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Fourth Quest Regular Trial Shipment

Bananas from Brazil to the U.K.

J.E. de Kramer-Cuppen
H. Harkema
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Report 735

Colophon

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Approved by	H. Maas

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The quality management system of Agrotechnology and Food Sciences Group is certified by SGS International Certification Services EESV according to ISO 9001:2000.

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 Brazil to the U.K. in September 2006. The goal of the trial shipment was to test the software and compare the power usage, temperature distribution and product quality of four test containers (with two different settings, Quest1 and Quest2) to those of two reference containers, which were shipped simultaneously at original settings.

Mean savings are 71% for Quest1 and 77% for Quest2. When accounting for the differences in dehumidification energy consumption, the mean savings are approximately 57% for Quest1 and 60% for Quest2.

The supply air of the Quest containers fluctuates in time, but with such a high frequency, that the fluctuations are hardly visible in the carton temperature data (measured with a 30 min period).

During Quest Regular Mode, the minimum supply temperature mostly does not reach supply setting, adaptation of the field software, after comparable issues for mandarin and apple, apparently did not help (enough) to prevent same for these banana shipments. Also, supply air of one test container becomes unstable during day 14. The reason is unclear, but seems to be connected to (the erroneously activated) dehumidification actions.

The carton temperatures in the Quest container are on the warm side, but with a satisfactory bandwidth. The Quest2 containers, with the cooler settings, are closer to setpoint then the Quest1 containers. The Quest1 containers are 2.1°C and the Quest2 containers 1.0°C further from the setpoint, while the bandwidth was 0.7°C and 0.9°C smaller.

Quality inspection at arrival did not show differences due to packing times or containers. No relation could be found between the average temperature and product quality. This indicates that the Quest regime did not change quality output compared to normal regime. Also, no indication of chilling injury was found.

Acknowledgements

This fourth real-life Quest trial was largely organized and performed by Maersk Line. Most of the data and information in this report was provided by Maersk employees. We especially would like to thank Mr. Lindhardt and Mr. Nielsen of Maersk's Centre Reefer Management, Mr Hofmann of Maersk's Reefer Management Great Britain and Mr. Barfod and Mr. de Castro Alves of Maersk's Reefer Operations - South America.

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. Dudly, Mr. Duraisamy, Mr. McIntosh, Mr. Whyte, Mr. Smith, Mr. Bazan and Mr. Bretherton.

Quality inspections at arrival was supported by MMS. We would like to thank Mr. Williams, Mr. Bishop and 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, Mr. v.d. Voort and Mrs. Somhorst for their help during the organisation of the trial and its preparations as well as the product quality assessments.

Finally, our thanks go to Fyffes Group Ltd, whose fruit was transported and who made quality inspection possible after transport and ripened the bananas.

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 and mandarins, it has been tested for bananas, melons and pineapples in September 2006. In order to exactly determine the amount of power reduction, a comparison was made with three standard controlled reefer containers. All six 40 ft. containers were loaded with bananas and were transported on the same vessel (Lexa Maersk). The shipment was from Brazil (Pecém) to the Netherlands (Rotterdam) and the U.K. (Thamesport). The transport time was 10 days to Rotterdam and 11 days to Thamesport.

Four test containers were equipped with and controlled by the "Quest Regular" software, also referred to as CCPC (Compressor-Cycle Perishable Cooling). The containers MWCU6613469 (Quest11) and MWCU6736376 (Quest12) were controlled according to CCPC settings set 1, the containers MWCU6760773 (Quest21) and MWCU6770642 (Quest22) according to CCPC settings set 2. The containers MWCU6816893 (Ref1) and MWCU6809404 (Ref2) served as reference containers. 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. Three atmosphere samplers were placed in each of the six containers. Fruit samples for quality evaluation (6 - 9 cartons per container) were taken from 5 or 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. Upon arrival at the Fyffes branches in Wakefield and Basingstoke (UK) a first quality inspection of the bananas was carried out. Subsequently the bananas were ripened during 6-7 days at the Basingstoke branch of Fyffes Group Ltd. After ripening the bananas were collected in Basingstoke and transported in a climate controlled van to A&F in Wageningen, The Netherlands. 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 one grower: Banesa from Morrosó in Brasil. The initial temperature of the bananas was around 34°C.

Figure 1 Cavendish banana

Figure 2 Cavendish banana open

2.2 Packaging and stowage

The bananas are packed in cardboard boxes and covered with plastic bags. The box size is 400x500 mm, stacked 9 boxes high (6 on a layer). In total 6 containers with 1080 cartons are 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).

2.3 Unit settings

The containers used were fitted with Carrier Thinline refrigeration units. The CCPC program (v. 9576) 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 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	40 m^3/hr

The CCPC settings were:	settings set 1	settings set 2
◊ Supply setpoint	12.8 °C = 55.0 F	11.3 °C = 52.3 F
◊ Return Air Pulldown Low Limit	15.3 °C = 59.5 F	14.8 °C = 58.6 F
◊ Return Air Low Limit	15.3 °C = 59.5 F	14.8 °C = 58.6 F
◊ Return Air High Limit	16.3 °C = 61.3 F	15.3 °C = 59.5 F
◊ Fan setting	Alternating	Alternating
◊ Vent setting	40 m^3/hr	40 m^3/hr

Defrost interval: was set to automatic and Humidity, Dehumidification and Bulb Mode were all set to OFF.

2.4 Voyage schedule

On September 12th until September 15th the containers were loaded with bananas. Subsequently, the containers were taken to the harbour of Pecém. The setup is shown in Table 2.

Table 2 Container setup

Container nr	Setup mode	Stuffing date	Commodity	Grower
MWCU 661 346 9	CCPC 1 (test 1 1)	14/9/2006	Banana	Banesa
MWCU 680 940 4	NORMAL (ref 2)	14/9/2006	Banana	Banesa
MWCU 676 077 3	CCPC 2 (test 2 1)	13/9/2006	Banana	Banesa
MWCU 673 637 6	CCPC 1 (test 1 2)	13/9/2006	Banana	Banesa
MWCU 677 064 2	CCPC 2 (test 2 2)	12/9/2006	Banana	Banesa
MWCU 681 689 3	NORMAL (ref 1)	15/9/2006	Banana	Banesa

All containers were loaded to the vessel (Lexa Maersk) during the night of September 17th.

Figure 3 Map of loading and departure locations

Figure 4 Map of the vessel route

The containers arrived in Rotterdam (The Netherlands) on September 27th and in Thamesport (U.K.) on September 28th. Figure 18 and Figure 19 in the appendix depict the mean temperature and relative humidity in September 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 and 18 Tiny tags inside the containers. Three 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. Such instruments were placed in 6 pallets at the bottom and ¾ in height.

Figure 5 shows the stowage 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 fitted with USDA-probes (on the bottom layer), measuring product temperature. Probe 1 was installed in pallet 1, Probe 2 was installed in pallet 2 and Probe 3 and 4 were installed in pallet 19 and 20.

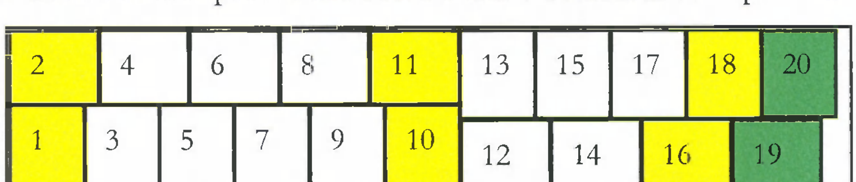


Figure 5 Container layout

2.6 Quality measurements

Banana pallets contained 9 layers of boxes. From each container at least 6 boxes were taken as sample boxes. These boxes were located on:

- Pallet 1, layer 1

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

Because 48 boxes were necessary for proper ripening 12 additional boxes were taken, maximal 3 per container. Upon arrival at the Fyffes branches in Wakefield and Basingstoke (UK) a first quality inspection of the bananas was carried out. Each box was given a code for the banana colour (figure 1) and for "dullness". In each box in three fingers "under peel damage" and pulp quality was judged.

Figure 6 Colour of banana, scale 2 – 7: 2 = green, 7 is yellow with sugarspots

The samples from containers MWCU6770642 and MWCU6736376 were taken on 29.09.06, and the samples from the container MWCU6816893 on 30.09.06, all three at Fyffes in Wakefield, UK. These sample boxes were transported in a climate controlled van (14.0°C) to Fyffes Basingstoke, UK and stored there until 2.10.06 at 14.5°C. On 2.10.06 sample boxes from the containers MWCU6760773, MWCU6613469 and MWCU6809404 were taken. Subsequently all samples were exposed to a ripening protocol of Fyffes. On 9.10.06 the bananas were collected in Basingstoke and transported in a climate controlled van (18°C) to A&F in Wageningen. The bananas were stored at 18°C/75% relative humidity (RH) as a simulation of shelf life.

Quality evaluations took place on 10.10.06 and 13.10.06, 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)
- Blackening of the peel (# of clusters with black spots) at day 3
- Sugar spots according to a scale 0 – 7; score per cluster

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

3 Temperatures

Figure 7 through Figure 10 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 20 through Figure 27 in the appendix. Time instance September 15th 15:30 is defined as t=0. 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 30°C. Since pull down is initiated at different time instances, the temperatures at t = 0 are not comparable, some bananas have already been cooled while others have not started to pull down yet (see Figure 20 through Figure 27 in the appendix). Pulp temperature readings vary as well (see Figure 28 through Figure 32 in the appendix in the appendix).

3.2 Temperature readings during pull down

Pull down was executed in normal mode for all containers. Containers ref 1, test12 and test22 start to pull down on September 13th (see Table 9 and Table 10 in the appendix). Ref 1 is set to 13.0°C for part of September 13th, but for rest of the pull down works at 13.3°C. Test12 and test22 both first pull down at 13.3°C, but are set to 13.0°C during September 14th to 16th. Containers ref2, test11 and test21 pull down at 13.3 °C and start on September 13th, 15th and 14th respectively.

CCPC software was installed and CCPC mode was activated in the harbour, around 23:00 September 16th. All settings are then set as defined in 2.3.

Also container test11 was first set to the correct values, but was erroneously put to normal mode at 13.3°C for the morning of September 17th. After activation of CCPC, its supply air setting was kept at 13.3 instead of 12.8°C until the morning of September 20th (see Table 9 in the appendix). This causes carton temperatures to be warmer than would normally be the case (compare carton temperatures with those of test21).

Container test12 was first set to the correct values, but erroneously put to normal mode at 12.8°C for the morning of September 17th (see Table 10 in the appendix). This causes a short additional pull down, which slightly influences the carton temperatures.

3.3 Temperatures at the start of the selected Quest Regular period

When comparing temperatures at the start of the Quest Regular period, (September 20th until 27th, t=135 – 303 h), we see that temperatures have become more but not fully comparable. Quest containers start off about 1°C warmer than the reference containers. (see Figure 20 through Figure 27 and Figure 33 through Figure 36 in the appendix).

Ref1 contains two relatively warm cartons in the middle pallets while the others are about 1°C cooler then those of test11. Besides the two warm cartons, temperatures of cartons of ref1 are comparable to those of test21. Both ref2 and test12 contain two warm cartons[1], while in general cartons of test12 are about 1°C warmer then those of ref2. Container test22 contains four warm cartons, compared to two in ref2. The other boxes are approximately 1°C warmer.

3.4 Supply air temperatures during Quest Regular Mode

During Quest Regular Mode, the minimum supply temperature mostly does not reach supply setting, but stops at about 13.0°C instead of 12.8°C for set 1 and at about 12.0°C instead of 11.3°C for set 2 (see Figure 28 to Figure 32 in the appendix). The compressor on time for set 1 is about 12 minutes, which should be long enough to reach setpoint. Adaptation of the field software, after comparable issues for mandarin and apple, apparently did not help (enough) to prevent same for these banana shipments. For set 2 the compressor on time is very short, approximately 3 minutes, which might (partly) explain this deviation.

Another interesting and somewhat worrying supply air issue is that supply air of test12 becomes unstable during day 14 (just after arrival, evening September 28th until morning 30th, see Figure 30 in the appendix. The minimum recorded supply air temperature suddenly drops down to very low values (around 9°C) for a day or so. The reason is unclear, but seems to be connected to (the erroneously activated) dehumidification actions.

[1] *NB: 3 loggers in the forelast door side pallet of Ref 2 have gone missing. This might influence average readings of this container to be cooler then would have been when these would not have gone missing.*

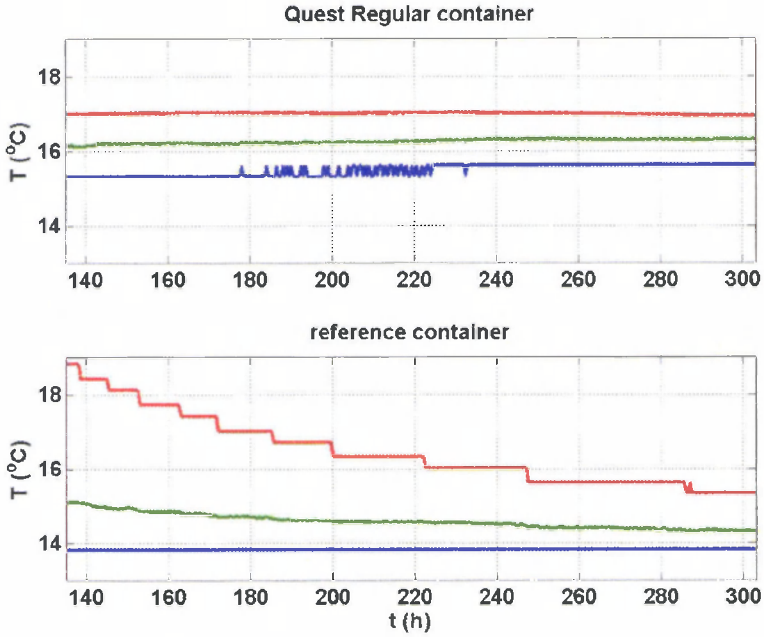


Figure 7 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-) , for Banana test11 and ref1

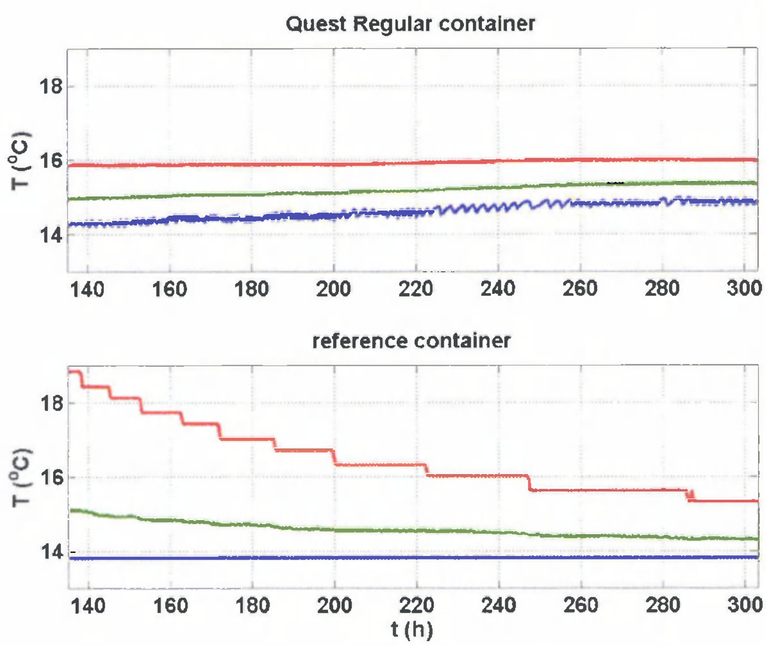


Figure 8 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-) , for Banana test21 and ref1

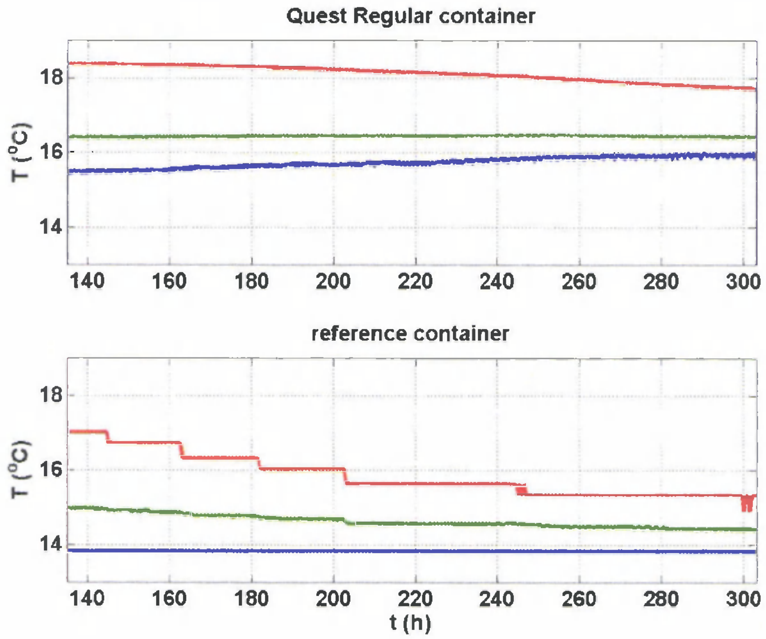


Figure 9 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-) , for Banana test12 and ref2

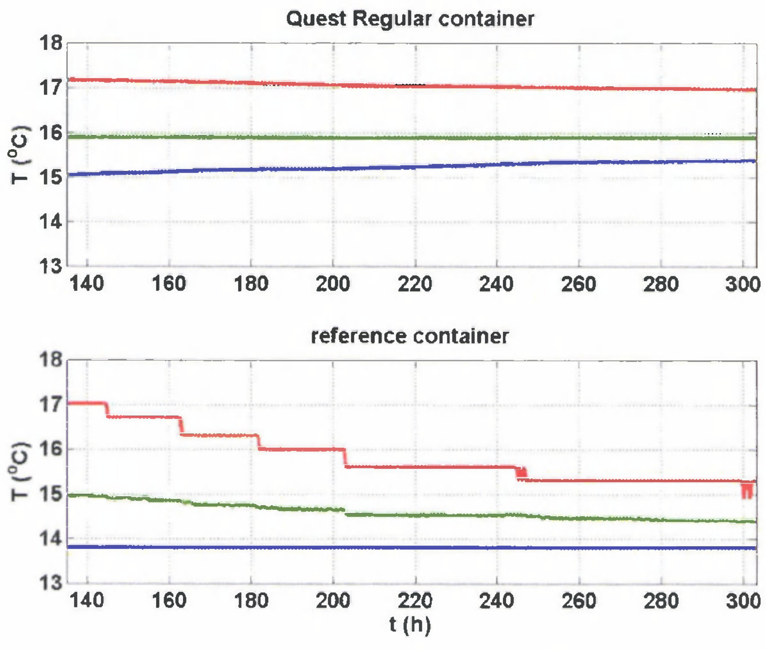


Figure 10 Temperature readings of Tiny Tags in cartons, coolest (-) and warmest (-) carton, as well as mean temperature for all cartons (-) , for Banana test22 and ref2

3.5 Temperature readings during Quest Regular Mode reference containers

The supply air of the Quest containers fluctuates in time, but with such a high frequency, that the fluctuations are hardly visible in the carton temperature data (measured with a 30 min period).

