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Quest Regular

Energy savings for reefer transport

Licensed Knowledge description

CONFIDENTIAL

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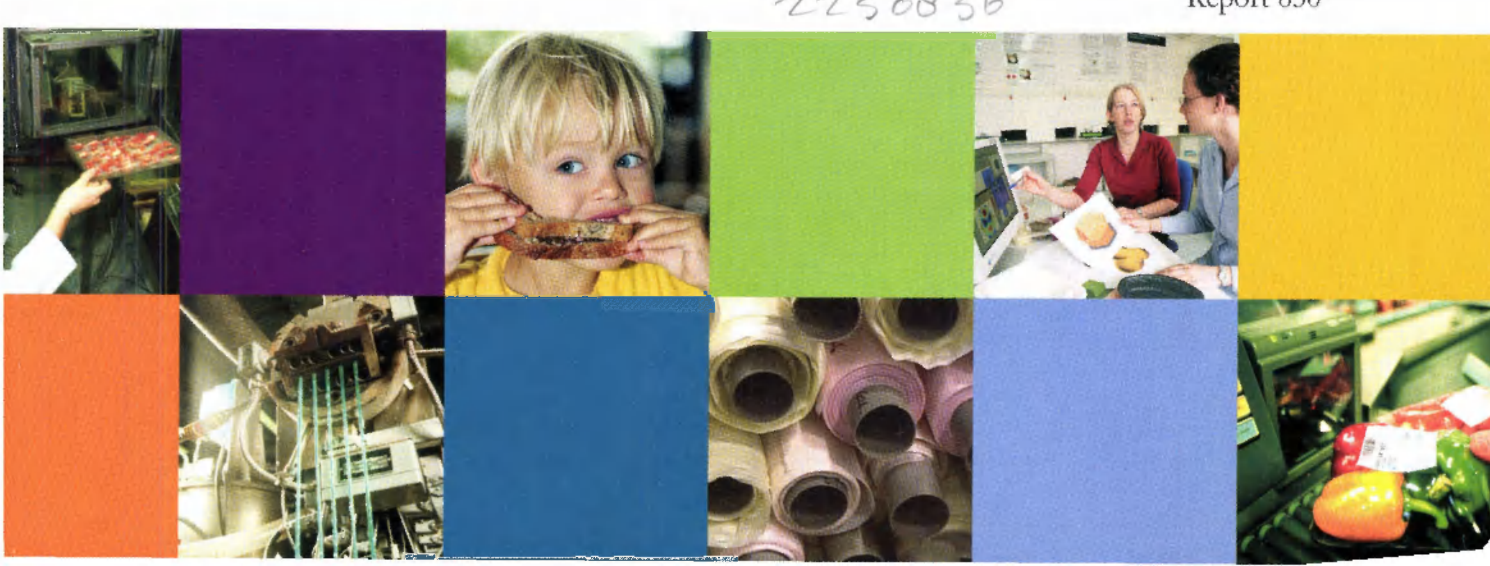
Report 850



Colophon

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Abstract

This report contains a description of the "Quest Regular for reefer containers" Knowledge of A&F, developed during the Quest project.

The Quest Regular principle is to save energy for reefer shipments of fruit and vegetables (perishable mode), without quality loss compared to normal shipments. This is achieved by switching the compressor on/off based on return air temperature limits; meanwhile the evaporator fans switch between high and low speed.

The Quest Regular principle, software functionality description, settings and guidelines have been developed by A&F on basis of product research and climate modeling. With the appropriate license, these can be used as a basis for embedded Quest Regular software, to be developed and implemented by reefer unit manufacturers.

Model simulations showed that energy savings of about 50% would be possible; ranging between 15 and 75% depending on ambient conditions, produce and setpoint.

In lab scale experiments for bell pepper, apple, kiwi, pear, pineapple, grape, banana and avocado the cycling control regime showed possible without reducing quality compared to standard supply air temperature control. For "MD2" Pineapple results were inconsistent. (This may be attributable to the low start quality of the fruit and the air transport prior to testing.)

A full-scale on-land pilot was performed (50 Hz) using a 40' reefer container filled with bell pepper. The power usage was reduced from 4.8 to 1.2 kW. The temperature variance of the air inside the cartons throughout the cargo increased from 1.4 to 1.6°C. After this on-land trial, a successful trial shipment was conducted, transporting mangoes from Brazil to Rotterdam.

Contents

1 Introduction

During the Quest project new climate control concepts for perishable products have been developed, aiming at reduction of energy use and optimisation of product quality. This report contains a description of the "Quest Regular for reefer containers" Knowledge of A&F, developed during this project.

1.1 Quest Regular developments of A&F

Quest Regular significantly reduces energy consumption for climate conditioning in transport and storage. "Quest Regular for reefer containers" has been developed to reduce energy consumption when transporting perishable products in reefer containers. The Quest Regular principle, software functionality description, settings and guidelines have been developed by A&F on basis of product research and climate modeling. With the appropriate license, these can be used as a basis for embedded Quest Regular software, to be developed and implemented by reefer unit manufacturers.

1.2 The Quest Regular principle

The Quest Regular principle is to save energy for reefer shipments of fruit and vegetables, without quality loss compared to normal shipments. This is achieved by switching the compressor on/off based on return air temperature limits; meanwhile the evaporator fans switch between high and low speed.

