Quest II produce quality research overview

doc. version: 2.0

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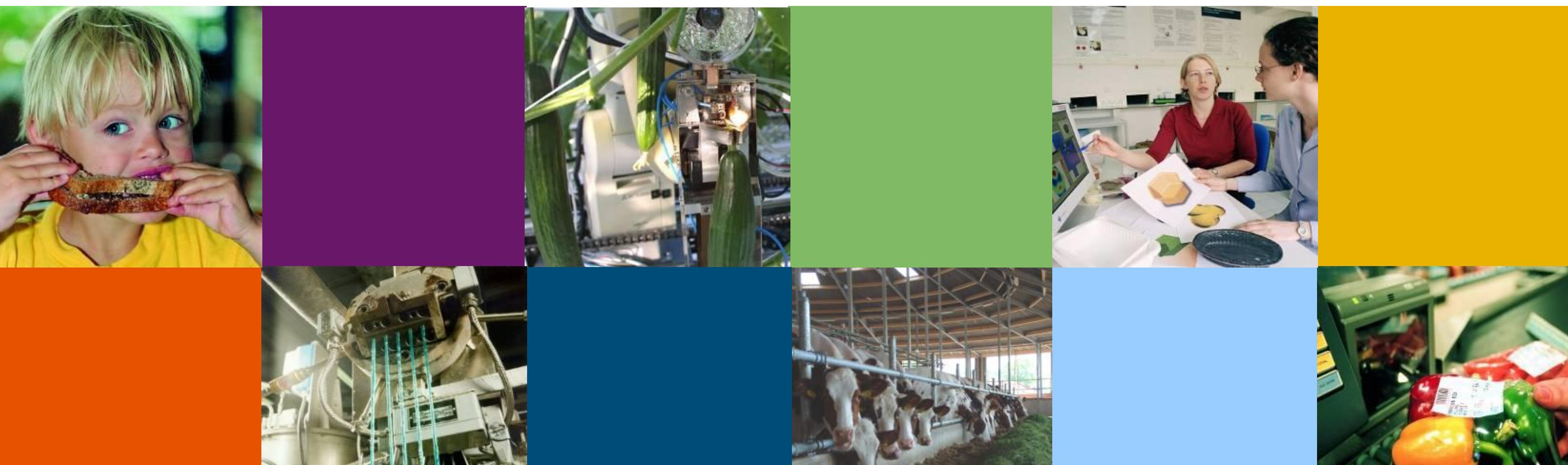
May 2012



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Title	Quest II produce quality research overview
document version	2.0
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Number	???
Date of publication	May 2012
Confidentiality	yes, till Jan. 2014
OPD code	07/235J

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Content

Summary

The Quest II control algorithm (patent pending), developed by Wageningen UR Food & Biobased Research together with Maersk Line and Carrier Transicold, reduces the energy consumption of reefer containers by approx. 65% without impairing produce quality. In the Quest II development project a lot of effort was spent on the labscale research towards produce quality effects of temperature variations, as from the beginning it has been a hard constraint that Quest II mat not impair produce quality during transport. Commodities subjected to labscale produce research are banana, pineapple, kiwi, grape, iceberg lettuce, chilled lamb meat and lily bulbs.

Quest II saves energy by allowing supply air temperature to vary and by reducing the air circulation rate when the heat load is small. On average in steady state the temperature of the warmest spot in the cargo is 1.0 °C warmer than supply air temperature for both Quest I and Quest II, while for non-Quest this is 0.8 °C.

In view of the nature of Quest II, the produce quality research is focused on three questions:

1. Do supply air temperature variations have a negative effect on produce quality?
2. What is the risk of chilling/freezing injury when produce gets colder than requested?
3. How is produce quality affected by warm spots?

The above questions are answered by simulating the long distance transport of selected batches of banana, pineapple, kiwi, grape, iceberg lettuce, chilled lamb meat and lily bulbs at four different temperature regimes in small climate rooms:

1. reference temperature – 3 °C
2. reference temperature + 3 °C
3. profile 1 (severe varation): min/avg/max = reference – 3.0 / reference / reference + 1.0
4. profile 2 (extreme variation): min/avg/max = reference – 6.0 / reference / reference + 1.5

Afterwards the quality of these batches is compared to the quality of a 5th batch stored at reference temperature.

