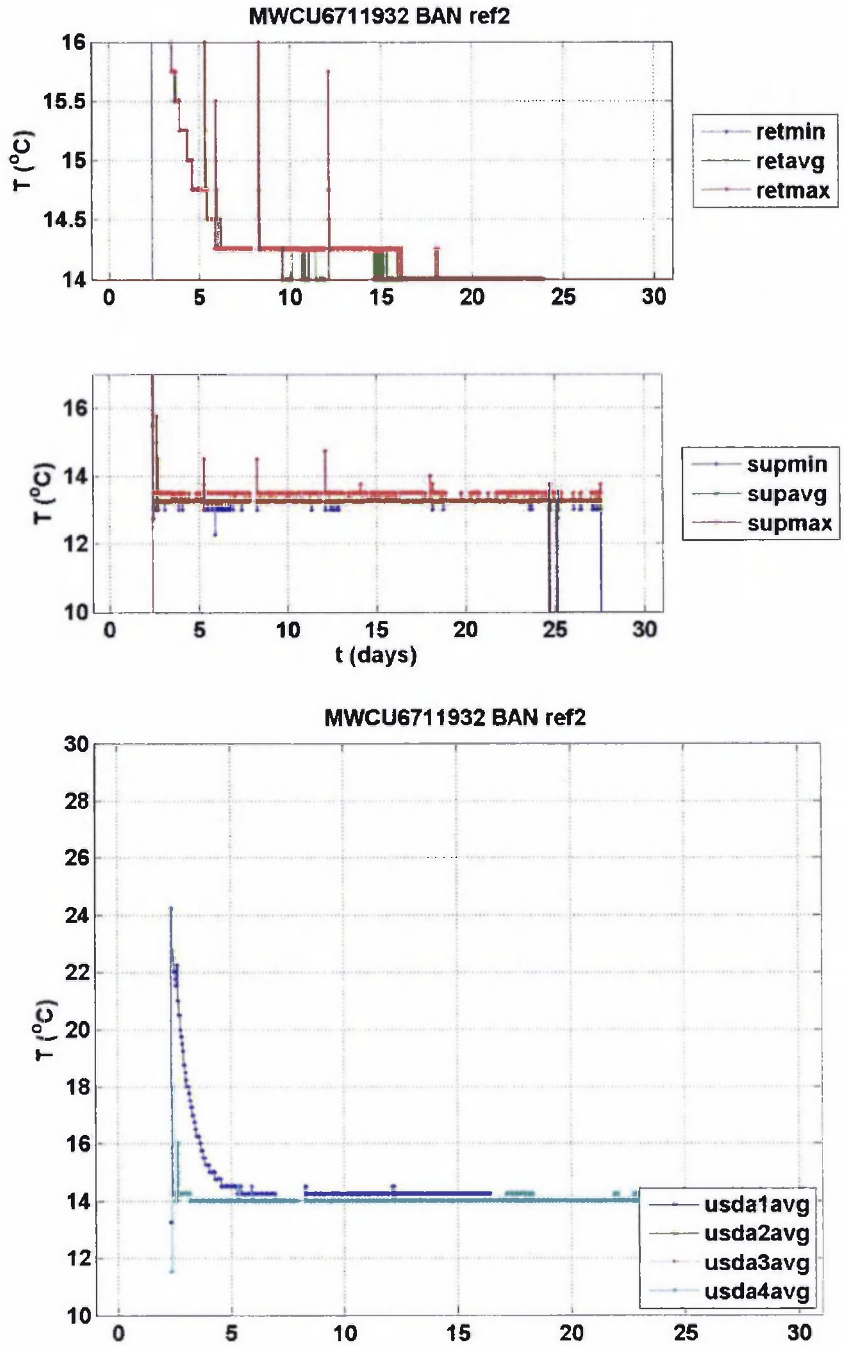

Figure 42 Temperature readings from the unit for the ref2 container.

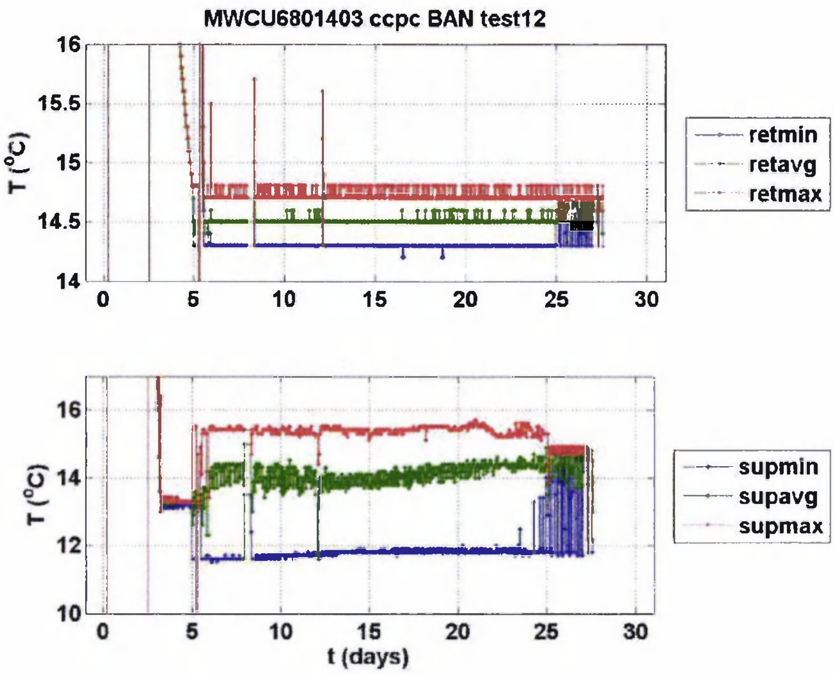

Figure 43 Temperature readings from the unit for the test12 container

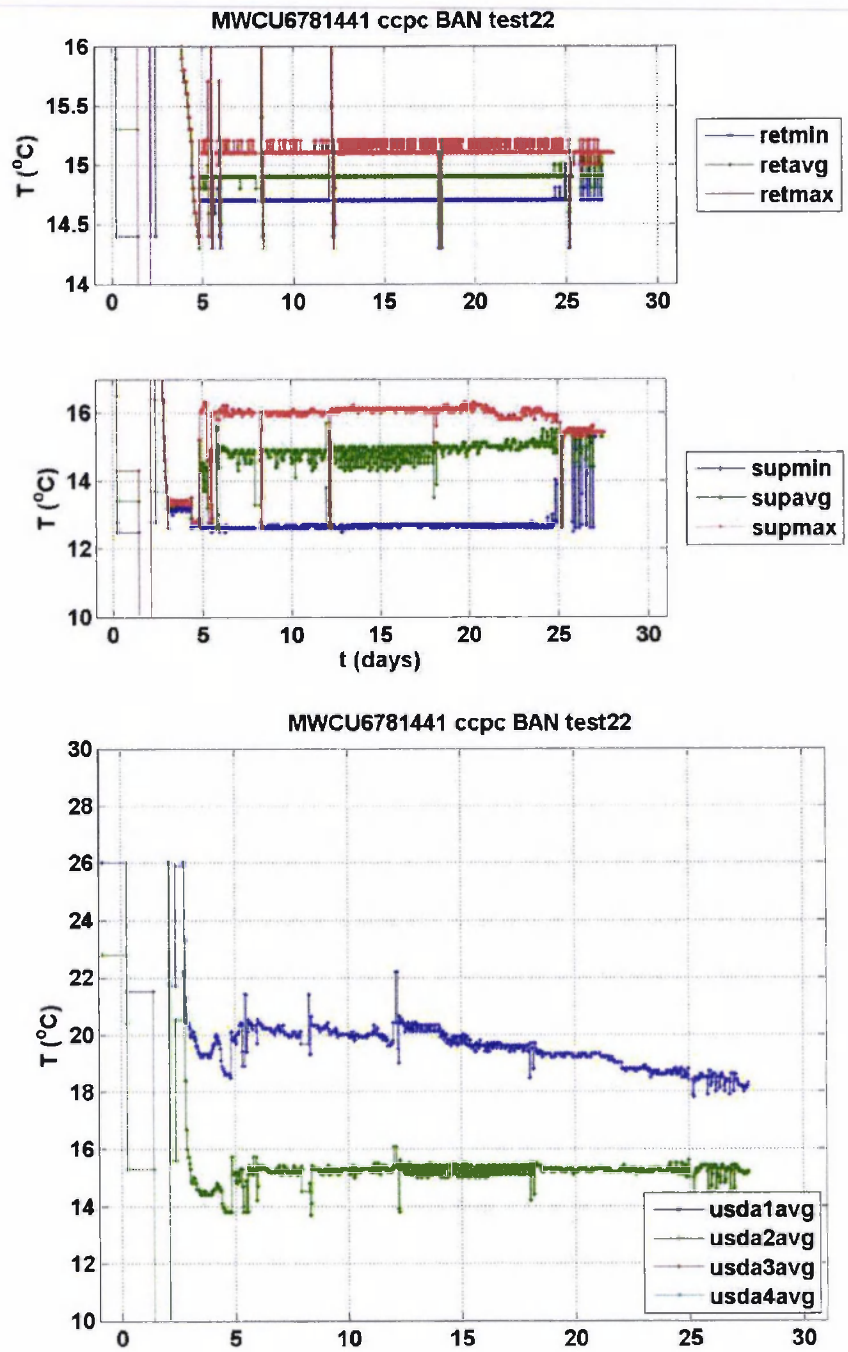

Figure 44 Temperature readings from the unit for the test22 container.

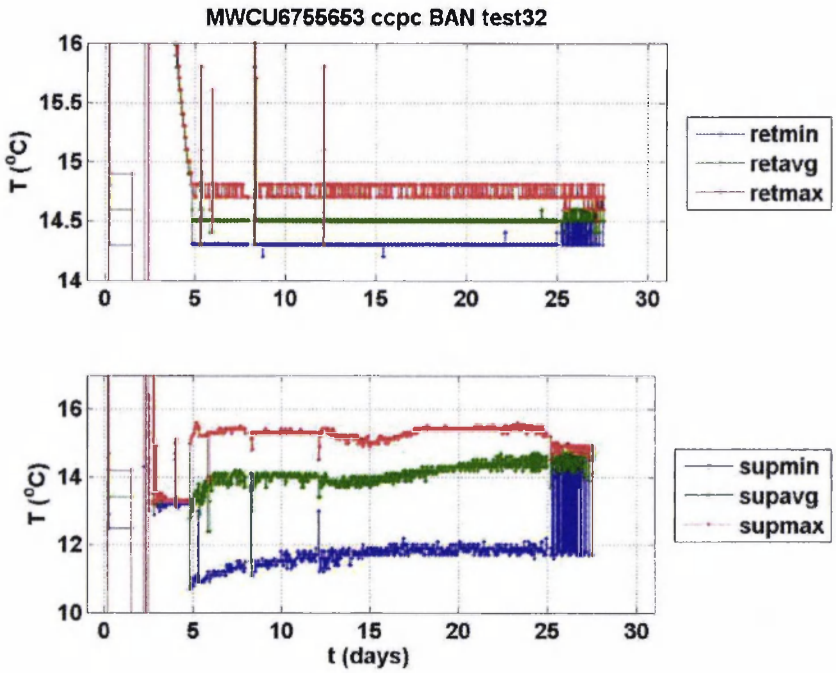

Figure 45 Temperature readings from the unit for the test32 container.

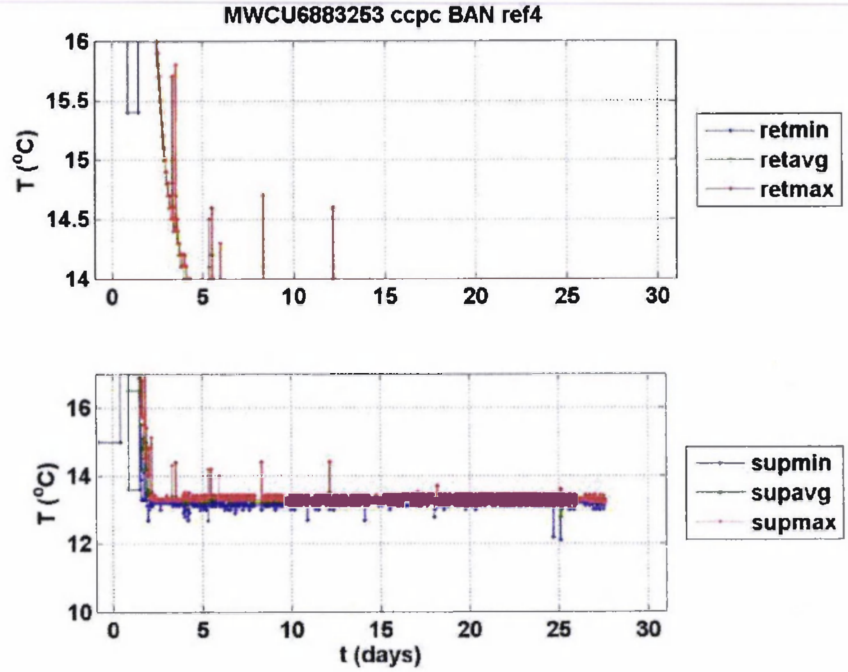

Figure 46 Temperature readings from the unit for the ref4 container.

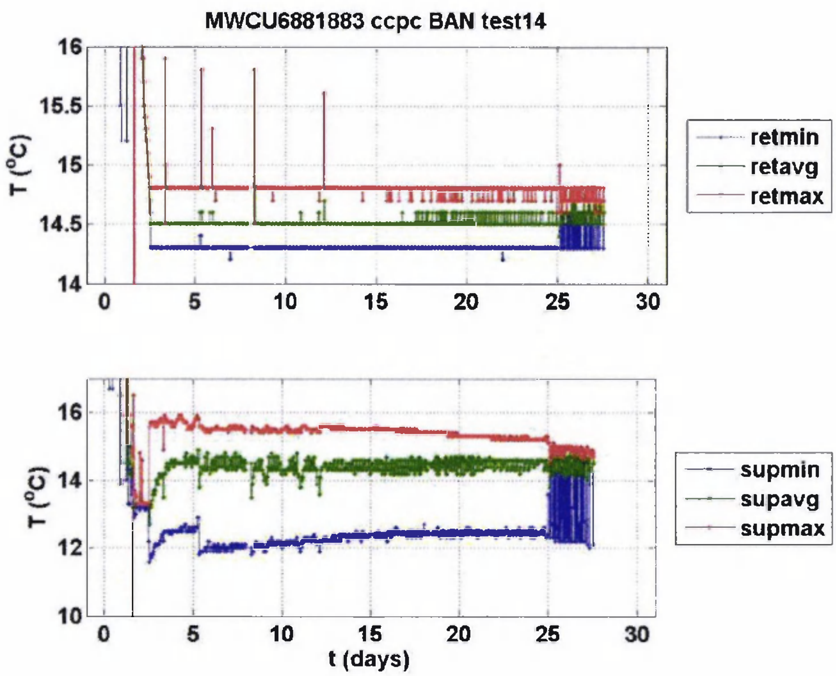

Figure 47 Temperature readings from the unit for the test14 container.