1.3 The Quest project

The basic principle was developed by A&F in a previous project called CEET (1998-2002). It was further developed during Quest (2002-2005). This EET[1] funded research project was a cooperation between: A&F (part of Wageningen UR), P&O Nedlloyd (acquired by Maersk), Carrier Transicold, Frugi Venta, Haluco, R&R Mechatronics and the Greenery.

1.4 License Agreement

With this Quest Regular Report A&F fulfils the provision to transfer the Knowledge as stated in clause 3.1 of the License Agreement (OPD 07/204a d.d. September 14th 2007).

[1] *The Quest and CEET projects were supported with a grant of the Dutch Programme EET (Economy, Ecology, Technology) a joint initiative of the Ministries of Economic Affairs, Education, Culture and Sciences and of Housing, Spatial Planning and the Environment. The programme is run by the EET Programme Office, a partnership of Senter and Novem.*

2 Research overview

In this chapter an overview of the Quest Regular reefer research during the EET Quest project is given.

2.1 Input from land storage experience and climate modelling

In on-land storage facilities, cycling temperature conditions are used for long term storage of e.g. apple and pear. A&F's positive experience with the quality achieved there, has given confidence for the applicability of the Quest Regular control strategy to reefer container transport. During Quest, a comparison between the Quest Regular controller design and the on-land facilities has been made and used to improve the Quest Regular control strategy.

Also, climate models have been used to determine the controller settings. Using model simulations, the Quest Regular settings and limits were determined for shipments with various commodities. The resulting temperature fluctuations were used as a basis for the lab scale product quality testing.

Furthermore, model simulations were done to assess the effect of Quest Regular, ventilation rates and circulation rates on the container climate and energy usage. These showed that energy savings of about 50% would be possible; ranging between 15 and 75% depending on ambient conditions, produce and setpoint.

2.2 Selection of products

For the Quest Regular product research, a number of high volume or high value products were selected for lab scale product research. These are representative for groups of products with certain temperature ranges and ventilation rates, so that they give a good overview of the applicability of Quest Regular. The selected products cover a wide range of products currently shipped with reefer containers. It is expected that other products in the category can be stored under similar temperature conditions.

2.3 Product research

For apple, avocado, banana, grape, kiwi, pear and pineapple, lab scale experiments have been performed. These experiments were conducted to investigate if the cycling control regime is possible without higher quality losses or higher quality variations compared to standard storage conditions. Focus was on chilling injury tests of produce stored at conditions similar to the coolest location in the container. For banana, pineapple and avocado it was also tested if quality enhancement is possible. Bell pepper and mango were tested on full container scale. The results are discussed in Chapter 6.

2.4 Full scale testing

With bell pepper a 2 pallet and a full scale on-land test have been performed. These tests showed significant energy reduction. In the first test the Quest Regular controller was tested in a partially loaded container. To simulate the effect of a full load, artificial air humidification and heat production was used as well as air flow resisting plates to cover the remaining floor area. Subsequently, a full-scale on-land pilot was performed (50 Hz), reducing the mean power consumption from 4.8 kW during continuous supply air temperature control to 1.2 kW during Quest Regular control; while the temperature variance of the air inside the cartons increased from 1.4 to 1.6°C.

In December 2005 a real-life shipment of mangoes from Brazil to the Netherlands was organized by Maersk Line, supported by Carrier and A&F. Power usage, temperature distribution and product quality of the Quest test container were compared to a reference container, which was shipped simultaneously at original settings. As the expected power savings were achieved, while the mango quality was fine, the trial shipment was very successful.

3 The Quest Regular principle

3.1 Same average temperature, allowing a bandwidth

The Quest Regular climate control strategy aims to maintain the same average temperature as in a normal shipment, but with an allowed band width, which enables energy savings. The supply air temperature has a low value during specific interval times. This value is lower than the value that is commonly considered a chilling temperature. 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.

3.2 Energy saving factors

The reduction in energy consumption is based on avoiding to run the cooling unit at inefficient part load conditions[2] as much as possible and using half speed fans during the compressor off periods. Also, less defrost effort will be necessary, which saves defrost energy and reduces defrost heat load to the produce.

3.3 Cycling compressor, fans and fresh air intake

The Quest Regular controller turns the compressor on and off, based on temperature measurements of the return air. By default, fan speed is cycled together with compressor, using half speed during compressor off periods and full speed during compressor on periods. If the necessary hardware is available, we recommend adding fresh air intake cycling: closing fresh air intake during compressor-off periods and opening it proportionally[3] during cooling periods.