Unsurprisingly, the produce quality results confirm that constant temperatures 3 °C above reference temperature have a distinct adverse effect on produce quality. Also 3 °C too cold yields disastrous results, especially in the setpoint range below +1 °C (freezing injury) and in the banana segment (12 ~15 °C) due to bananas' high sensitivity to chilling injury. None of the commodities suffered from the severe temperature profile.

The findings with respect to produce quality have been used to design the Quest II control:

1. In order to avoid hot spots Quest II only reduces the internal air circulation if heat load is low.
2. Temperature variations are milder than the severe variation used in produce quality research.
3. Quest II aims to control the average of supply and return temperature to the reference temperature, while obeying a set lower limit for time-averaged supply temperature. For reference temperatures between +1 and +12 °C or above + 15 °C the lower limit is reference temperature – 1 °C, otherwise the lower limit equals the reference temperature.

Extensive produce quality research inspires confidence to the safety of applying Quest II. The tests provided no evidence that Quest II might have an adverse effect on produce quality. Also,

the limits found in the produce quality research, were used in the design of Quest II, in order to make sure that Quest II stays away from those limits.

1 Introduction

Quest II is an improved version of Quest I. The improvement comes in terms of bigger energy savings, while preserving produce quality. While Quest I saves about 50% energy as compared to non-Quest, Quest II even saves about 65% energy. Quest II, like Quest I, does no longer aim to control supply air temperature at setpoint all the time. Instead both Quest II and Quest I allow supply air temperature to vary. Yet, in terms of temperature control, there are differences between Quest II and Quest I. In the Quest II development project a major part of the project's effort has been aimed at investigating the possible produce quality effects.

Already in the Quest I development project (2002 – 2007) major research efforts were aimed at investigating the effect of Quest I induced temperature oscillations on produce quality. The commodities included in the labscale research at the time were iceberg lettuce, nectarine, lily bulb, banana, grape, pineapple, avocado, kiwi, apple, pear, bell pepper. Only for pineapple and lily bulbs the results were somewhat ambiguous, for all other commodities no indication was found that Quest I would impair produce quality (see de Kramer-Cuppen *et al.*, 2007; van de Boogaard and de Kramer-Cuppen, 2006; de Kramer-Cuppen *et al.*, 2008). Since then millions of Quest I shipments have been conducted without impairing produce quality.

In the Quest II development project again extensive labscale research was performed towards produce quality effects of temperature variations, as Quest II needed to be as safe for the produce quality during transport as Quest I is. The typical difference with the Quest I produce research is that in Quest II the imposed temperature variations during the labscale research were more severe. Commodities subjected to labscale produce research are banana, pineapple (Harkema *et al.*, 2009a); kiwi, grape, iceberg lettuce (Harkema *et al.*, 2009b); chilled lamb meat (Harkema *et al.*, 2009c); and lily bulbs (Harkema and Lukasse, 2011). These commodities were selected because of their known temperature sensitivity and/or the large volumes in which they are globally transported. This produce quality research was followed by hundreds of field trials performed with beta-versions of Quest II. Each of these trials was designed to send two identical containers simultaneously, one running Quest II and the other non-Quest or Quest I. Upon arrival independent surveyors evaluated produce quality in both containers. The main objective was to get to know the acceptable limits of temperature variations and to make sure that the Quest II temperature control design avoids exceeding those limits.

This report gives an overview of the produce quality research done in the Quest II project and how that relates to the Quest II control methodology. Therefore first section 2 explains the typical supply and return air temperature characteristics occurring in a Quest II – controlled reefer and compares these to both Quest I and non-Quest. Section 2.3 then discusses the typical carton temperatures occurring in a Quest II – controlled reefer. After this introduction of Quest II temperatures section 4 explains the set-up of the labscale produce quality experiments. Then section 5 gives an overview of the results from all the Quest II labscale produce quality research. The discussion in section 6 is meant to interpret and summarize all those results. Finally the overall conclusion is drawn in section 7.