The temperature data for the Quest Regular period (September 20th until 27th, t=135 – 303 h) have been summarized in Table 3 through Table 7. The tables contain information on the temperatures of the coolest and warmest cartons as well as the mean temperature of all cartons combined.

First of all, the deviation from the given setpoint is important (see column 3 of Table 4 and Table 7). The mean carton temperature of the Quest1 containers is 16.7°C. The mean carton temperature of the Quest2 containers is 15.6°C. The mean carton temperature of the reference containers is 14.6°C. Thus, the Quest1 containers are 2.1°C and the Quest2 containers 1.0°C further from the setpoint of 13.3°C than the reference containers.

Secondly, the maximum bandwidth of the carton temperatures is considered (see column 2 and 4 of Table 3 and Table 6). Looking at the lowest and highest temperatures measured in the cartons, the maximum temperature difference between the coolest and warmest cartons was 2.0°C in the Quest1 containers, 2.0°C in the Quest2 containers and 4.1°C in the reference containers. Thus, in the most extreme situation, both sets of Quest containers had a 2.1°C smaller maximum temperature bandwidth than the reference containers.

Thirdly, the mean bandwidth of the carton temperatures is considered (see column 2 and 4 of Table 4 and Table 7). Looking at the mean of the carton temperatures in time, the temperature difference between the coolest and warmest cartons was 1.6°C in the Quest1 containers, 1.4°C in the Quest2 containers and 2.3°C in the reference containers. Thus, on average, the Quest1 containers had a 0.7°C and the Quest1 containers a 0.9°C smaller temperature bandwidth than the reference containers.

Fourthly, the deviation of the coolest carton from the given setpoint is important (see column 2 of Table 7 and Table 7). The coolest cartons of the Quest1 containers were 2.3°C and the Quest2 containers 1.8°C above setpoint. The coolest cartons of the reference containers are 0.5°C above setpoint. Thus, the coolest cartons of the Quest1 containers are 1.8 °C and the Quest2 containers 1.3°C further from the setpoint than the reference containers.

Finally, the deviation of the warmest cartons from the given setpoint is important (see column 4 of Table 7 and Table 7). The warmest cartons of the Quest1 containers were 3.9°C and the Quest2 containers 3.2°C above setpoint. The warmest cartons of the reference containers are 2.8°C above setpoint. Thus, the warmest cartons of the Quest1 containers are 1.1°C and the Quest2 containers 0.4°C further from the setpoint than the reference containers.

Table 3 The ranges of the minimum, maximum and mean carton temperature readings (from September 20th 00:00 to 27th 00:00 for banana)

	min carton T (°C)	mean carton T (°C)	max carton T (°C)
Quest container 11	15.3 to 15.6	16.9 to 17.0	16.1 to 16.3
Quest container 21	14.2 to 15.0	14.9 to 15.4	15.8 to 16.0
reference cont. 1	13.8 to 13.8	14.3 to 15.1	15.3 to 18.8
Quest container 12	15.4 to 16.0	16.4 to 16.5	17.7 to 18.4
Quest container 22	15.0 to 15.4	15.9 to 15.9	17.0 to 17.2
reference cont. 2	13.8 to 13.8	14.4 to 15.0	14.9 to 17.0

Table 4 The mean of the minimum, maximum and mean carton temperature readings

	mean min carton T (°C)	mean mean carton T (°C)	mean max carton T (°C)
Quest container 11	15.5	17.0	16.2
Quest container 21	14.9	15.2	15.9
reference cont. 1	13.8	14.6	16.4
Quest container 12	15.7	16.4	18.1
Quest container 22	15.2	15.9	17.0
reference cont. 2	13.8	14.6	15.8

Table 5 The deviations from setpoint for the minimum, maximum and mean carton temperature readings

	dev min carton T (°C)	dev mean carton T (°C)	dev max carton T (°C)
Quest container 11	2 to 2.3	3.6 to 3.7	2.8 to 3
Quest container 21	0.9 to 1.7	1.6 to 2.1	2.5 to 2.7
reference cont. 1	0.5 to 0.5	1 to 1.8	2 to 5.5
Quest container 12	2.1 to 2.7	3.1 to 3.2	4.4 to 5.1
Quest container 22	1.7 to 2.1	2.6 to 2.6	3.7 to 3.9
reference cont. 2	0.5 to 0.5	1.1 to 1.7	1.6 to 3.7

Table 6 The deviations from setpoint for the mean of the minimum, maximum and mean carton temperature readings

	dev mean min carton T (°C)	dev mean mean carton T (°C)	dev mean max carton T (°C)
Quest container 11	2.2	3.7	2.9
Quest container 21	1.6	1.9	2.6
reference cont. 1	0.5	1.3	3.1
Quest container 12	2.4	3.1	4.8
Quest container 22	1.9	2.6	3.7
reference cont. 2	0.5	1.3	2.5

Table 7 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)
Quest11 & ref1	-1.7	-2.4	+0.2
Quest21 & ref1	-1.1	-0.6	+0.5
Quest12 & ref2	-1.9	-1.8	-2.3
Quest22 & ref2	-1.4	-1.3	-1.2

Overall, carton temperatures in the Quest container are on the warm side, but with a satisfactory bandwidth. The Quest2 containers, with the cooler settings, are closer to setpoint then the Quest1 containers. The Quest1 containers are 2.1°C and the Quest2 containers 1.0°C further from the setpoint, while the bandwidth was 0.7°C and 0.9°C smaller. The coolest cartons were 1.8, respectively 1.3°C further and the warmest cartons 1.1°C and 0.4°C further from the setpoint.

USDA readings during the trip are shown in Figure 28 to Figure 32 in the appendix. In accordance with the above, temperatures in the Quest containers lay further above setpoint than USDA readings of the reference containers.

3.6 Temperatures at the end of the trip

Figure 37 through Figure 40 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 twice a day during the sea voyage. Time and energy data were taken from the kWh meters, see Figure 11. Time axis is such that t = 0 starts at September 17th 2006 18:00.

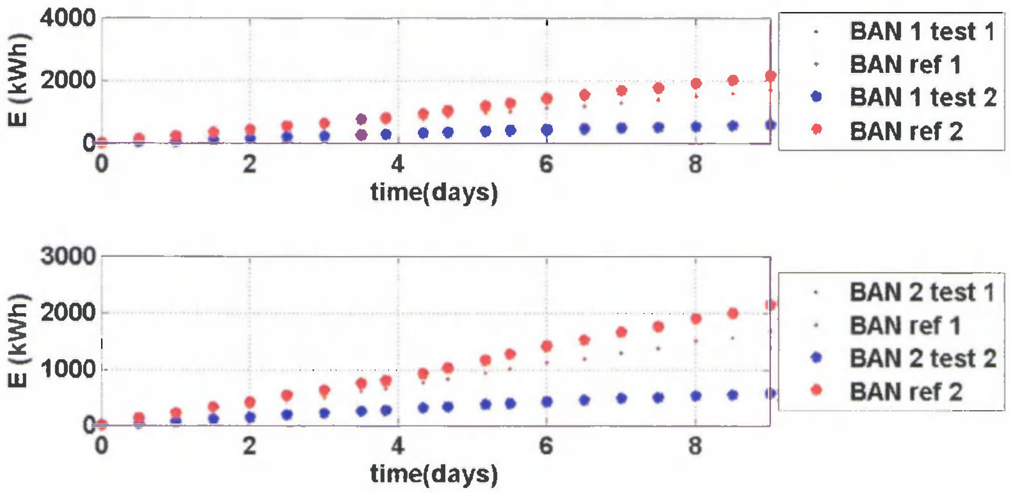


Figure 11 Energy readings as a function of time for both container sets

The reference containers used 1676 and 2127 kWh in 216 hour, a mean power usage of 7.8 and 9.8 kW. The Quest1 containers (test11 and test12) used 524 and 566 kWh in 216 h, a mean power usage of 2.4 and 2.6 kW, which is 69 and 73% less compared to the reference containers. The Quest2 containers (test21 and test22) used 417 and 440 kWh in 216 h, a mean power usage of 1.9 and 2.0 kW, which is 75 and 79% less compared to the reference containers. The power and savings per day are shown in Figure 12. Mean savings of Quest1 are 71%. Mean savings of Quest2 are 77%.

Although at the start of the trip dehumidification was set OFF, all banana containers have dehumidification energy readings, except banana test22. This explains a large part of the power usage difference between the two reference banana containers. The mean dehumidification energy in the power calculation period above is 0.2 kW for test11 and test12[2], 1.6 kW for ref1 and 3.1 kW for ref2. When subtracting the dehumidification energy consumption, the reference containers had a mean power usage of 6.2 and 6.7 kW. The Quest1 containers (test11 and test12) then had a mean power usage of 2.2 and 2.4 kW, which is 65 and 64% less compared to the reference containers. The Quest2 containers (test21 and test22) had a mean power usage of 1.9 and 2.0 kW, which is 69 and 70% less compared to the reference containers. Another factor to be taken into account is the additional cooling effort due to the dehumidification heating. This is

[2] *Test21 only had dehumidification energy recorded outside this period*

approximately 66% of the heating effort. When also subtracting the estimated additional cooling effort, the reference containers had a mean power usage of 5.1 and 4.6 kW. The Quest1 containers (test11 and test12) then had a mean power usage of 2.1 and 2.3 kW, which is 59 and 55% less compared to the reference containers. The Quest2 containers (test 21 and test 22) had a mean power usage of 1.9 and 2.0 kW, which is 63 and 56% less compared to the reference containers. Mean savings are then 57% for Quest1 and 60% for Quest2.

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 47 through Figure 50 in the appendix. (For comparison, also the active hours and defrost time of the units are shown.) Compressor off time intervals for Quest1 last approximately 40 - 70 minutes, about 3 - 5 times as long as the compressor-on time intervals. Compressor off time intervals for Quest2 last approximately 10 - 25 minutes, about 3 - 7 times as long as the compressor-on time intervals. 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.

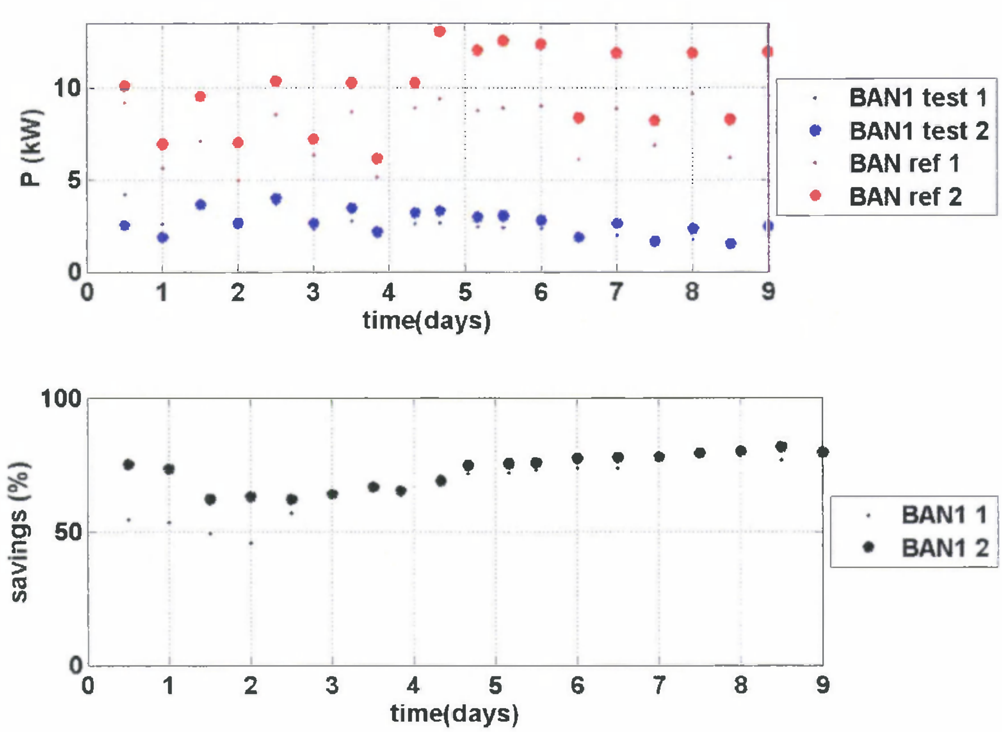


Figure 12 Power and savings as a function of time for both container set 1

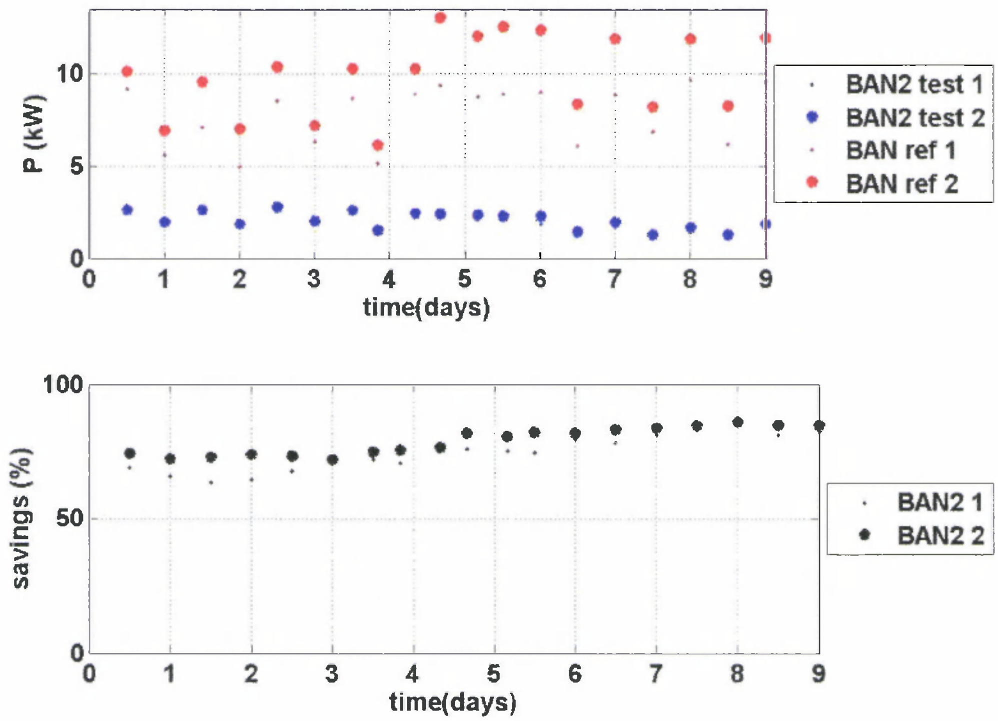


Figure 13 Power and savings as a function of time for container set 2

5 Evaluation of fruit quality

5.1 Quality at arrival

According to the first impressions at arrival from David Shields (Fyffes Quality Control Manager) the bananas from container MWCU6613469 (Quest11) had a bright green colour. Some bananas were damaged, but this is not due to the climate in the container. About bananas from the other containers no comment from Fyffes' staff members was noted.

Incidentally a box with some yellow bananas was found at arrival, i.e. box number 19/5, which was located on top of pallet 18 in the Reference 1 container. One more box with some yellow bananas was found in one of the Quest containers in Wakefield (number unknown, location unknown). It is assumed that the location (container, pallet, layer) of *incidentally* found yellow bananas is a matter of coincidence. No serious "under skin damage" (dark colouring in the tissue beneath the upper layer of the skin) was found: "under skin damage" is considered to be a symptom of chilling injury. Pulp quality was good.

5.2 Packing date and packing method

The six containers were loaded in a time range of about 3 days. The packing time can be deduced from a 5 digit code, stamped on each box. It is concluded that all bananas were grown on the same farm and that the "oldest" bananas were packed between 11 September 18:00 h and 12 September 06:00 h local time and the "youngest" bananas on 15 September between 12:00 h and 18:00 h local time. Table 8 gives an overview of the containers and the amount and type of cartons they contained.

Table 8 Containers and packing code.

	packing code on sample boxes											
container	11-3	12-2	12-3	13-1	13-2	13-3	14-1	14-2	14-3	15-1	15-2	???
MWCU 681 689 3 (Ref 1)										3	6	
MWCU 680 940 4 (Ref 2)							4	2				
MWCU 661 346 9 (Quest 1-1)								6	1			1
MWCU 673 637 6 (Quest 1-2)		1	2	4								
MWCU 676 077 3 (Quest 2-1)	2				2	2						
MWCU 677 064 2(Quest 2-2)		9										

example:
13-1 packing time: 13 september, 06:00 - 12:00 h
13-2 packing time: 13 september, 12:00 - 18:00 h
13-3 packing time: 13 september, 18:00 - 14 september 06:00 h

Table 8 shows that loading of the containers took about 3 days, the "youngest" bananas were loaded in one of the reference containers; an analysis of the effect of the packing date on the quality of the bananas is therefore justifiable, in order to determine whether possible differences in quality are due to the container or to the age of the bananas. The bananas from container

MWCU 676 077 3 (Quest21) were very small; these fruits were packed per cluster or per two small clusters in a plastic bag. In the other containers fruits were packed in one plastic bag per carton.