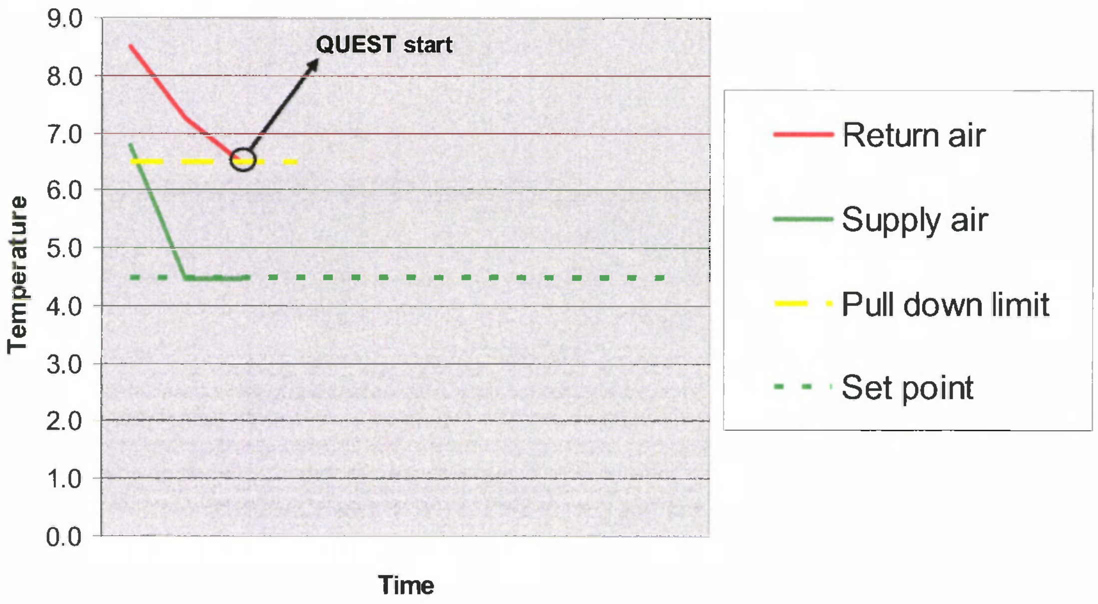
[2] *The savings achieved when using Quest Regular therefore depend on the efficiency of the cool-unit at part load compared to full load (i.e. full capacity) conditions; as well as the capability of the Quest Regular embedded software to work at full capacity during cooling..*

[3] *The average amount of ventilation should still be as specified. Therefore, when the fresh air intake is closed part of the time, a larger amount of fresh air intake is needed during the time it is opened.*

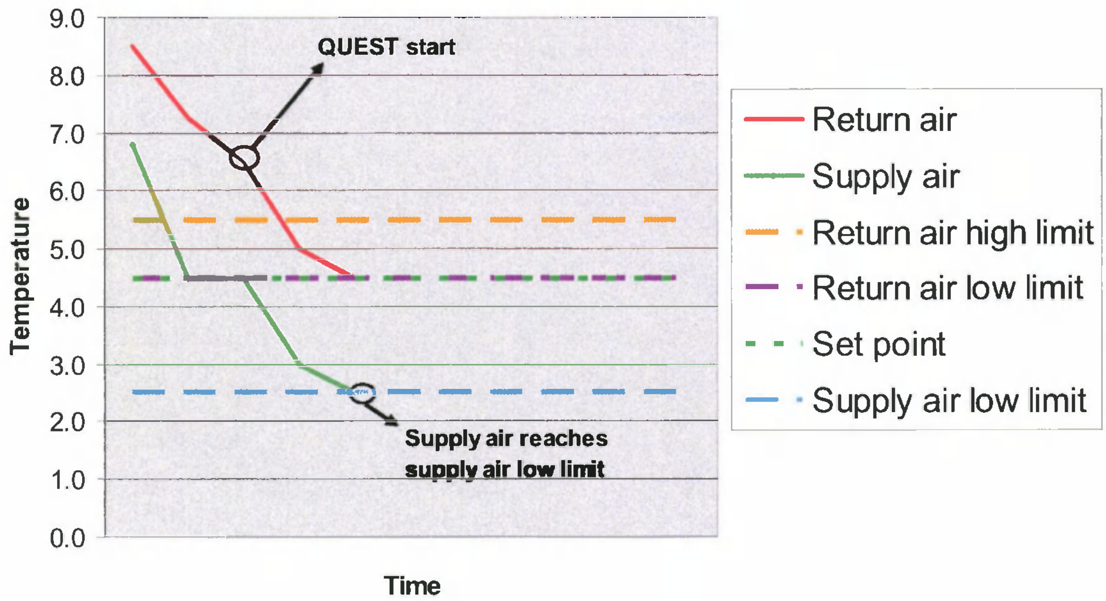
4 The Quest Regular regulation method

The following graphs show a step by step explanation of the Quest Regular regulation method. The temperatures and settings shown are an example; the specific values depend on the (Bill of Lading) setpoint, see 5.