Appendix V: Snapshot pictures of carton temperature readings

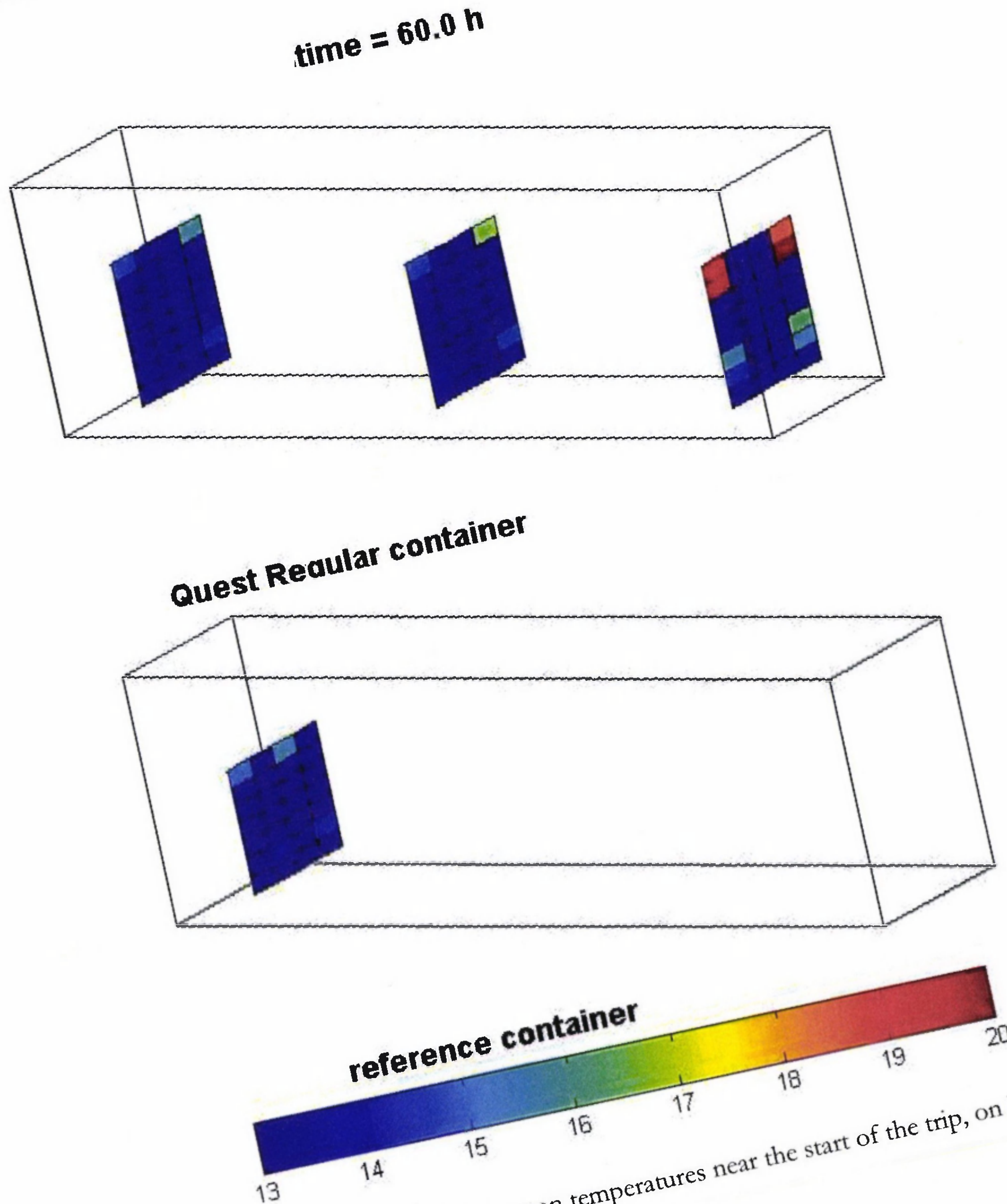

Figure 48 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test11 and ref1

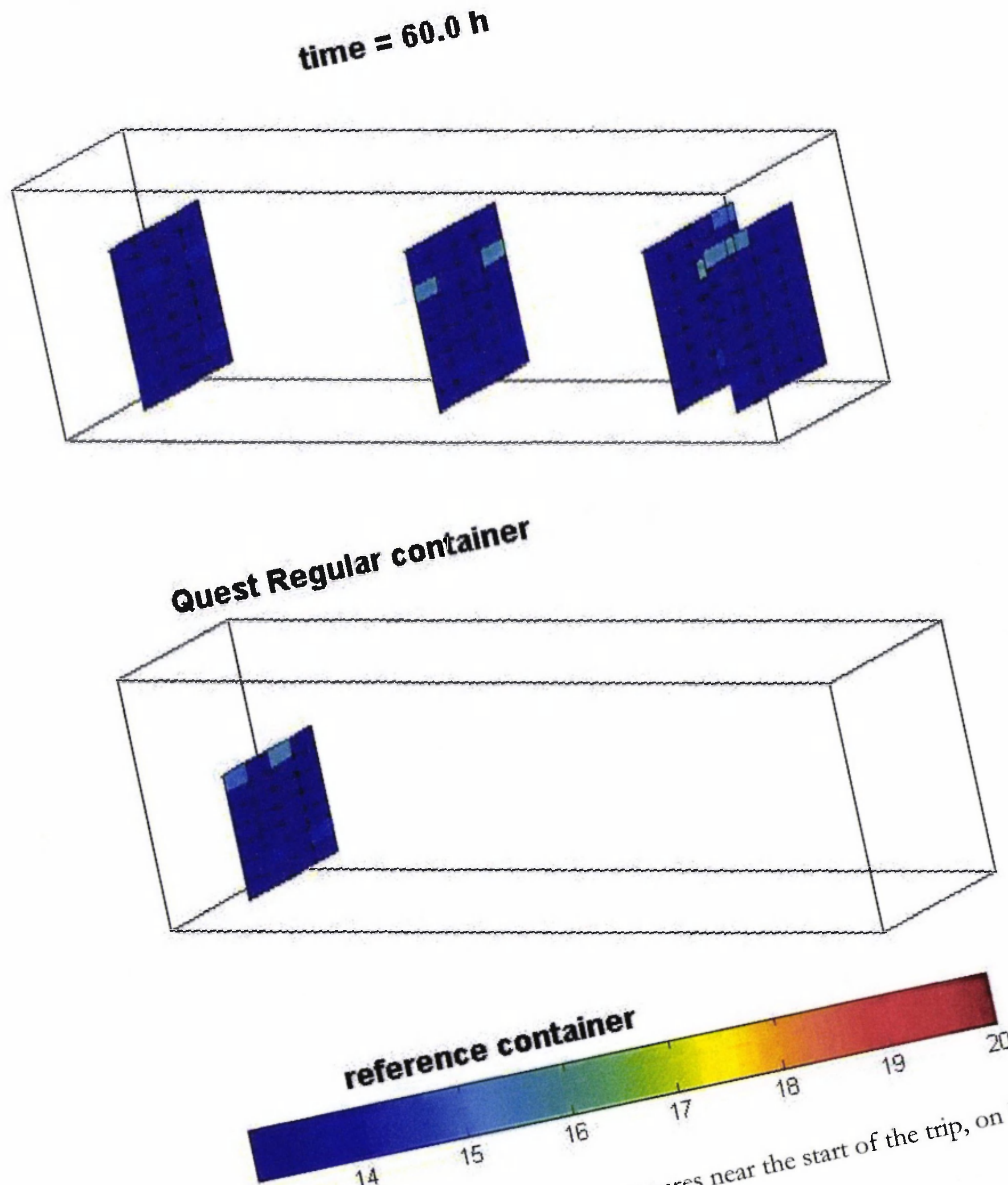

Figure 49 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test21 and ref 1

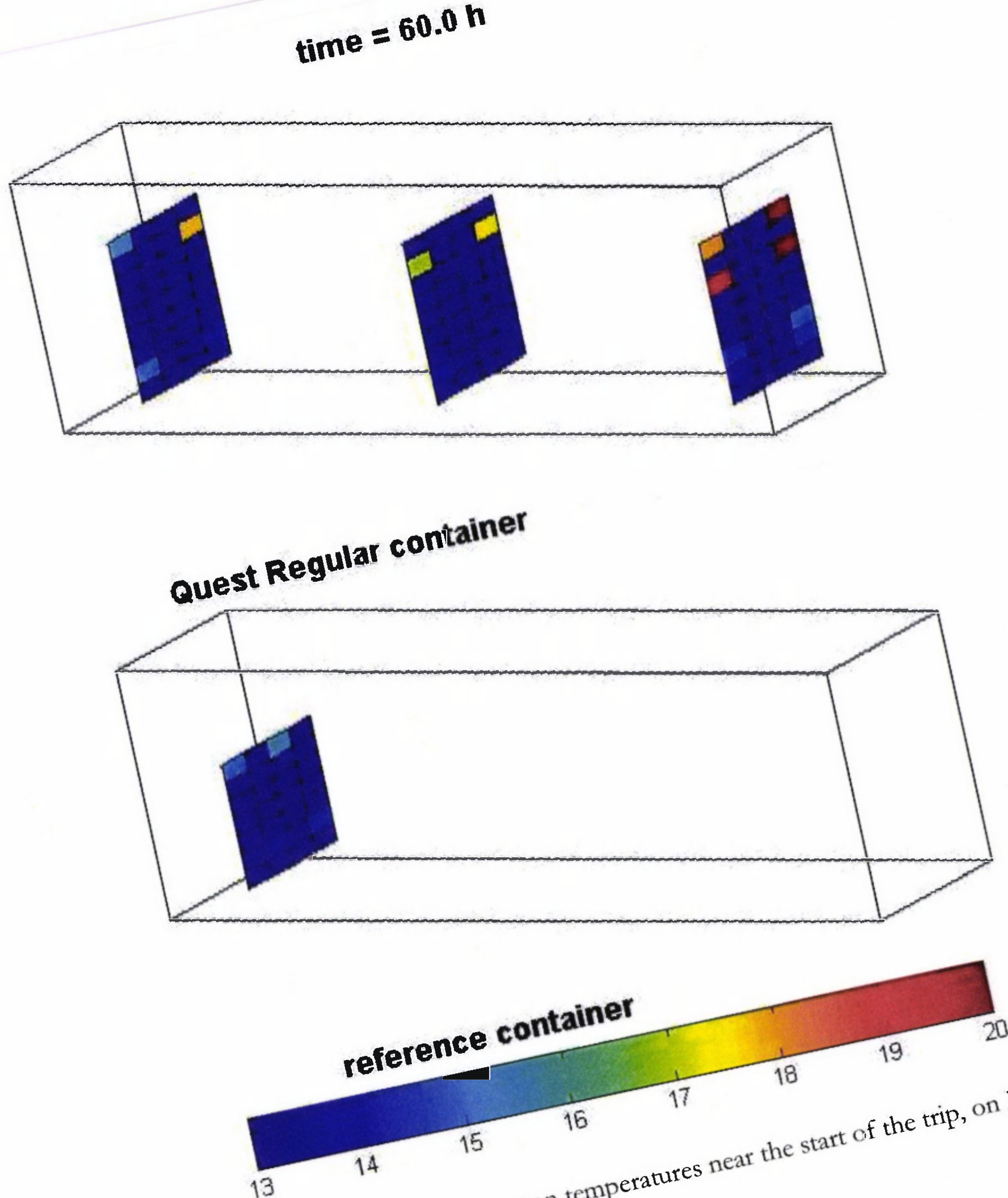

Figure 50 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test31 and ref1

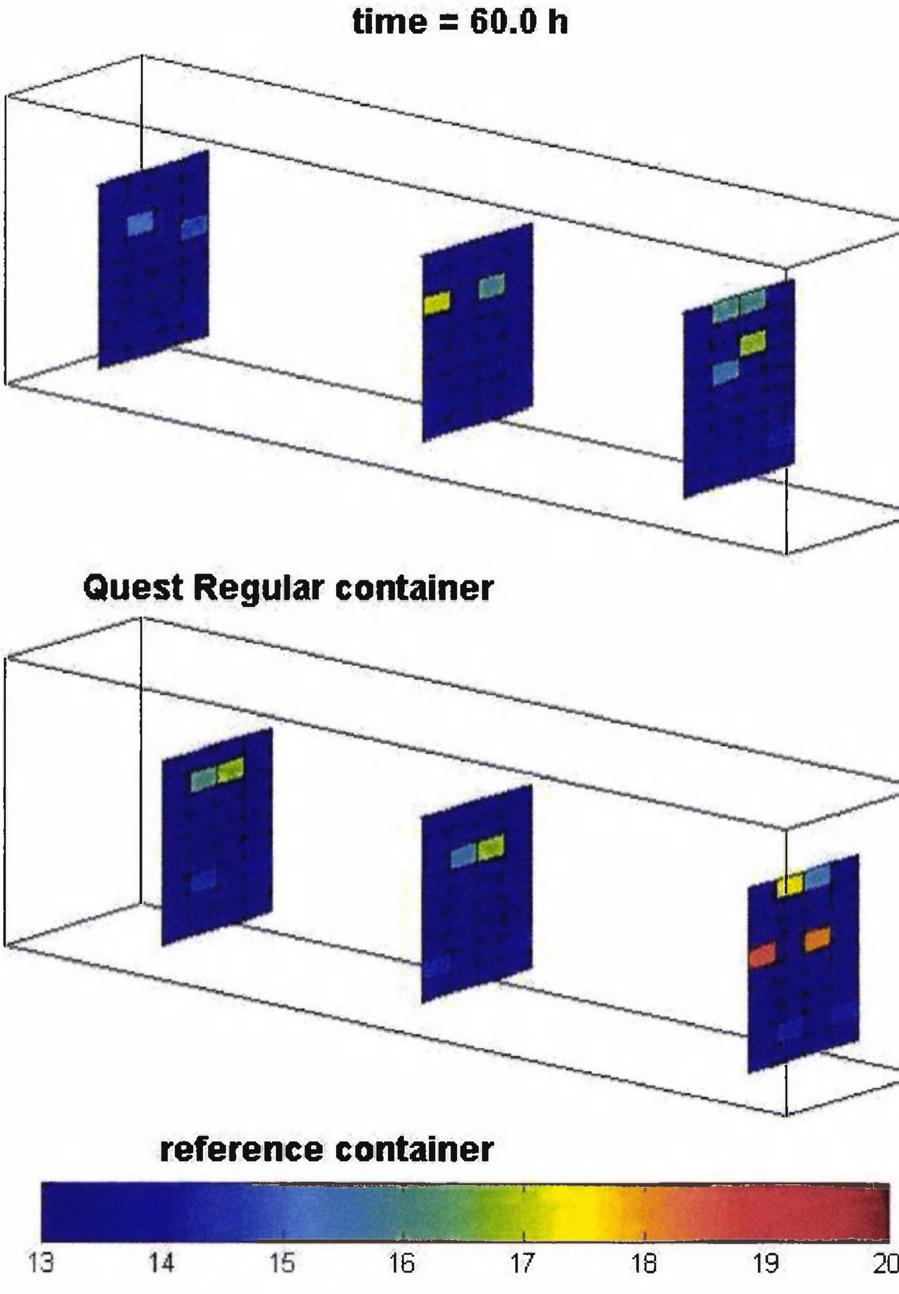

Figure 51 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test12 and ref 2

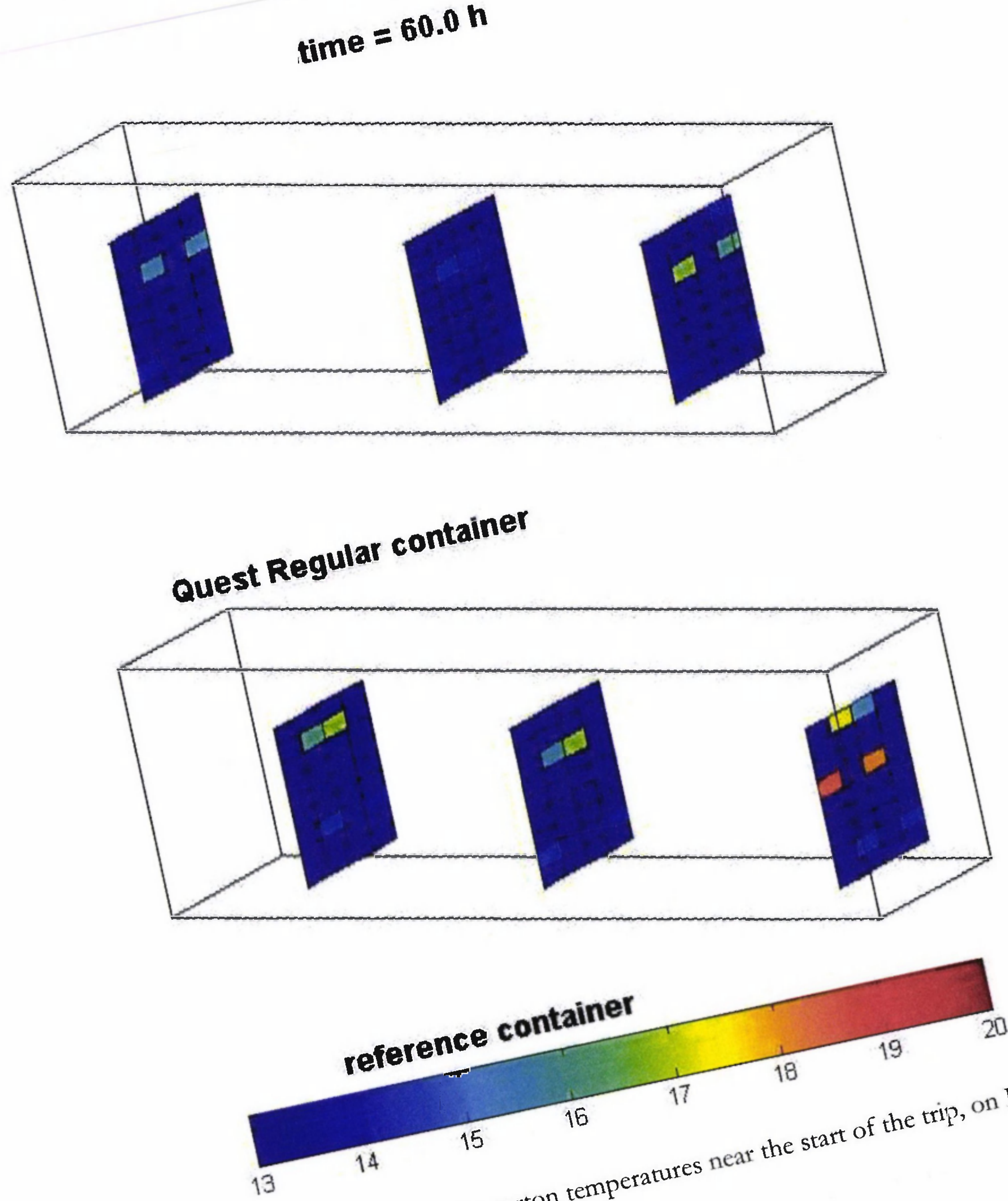

Figure 52 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test22 and ref2

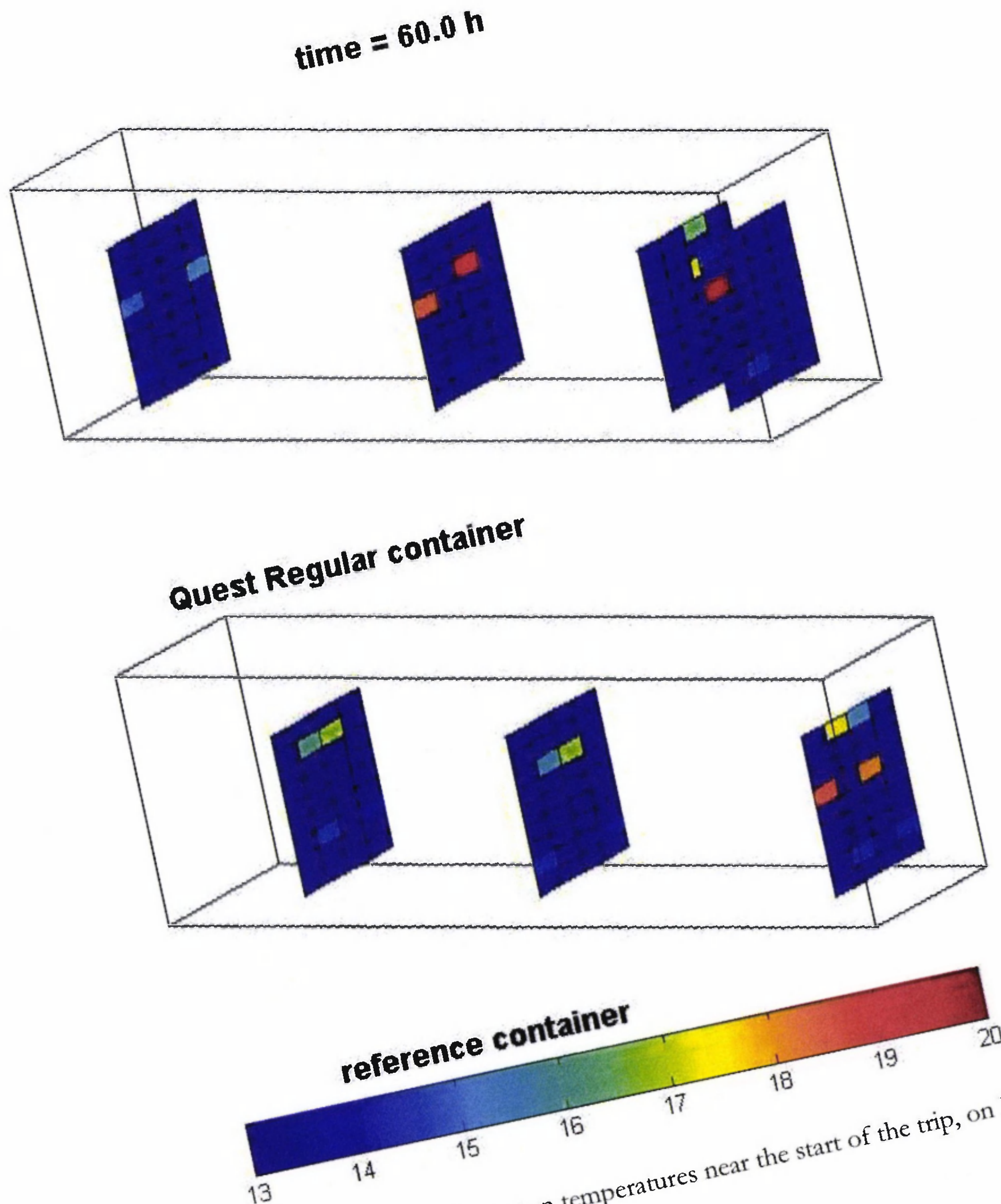

Figure 53 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test32 and ref2

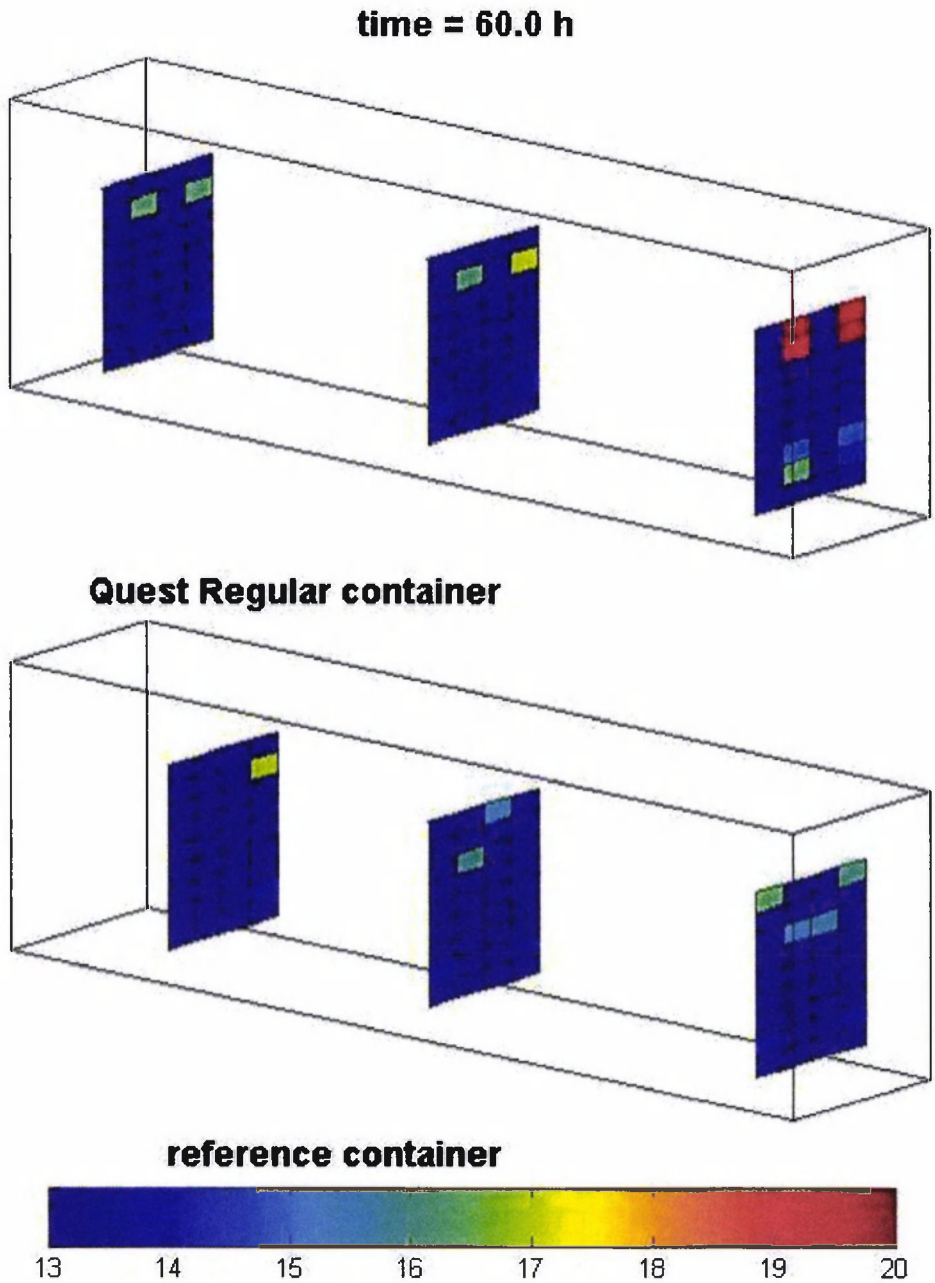

Figure 54 Tiny Tag readings of the carton temperatures near the start of the trip, on December 9th, test14 and ref4