Figure 14 and Figure 15 show that colour, black spots and sugars spots depend on the packing time. Bananas from packing time's 11-3, 13-2, 13-3 (small fruits, packed per cluster) and 14-1 and 14-2 are less green at days 0 and 3 of shelf life and have less black spots and sugar spots after 3 days of shelf life than the bananas with the other packing date codes. It is clear that bananas with a high colour index at day 0 and 3 have more black spots and more sugar spots than bananas with a lower colour index. This is a strong indication that black spots are due to ageing and are not caused by chilling.

After 3 days of shelf life in some boxes with packing date 14-2 (Quest1) and 14-3 (Ref2) bananas were found in stage 5 (green tips) with sugar spots.

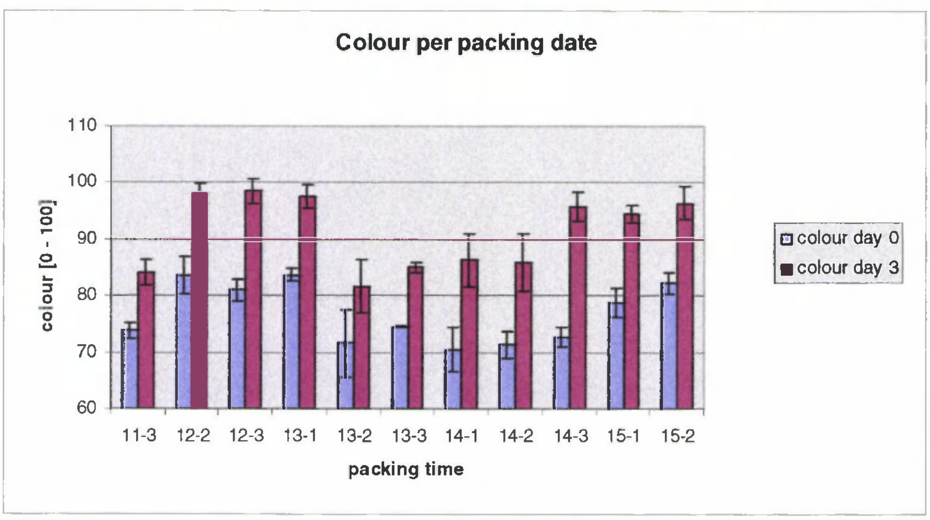


Figure 14 Colour of ripened bananas on day 0 and day 3 of shelf life of bananas with different packing dates.

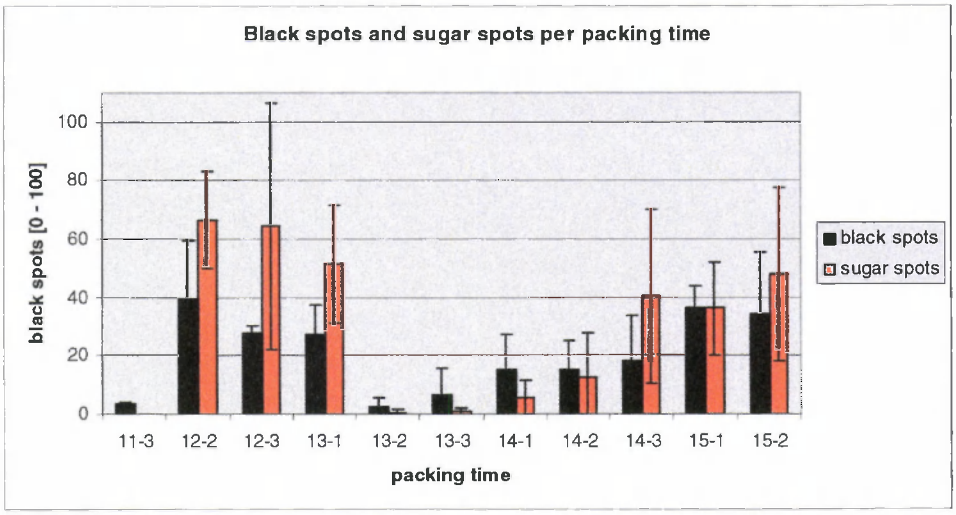


Figure 15 Black spots and sugar spots on day 3 of shelf life of bananas with different packing dates.

5.3 Average temperature and quality

In Figure 16 the effect of the average temperature on the colour on day 0 and day 3 of shelf life is shown. Figure 16 shows the data of all containers. Figure 17 shows the temperature effect on the occurrence of a dull grey haze on the fruits. Both figures show that no effect of the average temperature was found. The dull grey haze is considered to be a symptom of chilling injury. The lowest average temperature of the bananas in this trial was 13.8°C, so chilling injury is not expected to occur. The score for dull grey was very low (0 – 7 on the index 0 – 100) and can be considered as "background level".

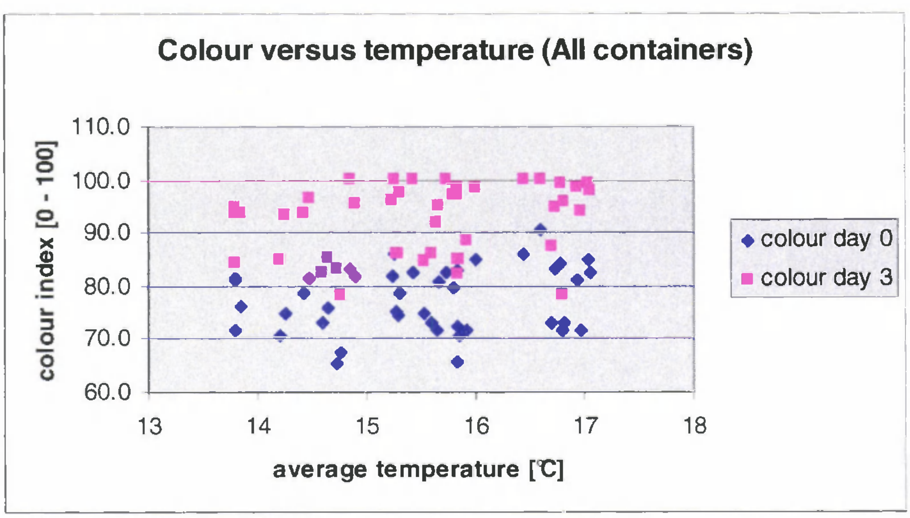


Figure 16 Effect of average temperature on colour of bananas from 6 containers.

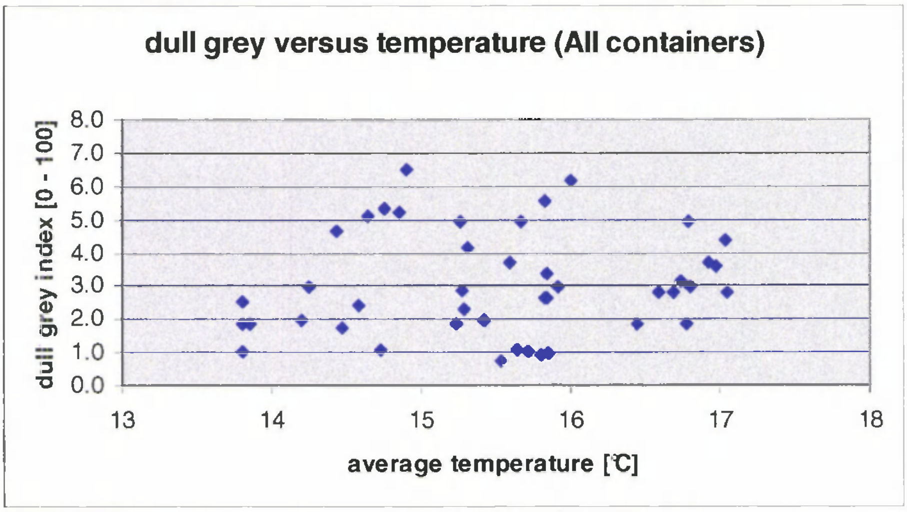


Figure 17 Effect of average temperature on the occurrence of dull grey haze on bananas from 6 containers.

5.4 Effect of containers

Because the containers were loaded with bananas with different packing date's (Table 8) and differences in quality due to the packing date were found containers cannot be compared.

6 Conclusions

6.1 Power savings

Mean savings of Quest1 are 71%. Mean savings of Quest2 are 77%. Although at the start of the trip dehumidification was set OFF, almost all banana containers have dehumidification energy readings. When accounting for the differences in dehumidification energy consumption, the mean savings are approximately 57% for Quest1 and 60% for Quest2.

6.2 Temperatures

The supply air of the Quest containers fluctuates in time, but with such a high frequency, that the fluctuations are hardly visible in the carton temperature data (measured with a 30 min period).

During Quest Regular Mode, the minimum supply temperature mostly does not reach supply setting, but stops at about 13.0°C instead of 12.8°C for set 1 and at about 12.0°C instead of 11.3°C for set 2 (see Figure 28 to Figure 32 in the appendix). Adaptation of the field software, after comparable issues for mandarin and apple, apparently did not help (enough) to prevent same for these banana shipments. Also, supply air of test12 becomes unstable during day 14 (just after arrival). The reason is unclear, but seems to be connected to (the erroneously activated) dehumidification actions.

The carton temperatures in the Quest container are on the warm side, but with a satisfactory bandwidth. The Quest2 containers, with the cooler settings, are closer to setpoint then the Quest1 containers. The Quest1 containers are 2.1°C and the Quest2 containers 1.0°C further from the setpoint, while the bandwidth was 0.7°C and 0.9°C smaller. The coolest cartons were 1.8, respectively 1.3°C further and the warmest cartons 1.1°C and 0.4°C further from the setpoint.

6.3 Product quality

Quality inspection at arrival did not show differences due to packing times or containers.

Main quality differences, determined after ripening and after three days of shelf life simulation, were due to the packing time. No comparison between containers could be made because bananas from different packing times were not equally distributed over the containers.

No relation could be found between the average temperature and product quality. This indicates that the Quest regime did not change quality output compared to normal regime.

No chilling injury was found at arrival, after ripening or after three days of shelf life simulation. This indicates that in none of the Quest or Reference containers the temperature was long enough under the chilling injury level to cause any harm.

References

[1] http://www.cdc.noaa.gov/cgi-bin/Composites/comp.pl

Appendix I: Ambient conditions between Brazil and Great Britain

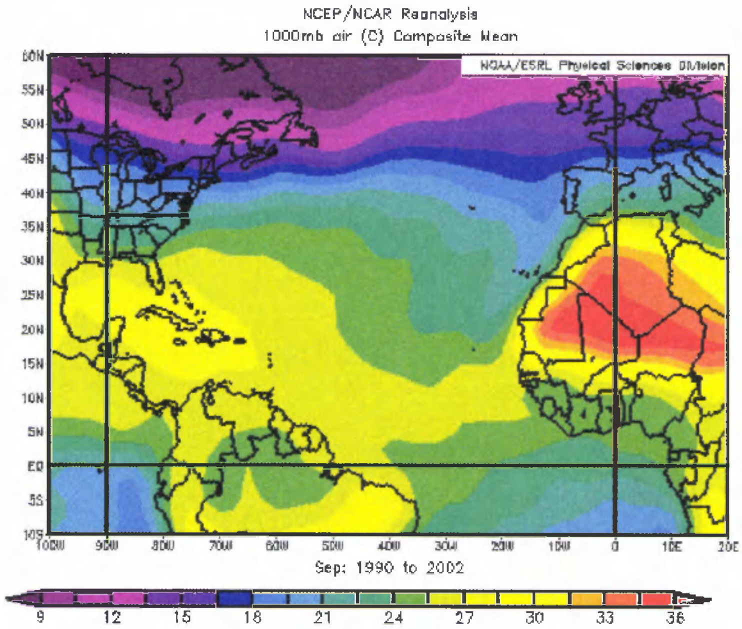


Figure 18 Mean September temperature between Brazil and Great Britain [1]

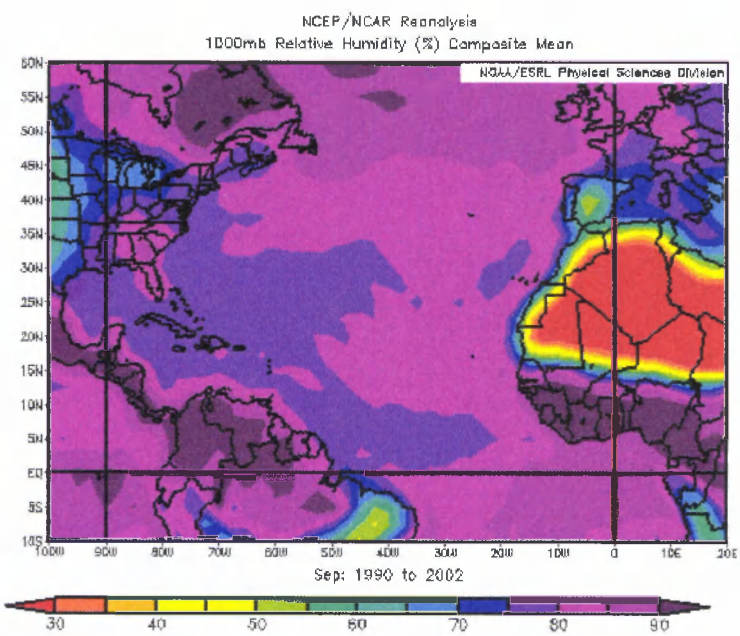


Figure 19 Mean September relative humidity between Brazil and Great Britain [1]

Appendix II: Settings and dehumidification during the trip

Table 9 Correctness of settings, activation and deactivation of CCPC and record of dehumidification energy > 0, ref 1, test11 and test21

date	time	ref1, settings (no AL)	ref1, dehum (1.6 kW)	test11, settings (no AL)	test11, dehum (0.24 kW)	test21, settings (AL64)	test21, dehum (0 kW)
13-sep	**morning**	set, SP 13.0	-	-	-	-	-
13-sep	**evening**	set OK	-	-	-	-	-
14-sep	**morning**	set OK	-	-	-	NORMAL, set 13.3	-
15-sep	**morning**	set OK	-	NORMAL, set 13.3	-	NORMAL, set 13.3	-
15-sep	**evening**	set OK	-	NORMAL, set 13.3	-	NORMAL, set 13.3	-
16-sep	**evening**	set OK	NO, OK	CCPC act, set OK	NO, OK	CCPC act, set OK	NO, OK
17-sep	**morning**	set OK	NO, OK	CCPC deact, SP = 13.3	DEHUM	OK	NO, OK
17-sep	**afternoon**	set OK	NO, OK	CCPC act, SP = 13.3	NO, OK	OK	NO, OK
17-sep	**evening**	set OK, departure	NO, OK	CCPC act, SP = 13.3, d.	NO, OK	OK, departure	NO, OK
18-sep	**evening**	set OK	NO, OK	OK	NO, OK	OK	NO, OK
19-sep	**evening**	set OK	DEHUM	OK	NO, OK	OK	NO, OK
20-sep	**morning**	set OK	DEHUM	CCPC act, set OK	DEHUM	OK	NO, OK
28-sep	**morning**	set OK, arrival	DEHUM	OK, arrival	DEHUM	OK, arrival	DEHUM
28-sep	**afternoon**	set OK	DEHUM	OK	DEHUM	OK	DEHUM
29-sep	**evening**	set OK	DEHUM	OK	DEHUM	OK	DEHUM
30-sep	**morning**	stripped	-	OK	DEHUM	OK	NO, OK
2-okt	**morning**	-	-	OK	DEHUM	OK	DEHUM (3H)
2-okt	**afternoon**	-	-	OK, stripped	DEHUM	OK, stripped	NO, OK

Table 10 Correctness of settings, activation and deactivation of CCPC and record of dehumidification energy > 0, ref2, test12 and test22

date	time	ref2, settings (no AL)	ref2, dehum (3.1 kW)	test12, settings (AL64)	test12, dehum (0.24 kW)	test22, settings (no AL)	test22, dehum (0 kW)
13-sep	**morning**	-	-	NORMAL, set 13.3	-	NORMAL, set 13.3	-
13-sep	**evening**	-	-	NORMAL, set 13.3	-	NORMAL, set 13.3	-
14-sep	**morning**	-	-	NORMAL, set 13.0	-	NORMAL, set 13.0	-
15-sep	**morning**		-	NORMAL, set 13.0	-	NORMAL, set 13.0	-
15-sep	**evening**	set OK	-	NORMAL, set 13.0	-	NORMAL, set 13.0	-
16-sep	**evening**	set OK	NO, OK	CCPC act, set OK	NO, OK	CCPC act, set OK	NO, OK
17-sep	**morning**	set OK	DEHUM	CCPC deact, SP = 12.8	NO, OK	OK	NO, OK
17-sep	**afternoon**	set OK	DEHUM	CCPC act, set OK	DEHUM (2H)	OK	NO, OK
17-sep	**evening**	set OK, departure	DEHUM	CCPC act, set OK, d.	DEHUM (2H)	OK, departure	NO, OK
18-sep	**evening**	set OK	DEHUM	OK	DEHUM	OK	NO, OK
19-sep	**evening**	set OK	DEHUM	OK	DEHUM	OK	NO, OK
20-sep	**morning**	set OK	DEHUM	OK	DEHUM	OK	NO, OK
28-sep	**afternoon**	set OK, arrival	DEHUM	OK, arrival	DEHUM	-, arrival	-
29-sep	**evening**	set OK	DEHUM	OK, stripped	DEHUM	-, stripped	-
30-sep	**morning**	set OK	DEHUM	-	-	-	-
2-okt	**morning**	set OK	DEHUM	-	-	-	-
2-okt	**afternoon**	stripped	-	-	-	-	-