2 Typical temperatures in a Quest II controlled reefer

Quest I saves energy by allowing supply air temperature to vary and by reducing the air circulation rate once the heat load reduces. Basically Quest II takes this a step further: larger and more rapid supply air temperature fluctuations, and air circulation better tuned to actual heat load. This section gives a simplified overview of the main characteristics of Quest II and how it differs from Quest I and non-Quest. For an exact, and therefore far more complex, description of the Quest II control methodology see Lukasse (2011). Table 1 summarizes the main differences between Quest II, Quest I and non-Quest. Section 2.1 discusses the Quest II control of supply and return air temperature in further detail. Section 2.2 explains the Quest II air circulation control. Finally, section 2.3 names the produce quality questions related to the main principles of Quest II operation. These questions are then addressed in the remainder of the document.

Table 1, some key characteristics of Quest II, Quest I and non-Quest.

	Quest II	**Quest I**	**non-Quest**
temp. control	supply temp. controlled to Quest setpoint.	return temp. controlled to setpoint + 0.75 °C.	supply temp. controlled to setpoint.
min. supply air temperature	setpoint – 6 °C	setpoint – 2 °C	setpoint
duration of periods with supply temperature below setpoint	4 minutes	10 to 30 minutes	N.A.
max. duration of periods with supply temperature below setpoint	max. 10 minutes.	max. 360 minutes.	N.A.
min. hourly averaged supply temperature	setpoint if setpoint between -5 and +1 °C or +12 and +15 °C, otherwise setpoint -1 °C.	setpoint – 2 °C for at most 6 hours after each other.	setpoint
air circulation (% of installed capacity)	10 to 100%	50 to 100%	100%

2.1 Supply and return air temperatures

Quest II cools at maximum capacity for four minutes. In those four minutes supply air temperature may drop as low as 6 °C below setpoint for a short moment. After four minutes cooling switches off while air circulation continues, until average supply air temperature equals the supply air temperature setpoint then four minutes of cooling at maximum capacity resumes and so on.

The two main differences between Quest I and Quest II in terms of supply and return air temperature control:

1. Quest II causes larger and more rapid supply air temperature fluctuations than Quest I.
2. Quest I aims to control the average return temperature at setpoint + 0.75 °C. Consequently the average supply air temperature depends on heat load: usually just above setpoint, but below setpoint at high heat load. Quest II controls the average supply air temperature to an intermediate variable, the Quest setpoint. It adjusts the Quest setpoint with the objective that over time the average of supply and return air temperature equals the user setpoint. To avoid too cold supply air temperature, especially during pulldown, the Quest setpoint is not allowed to drop more than 1 °C below setpoint. In temperature setpoint ranges where cargos are susceptible to chilling/freezing injury the Quest setpoint is not allowed to drop below setpoint; this applies to setpoints between -5 °C and +1 °C and to setpoints between +12 and +15 °C.

Some typical downloads are shown in Fig. 1 through Fig. 4. (time interval is 12 hrs.). Fig. 5 presents supply and return air temperatures on a much smaller timescale, as registered in one of the Quest II trial shipments.