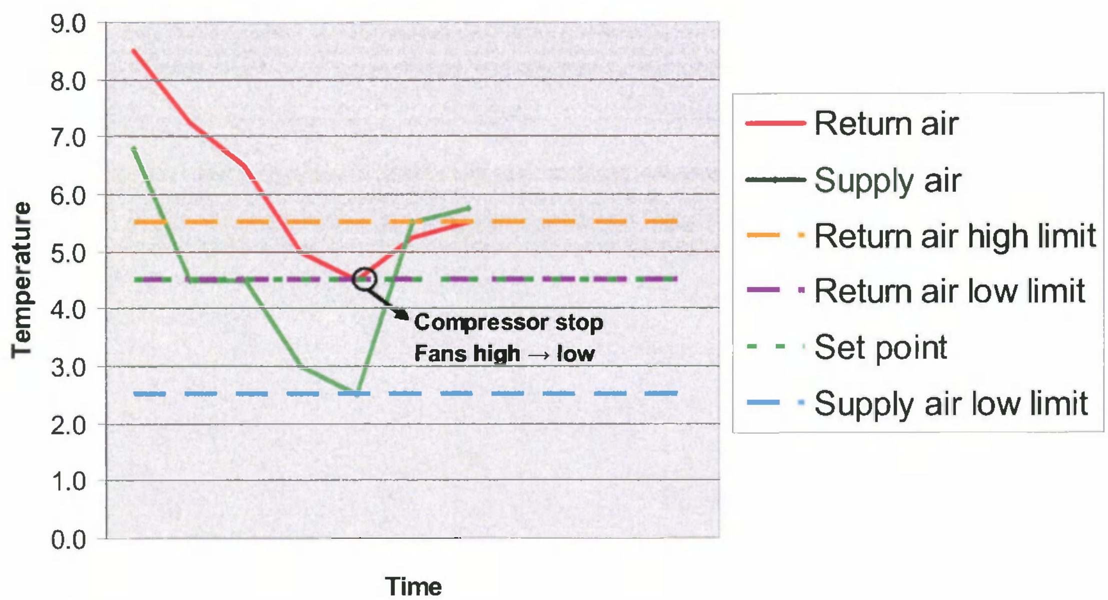
The first graph shows the starting point of Quest. The reefer unit first executes a normal pull down, with the supply air temperature dropping down to the (Bill of Lading) "Setpoint" (Tsp) until the return air has reached the "Pull down low limit" (Tpd2start).



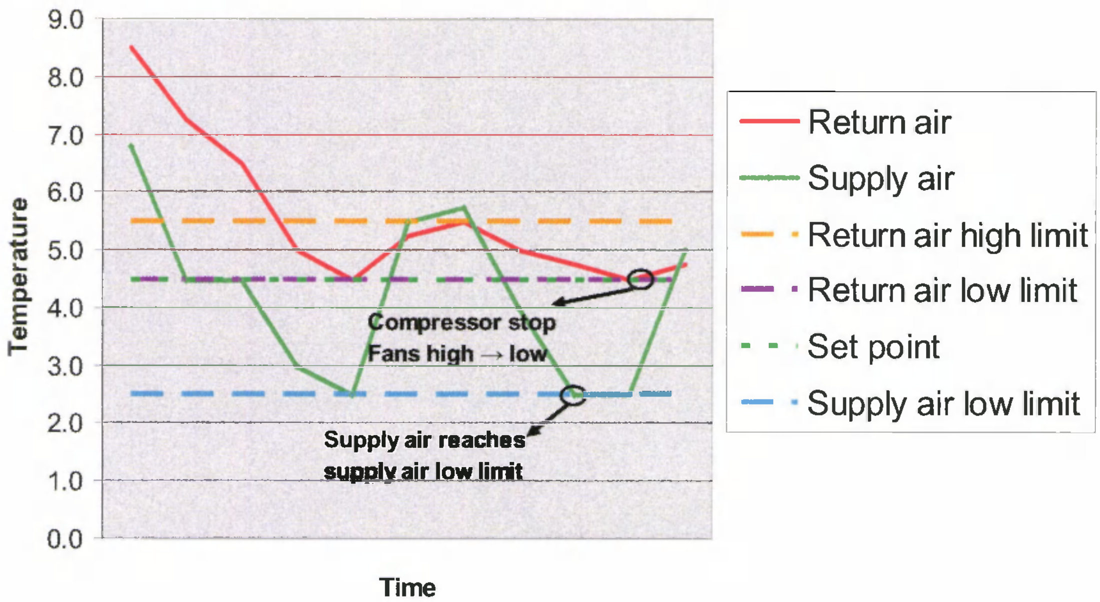
When the return air has reached this "Pull down limit", Quest Regular starts. The setpoint for the supply air is set to the "supply air low limit" (Tsupsp). (Fans are set to high speed and fresh air intake is open.) Supply air temperature will then drop below setpoint, allowing the compressor to run at high or even full capacity. The return air will start to drop down faster.



When the supply air reaches its low limit, it is kept at this temperature until the return air reaches the "Return air low limit" (Tllim). At that moment, the compressor is turned off and fans are set to low speed. (If possible, the fresh air intake is closed simultaneously.) Supply and return air will then (naturally) drift up as shown in the graph below.