Appendix III: Carton temperatures

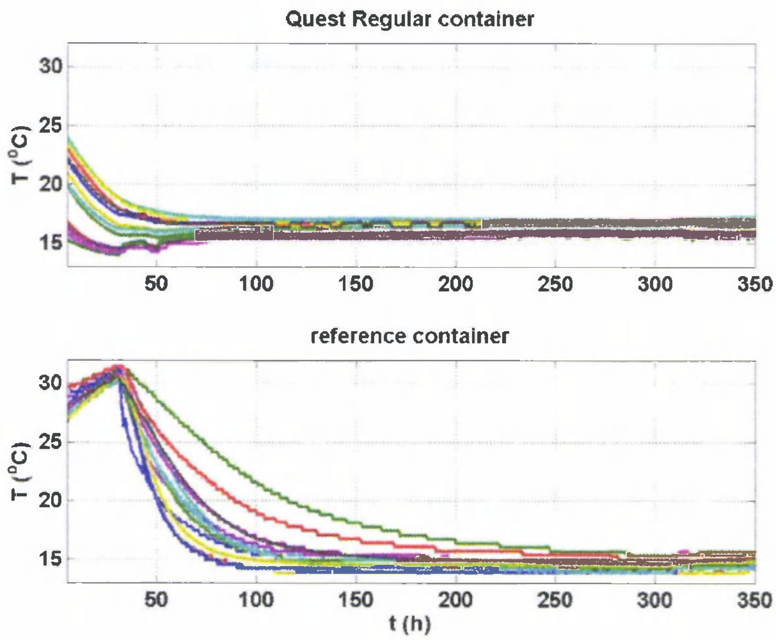


Figure 20 Temperature readings of Tiny Tags in cartons, all data, for Banana ref1 and test11

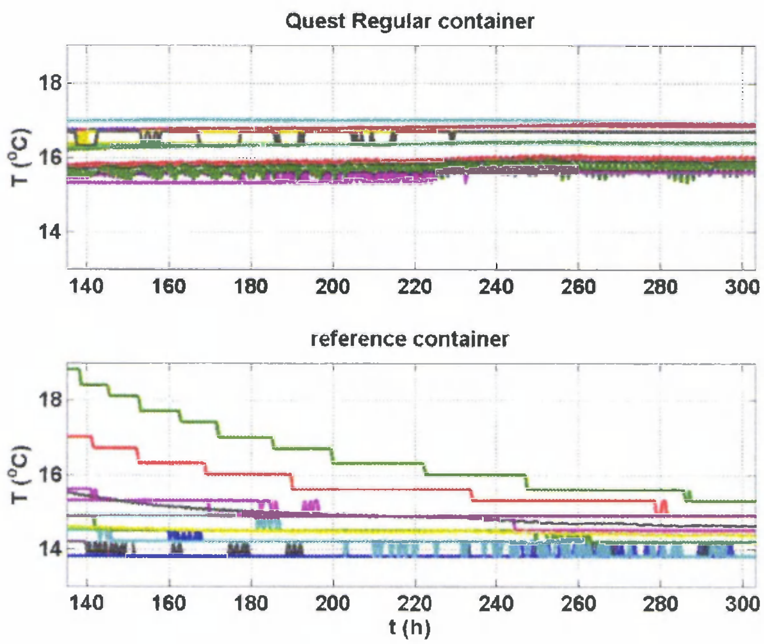


Figure 21 Temperature readings of Tiny Tags in cartons, zoom in, for Banana ref1 and test11

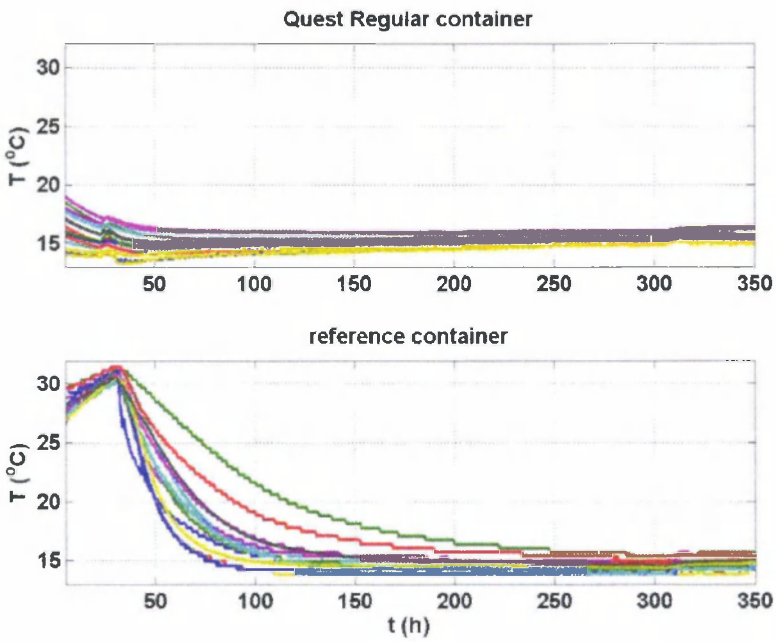


Figure 22 Temperature readings of Tiny Tags in cartons, all data, for Banana ref1 and test21

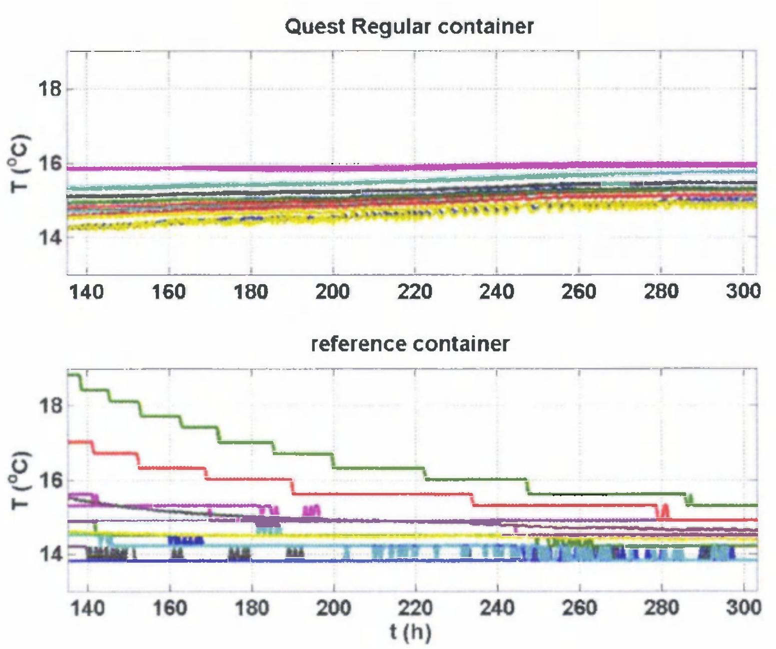


Figure 23 Temperature readings of Tiny Tags in cartons, zoom in, for Banana ref1 and test21

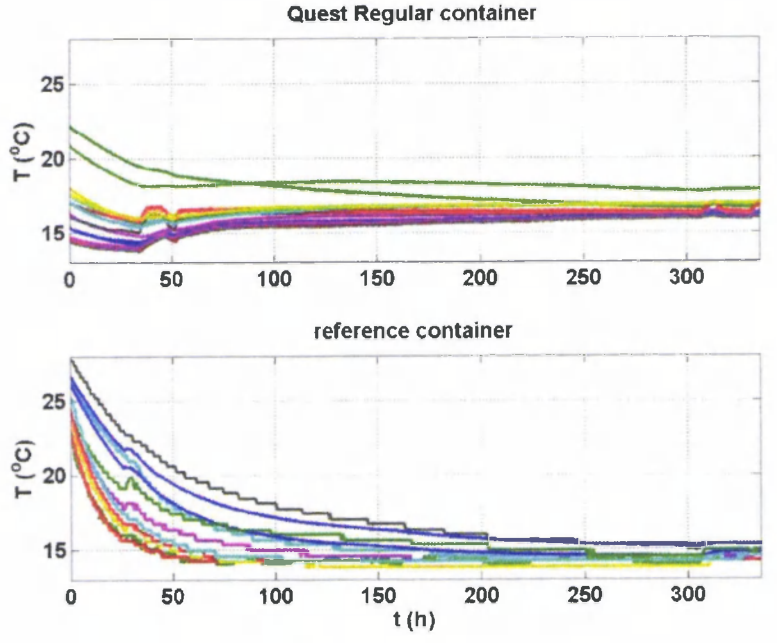


Figure 24 Temperature readings of Tiny Tags in cartons, all data, for Banana ref2 and test12

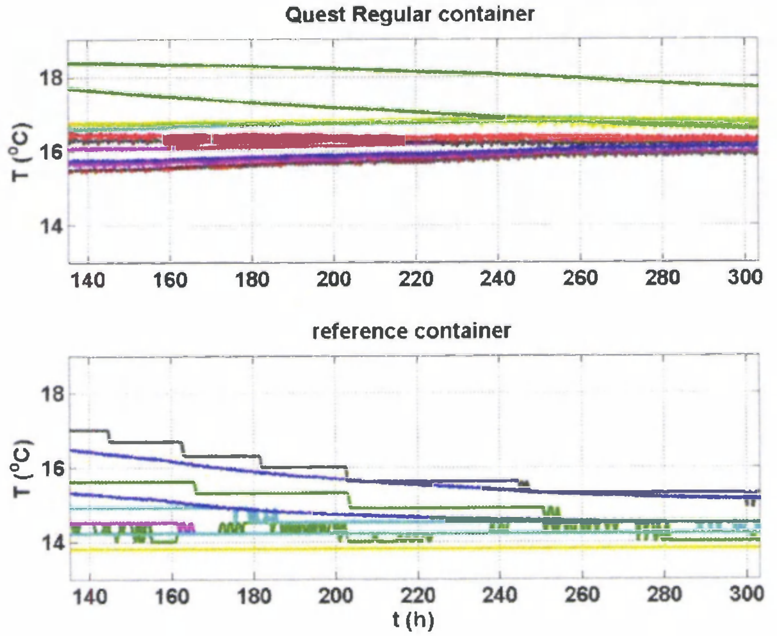


Figure 25 Temperature readings of Tiny Tags in cartons, zoom in, for Banana ref2 and test12

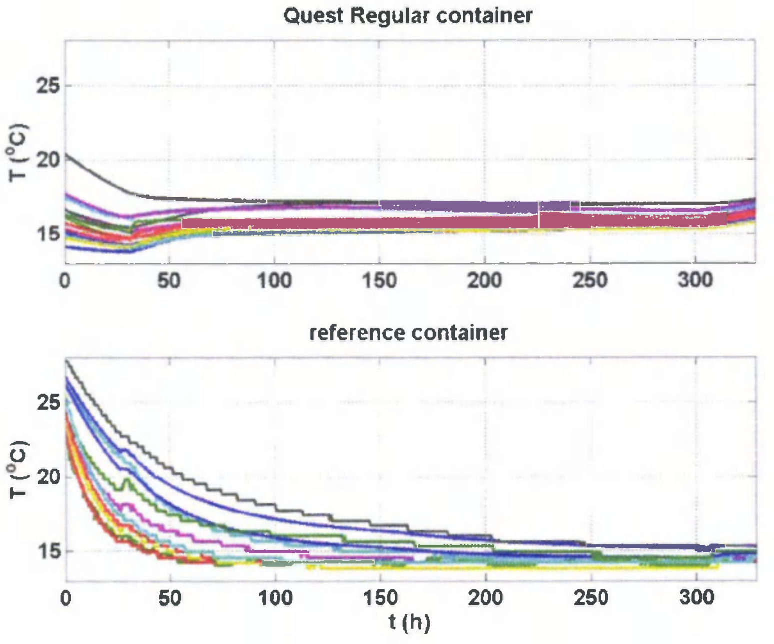


Figure 26 Temperature readings of Tiny Tags in cartons, all data, for Banana ref2 and test22

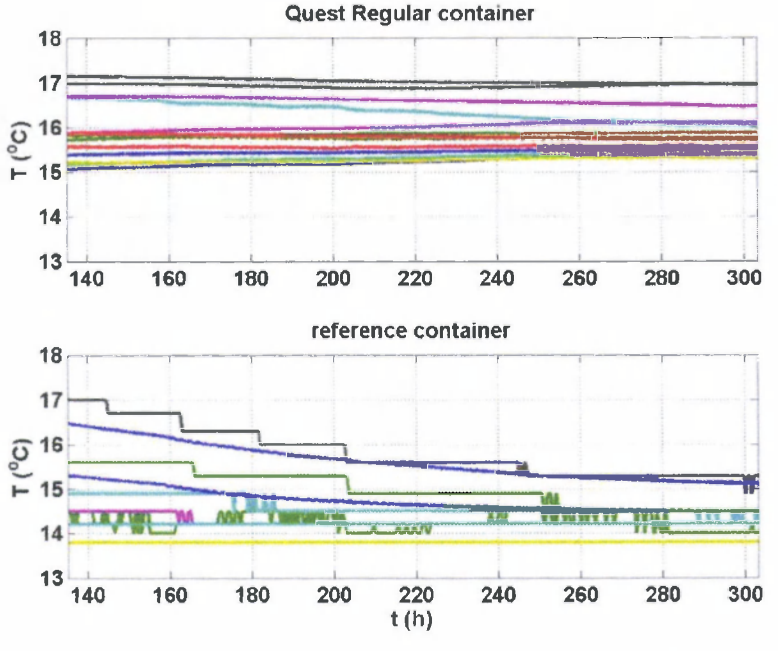


Figure 27 Temperature readings of Tiny Tags in cartons, zoom in, for Banana ref2 and test22

Appendix IV: Unit temperature readings as a function of time

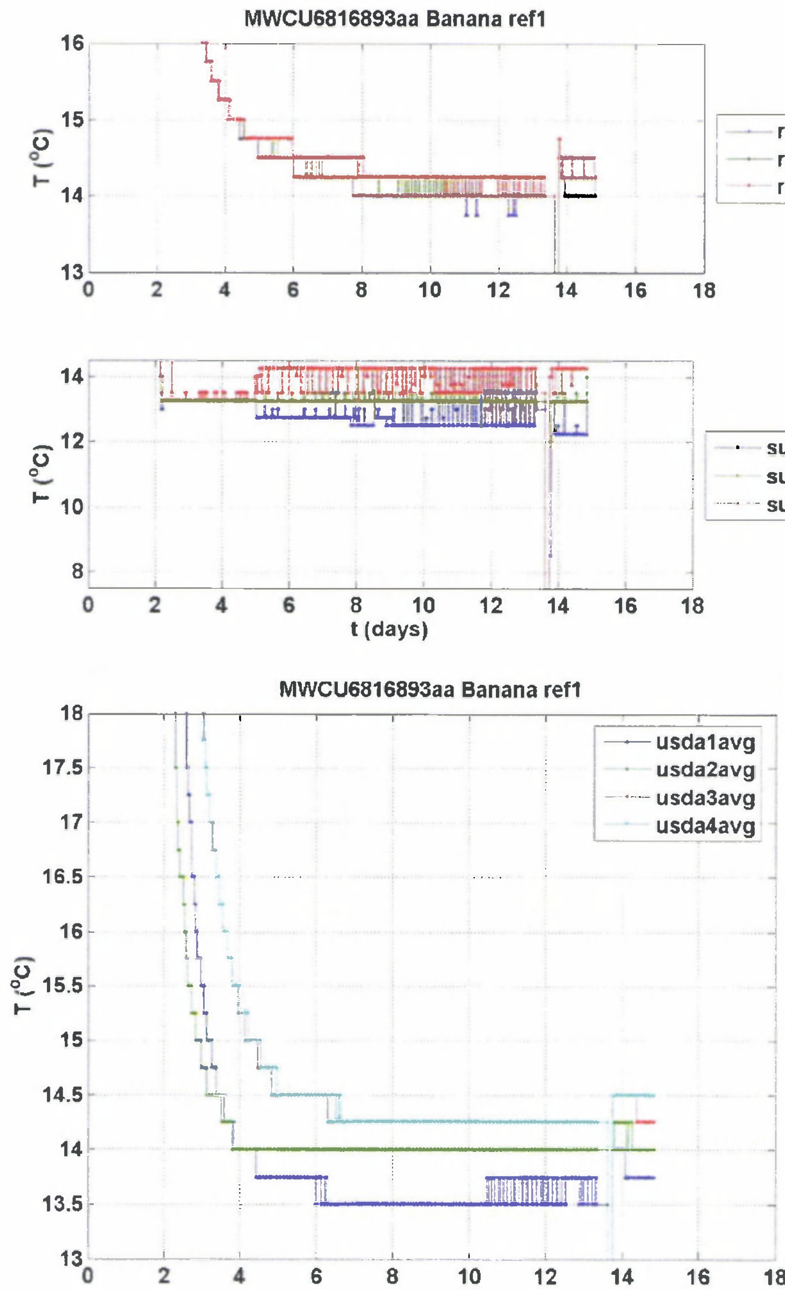


Figure 28 Temperature readings from the unit for the Banana ref 1 container.