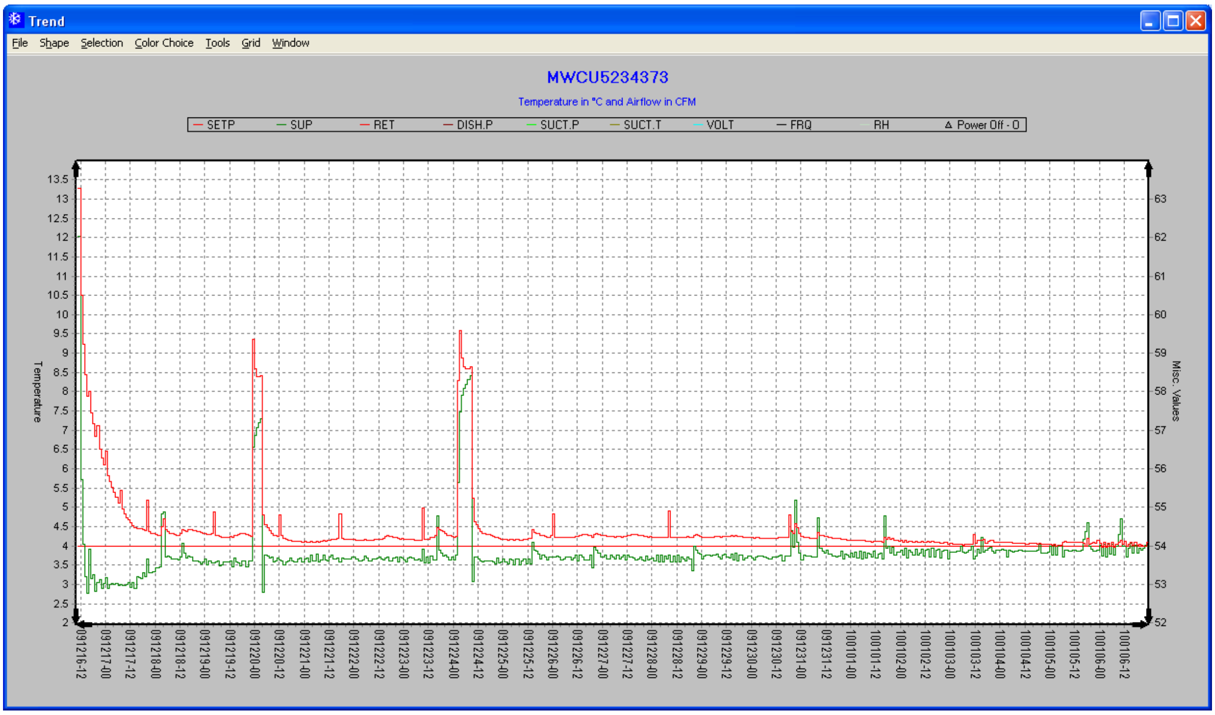

Fig. 1, Quest II citrus trial shipment (hourly averaged temperatures).