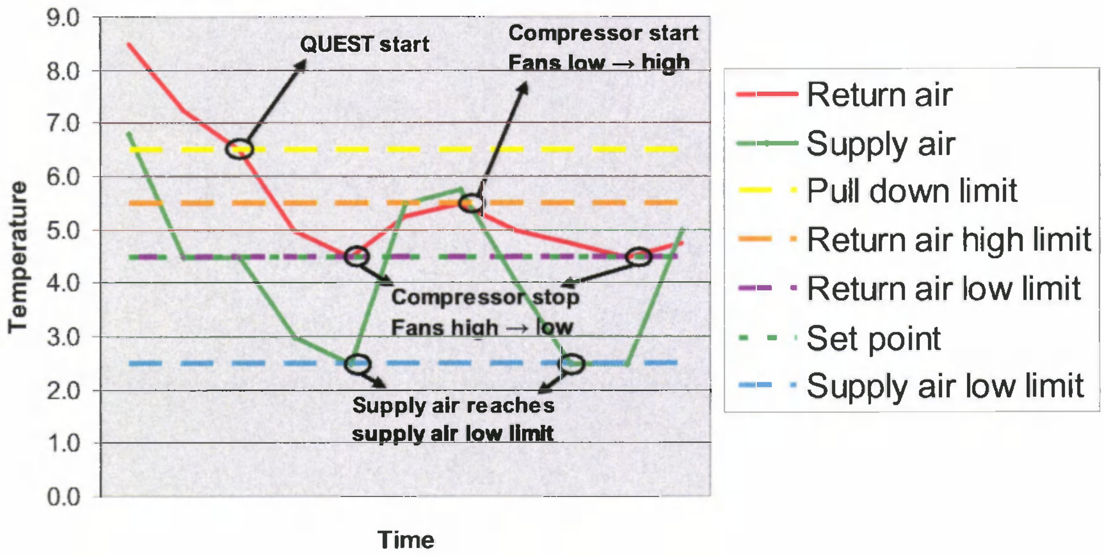


When the return air reaches the "Return air high limit" (Thlim), the compressor is turned on again (fans are set to high speed and fresh air intake is put open). The next cycle starts: the supply air is brought to its low limit (Tsupsp) and the return air temperature will drop down again. When the return air reaches the "Return air low limit" (Tllim), the compressor is stopped and fans are turned from high to low speed, and so forth.


9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Temperature
Time
Compressor stop
Fans high → low
Supply air reaches
supply air low limit
Return air
Supply air
Return air high limit
Return air low limit
Set point
Supply air low limit

5 The Quest Regular settings table

A summary of the Quest regulation method is shown in the graph below. The temperatures and settings shown are an example; the specific values depend on the (Bill of Lading) setpoint.



The settings for the various limits are given in the following table. All temperatures are given in °C.

Tsp >=	-1	1	12	15
Tsp <	**1**	**12**	**15**	**30.1**
Tsupsp	-2	Tsp - 2	Tsp - 1.5	Tsp - 4
Tllim	Tsp + 0.5	Tsp	Tsp+1	Tsp
Thlim	Tsp + 1	Tsp + 1	Tsp + 1.5	Tsp + 1
Tpd2start	Tsp + 2	Tsp + 2	Tsp + 2.5	Tsp + 2
FAN MODE	ALT	ALT	ALT	ALT

Table 1 Settings table

NB 1: When a cooling period lasts longer than 6 hours, a safety precaution should be taken: return to normal mode for 24 hours, then start Quest and try again.

NB 2: The correctness of settings for Tsp>= 15 has not been tested.

NB 3: The settings for the "banana range" (12 – 15°C) were chosen on the safe (i.e. warm) side because bananas are more susceptible to chilling than other produce. Using these values will give a 0.5 °C higher temperature of the cartons than in "normal mode" transport. This may lead to slightly increased ripening speed. We expect that temperatures will be better comparable when limits are set 0.5°C lower. Also, probably no chilling will arise, but we have not (yet) been able to perform a trial shipment to validate that chilling does not arise at these alternative settings: Tsupsp = Tsp-2, Tllim = Tsp+0.5, Thlim = Tsp+1, Tpd2start = Tsp+2.

NB 4: Fan mode = ALT means cycling between high and low speed fans, high during the compressor-on periods and low during the compressor-off periods.

6 Quest Regular product research

Various products were tested for quality effects of Quest Regular compared to normal storage. For apple, grape, kiwi and pear lab scale experiments have been performed to investigate if the cycling control regime is possible without higher quality losses or higher quality variations compared to standard storage conditions. For banana, avocado and pineapple, it was also investigated if longer storage time and/or longer shelf life could be achieved by applying a cycling temperature regime. Bell pepper and mango were tested on full (40' container) scale.

6.1 Goal of the experiments, research strategy

The aims of the product research part in this project were:

- Comparison of the effect of the standard transport temperature on the quality of the commodity with a fluctuating temperature, resulting in a mean temperature which is *similar to* the standard temperature. The profile of the fluctuating temperature is a simulation of an on/off cooling regime leading to energy saving. These types of profiles were applied in all commodities involved in this project.
- Comparison of the effect of the standard transport temperature on the quality of the commodity with a fluctuating temperature, resulting in a mean temperature which is *below* the standard temperature. The profile of the fluctuating temperature is a simulation of an on/off cooling regime leading to energy saving and potentially to quality improvement. Quality improvement can be translated into a longer transport time without quality loss. Starting point is that lowering the average temperature below the generally known "standard temperature" is a method to improve quality. These types of profiles were applied in banana, pineapple and avocado.

As an example Figure 1 shows an example of the two types of temperature profiles.