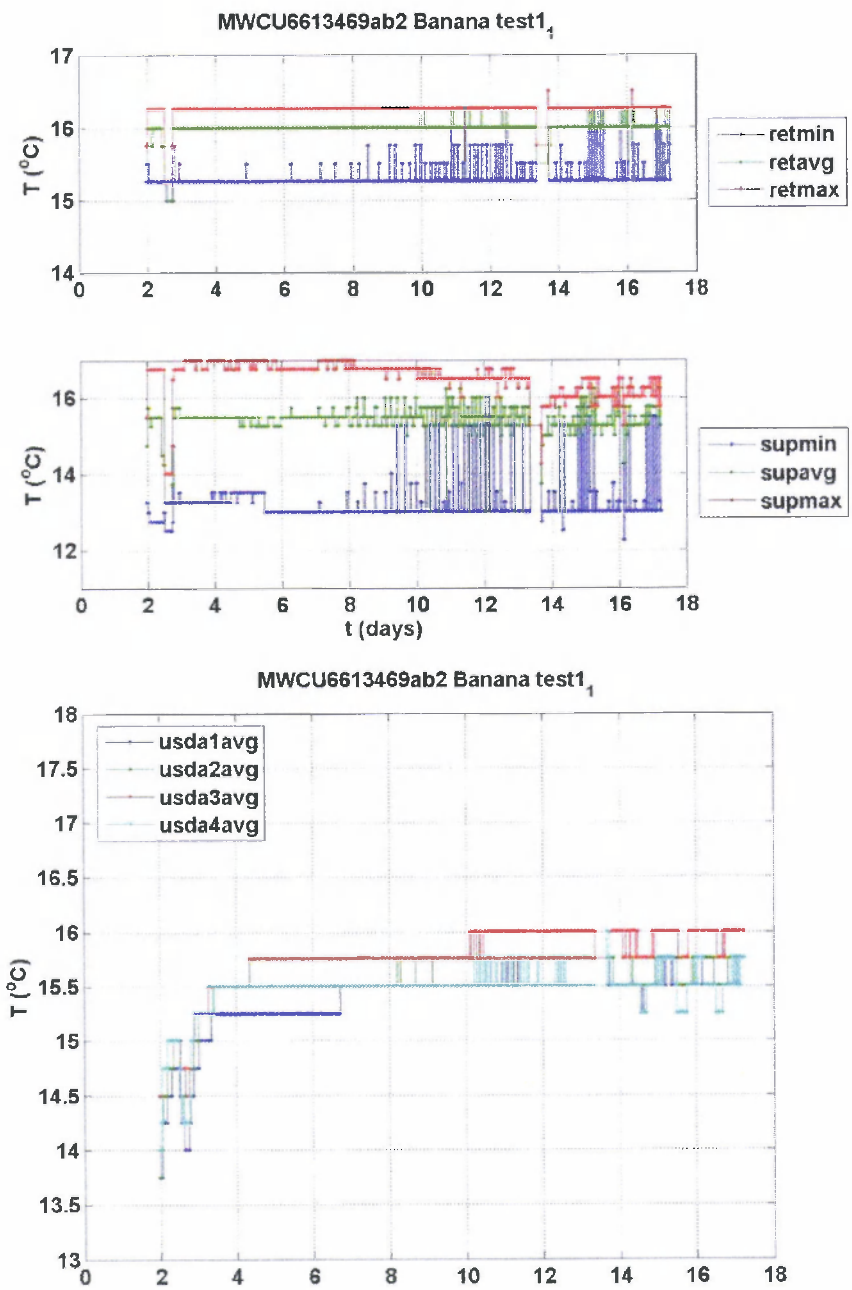


Figure 29 Temperature readings from the unit for the Banana test11 container

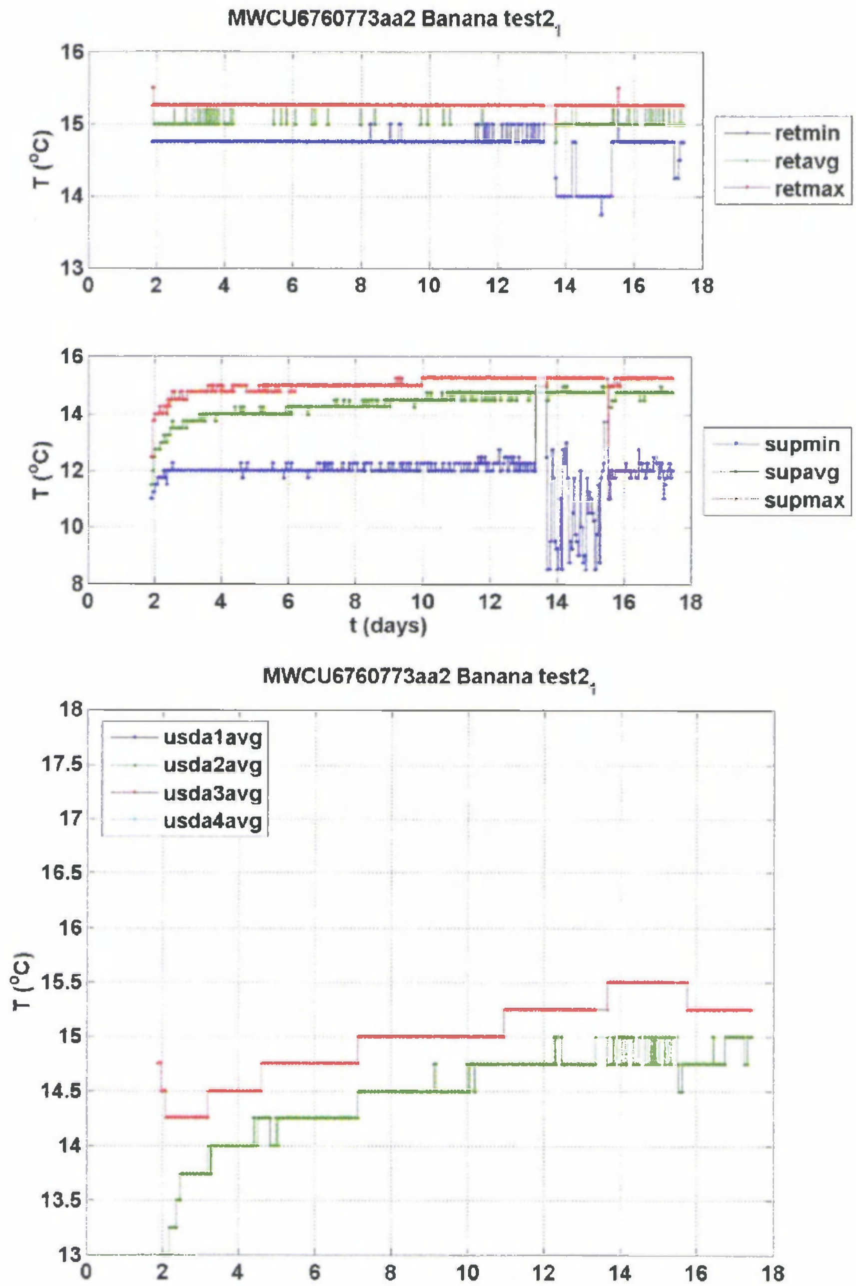


Figure 30 Temperature readings from the unit for the Banana test21 container.

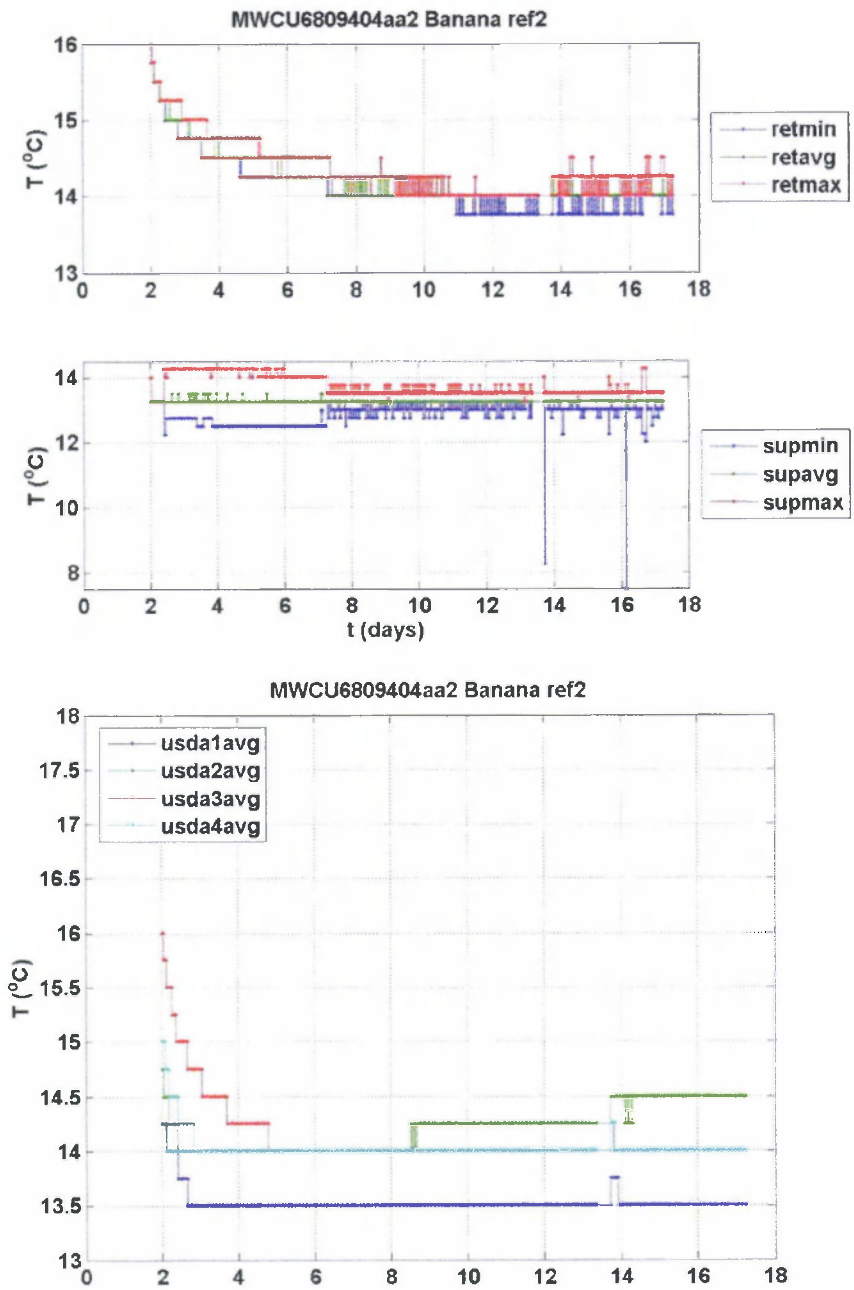
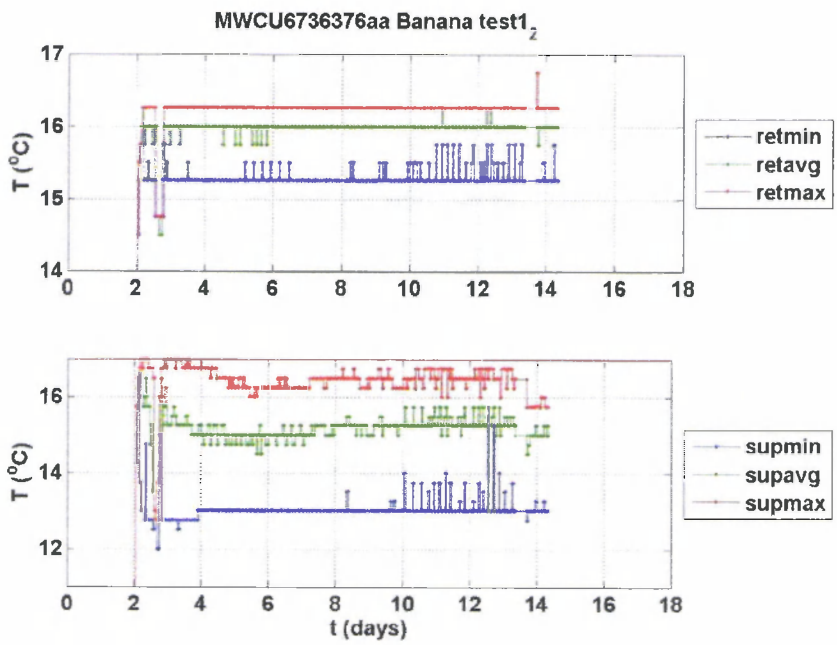
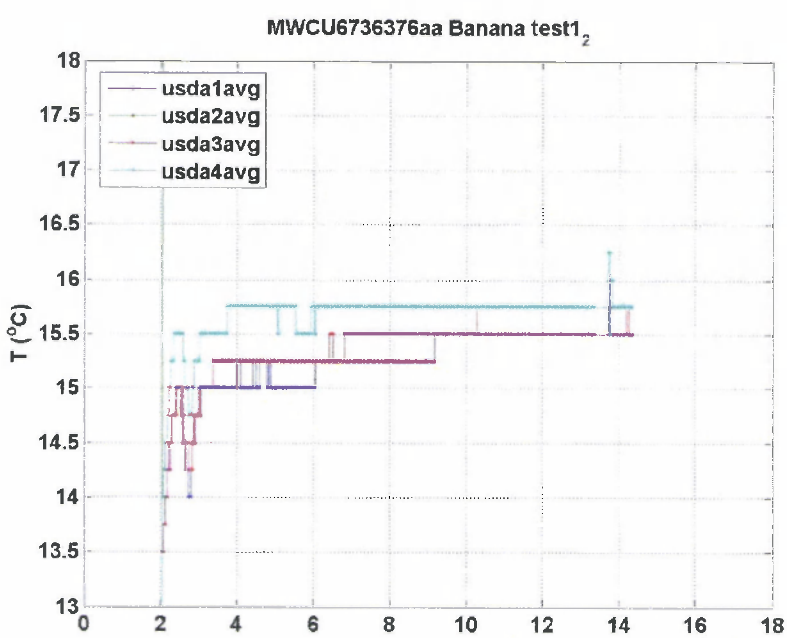


Figure 31 Temperature readings from the unit for the Banana ref 2 container.





Temperature readings from the unit for the Banana test12 container

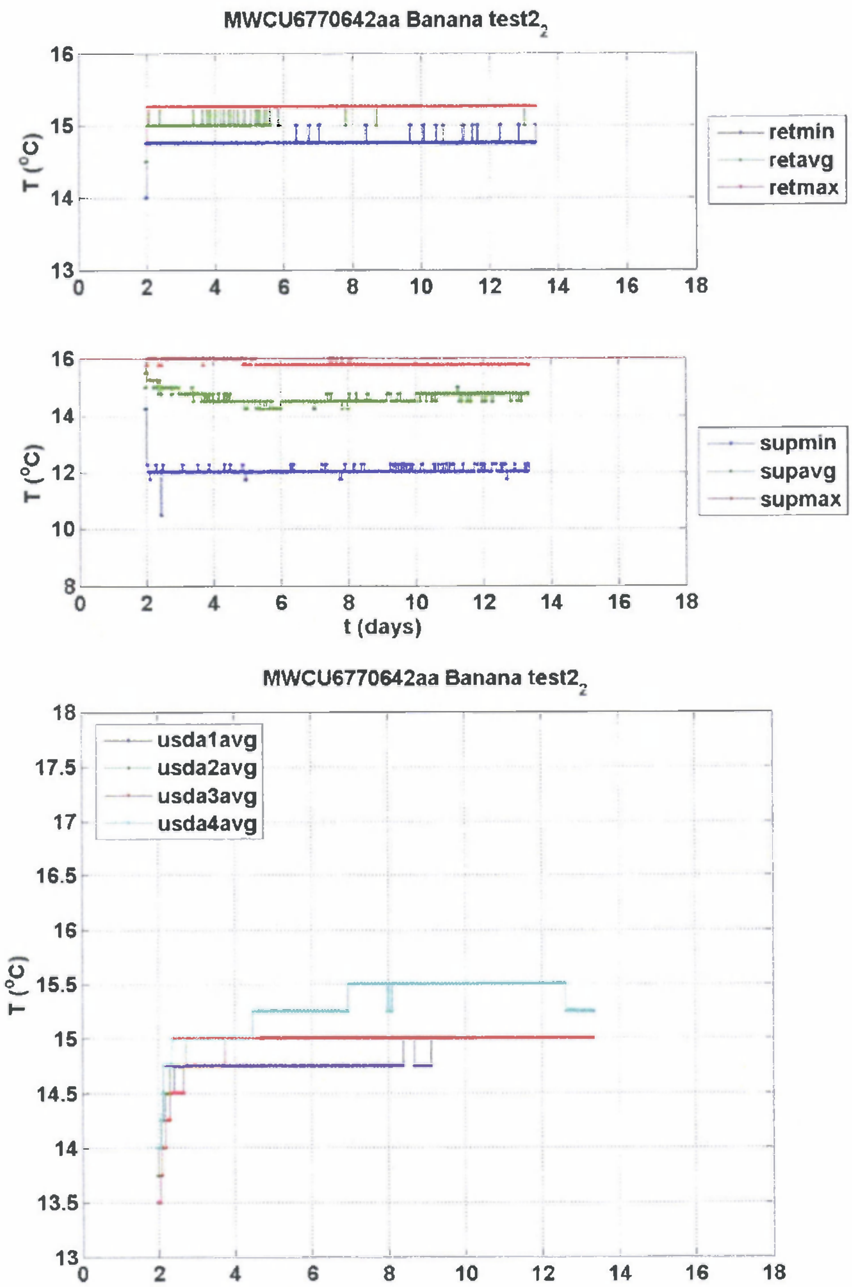


Figure 32 Temperature readings from the unit for the Banana test22 container.