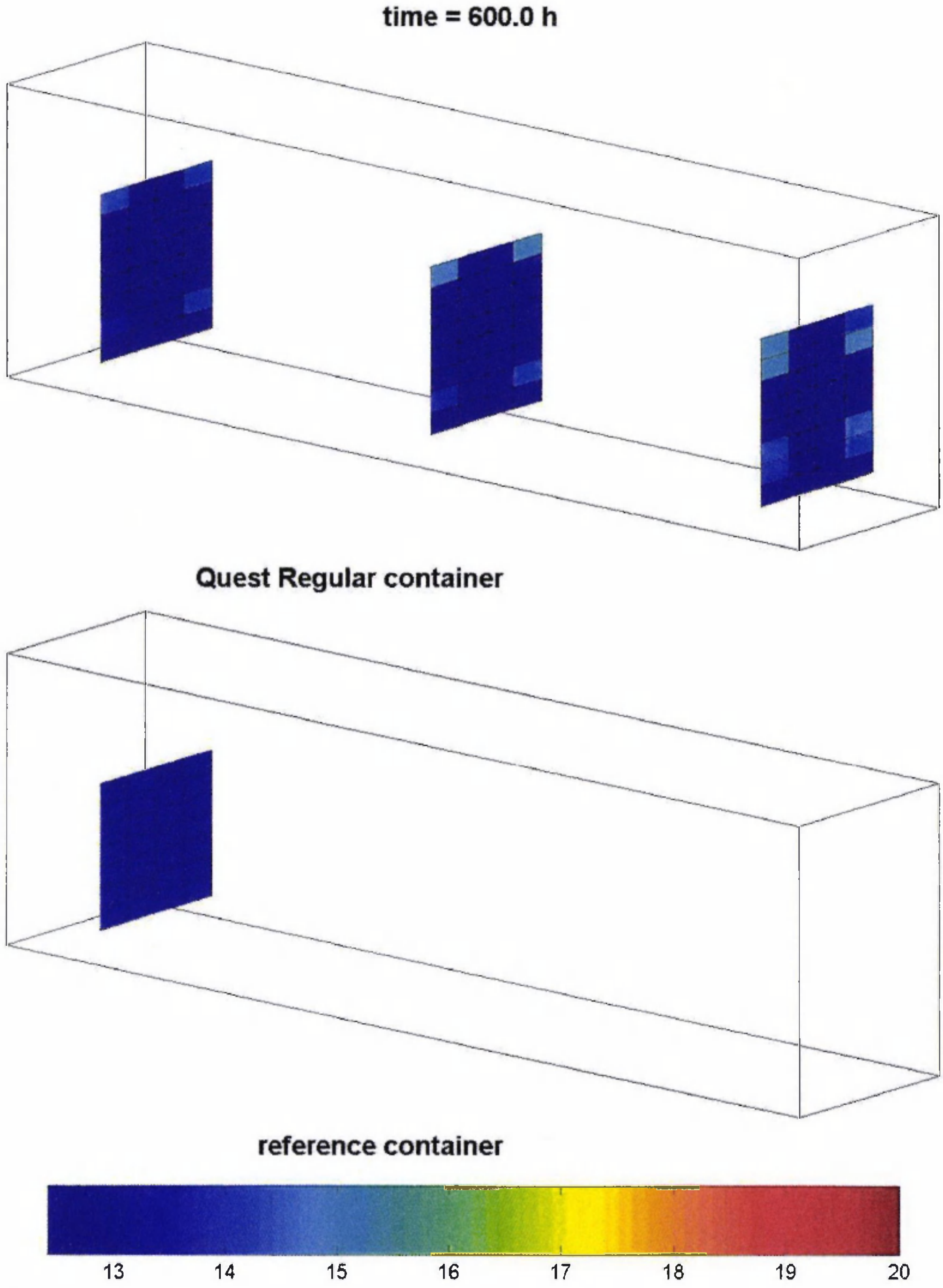

Figure 55 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test11 and ref 1

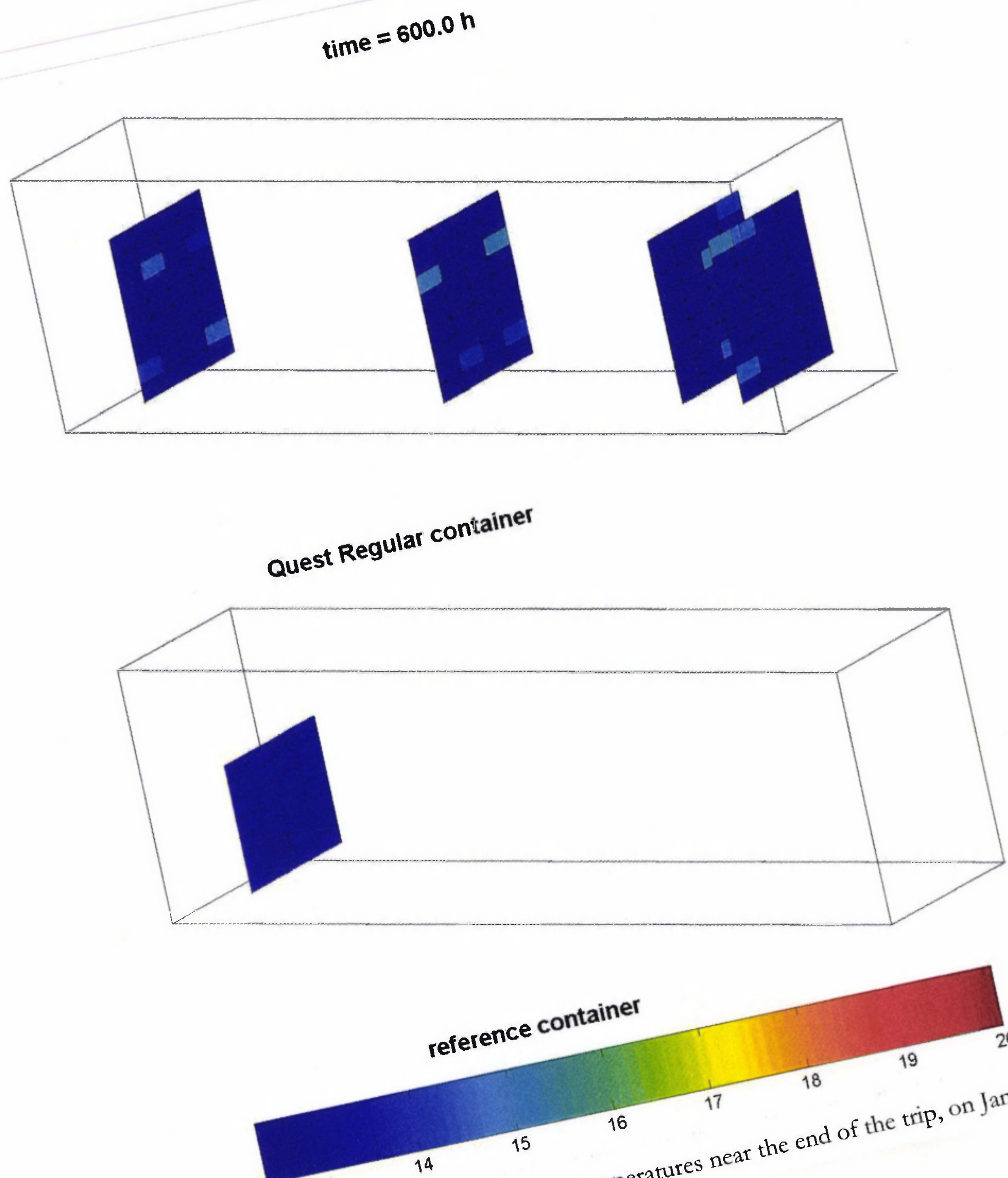

Figure 56 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test21 and ref1

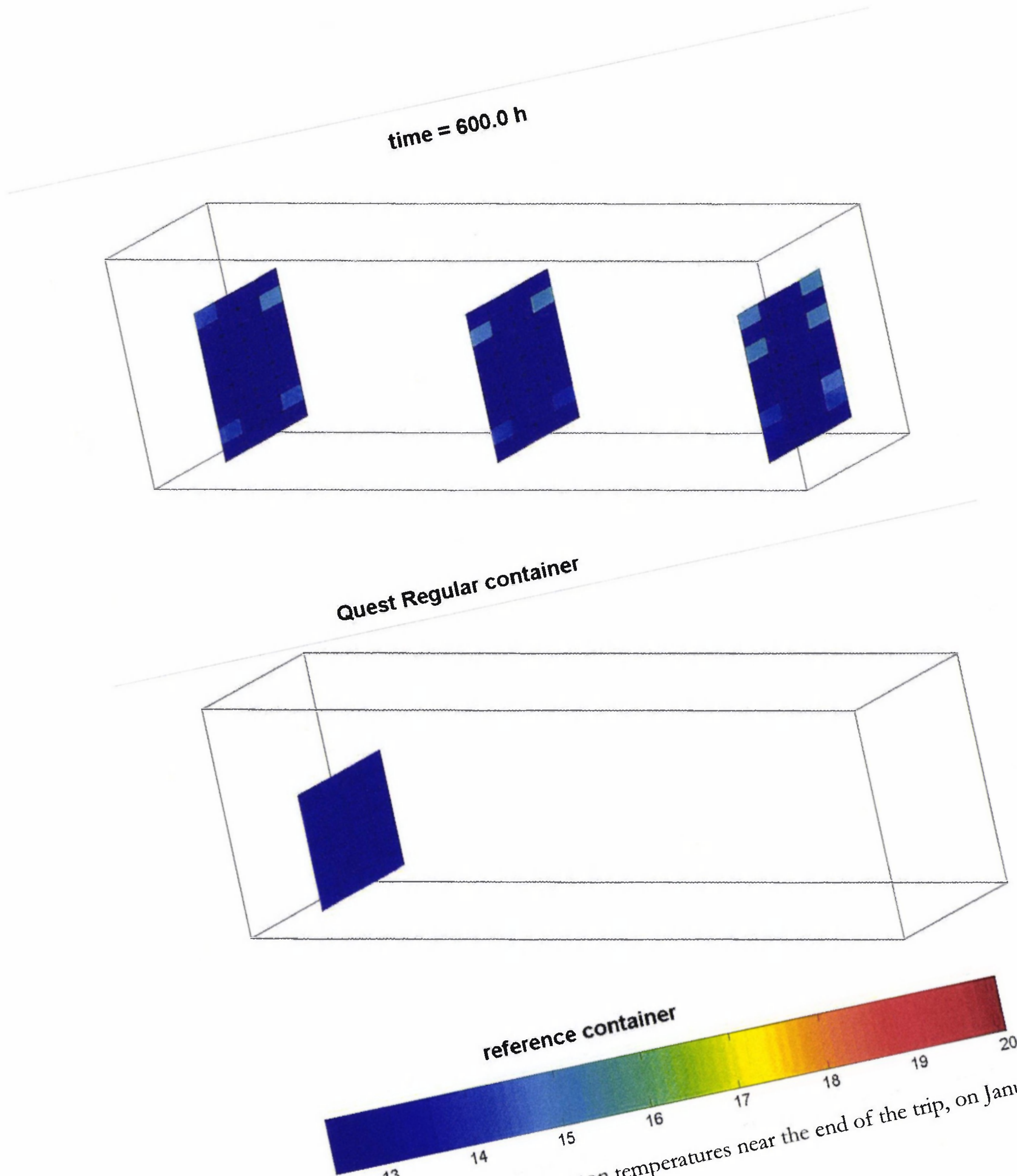

Figure 57 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test31 and ref1

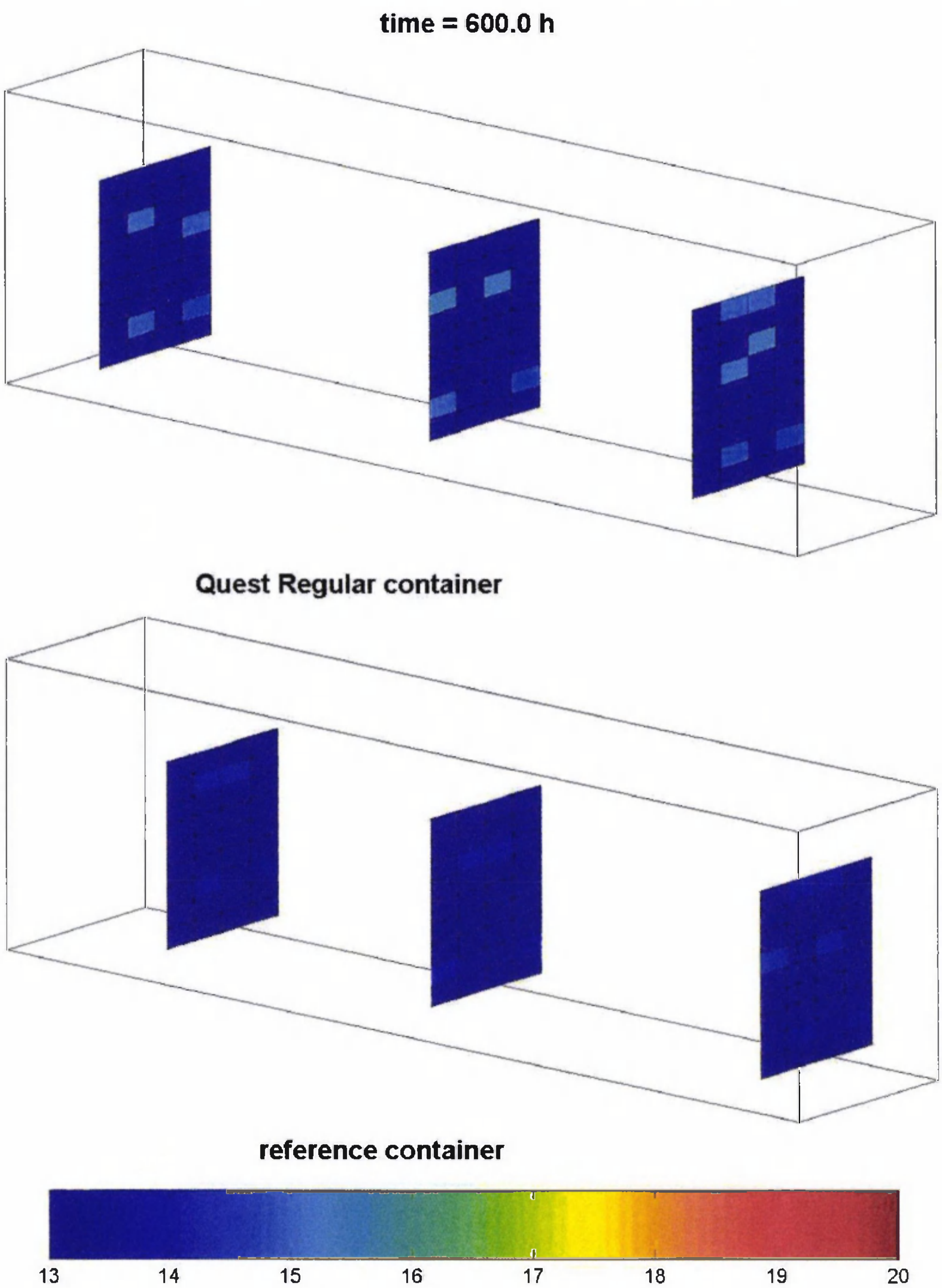

Figure 58 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test12 and ref2

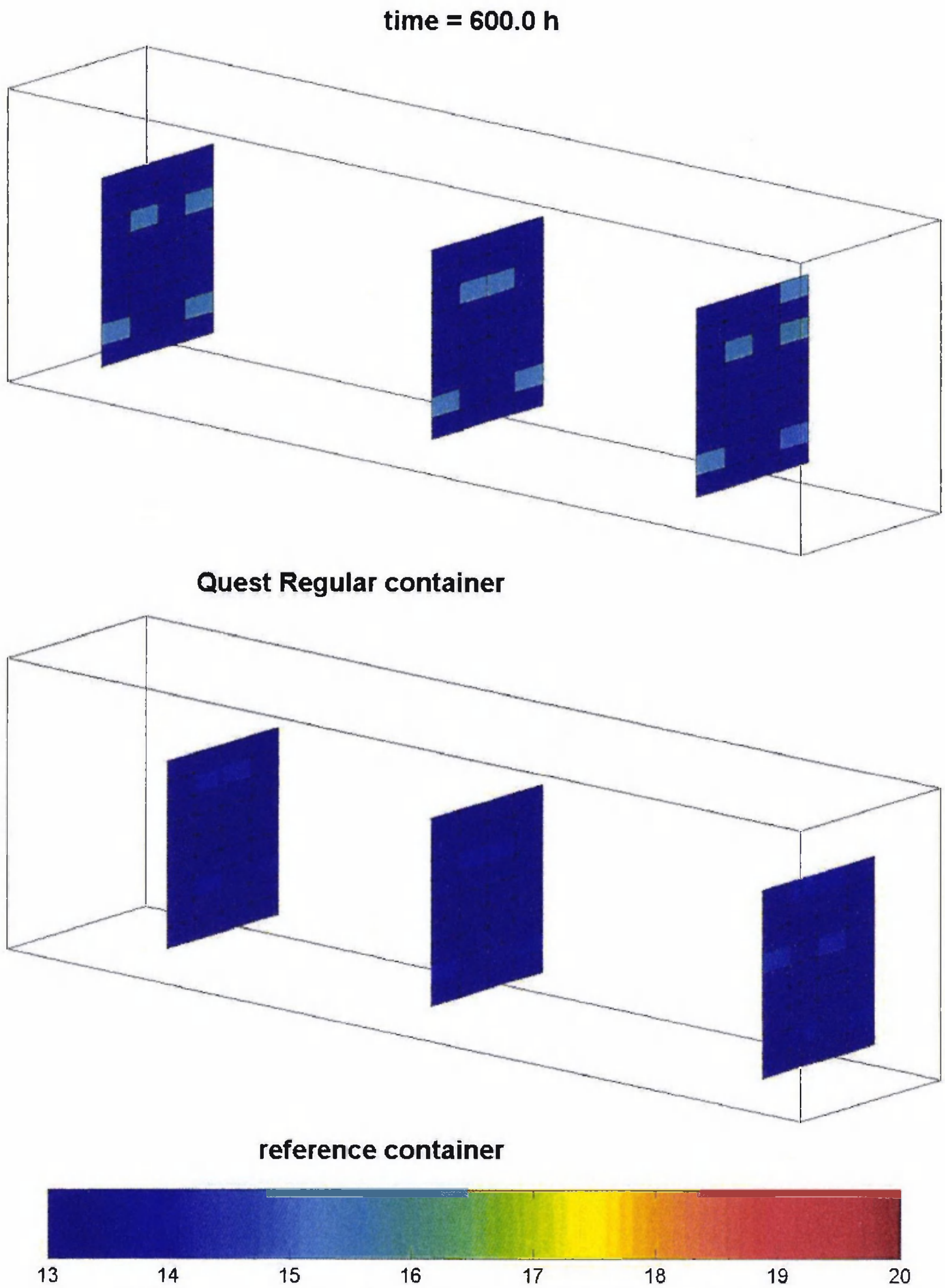

Figure 59 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test22 and ref2

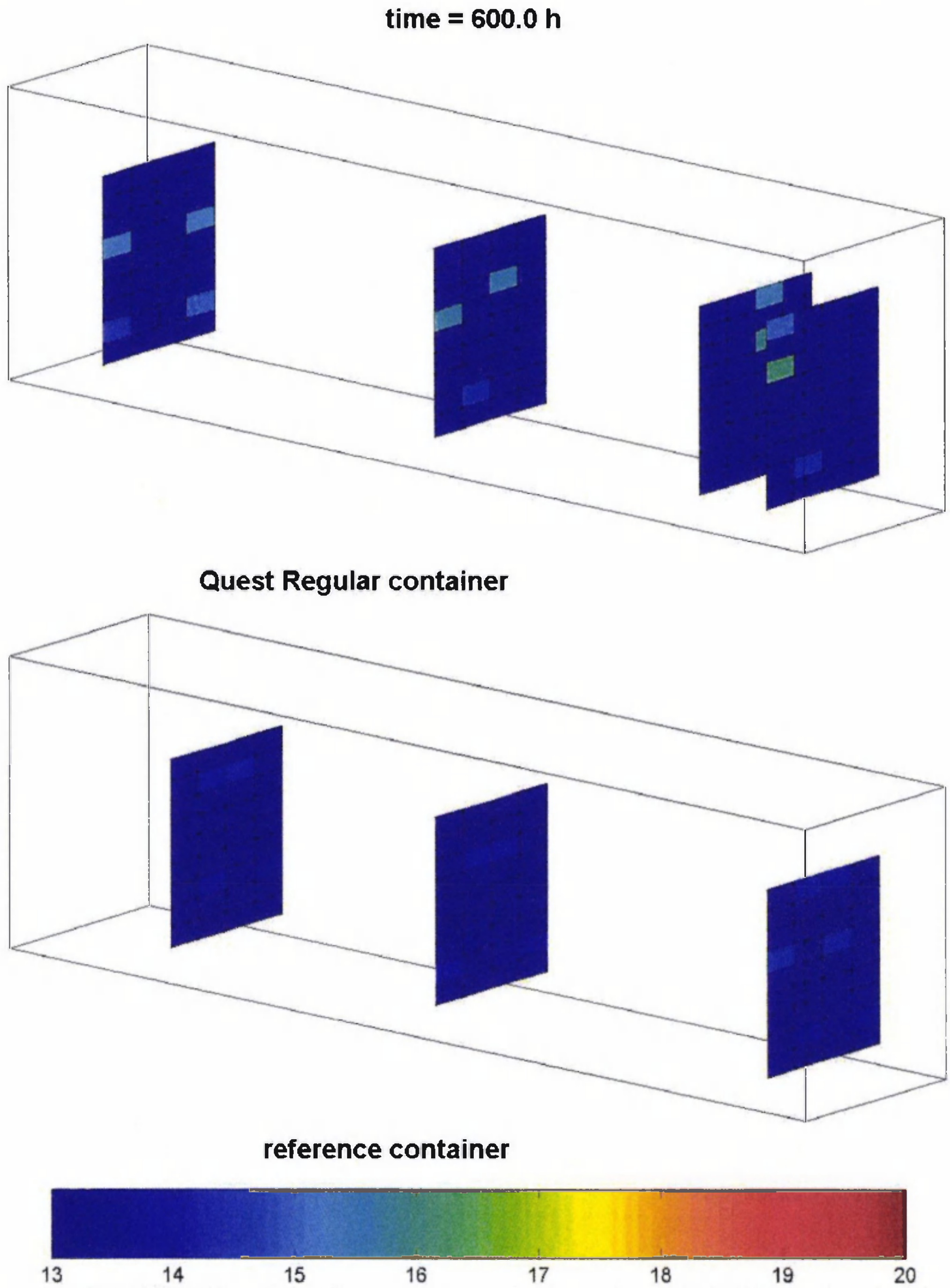