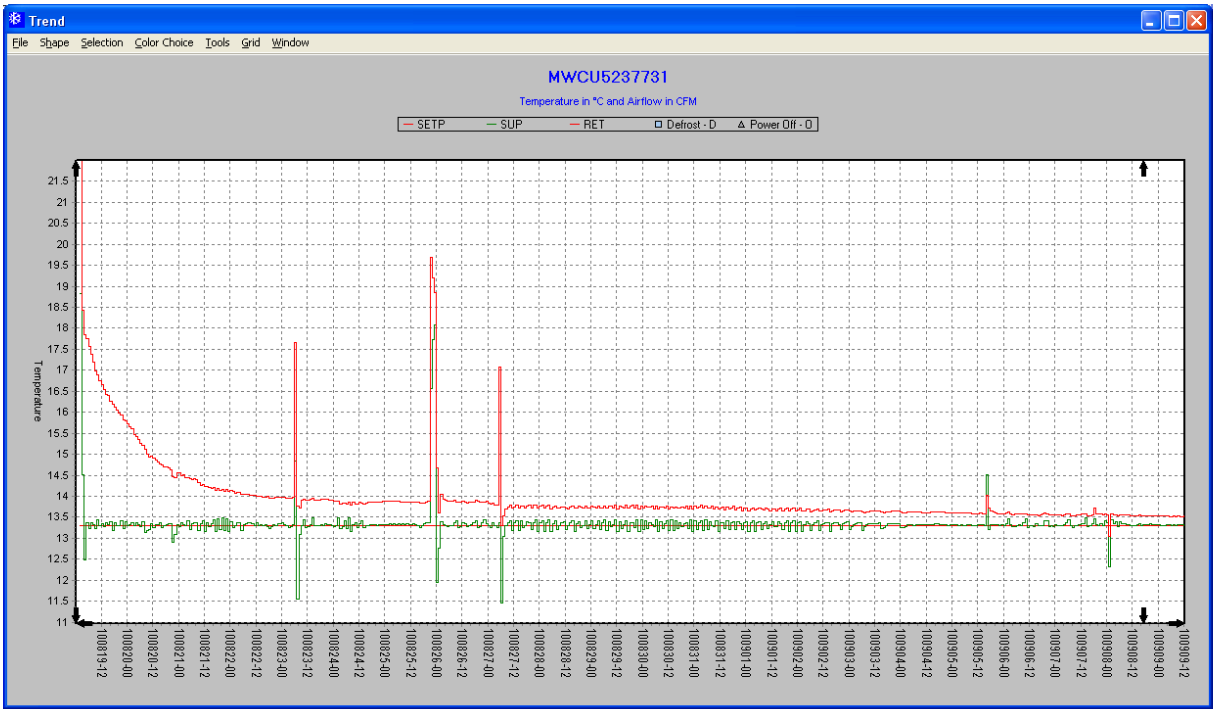

Fig. 2, Quest II banana trial shipment (hourly averaged temperatures).

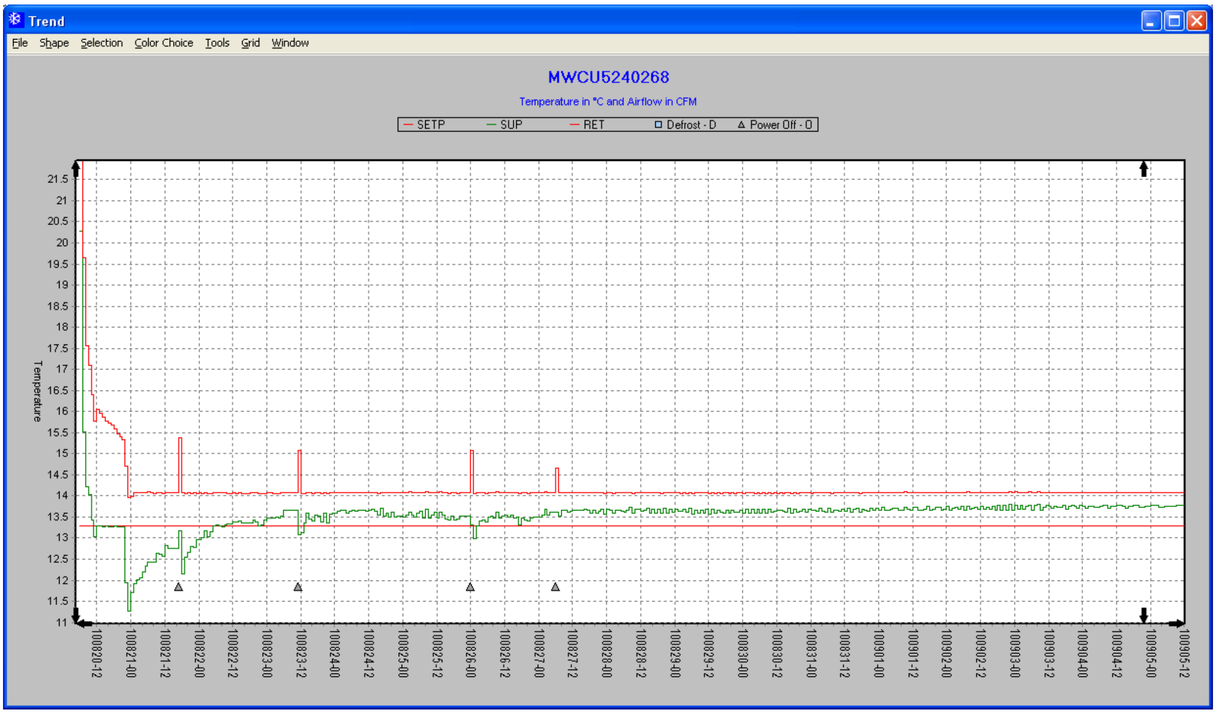

Fig. 3, Quest I banana shipment (hourly averaged temperatures).