Appendix V: Snapshot pictures of carton temperature readings

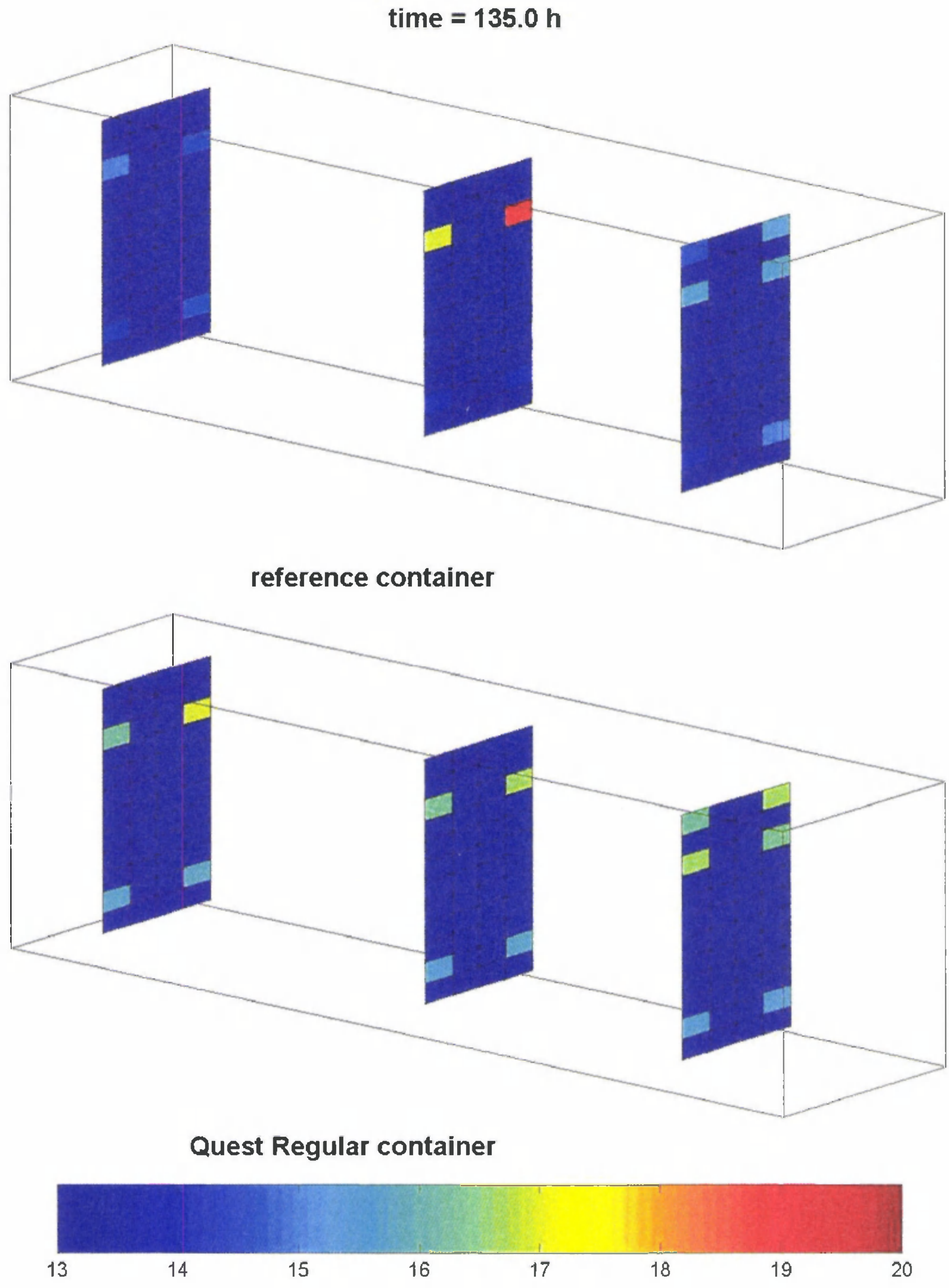


Figure 33 Tiny Tag readings of the carton temperatures near the start of the trip, on September 20th 00:00, Banana ref1 and test11

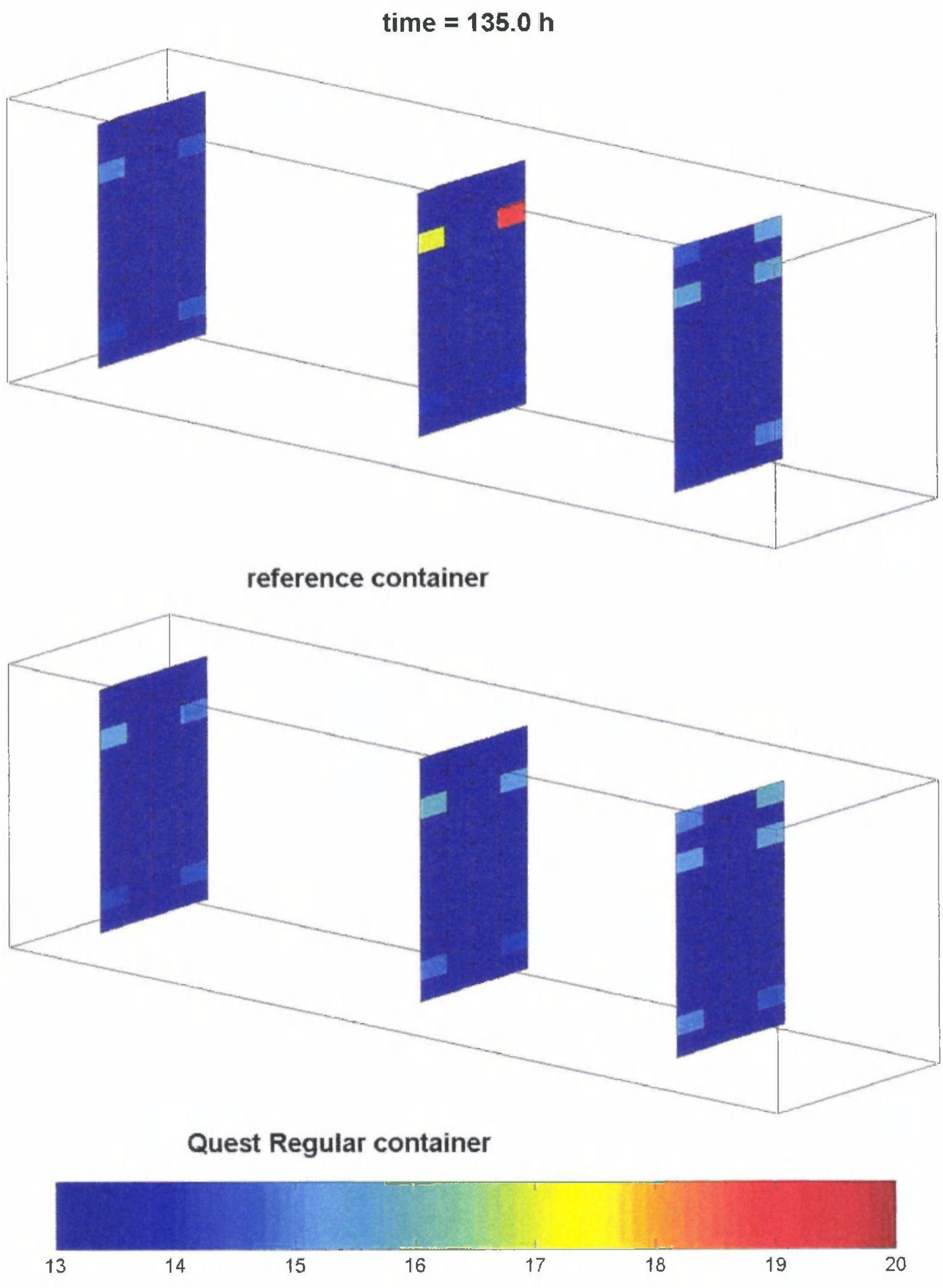


Figure 34 Tiny Tag readings of the carton temperatures near the start of the trip, on September 20th 00:00, Banana ref1 and test21

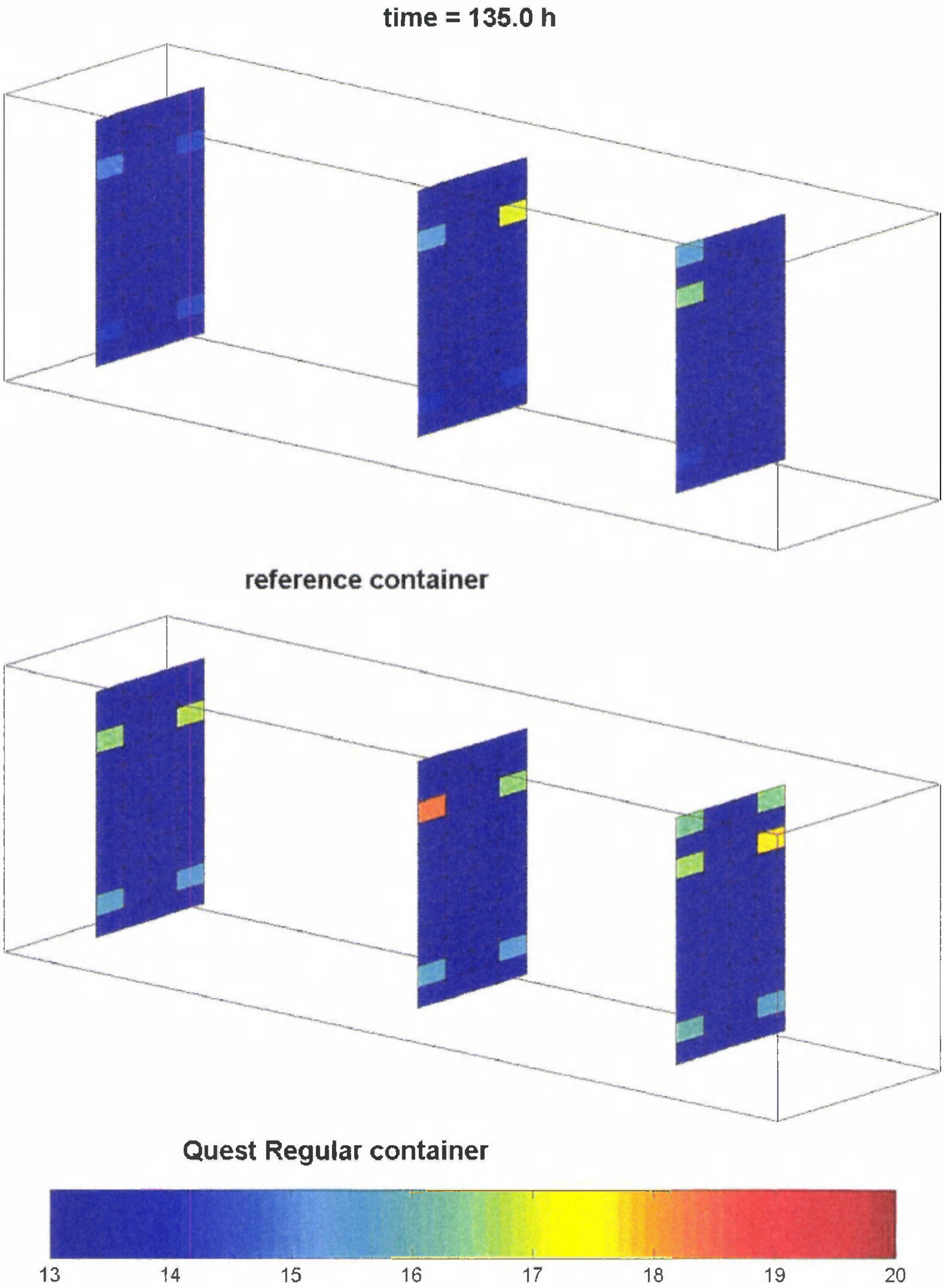


Figure 35 Tiny Tag readings of the carton temperatures near the start of the trip, on September 20th 00:00, Banana ref2 and test12

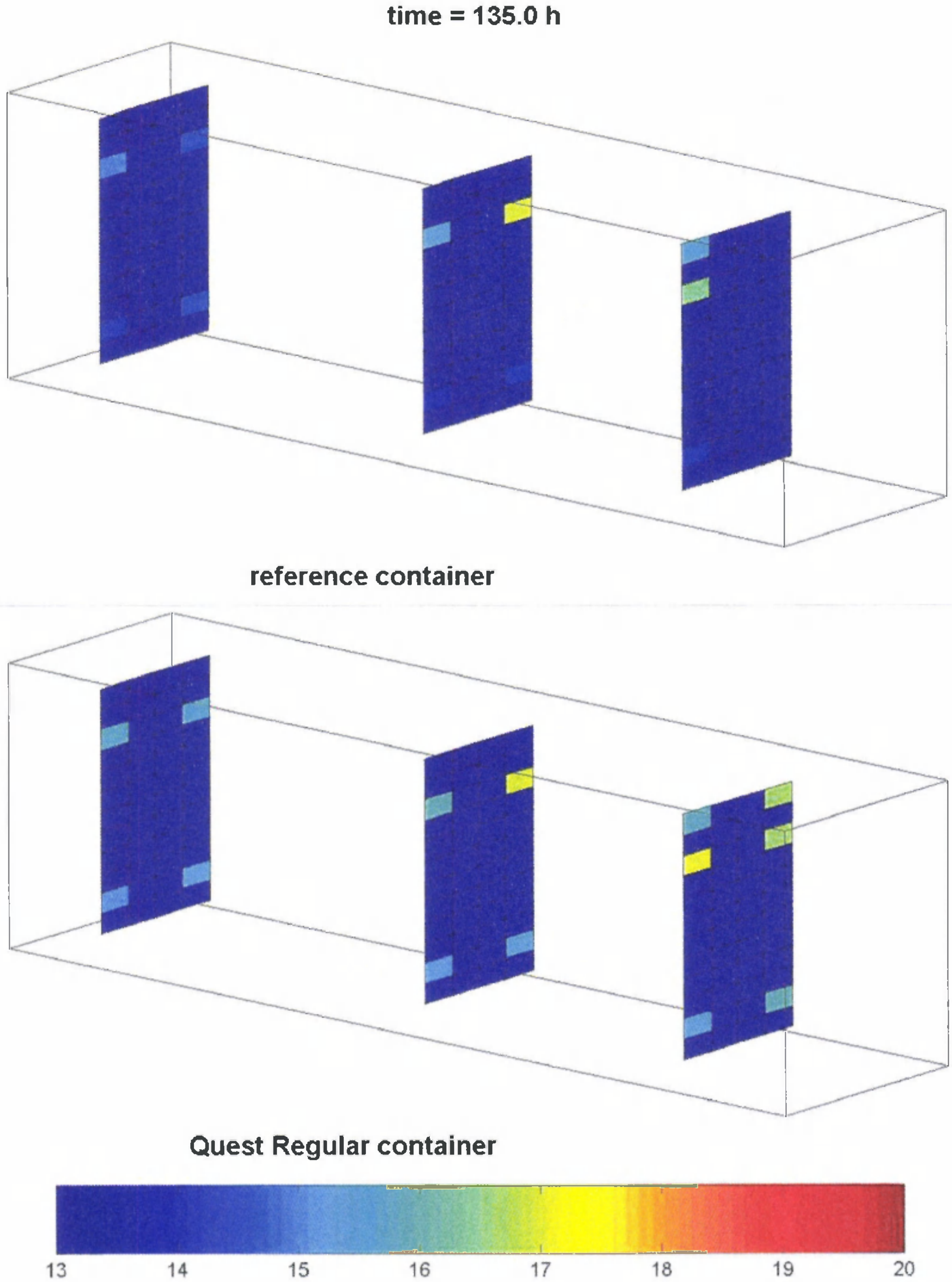


Figure 36 Tiny Tag readings of the carton temperatures near the start of the trip, on September 20th 00:00, Banana ref2 and test22

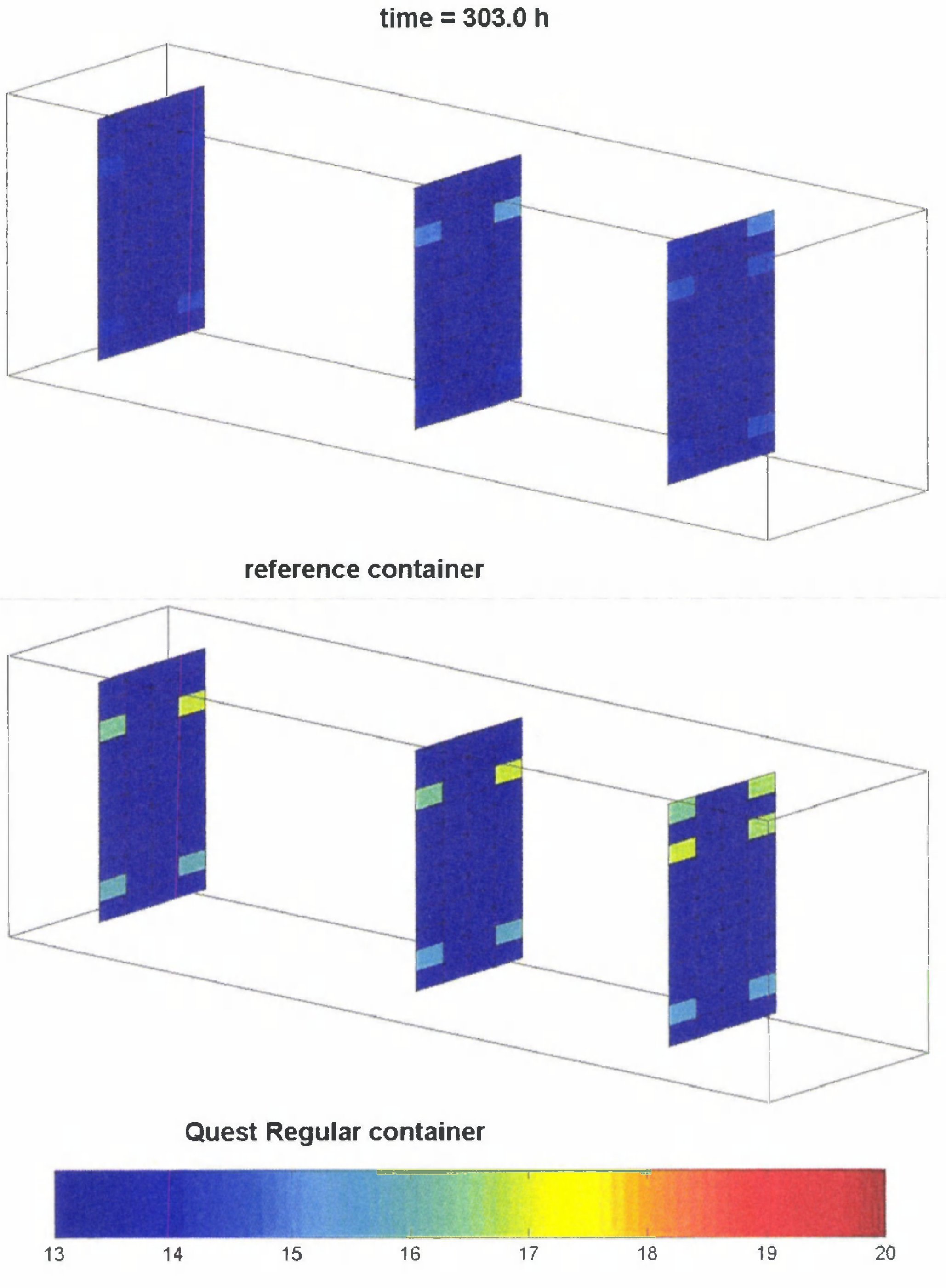


Figure 37 Tiny Tag readings of the carton temperatures near the end of the trip, on September 27th 00:00, Banana ref1 and test11