Figure 60 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test32 and ref2

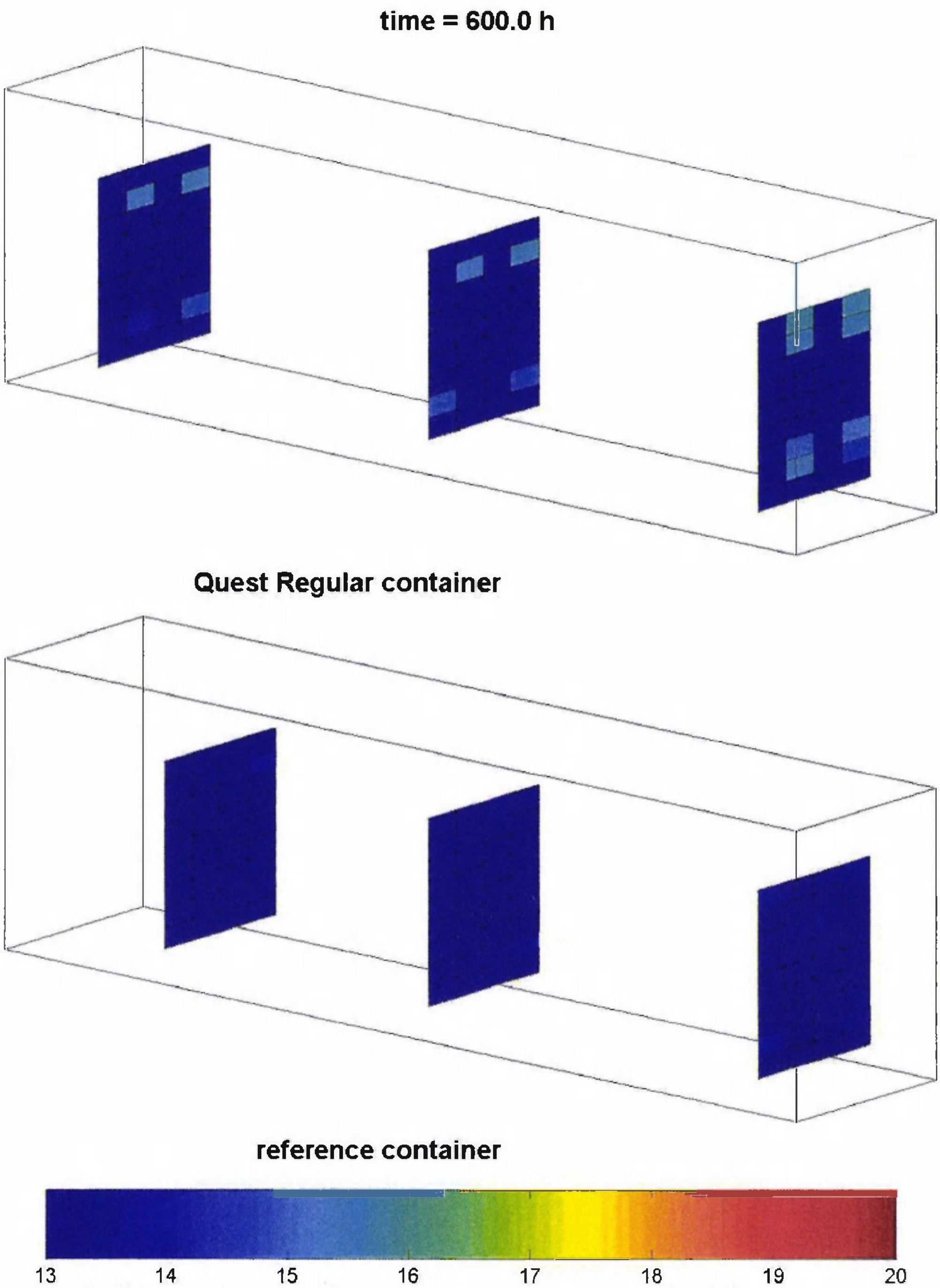

Figure 61 Tiny Tag readings of the carton temperatures near the end of the trip, on January 1st, test14 and ref4

Appendix VI: Ambient temperatures

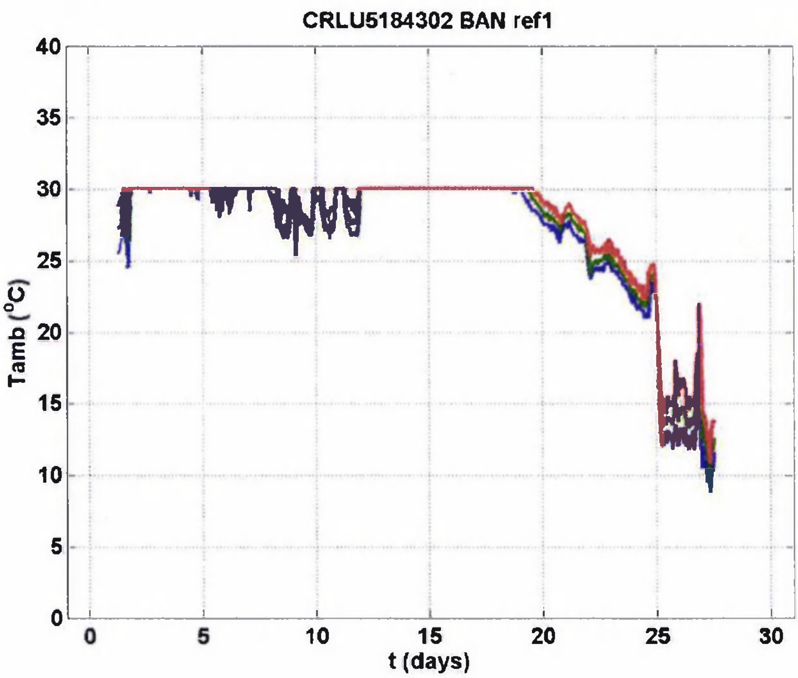

Figure 62 Ambient temperature readings from the unit of container ref1

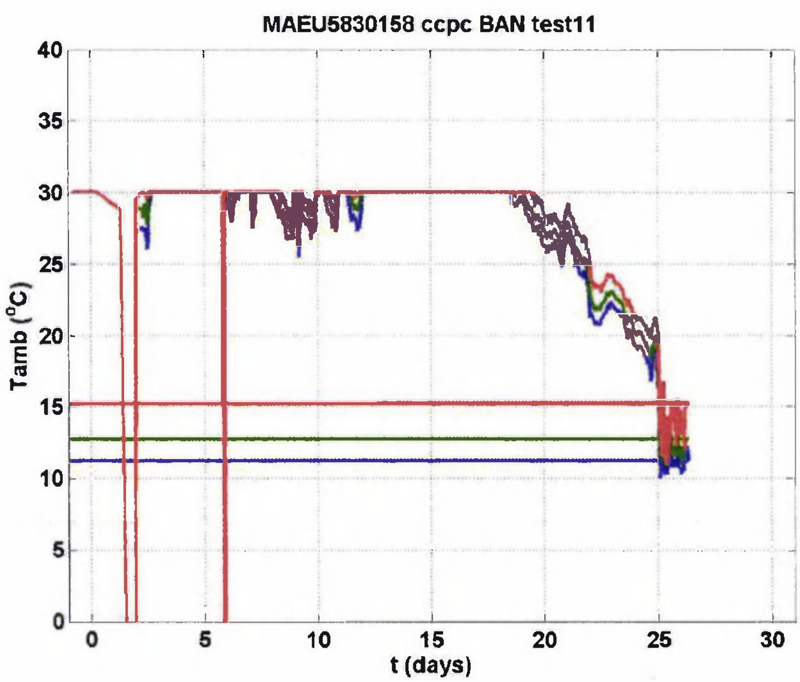

Figure 63 Ambient temperature readings from the unit of container test11

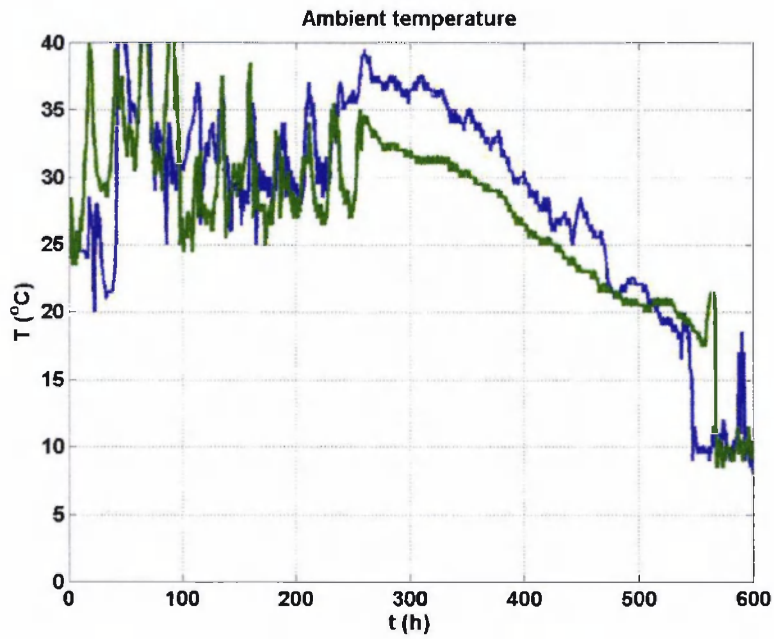

Figure 64 Ambient temperature readings from the IButton on the outside of the containers test11 (-) and ref1 (-)