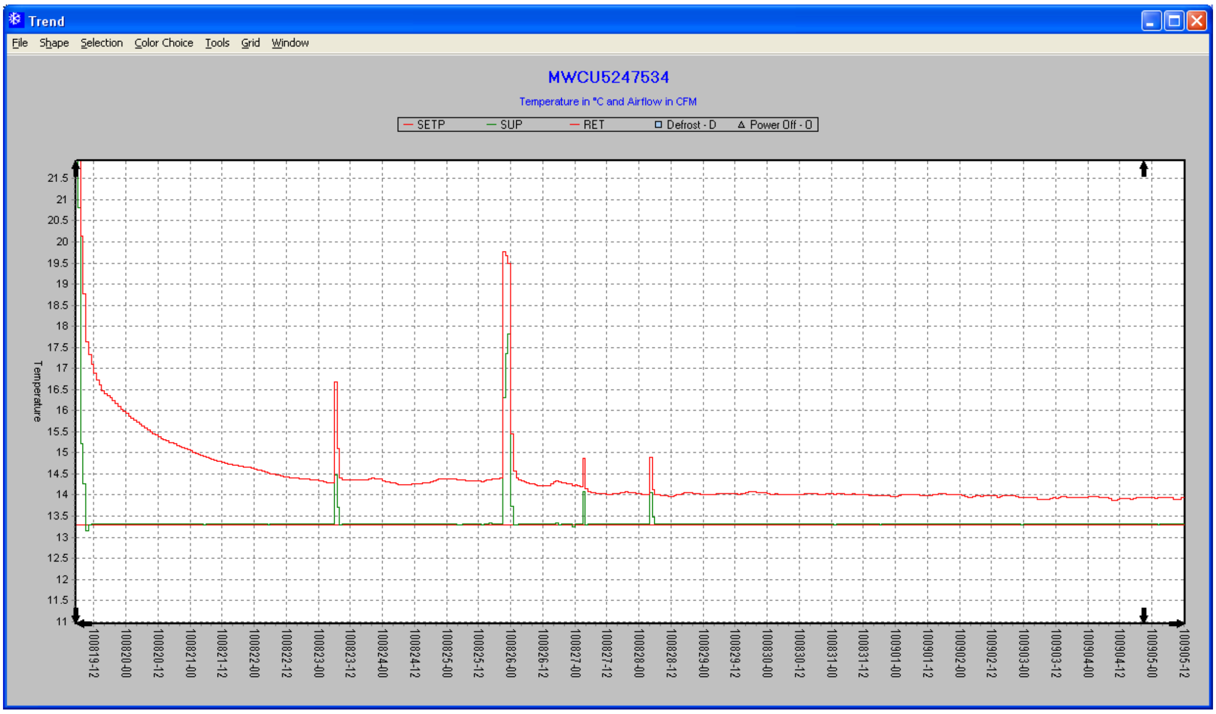

Fig. 4, non-Quest banana shipment (hourly averaged temperatures).