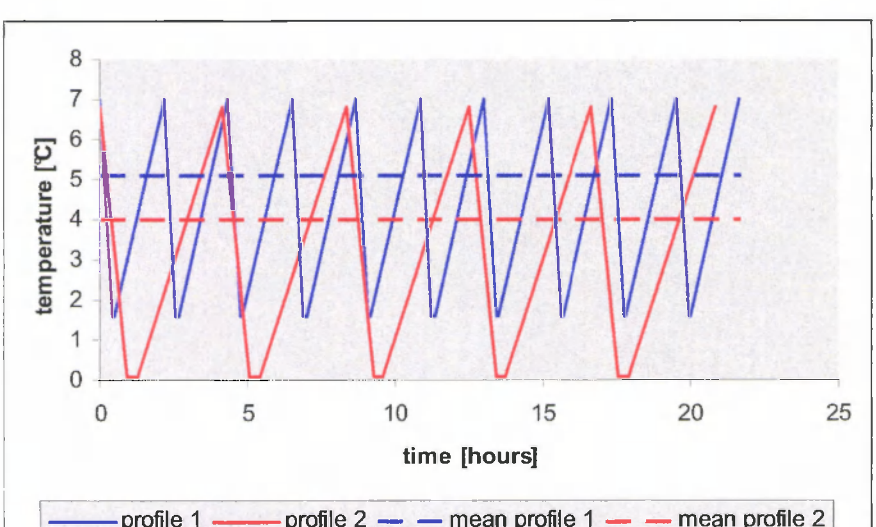


Figure 1. Profile 1: fluctuating temperature in order to save energy; Profile 2: fluctuating temperature in order to improve quality.

6.2 Methods

Every commodity was subjected to at least the following treatments:

- Standard transport temperature.
- Temperature below the standard transport temperature.
- One or more profiles of a fluctuating temperature between certain boundaries.

Depending on the commodity, other transport temperatures and/or fluctuating temperatures were applied. In these treatments temperature refers to the temperature of the air around the product. The temperatures in the experiments were based on expert knowledge and model simulations of the climate on container scale. The model predicts the climate in the load, headspace and T-bar, based on specific temperature ranges, package and product. From these values an estimate for the fluctuations was made. After the storage period the product's quality was examined. This was repeated after and sometimes during a shelf life period.

6.3 Results

Performing experiments with products that are grown outside Europe and that have to be transported for a long time before experiments start is a fact that had to be accepted in this project. Especially for perishables with a relatively short maximum transport time (pineapple and banana) an effect of the long "pre-experiment" transport time on product quality may have influenced the (lab scale) experimental results. Real life transports are needed to validate results in practice.

6.3.1 Apple

For "Golden Delicious" apples the standard transport temperature was 0°C. The temperature fluctuated between -0.5°C and 0.5°C, with a cooling down period of 30 out of 90 min. Transport simulations were applied for 28 days. No negative effects of the fluctuating temperature were observed on firmness after transport and shelf life, nor colour development and sugar content (°Brix) after transport. After transport at fluctuating temperature weight loss was a little higher and sugar content after shelf life was a bit lower. Since RH was not controlled similar to transport conditions, weight losses can not be compared.

In conclusion:

- Application of fluctuating temperature in order to save energy is possible
- Fluctuating temperature in order to improve quality was not investigated for apple.

6.3.2 Avocado

For "Hass" avocados the standard transport temperature was 5.1°C, but avocados also were continuously subjected to lower temperatures, down to 0.5°C. Fluctuating temperatures were applied in order to save energy: the average of these profiles was around 5.1°C. Extra profiles (average temperature 3-4°C) were enforced aiming to improve quality. The various profiles are summarized in the following table:

Experiment nr.		Cooling time (min)		Boundaries (°C)		Mean T
		on	off	low	High	(°C)
exp. 1	profile 1	54	58	4.1	6.4	5.2
	profile 2	28	74	1.3	5.7	3.9
	profile 3	51	178	0.1	6.8	3.6
	continuous 1					5.3
	continuous 2					3.5
	continuous 3					2.3
exp. 2	profile 1	30	100	1.6	7.0	4.6
	profile 2	75	170	0.1	6.8	4.0
	profile 3	245	295	0.1	6.8	3.4
	profile 4	330	435	0.1	7.7	3.8
	continuous 1					5.2
	continuous 2					4.0
	continuous 3					0.8
exp. 3	profile 1	30	100	1.6	7.0	4.6
	profile 2	75	170	0.1	6.8	4.2
	profile 3	245	295	0.1	6.8	3.1
	continuous 1					5.2
	continuous 2					3.1
	continuous 3					0.5

Table 2 Temperature fluctuations in the various avocado experiments

Transport time was at least 21 days. Fluctuating temperatures were possible without negative effects, compared with the standard temperature. Some profiles slowed down colour development and softening, but with increasing transport time internal discolouration appeared which was comparable to a continuous temperature of 5°C. This internal discolouration was the bottleneck for longer transport; it was not affected by the profiles of fluctuating temperatures.
At continuous temperatures lower than 5°C (standard temperature) the "Hass" avocados could be transported for a longer time. At 0.5°C almost no internal discolouration was observed! This is contradictory to the literature and to "common knowledge". In general transport at a temperature lower than 5°C is not recommended because of the risk of chilling injury. In 3 out of 3 experiments in this project no chilling injury was observed in "Hass" avocados, stored at temperatures lower than 5°C.