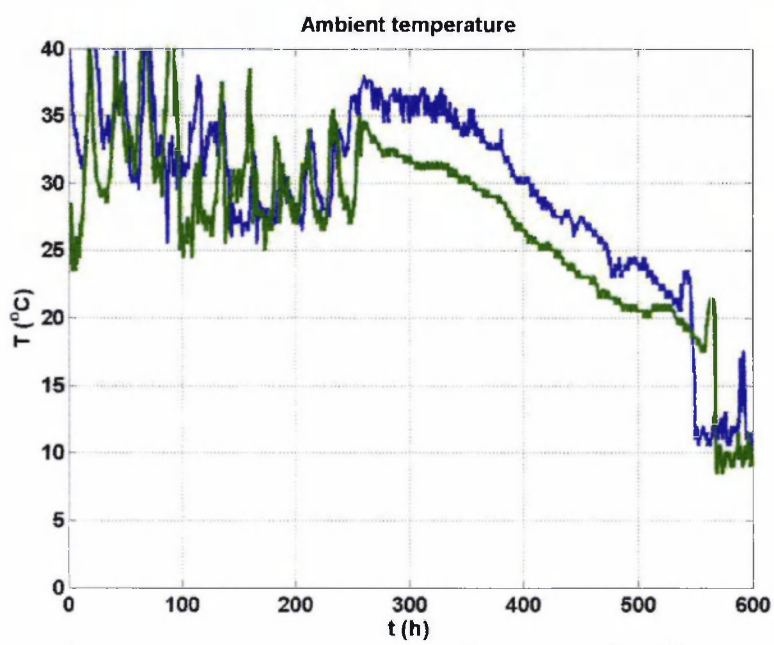

Figure 65 Ambient temperature readings from the IButton on the outside of the containers test21 (-) and ref1 (-)

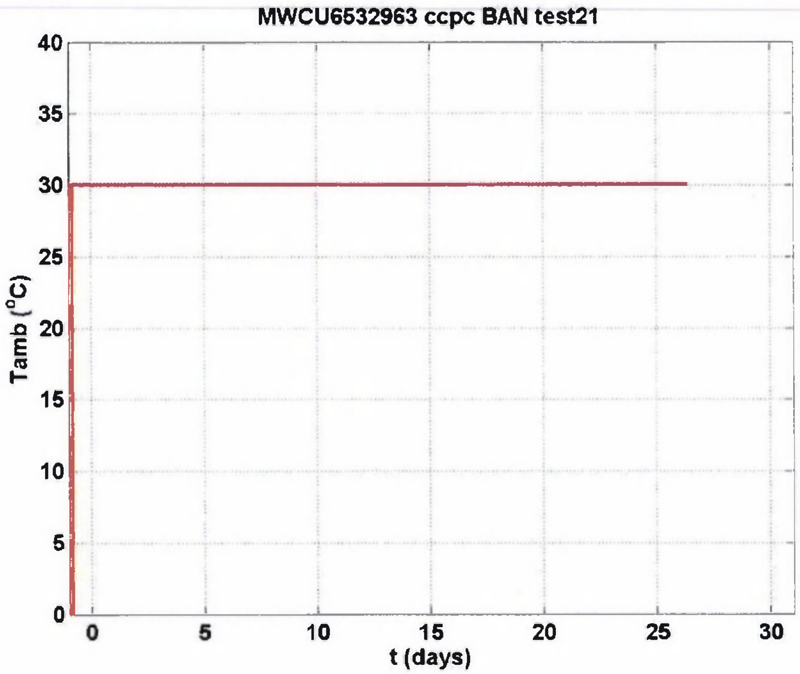

Figure 66 Ambient temperature readings from the unit of container test21

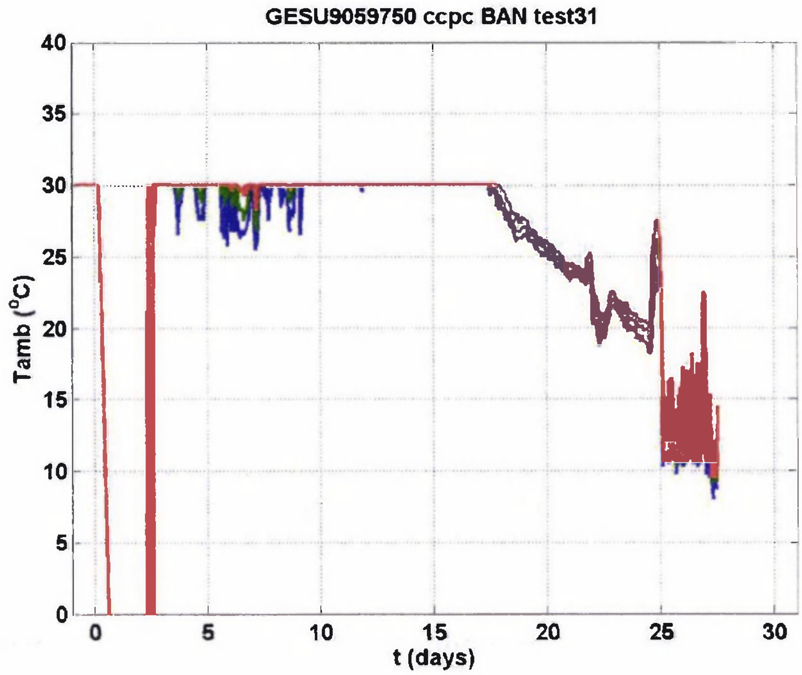

Figure 67 Ambient temperature readings from the unit of container test31

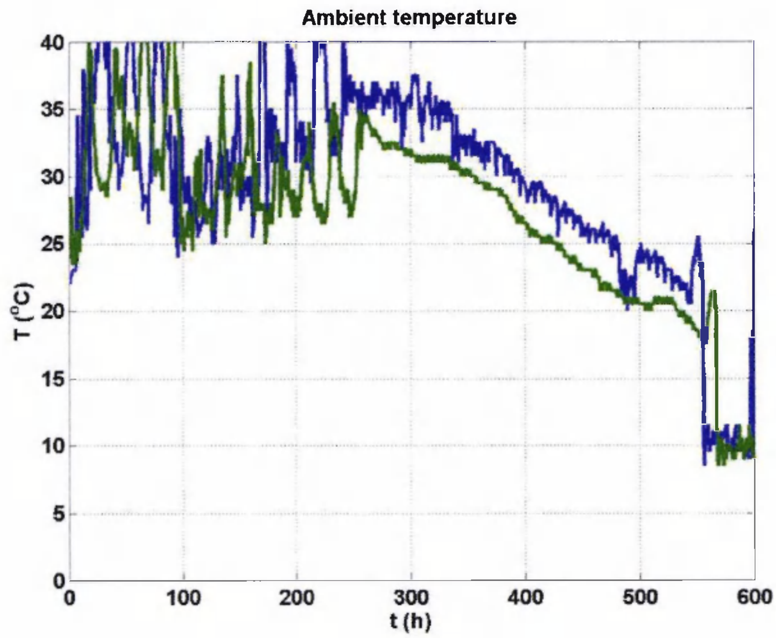

Figure 68 Ambient temperature readings from the IButton on the outside of the containers test31 (-) and ref1 (-)

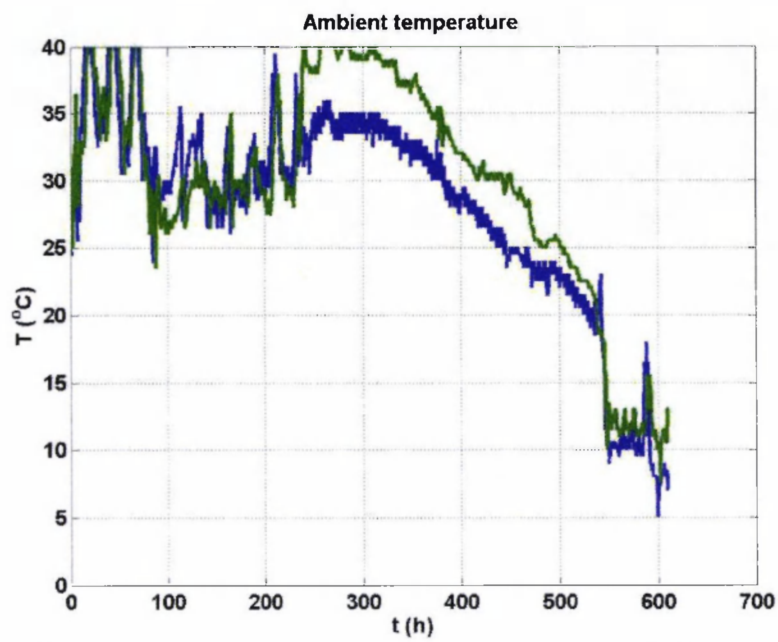

Figure 69 Ambient temperature readings from the IButton on the outside of the containers test12 (-) and ref2 (-)

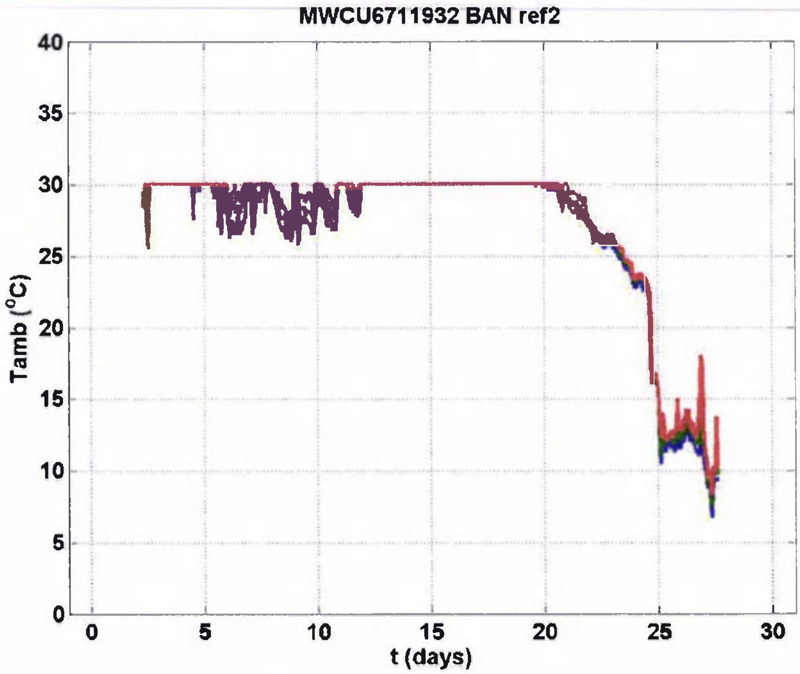

Figure 70 Ambient temperature readings from the unit of container ref2

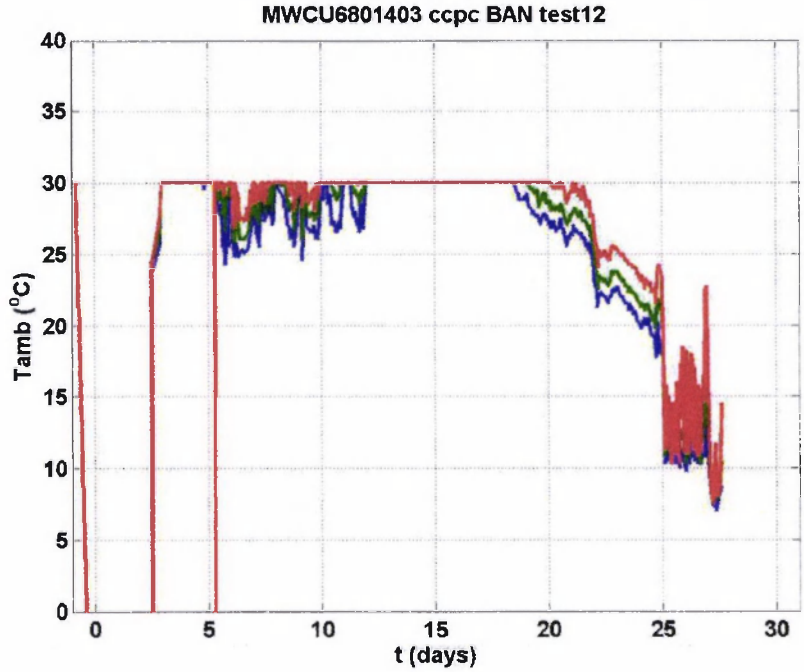

Figure 71 Ambient temperature readings from the unit of container test12

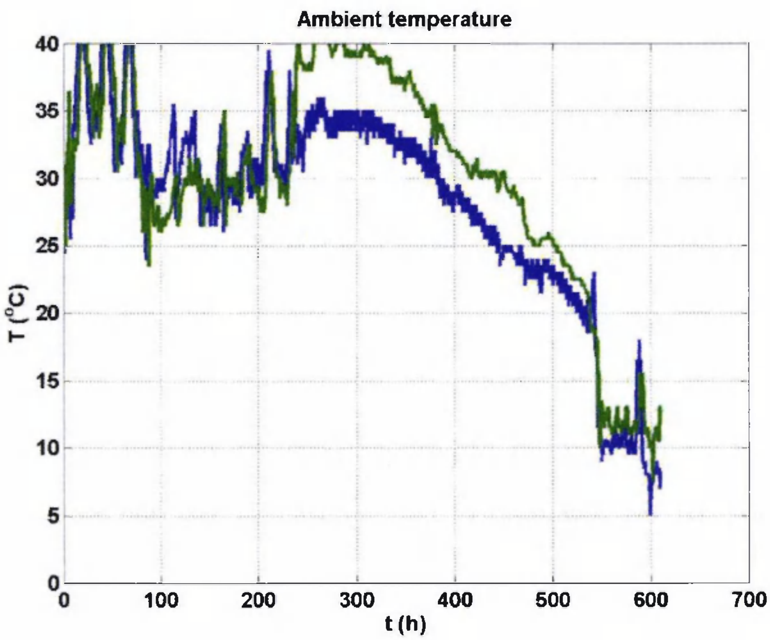

Figure 72 Ambient temperature readings from the IButton on the outside of the containers test22 (-) and ref2 (-)

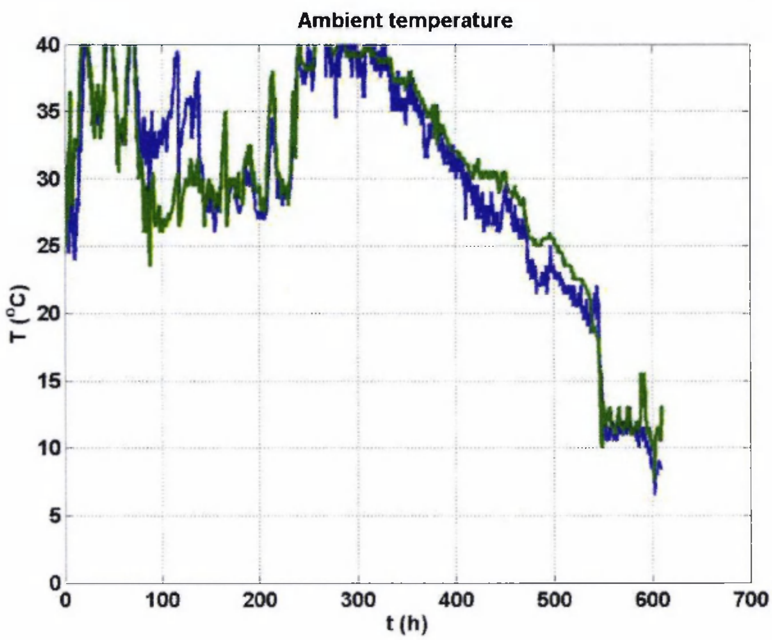

Figure 73 Ambient temperature readings from the IButton on the outside of the containers test32 (-) and ref2 (-)