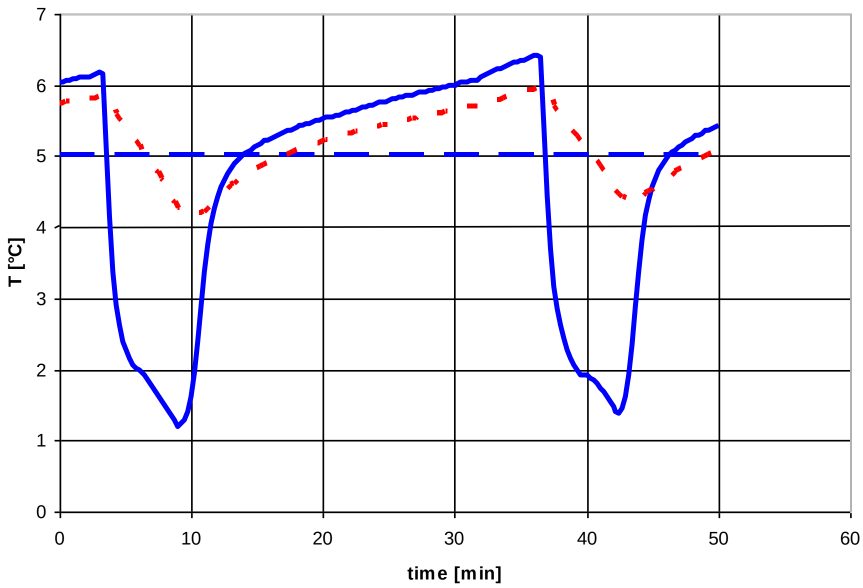

Fig. 5, typical Quest II temperatures with no averaging applied: supply air temperature setpoint (blue dashed), supply air temperature (blue solid) and return air temperature (red).

2.2 Air circulation

Just simply reducing the air circulation rate inside a reefer container carries the risk of irresponsibly increasing temperature pulldown times and temperature gradients throughout the cargo. Therefore Quest II reduces the air circulation rate only when that does not, or at least not significantly, increase temperature gradient throughout the cargo. Table 2 summarizes the temperatures observed during trial shipments with a Quest II beta version which equals the final version.

Table 2, average steady state temperature gradient in reefer containers observed over hundreds of trial shipments within the Quest II project.

type of control	warmest - coldest steady state cargo temp. [°C]	avg. USDA – setpoint during steady state [°C]	duration of temperature pulldown in banana shipments [days]	avg. no. of defrosts per day in shipments at setpoints 3.5 ~ 10 °C [°C] with defrost interval set at 'auto'
Quest II	1.0	0.3	0.52	0
Quest I	1.0	0.8	0.45	0.6
non-Quest	0.8	0.6	0.69	1.0
shipments	48	48	18	6

The remainder of this section provides some further explanation on the contents of Table 2:
Column 2. The warmest minus the coldest steady state temperature is an average based on all trials done within the Quest II development project since Aug. 2010. This involves 16 non-Quest, 11 Quest I and 21 Quest II shipments. Trial shipments ranged from setpoint -1.0 °C (chilled meat) till +16 °C (potted plants), bananas make up for about 30% of these trials.
Column 3. Pulldown time is defined as the time between first power-up and the moment when the return temperature falls below setpoint minus 3 °C. The numbers with respect to duration of temperature pulldown in banana shipments are averages taken over 4 non-Quest, 7 Quest I and 7 Quest II shipments. Quest I and Quest II outperform non-Quest by allowing a short periods with supply temperature colder than setpoint, without exceeding the chilling injury limit.
Column 4. Average number of defrosts per day is an average taken over 2 non-Quest, 1 Quest I and 3 Quest II shipments with citrus. In all shipments the defrosting was adequate. The typical problems inherent to insufficient defrosting did not occur in any of the trials. Quest I defrosts less often than non-Quest as the auto-defrost algorithm takes into account the effect of ice melting off the coil during compressor-off periods. Quest II outperforms Quest I in this perspective as it comes with a refined defrost control that optimizes the auto-defrost algorithm's exploitation of these compressor-off periods.

2.3 Relating Quest II characteristics to produce quality effects

Knowing the characteristics of Quest II, three produce quality related questions arise naturally:

1. Do the supply air temperature variations have a negative effect on produce quality, especially in the cartons sitting in the lower tier close to the container's bulkhead?
2. If supply air temperature setpoint reduces below shipper's requested setpoint, what is then the risk of inducing chilling/freezing injury?

3. If reduced air circulation would lead to warm spots at the container's door end, what would that mean to produce quality?

These three questions are addressed in the labscale produce research, as shown in the next sections.

3 Temperatures inside the packaging in a Quest II reefer

Though Quest II supply air temperatures may vary (Fig. 5), these variations hardly propagate into the cartons containing the produce. Several factors contribute to the effective dampening of the supply air temperature variations: thermal inertia of the packaging and produce, limited share of airflow that really flows into the packaging, high frequency of supply air temperature variations. Fig. 6 shows temperatures registered inside a carton positioned in the lower tier close to the reefer unit. Obviously temperatures in cartons further away from the place where supply air enters the container are even more stable.