In conclusion:

- Energy saving by application of fluctuating temperatures is possible.
- Fluctuating temperature profiles can be found that slow down colour and firmness development, compared to the continuous temperature of 5°C.
- Longer transport time by application of fluctuating temperatures is not recommended because of internal discolouration comparable to that at a continuous temperature of 5°C.

6.3.3 Banana

First, an experimental study was done in collaboration with Kasetsart University, Bangkok, Thailand. Thai bananas ("Sucrier" and "Gros Michel") were stored at various temperatures with intermittent storage at 20°C. The test showed that the two investigated cultivars can have a longer storage life than at 12°C, if they are stored at lower temperature and subjected to the right cycle of intermittent warming. Shelf life was not taken into account. The effect on shelf of the best treatments needs further investigation. Nonetheless, it shows that a cycling cooling regime may not only have no negative impact on some products, it may even mean that some products, especially those showing chilling injury, have an improved quality.

Three experiments concerning "Giant Cavendish" bananas were performed. The standard transport temperature was 13.0°C and the transport simulation time was 14 days. Fluctuating temperatures in order to save energy (average temperature 13°C) as well as to attempt quality improvement (average temperature 11.5°C) were applied. Three profiles were applied:

- Energy saving: 14.6°C – 11.1°C (profile 1)
- Energy saving: 16.3°C – 13.1°C (profile 2)
- Quality improvement + energy saving: 13.2°C – 9.6°C (profile 3)

The temperature profile applied during the various Cavendish experiments are summarized in the table below:

Experiment nr.		Cooling time (min)		Boundaries (°C)		Mean T	Remarks
		on	off	low	high	°C	
exp. 1	profile 1	75	120	11.1	14.6	12.8	PE bag
	profile 3	70	110	9.6	13.2	11.3	PE bag
	continuous 1					12.9	PE bag
	continuous 2					11.5	PE bag
	continuous 3					8.4	PE bag
exp. 2	profile 1	75	120	11.1	14.6	12.7	PE bag + wet tissue
	profile 2	52	68	13.1	16.3	14.7	PE bag + wet tissue
	continuous 1					13.0	PE bag + wet tissue
	continuous 2					14.8	PE bag + wet tissue
	continuous 3					8.7	PE bag + wet tissue
exp. 3	profile 2a	52	68	13.1	16.2	14.7	PE bag + wet tissue
	profile 2b	52	68	13.1	16.2	15.2	original banana box
	continuous 14.5°C					14.6	PE bag + wet tissue
	continuous 14.5°C					15.9	original banana box
	continuous 13°C					13.2	PE bag + wet tissue
	continuous 13°C					13.3	original banana box

Table 3 Temperature fluctuations in the various banana experiments

Because of quality loss during shelf life (increased dull grey on the skin) the energy saving profile 1 did not succeed. After exposure to profile 2 bananas showed less dull grey colouring, then storage at 13°C continuously. The appearance of sugar spots was slightly increased. Exposure to profile 3 increased the dull grey colouring of the skin.

In conclusion:

- Thai dessert bananas "Sucrier" and "Gros Michel" show improved quality, i.e. longer storage time, when stored under cycling temperature conditions.
- For Cavendish banana, energy saving by application of a fluctuating temperature with an average temperature above the standard temperature is possible. Sugar spots may appear a bit sooner after exposure to the fluctuating temperature. The amount of grey discoloration is somewhat smaller.

6.3.4 Grapes

For "Palieri" grapes temperatures were fluctuated between -1.5°C and 1.5°C (profile 1) and -0.5°C and 2.5°C (profile 2). Both profiles aimed to save energy and cooled down for 30 out of 90 minutes. Fluctuating temperature in order to improve quality was not investigated for grapes. Transport simulations were applied for 14 and 21 days.

No significant quality loss was observed and none of the quality parameters (disconnected grapes, cracked grapes, rotten grapes) showed differences between simulations. However: the fluctuating temperatures that were maintained in the cold store were strongly levelled off in the boxes with grapes. Temperatures on box level varied from 0°C – 2°C.

In conclusion:

- Energy saving by fluctuation of the temperature is possible within the temperature range 0°C – 2°C. This conclusion is based on grapes without significant quality loss.

6.3.5 Kiwi

For "Hayward" kiwis the standard transport temperature was 0.1°C. The temperatures were fluctuated between -0.8°C and 0.8°C (profile 1, energy saving), with a cooling down period of 37 out of 90 minutes. Also a temperature fluctuation from -2.8 to 1.2°C was applied (profile 2, energy saving + improving quality), with a cooling down period of 10 out of 60 minutes. Transport simulations were applied for 28 days.

No negative nor positive effects of the fluctuating temperatures were observed in firmness, glassiness, sugar content (°Brix), stem end rot or weight loss.

In conclusion:

- Energy saving by fluctuating the temperature is possible with equal quality, however quality was not improved.

6.3.6 Pear

For "Conference" pears the standard transport temperature was 0°C. The temperature fluctuated between -0.5°C and 0.5°C, with a cooling down period of 30 out of 90 min. Transport simulations were applied for 28 days.

No negative effects of the fluctuating temperature were observed in colour development and sugar content (°Brix). After transport at the fluctuating temperature weight loss was a little higher and the pears were less firm. Since RH was not controlled similar to transport conditions, weight losses and the related firmness can not be compared.