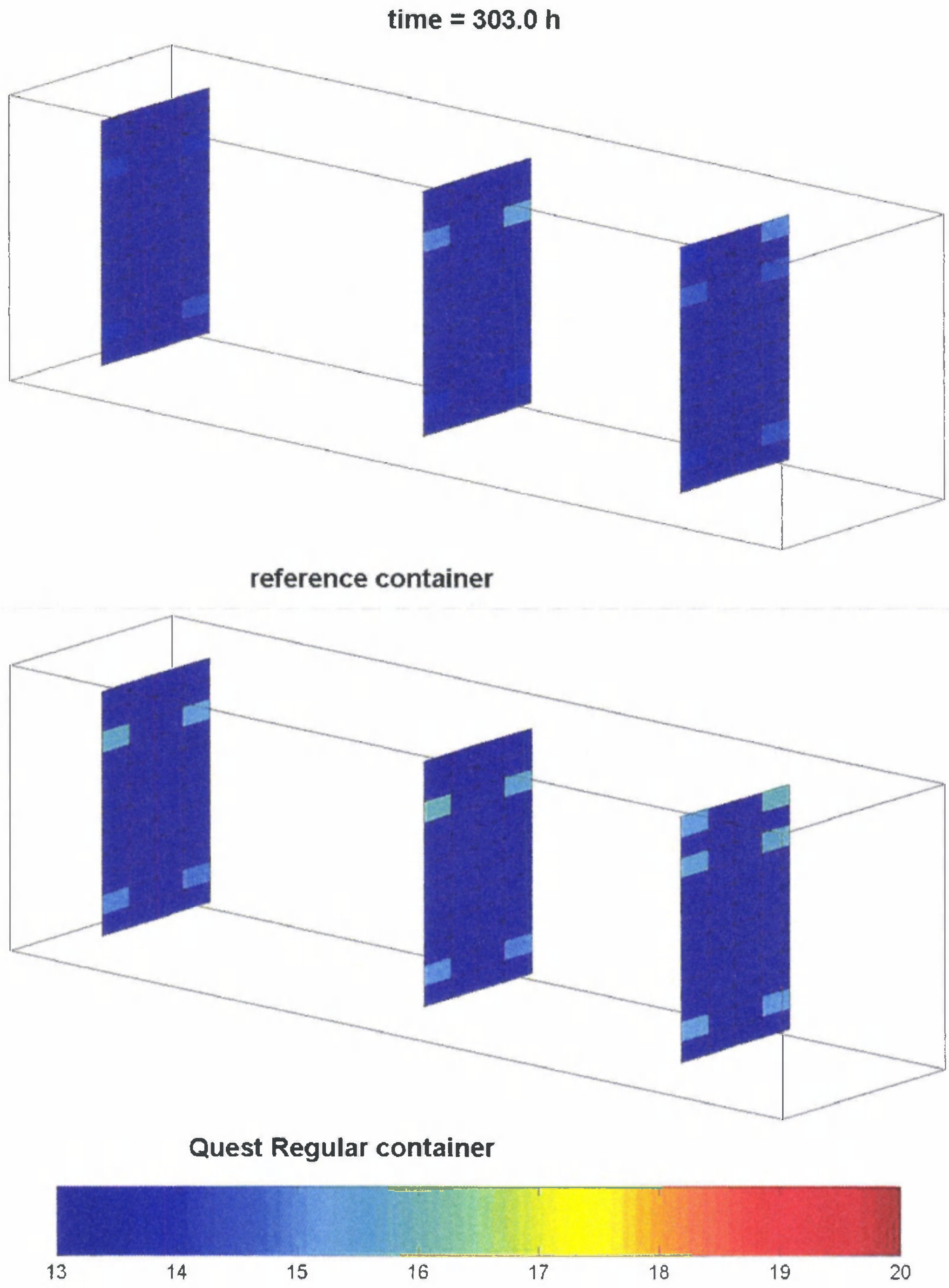


Figure 38 Tiny Tag readings of the carton temperatures near the end of the trip, on September 27th 00:00, Banana ref1 and test21

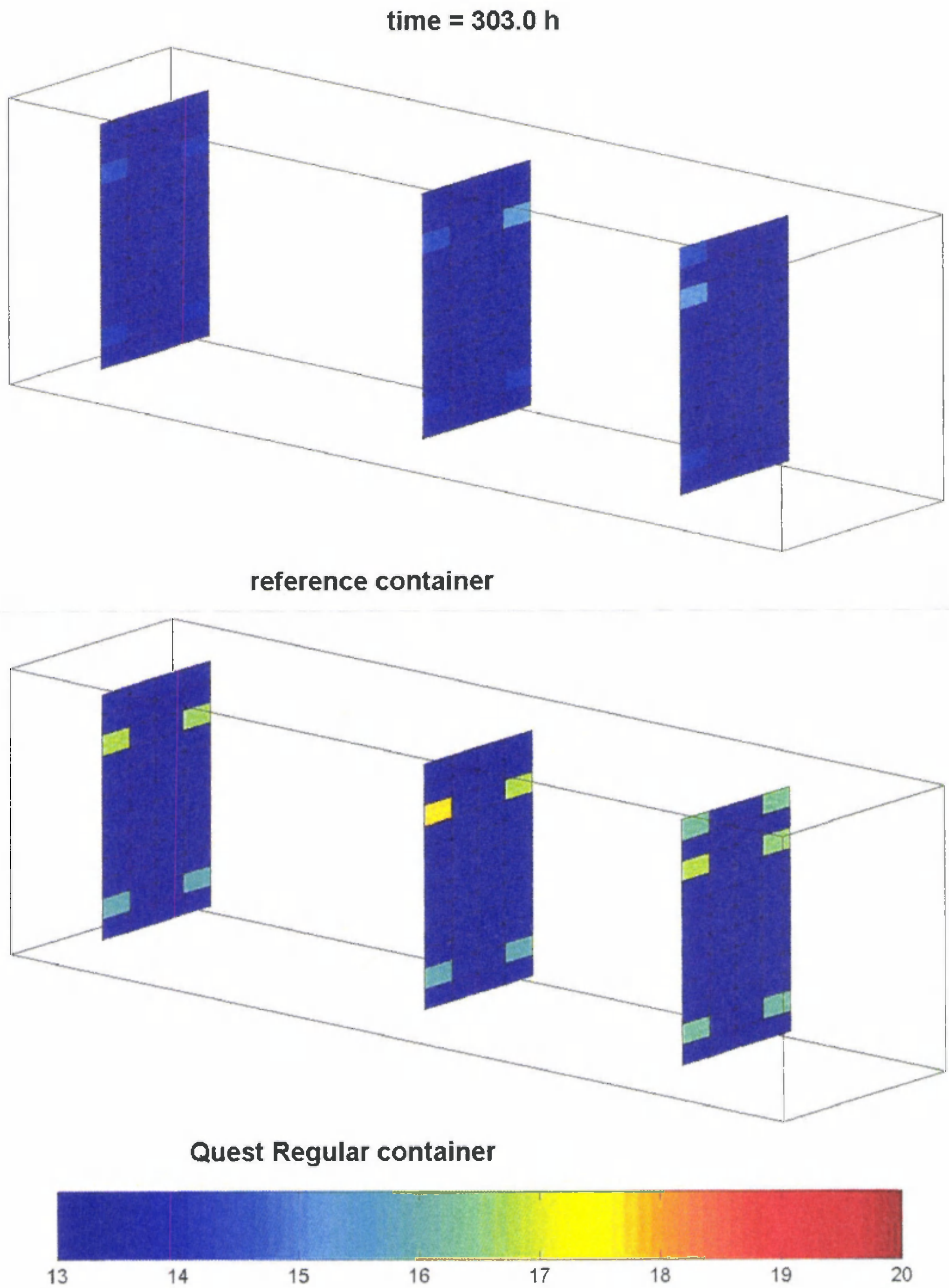


Figure 39 Tiny Tag readings of the carton temperatures near the end of the trip, on September 27th 00:00, Banana ref2 and test12

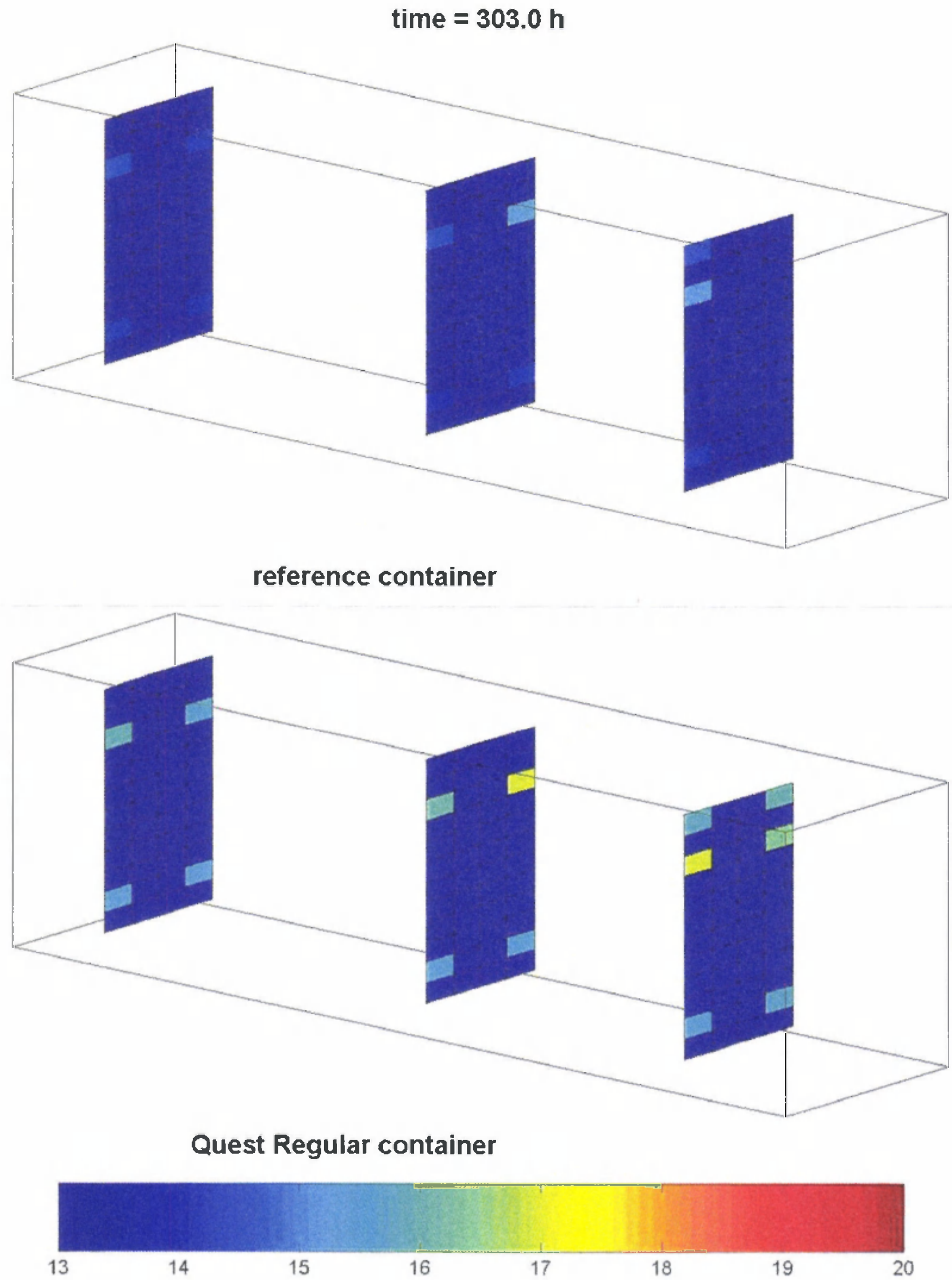


Figure 40 Tiny Tag readings of the carton temperatures near the end of the trip, on September 27th 00:00., Banana ref2 and test22

Appendix VI: Ambient temperatures

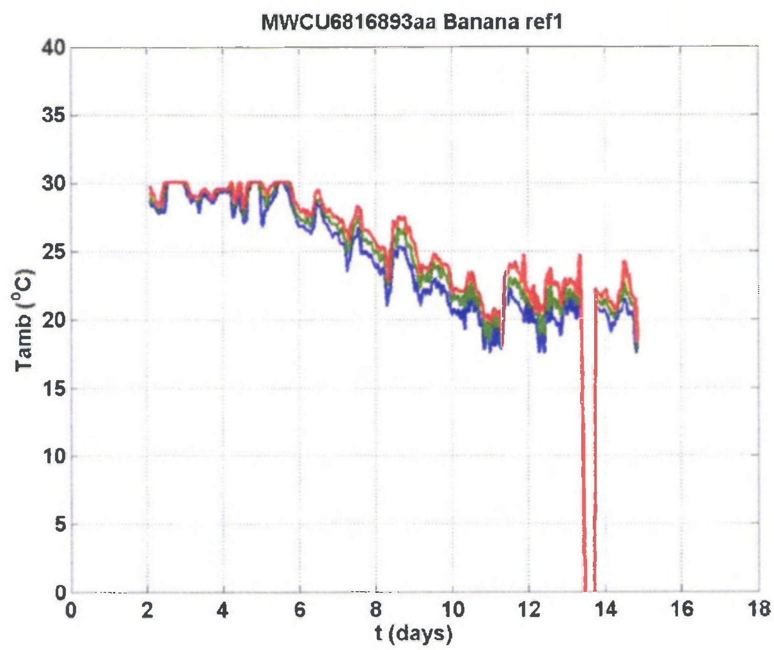


Figure 41 Ambient temperature readings from the unit, Banana ref 1

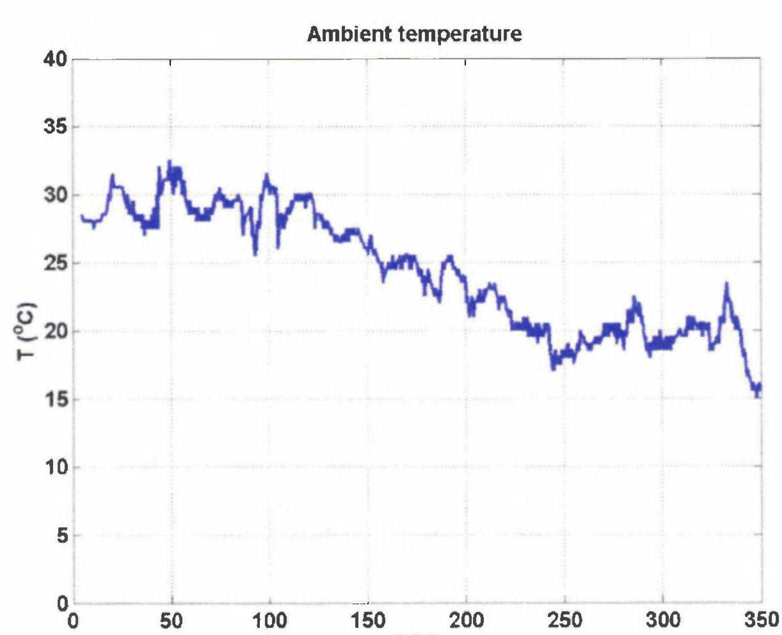


Figure 42 Ambient temperature readings form the Tiny Tag/Ibutton on the outside of the container, Banana test11

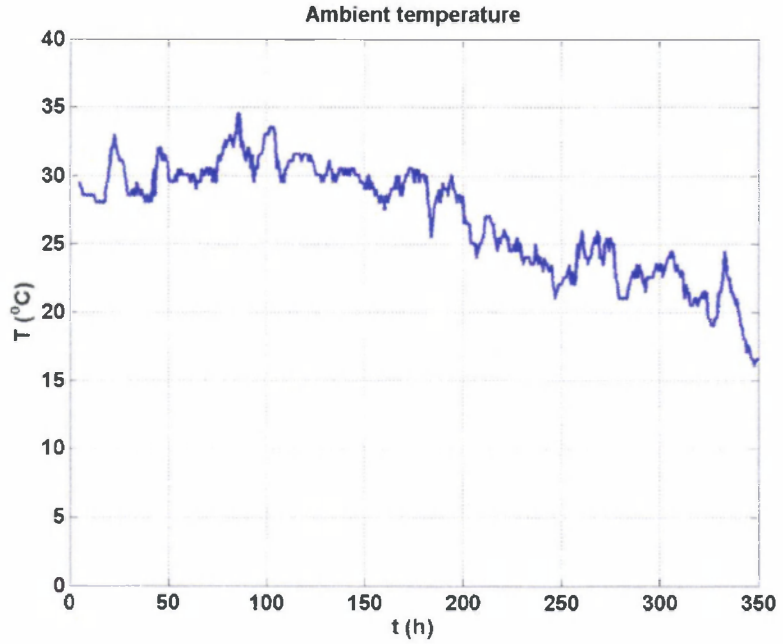


Figure 43 Ambient temperature readings form the Tiny Tag/Ibutton on the outside of the container, Banana test21

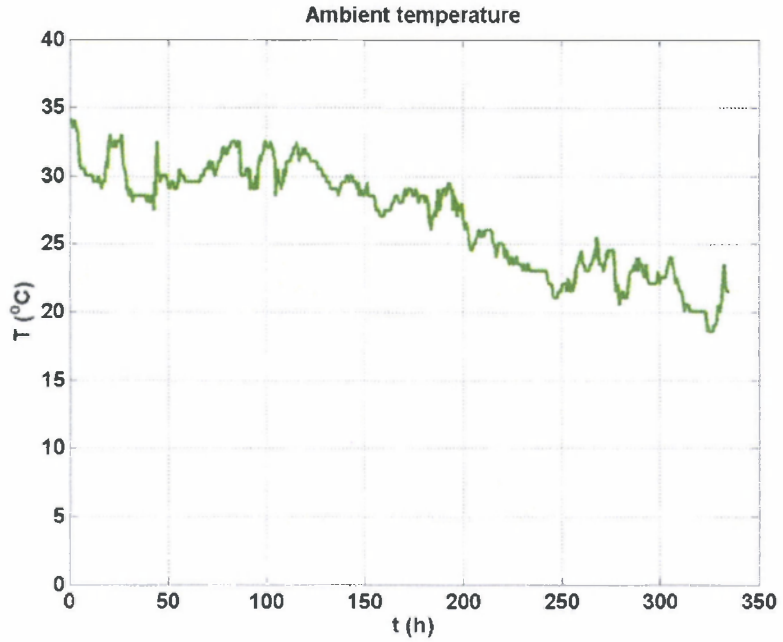


Figure 44 Ambient temperature readings form the Tiny Tag/Ibutton on the outside of the container, Banana ref2