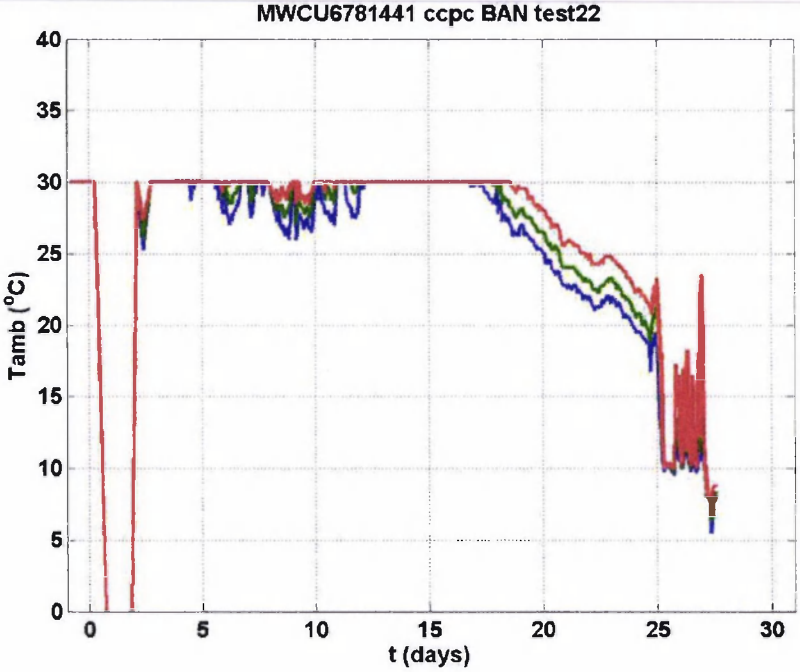

Figure 74 Ambient temperature readings from the unit of container test22

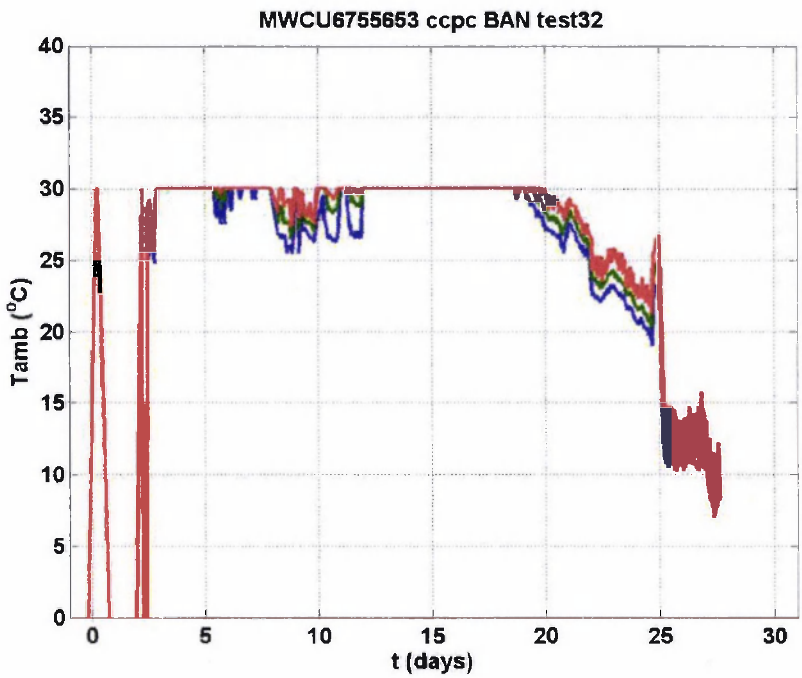

Figure 75 Ambient temperature readings from the unit of container test32

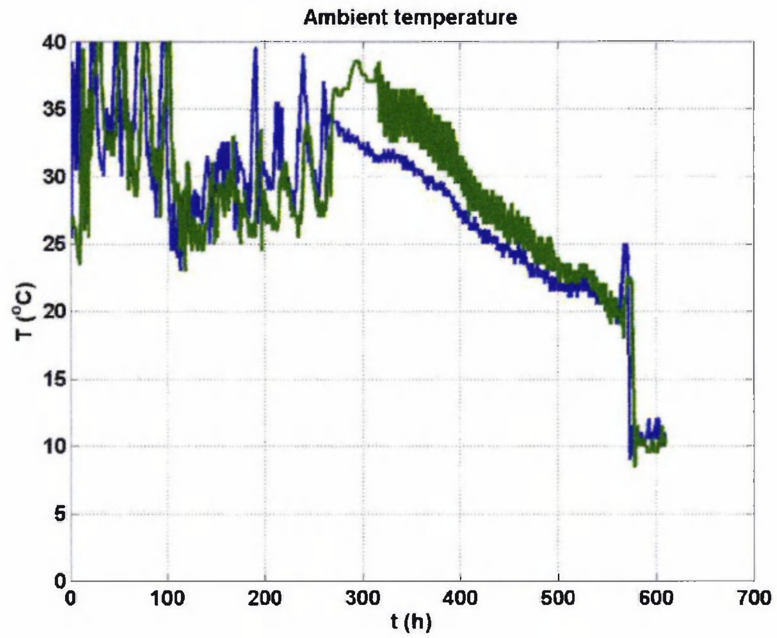

Figure 76 Ambient temperature readings from the IButton on the outside of the containers test14 (-) and ref4 (-)

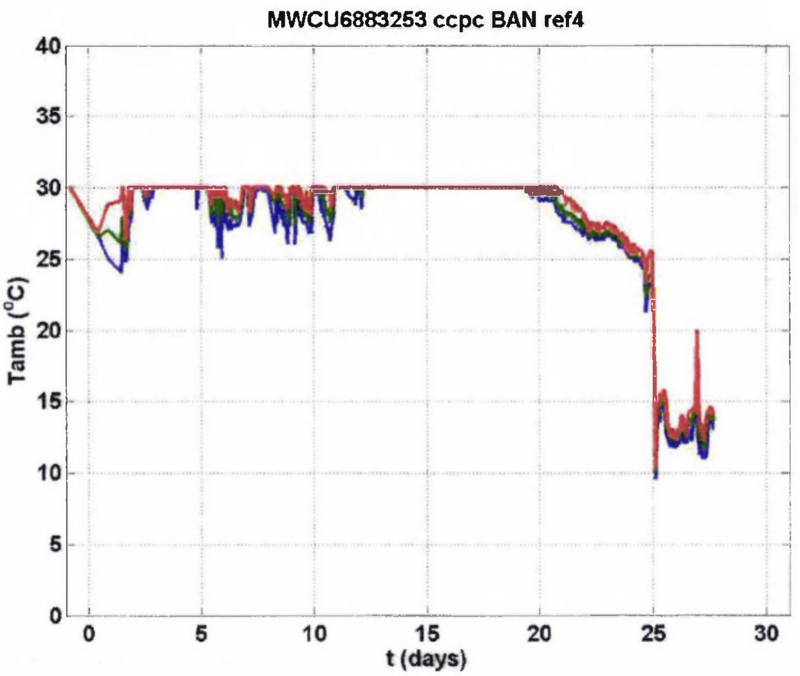

Figure 77 Ambient temperature readings from the unit of container ref4

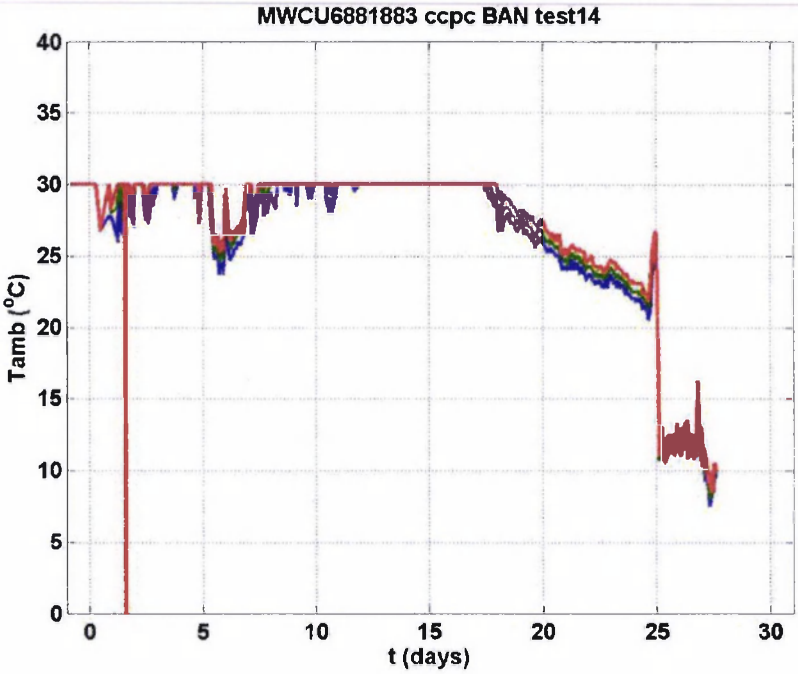

Figure 78 Ambient temperature readings from the unit of container test14

Table 26 The ambient temperatures for all containers

Container	Min T (°C)	Max T (°C)	Mean T (°C)	Deviation T (°C)
Test11	8.0	52.0	28.5	8.2
Test21	10.5	45.5	28.6	7.1
Test31	8.5	53.0	28.9	7.5
Ref1	8.5	48.5	26.7	6.7
Test12	5.5	49.0	28.2	8.4
Test22	5.0	50.5	27.7	7.4
Test32	8.5	50.5	29.4	8.4
Ref2	10.0	48.0	29.7	8.0
Test14	9.0	45.5	27.5	6.1
Ref4	8.5	43.5	28.2	6.3

Table 27 Deviation of ambient temperatures for Quest containers and reference container

	ΔT minimum (°C)	ΔT mean (°C)	ΔT maximum (°C)
Test 11 & ref 2	2.0	1.2	-4.0
Test 21 & ref 2	-0.5	1.1	2.5
Test 31 & ref 2	1.5	0.8	-5.0
Test 12 & ref 2	4.5	1.5	-1.0
Test 22 & ref 2	5.0	2.0	-2.5
Test 32 & ref 2	1.5	0.3	-2.5
Test 14 & ref 4	-0.5	0.7	-2.0

Appendix VII: Unit activity graphs

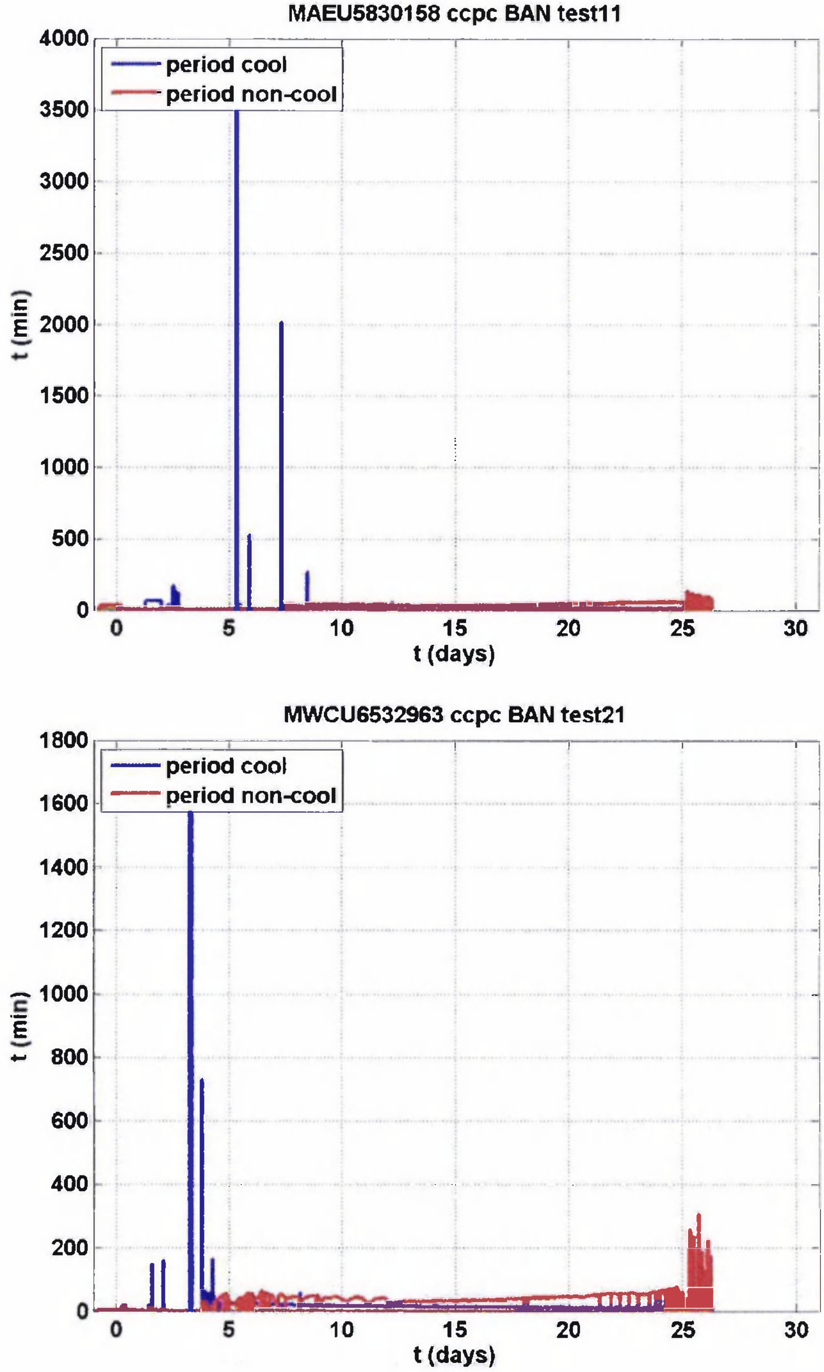

Figure 79 The number of minutes per cooling and non-cooling as a function of time for the Quest1 test containers. At each time instant during the voyage when a period is finished a bar is drawn with the number of minutes that that period has lasted. If the period is smaller then an hour, the bars turn into a line.

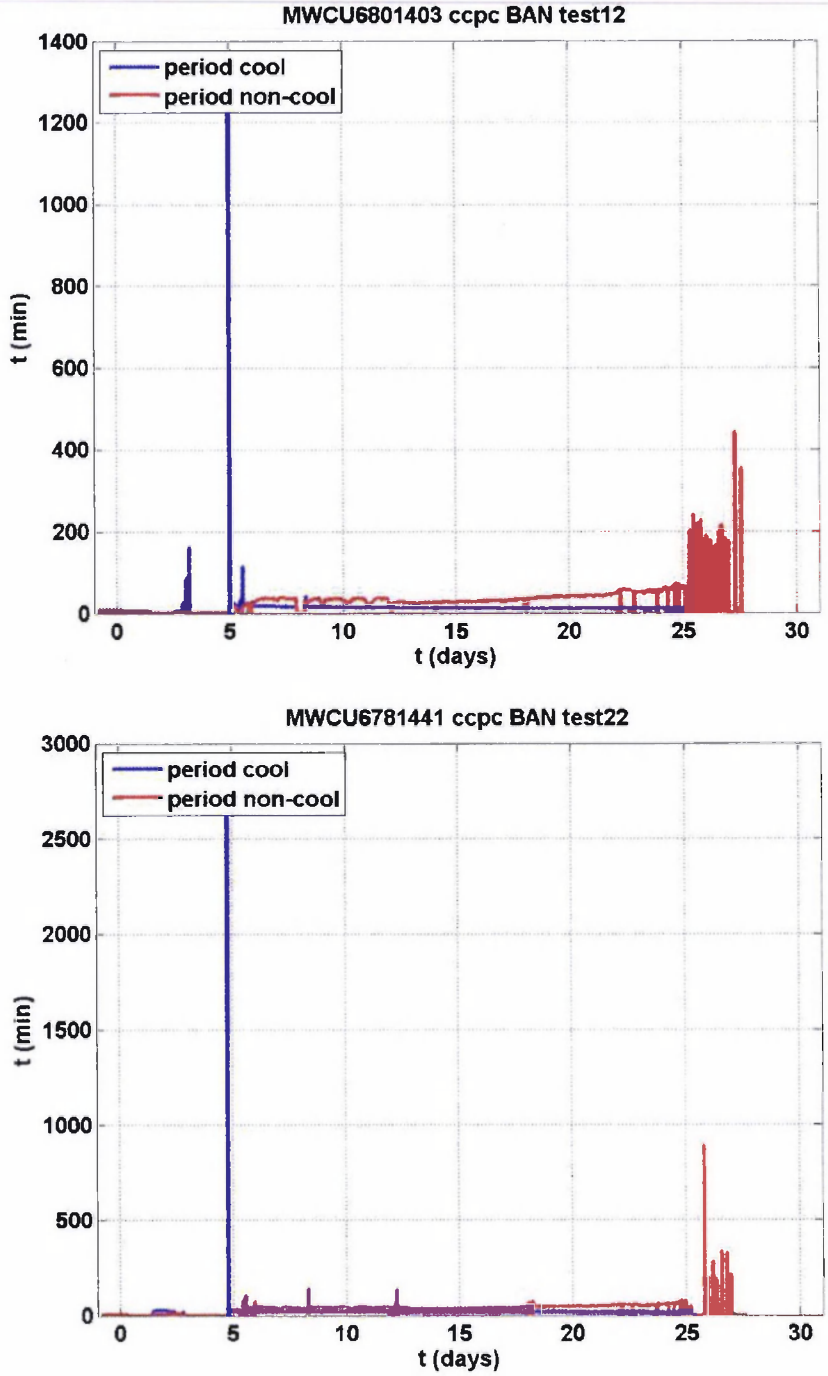

Figure 80 The number of minutes per cooling, non-cooling and defrost period as a function of time for the Quest2 test containers. At each time instant during the voyage when a period is finished a bar is drawn with the number of minutes that that period has lasted. If the period is smaller then an hour, the bars turn into a line.

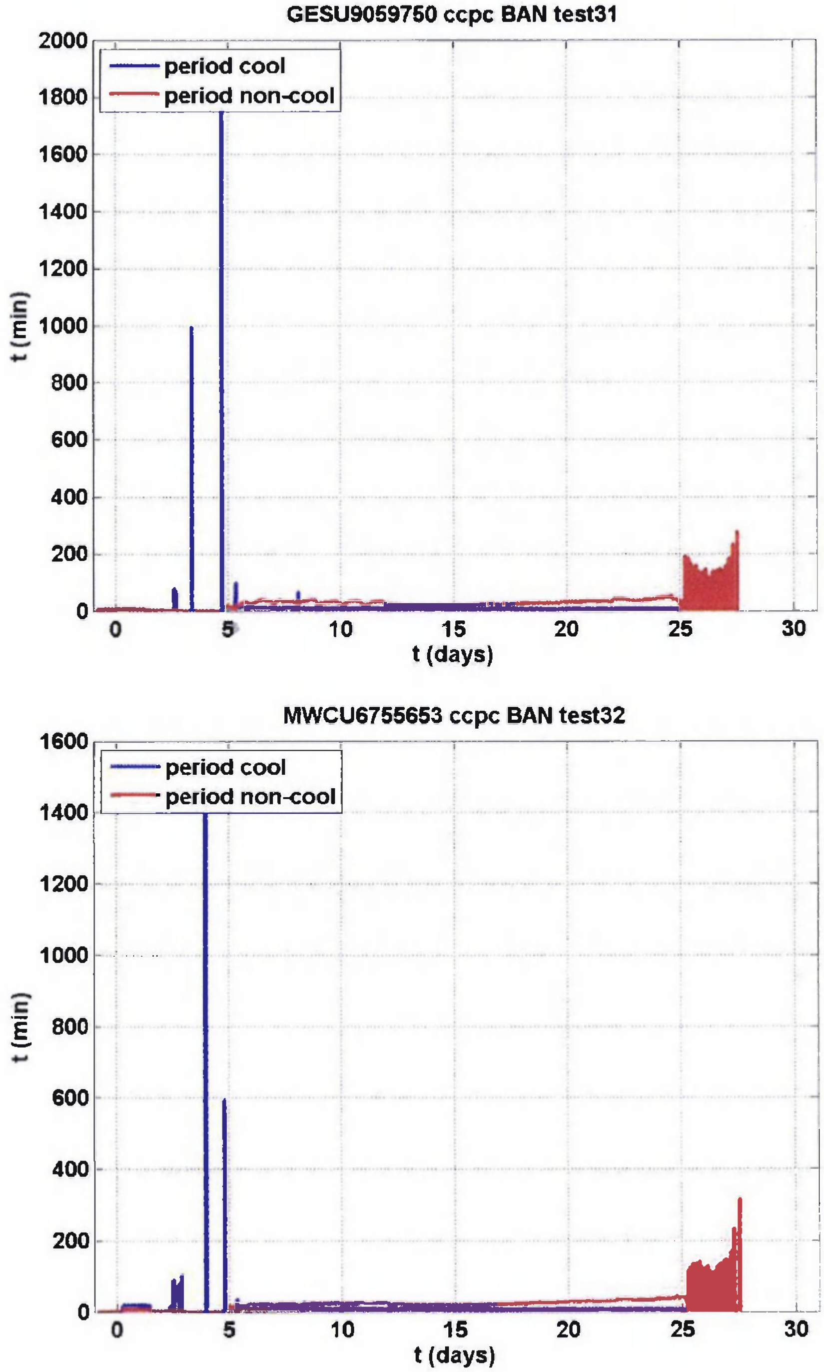

Figure 81 The number of minutes per cooling and non-cooling period as a function of time for the Quest3 test containers. At each time instant during the voyage when a period is finished a bar is drawn with the number of minutes that that period has lasted. If the period is smaller then an hour, the bars turn into a line.