In conclusion:

- Application of fluctuating temperature in order to save energy is possible, weight loss and firmness effects need to be checked in a pilot shipment
- Fluctuating temperature in order to improve quality was not investigated for pear.

6.3.7 Pineapple

Pineapple experiments were performed with the cultivars "MD2" (2 experiments) and "Smooth Cayenne" (1 experiment). The standard temperature varied (7.4 – 7.9°C) and the transport simulation time was 13 - 14 days. Fluctuating temperatures with an average temperature above, as well as similar to, and below the standard temperature were applied. The temperature profiles are summarized in the table below:

Product	Experiment nr.		Cooling time (min)		Boundaries (°C)		Mean T
			on	off	low	high	°C
Pineapple MD2	exp. 1	profile 1	30	60	6.5	8.5	
		continuous 1					7.4
		continuous 2					8.2
		continuous 3					9.0
	exp. 2	profile 1	55	78	6.2	9.4	7.5
		profile 2	22	76	3.8	8.3	6.2
		profile 3	52	212	1.2	8.9	5.3
		continuous 1					7.9
		continuous 2					6.3
		continuous 3					5.7
Pineapple Smooth Cayenne	exp. 1	profile 1	30	60	7.5	9.0	8.6
		profile 2	10	50	4.0	9.2	6.0
		continuous 1					6.9
		continuous 2					7.3
		continuous 3					7.8
		continuous 4					9.5

Table 4 Temperature fluctuations in the various pineapple experiments

The results in the experiments concerning energy saving by fluctuating temperature were not consistent for MD2. In the MD2 experiment, after transport at fluctuating temperature, colour development during shelf life was faster, glassiness after transport and during shelf life was increased, and fruits softened faster during shelf life. In the two experiments with Smooth Cayenne, fluctuating temperature could be applied without extra quality problems. The profile of fluctuating temperature, applied in order to attempt quality improvement did not gain possibilities for longer transport. Low temperature problems (chilling injury) were not observed.

In conclusion:

- Energy saving by application of fluctuating temperatures is possible for Smooth Cayenne.
- Energy saving by application of fluctuating temperatures may not be possible for MD2.
- Application of fluctuating temperatures did not show quality improvements.

6.3.8 Product research results summary

For bell pepper, apple, kiwi, pear, pineapple, grapes, banana and avocado the cycling control regime showed possible[4] without reducing quality compared to standard storage conditions. For "MD2" Pineapple results were inconsistent. (This may be attributable to the low start quality of the fruit and the air transport prior to testing.)

For avocado, cycling with a lowered average temperature[5] showed positive effect on colour development and softening. Also, Thai dessert bananas "Sucrier" and "Gros Michel" show improved quality, i.e. longer storage time, when stored under cycling temperature conditions. The product research results are summarized in the table below.

[4] *Please note that it is practically impossible to test for all possible varieties, place of origin or harvest periods. As in all produce research it is impossible to give guarantees for all possible produce transported as biological variation is huge and will vary in time. However, a proof of principle was given using a wide range of products, comparing quality for cycling versus normal mode. This gives great confidence in he applicability of Quest* Regular.

[5] *Note that "quality improvement profiles" refers to product specific adapted temperature profiles, which lower the average temperature compared to normal transport. This is a different type of temperature profile than the normal Quest* Regular *profile discussed in chapters 3 and 4.*

	Temperature profile aimed at energy saving	Temperature profile aimed at quality improvement	Remarks
Bell pepper	Possible	Not investigated	
Apple "Golden Delicious"	Possible	Not investigated	Check weight loss in pilot
Avocado "Hass"	Possible	Positive effect on colour development and softening, but more internal discolouration with increasing transport time (not due to the profile or chilling)	No chilling injury, contrary to literature and common knowledge
Thai dessert bananas "Sucrier" and "Gros Michel"		Positive, i.e. longer storage time	
Banana "Giant Cavendish"	Profile with higher mean temperature is possible	Not recommended due to chilling sensitivity	More dull grey discolouration at lower temperature, earlier appearance of sugar spots at higher temperature
Grapes "Palieri"	Possible within the range 0°C – 2°C	Not investigated	Based on grapes without significant quality loss
Kiwi "Hayward"	Possible	Improved quality was not obtained	No chilling injury
Pear "Conference"	Possible	Not investigated	Check weight loss and firmness in pilot
Pineapple "MD2"	Results inconsistent	Improved quality was not obtained	No chilling injury
Pineapple "Smooth Cayenne"	Possible	Improved quality was not obtained	No chilling injury
Mango	Possible	Not investigated	No chilling injury

Table 5 Possibilities and recommendations concerning energy saving and/or quality improvement by fluctuating supply air temperature.

7 Conclusions

Applying Quest Regular as described in this document can reduce the energy consumption of container transport refrigeration by 50% (savings vary depending on unit specifications, ambient conditions, produce, ventilation settings and setpoint). Due to the nature of product research, it can not be excluded that any given product will not a negative effect on produce quality might occur. However, extensive product experiments have shown that cycling temperatures such as could occur when applying Quest Regular do not harm produce quality of several types of fruit and vegetables.