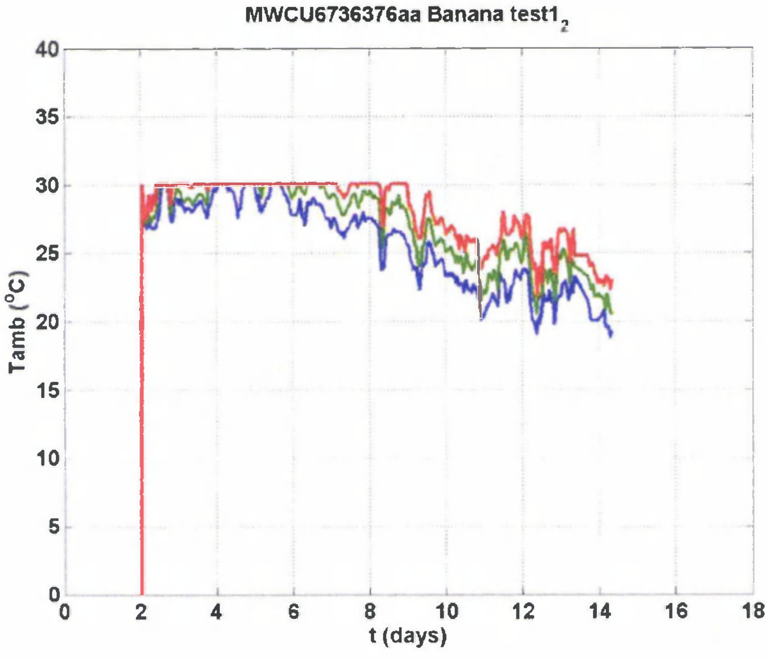


Figure 45 Ambient temperature readings from the unit, Banana test12

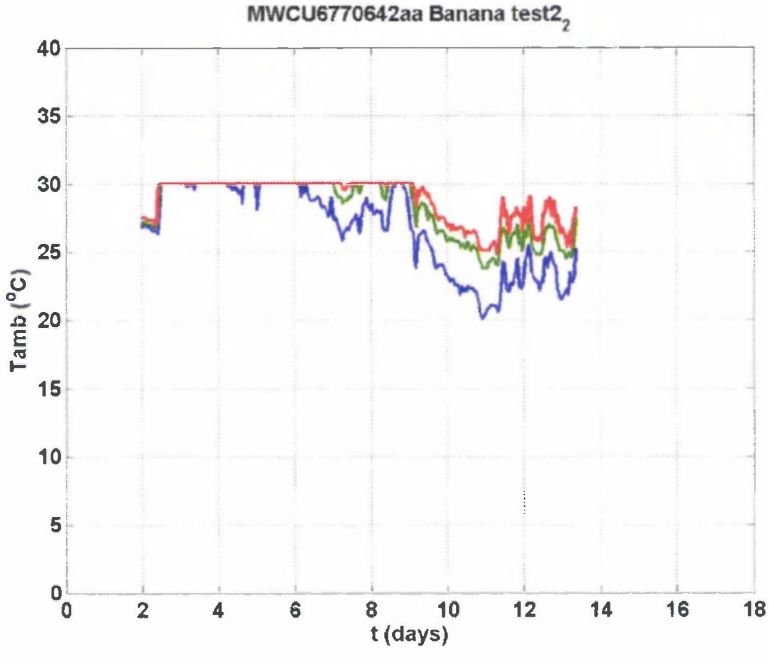
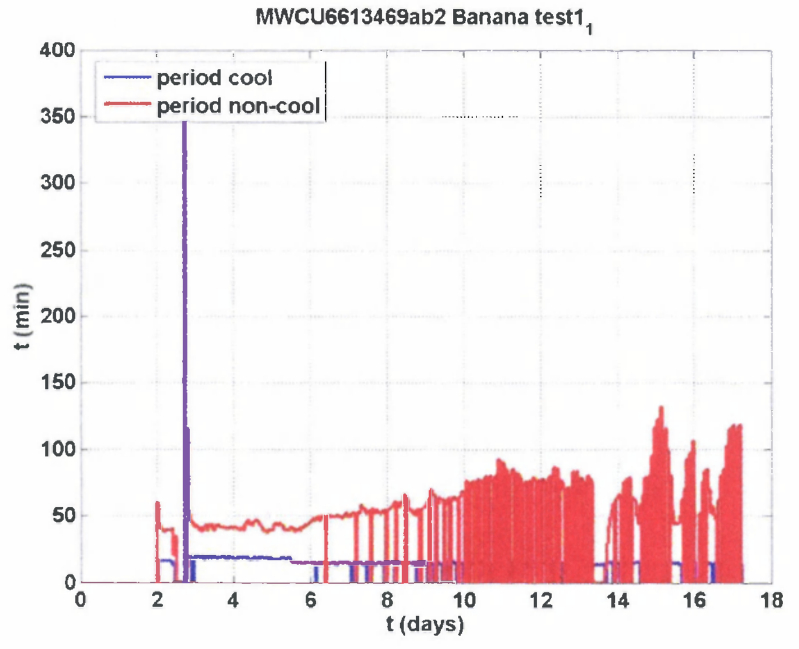


Figure 46 Ambient temperature readings from the unit, Banana test22

Appendix VII: Unit activity graphs



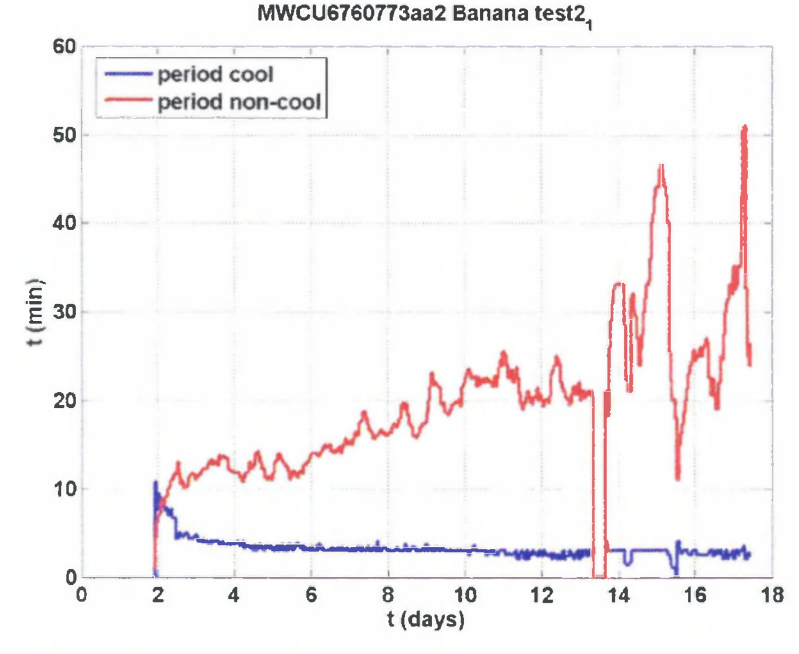


Figure 47 The number of minutes per cooling, non-cooling and defrost period as a function of time for the Quest Banana 1 test containers. At each time instant during the voyage when a period is finished a bar is drawn with the number of minutes that that period has lasted. If the period is smaller then an hour, the bars turn into a line.

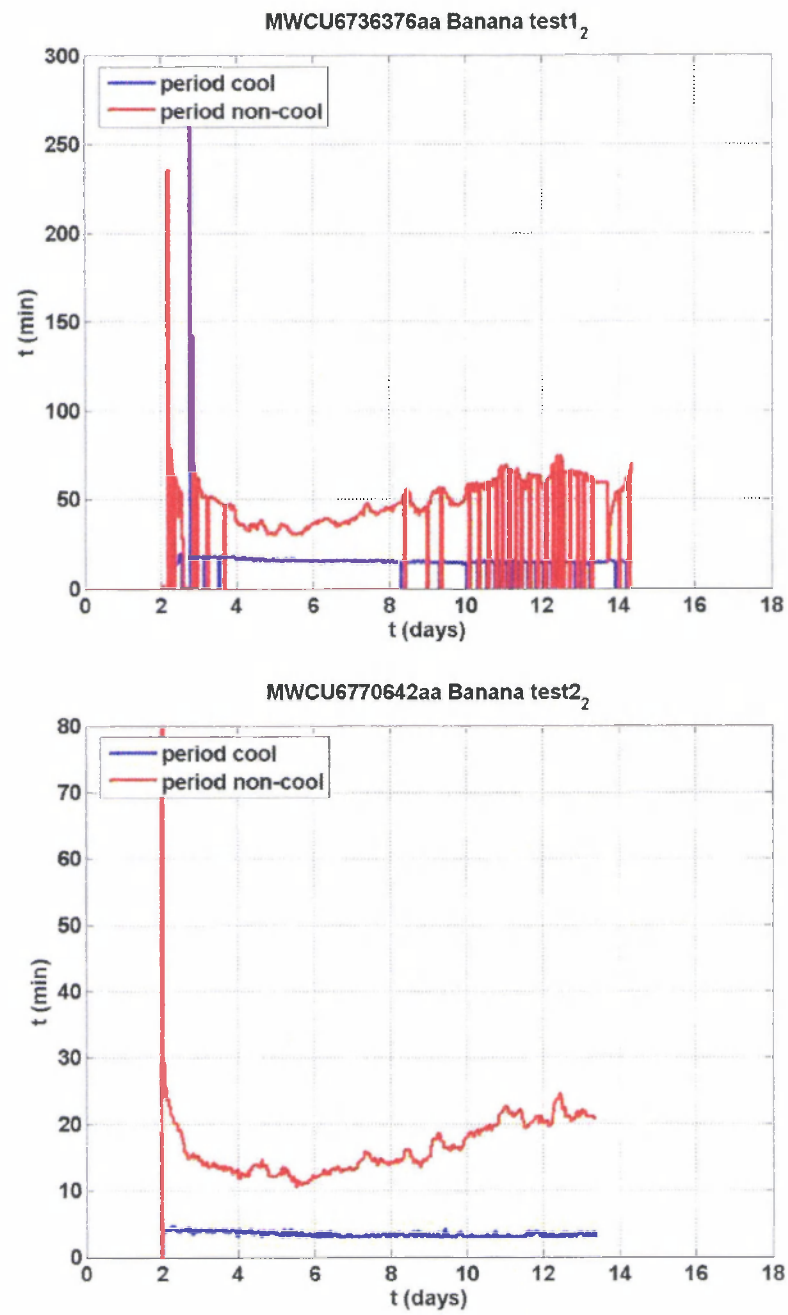


Figure 48 The number of minutes per cooling, non-cooling and defrost period as a function of time for the Quest Banana 2 test containers. At each time instant during the voyage when a period is finished a bar is drawn with the number of minutes that that period has lasted. If the period is smaller then an hour, the bars turn into a line.

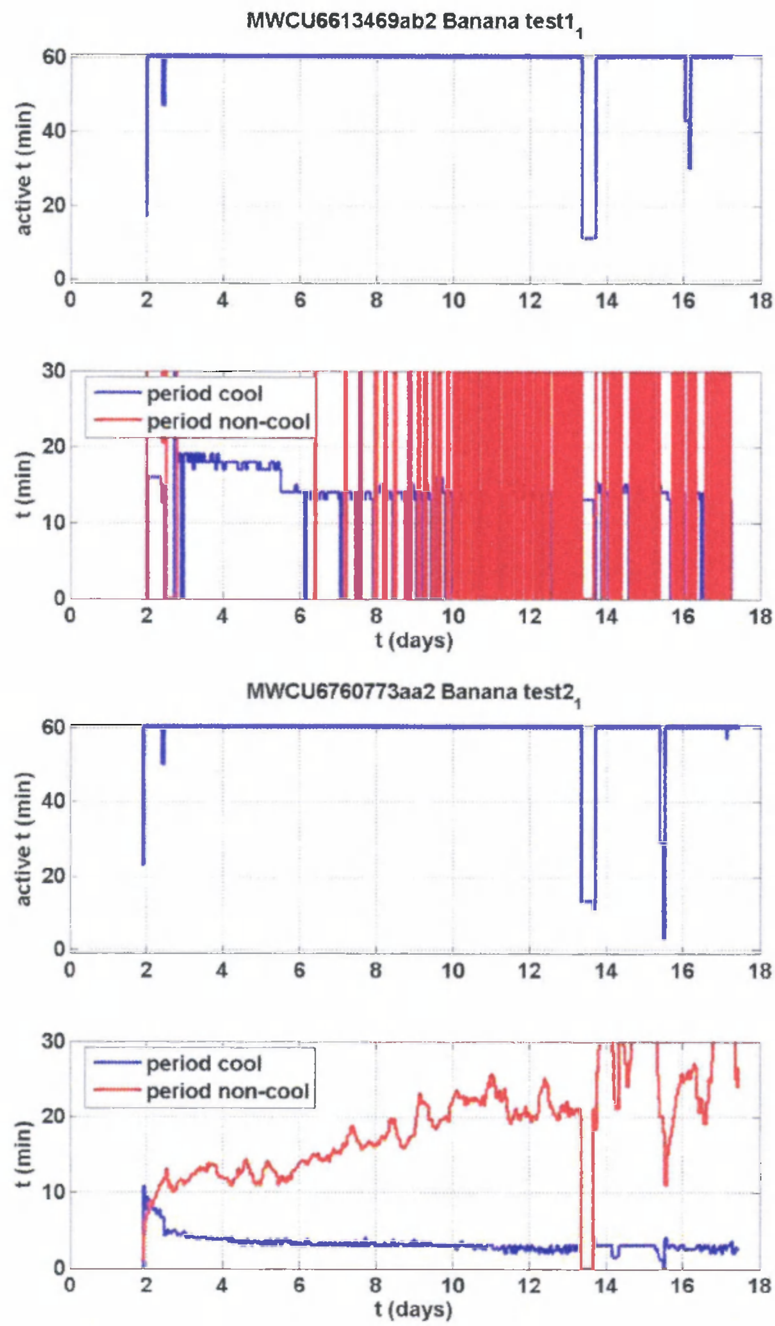


Figure 49 The number of minutes activity and zoom-in of the number of minutes per cooling /non-cooling as a function of time for the Banana 1 test containers. Every hour of the trip the number of minutes that was used for defrost was recorded. The number of minutes the unit was active was recorded as well, which is mostly 60 min/hour but sometimes less.

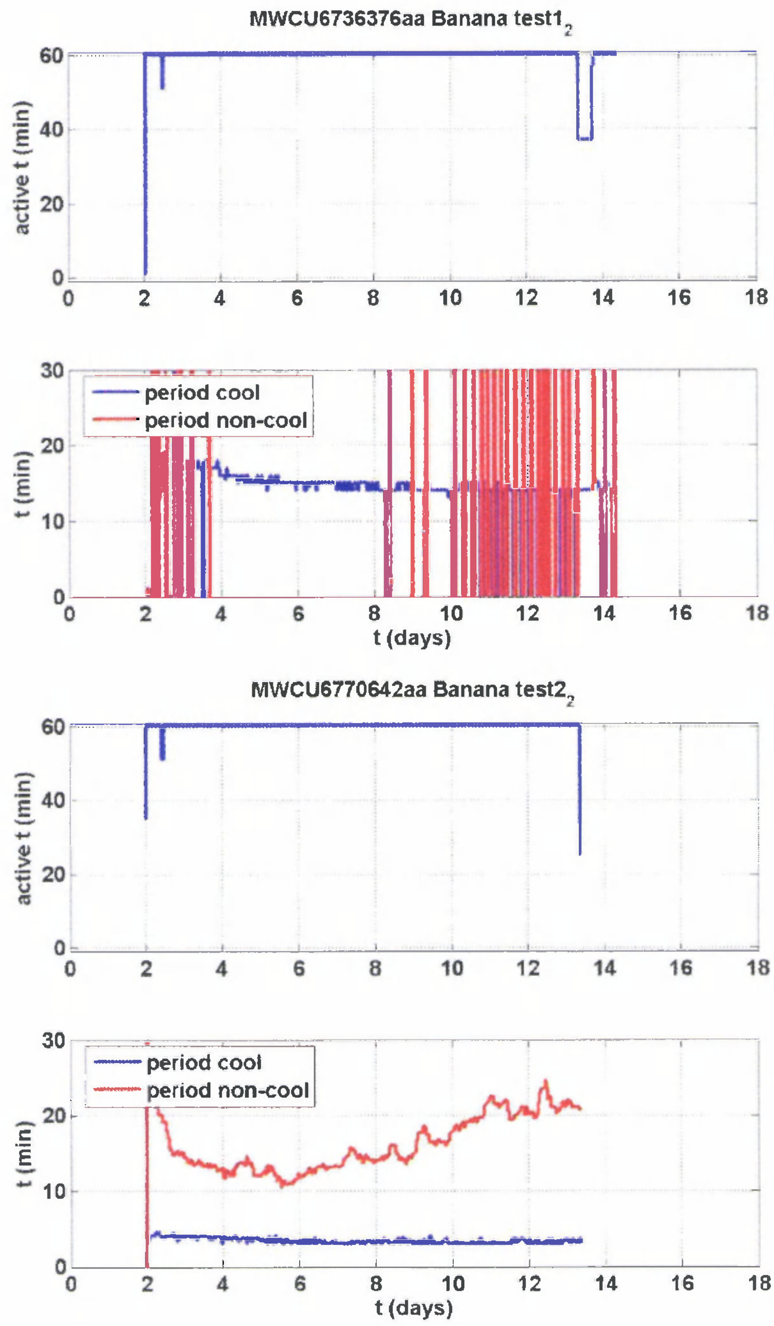


Figure 50 The number of minutes activity and zoom-in of the number of minutes cooling /non-cooling as a function of time for the Banana 2 test containers. Every hour of the trip the number of minutes that was used for defrost was recorded. The number of minutes the unit was active was recorded as well, which is mostly 60 min/hour but sometimes less.