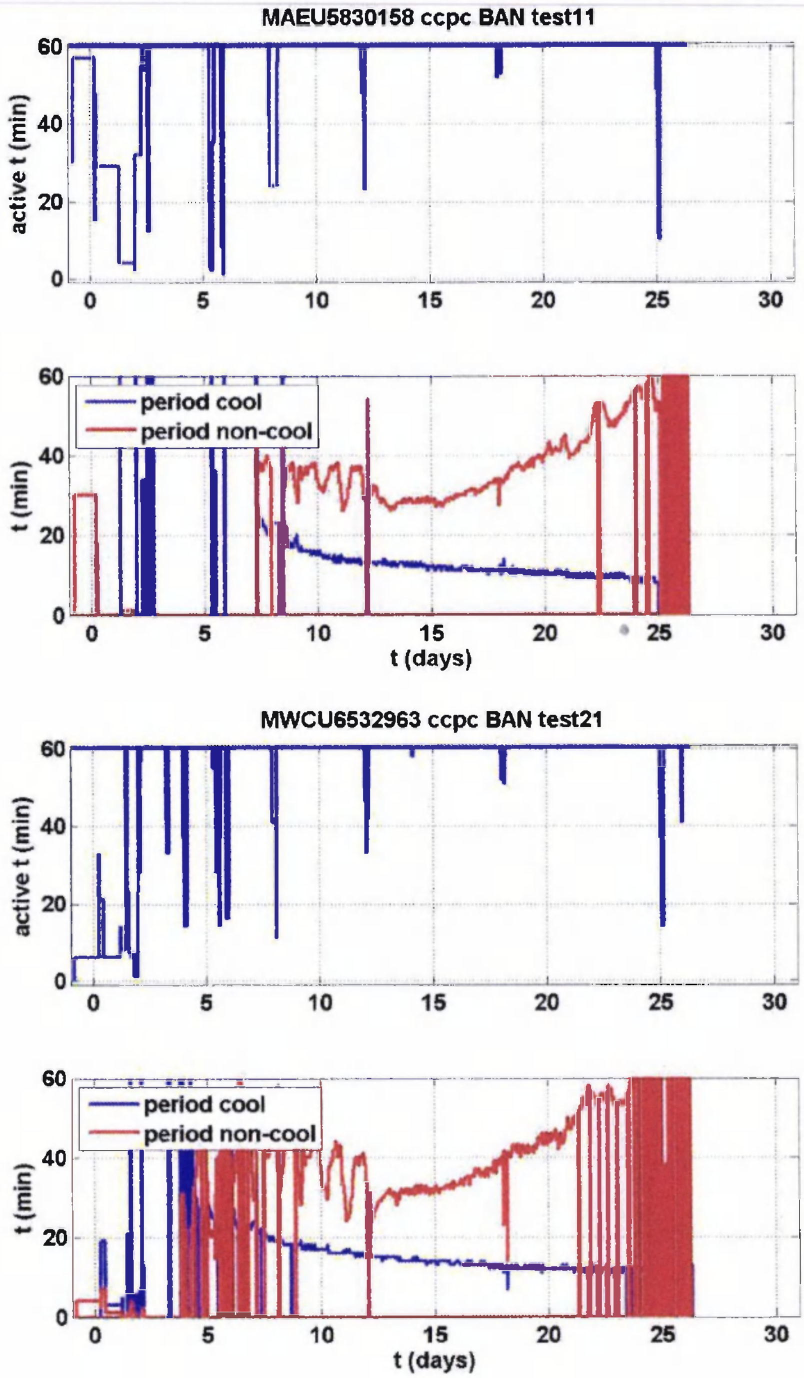

Figure 82 The number of minutes activity and zoom-in of the number of minutes per cooling /non-cooling as a function of time for the Quest1 containers. Every hour of the trip the number of minutes that was used for cooling/non-cooling was recorded. The number of minutes the unit was active was recorded as well, which is mostly 60 min/hour but sometimes less.

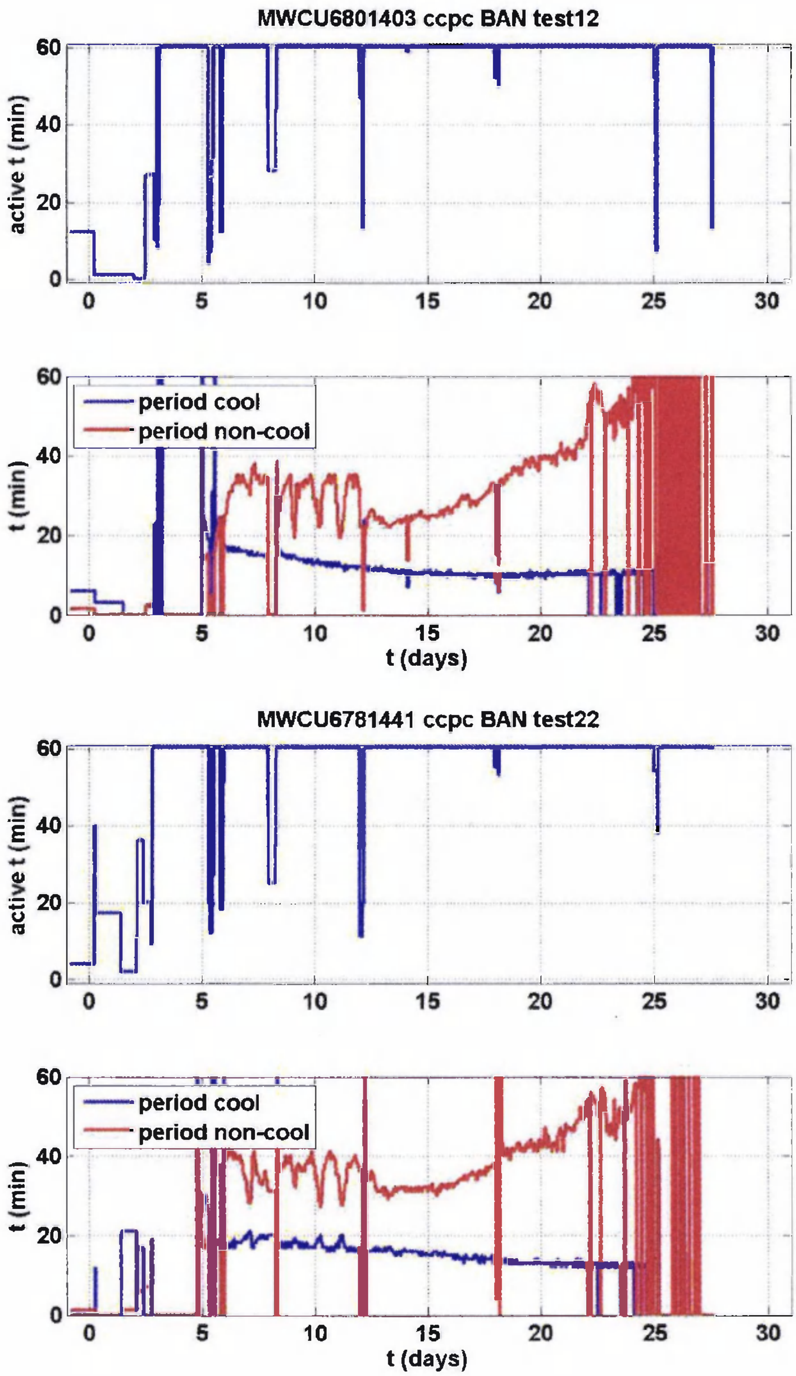

Figure 83 The number of minutes activity and zoom-in of the number of minutes cooling / non-cooling as a function of time for the Quest2 containers. Every hour of the trip the number of minutes that was used for cooling/non-cooling was recorded. The number of minutes the unit was active was recorded as well, which is mostly 60 min/hour but sometimes less.

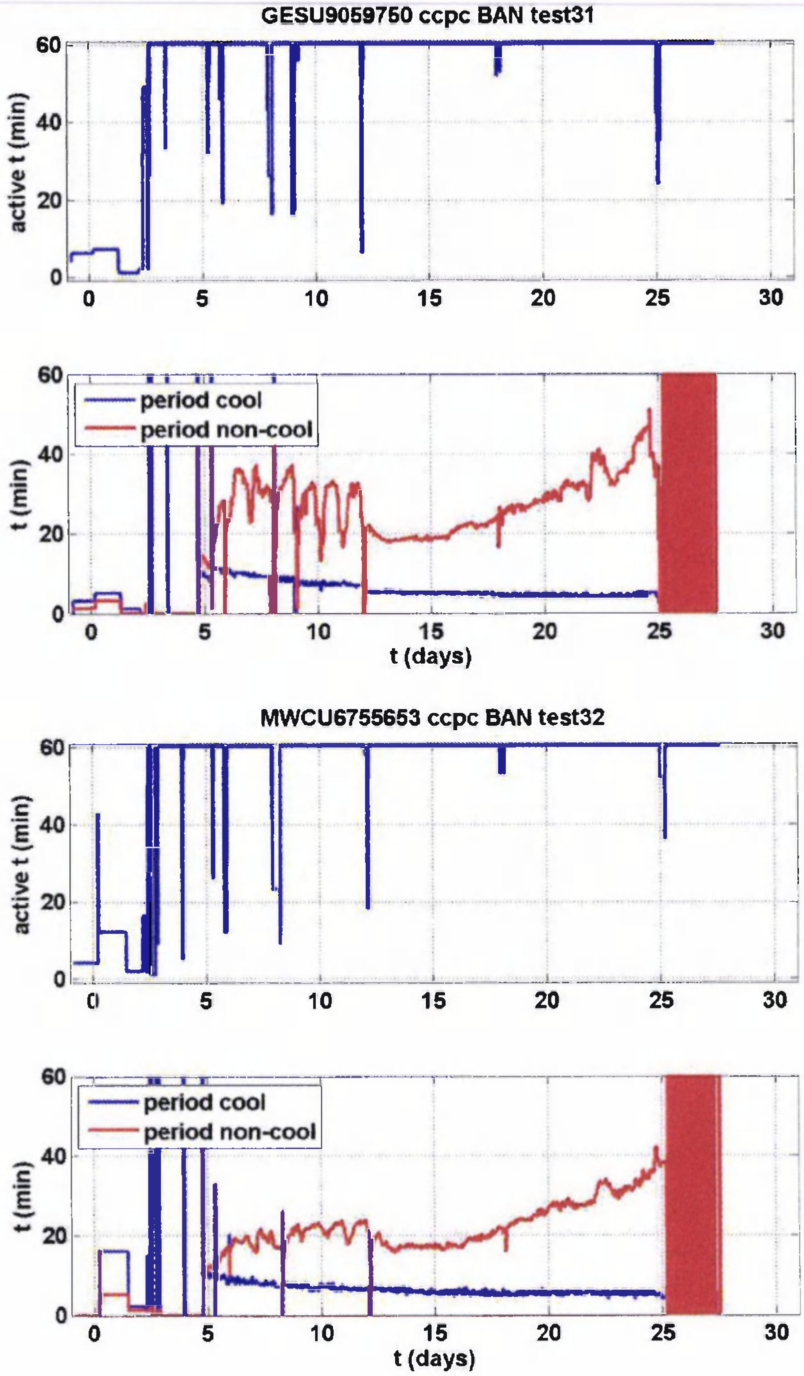

Figure 84 The number of minutes activity and zoom-in of the number of minutes cooling / non-cooling as a function of time for the Quest3 test containers. Every hour of the trip the number of minutes that was used for cooling/non-cooling was recorded. The number of minutes the unit was active was recorded as well, which is mostly 60 min/hour but sometimes less.

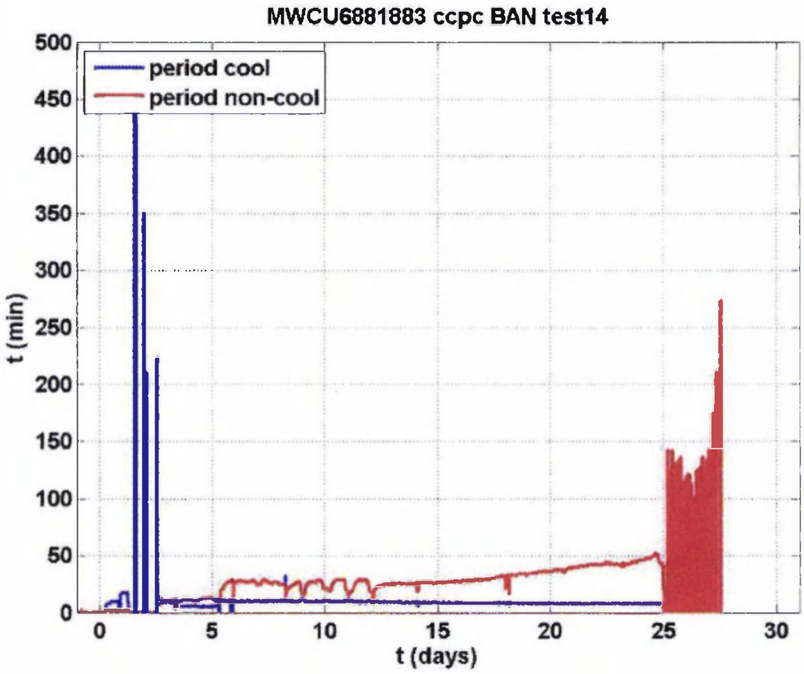

Figure 85 The number of minutes per cooling and non-cooling period as a function of time for the Quest1-scroll test container.

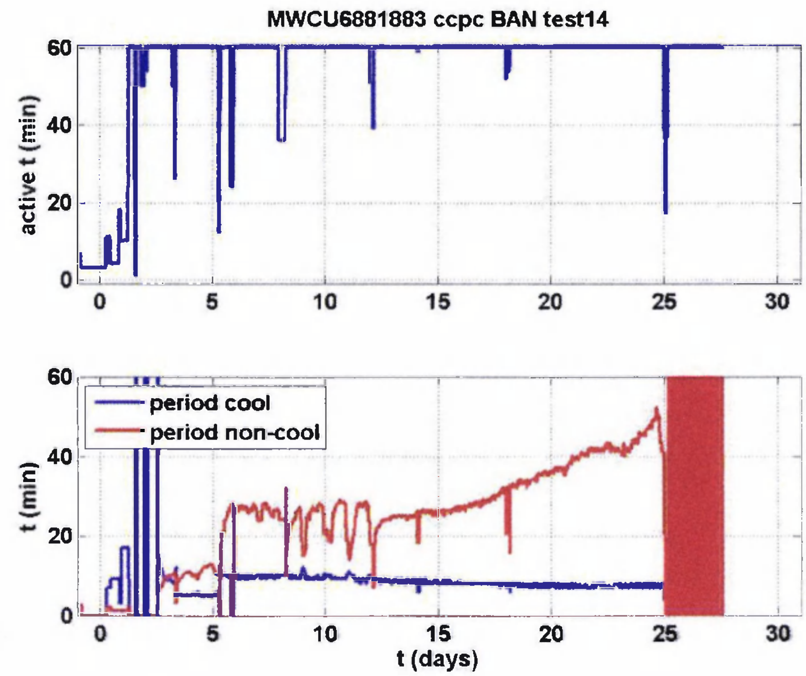

Figure 86 The number of minutes activity and zoom-in of the number of minutes cooling /non-cooling as a function of time for the Quest1-scroll test container.

Appendix VII: Supply temperature error and cooling period graphs

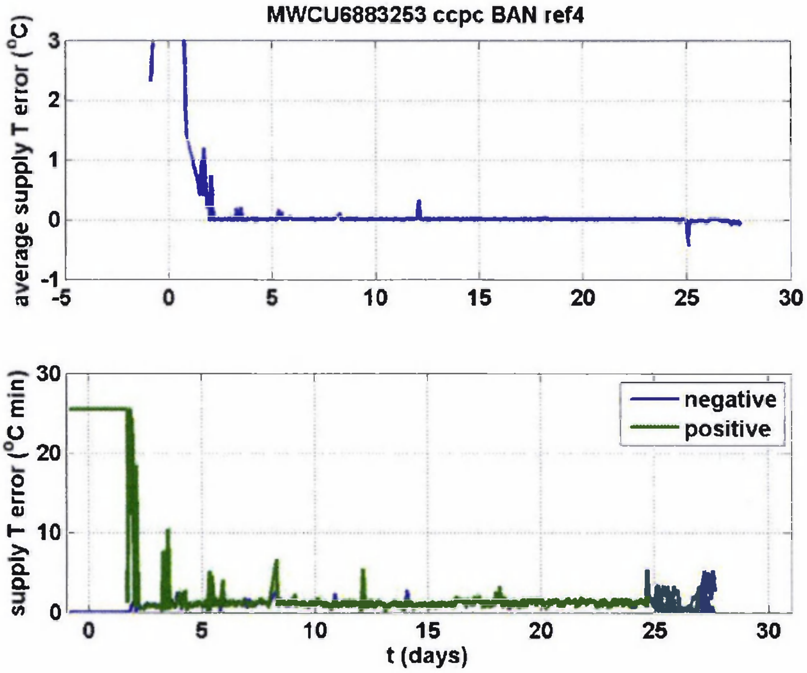

Figure 87 Supply error readings for ref4

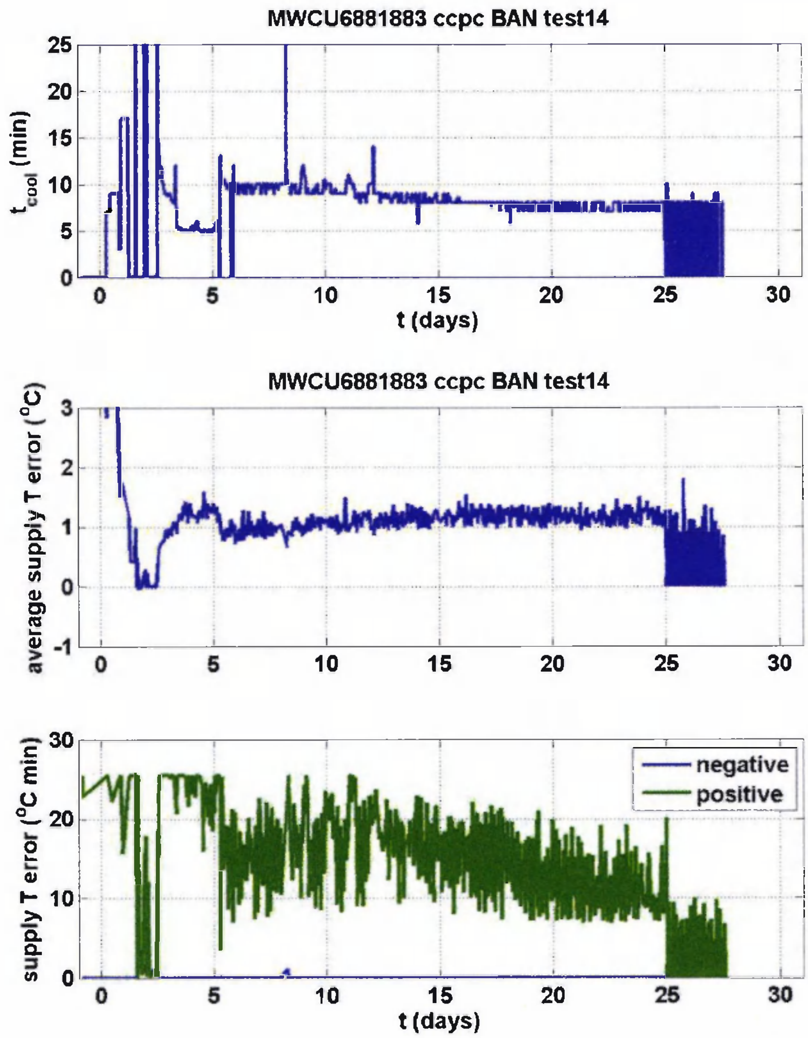

Figure 88 Cooling period lengths and supply temperature errors for test14

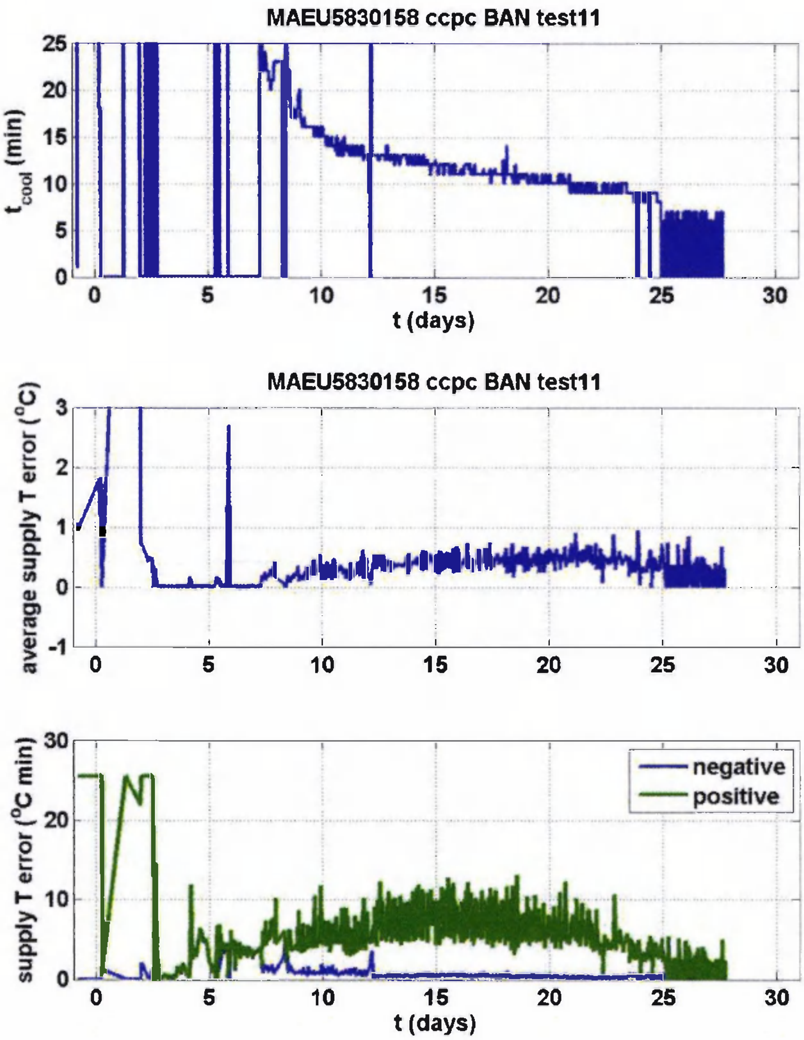

Figure 89 Cooling period lengths and supply temperature errors for test11

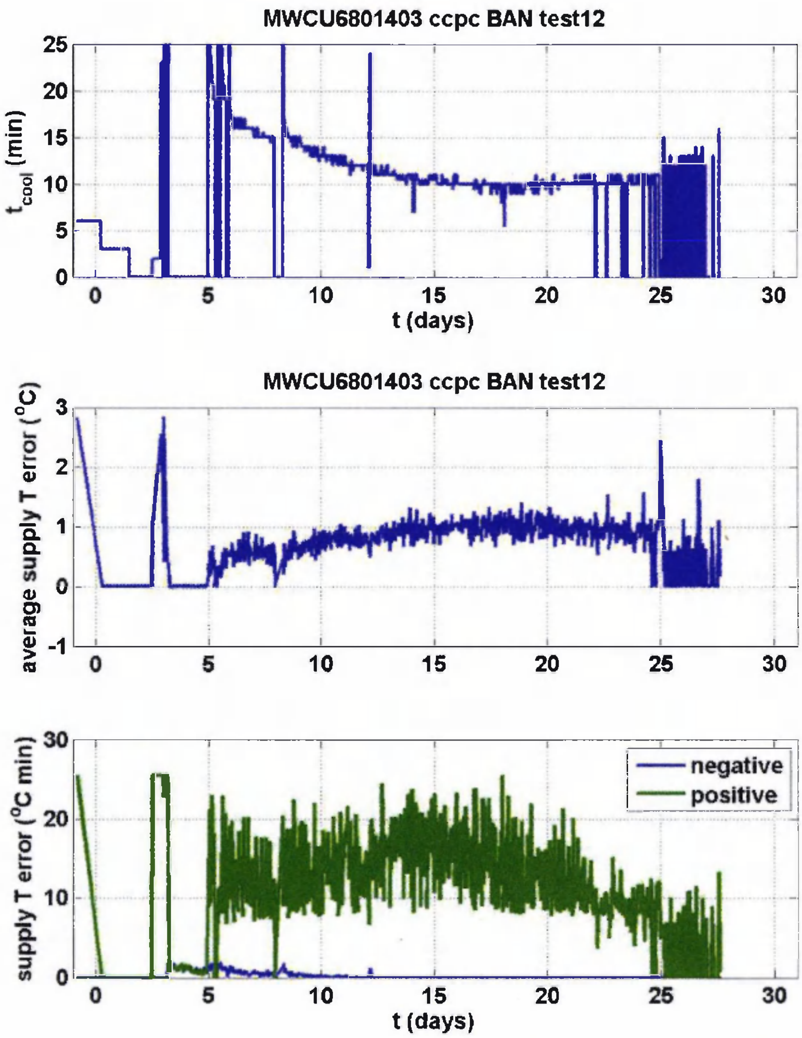

Figure 90 Cooling period lengths and supply temperature errors for test12

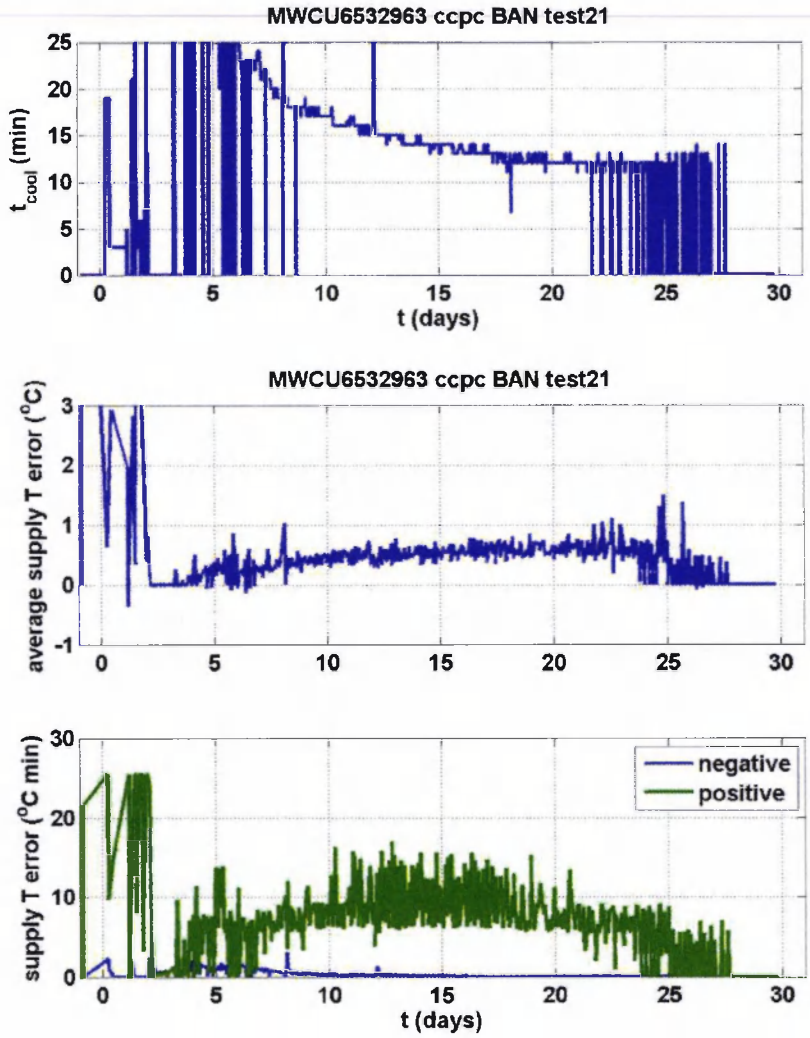

Figure 91 Cooling period lengths and supply temperature errors for test21

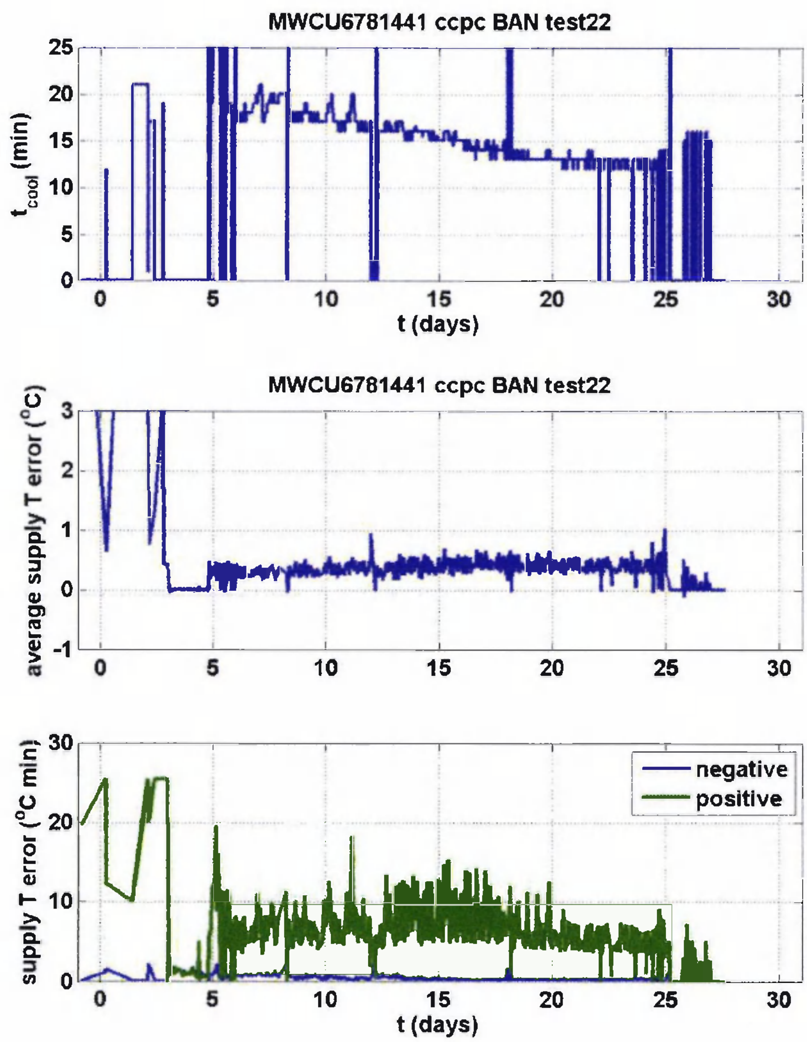

Figure 92 Cooling period lengths and supply temperature errors for test22

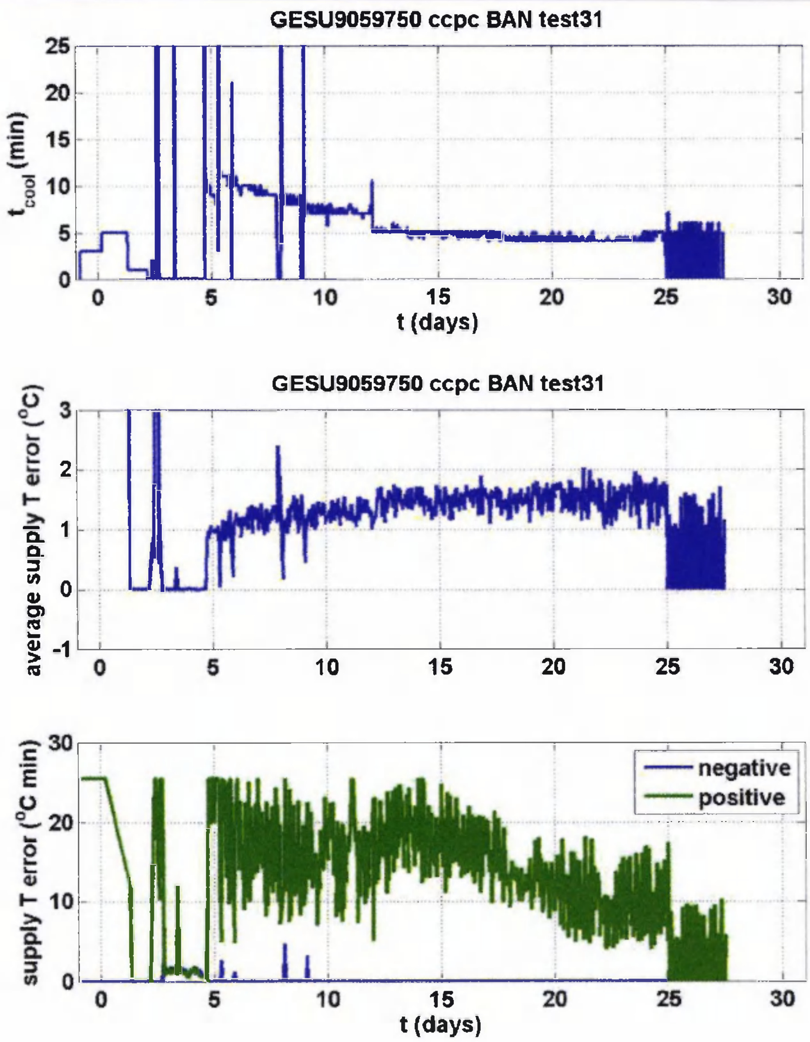

Figure 93 Supply error readings for test31

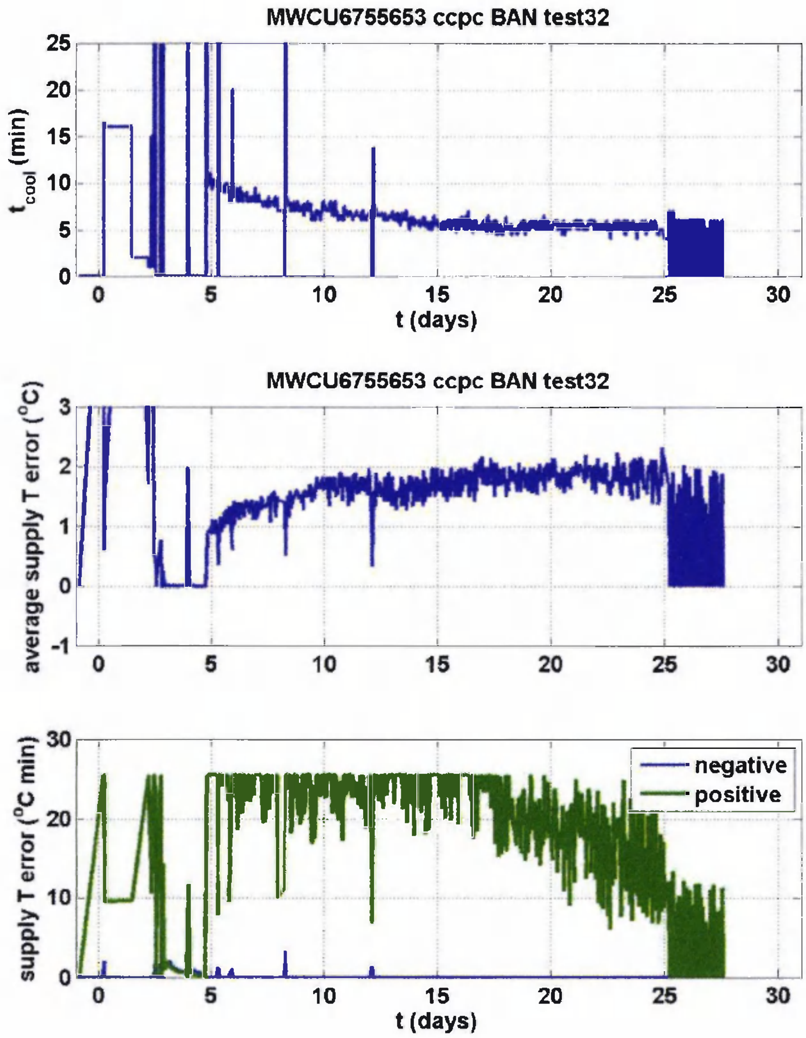

Figure 94 Cooling period lengths and supply temperature errors for test32