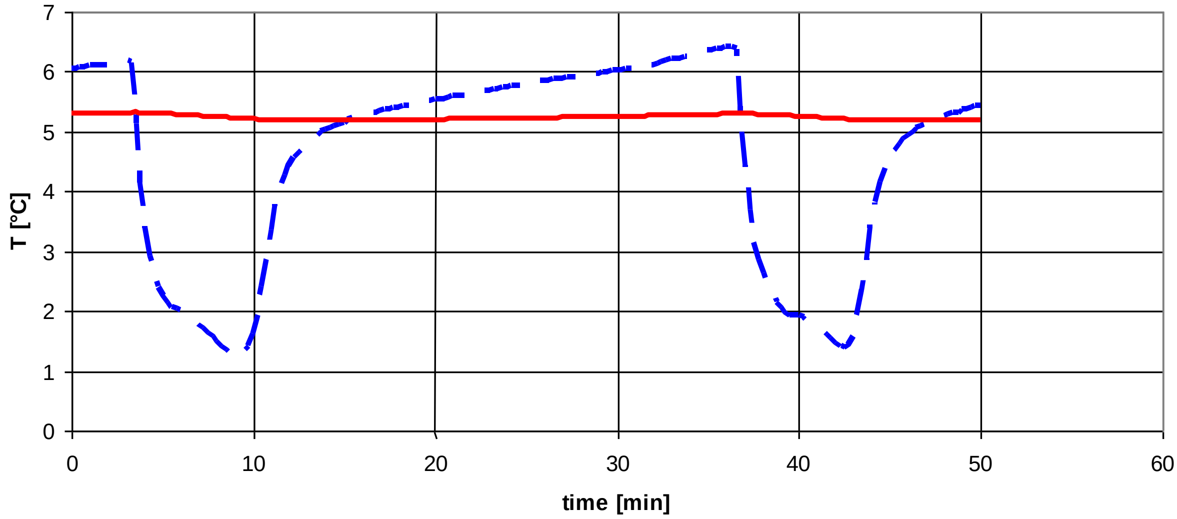

Fig. 6, Quest II supply air temperature (blue dashed) and temperature inside a carton at lower tier close to the location where supply air enters the container (red solid).

4 Methodology of labscale produce research

The typical stepwise procedure in all labscale experiments is depicted in Fig. 7.

step 1: initial quality analysis

↓

step 2: transport simulation (± 20 days at five different temperature regimes)

↓

step 3: quality analysis after transport

↓

step 4: shelf life simulation (± 5 days at 18 °C)

↓

step 5: final quality analysis

Fig. 7, typical chronological steps in labscale produce quality experiments.

In all labscale experiments, the produce is selected:
- to originate from one batch (same harvest date, same origin),
- to be a temperature-sensitive cultivar and
- to be packed as usual during container transport.

For example in the experiment with grapes this meant a cultivar with low sugar content was selected, so that it is one of the grape cultivars most susceptible to freezing injury.

In all experiments the test material is equally divided over five climate rooms. At least six cartons per temperature treatment are used. Each climate room has its own temperature regime. Table 3 lists the applied temperature regimes and corresponding motivation.

Table 3, the five typical temperature treatments applied.

no.	description	Purpose
1.	reference temperature	Reference
2.	reference temperature – 3 °C	cause chilling/freezing injury to create comparison material for quality evaluation of the produce subjected to temperature profiles, or collect evidence that even 3°C below reference does no harm.
3.	reference temperature + 3 °C	see what the harm of hot spots is, which might result from too rigorous reduction of air circulation.

4.	profile 1 (severe varation): min/avg/max = reference – 3.0 / reference / reference + 1.0 °C, with a cycle period of 60 minutes	see if a severe supply air temperature variation harms produce quality
5.	profile 2 (extreme variation): min/avg/max = reference – 6.0 / reference / reference + 1.5 °C, with a cycle period of 180 minutes	see if an extreme supply air temperature variation harms produce quality

See Fig. 8 for an example of realized supply air temperature profiles in one of the labscale tests.

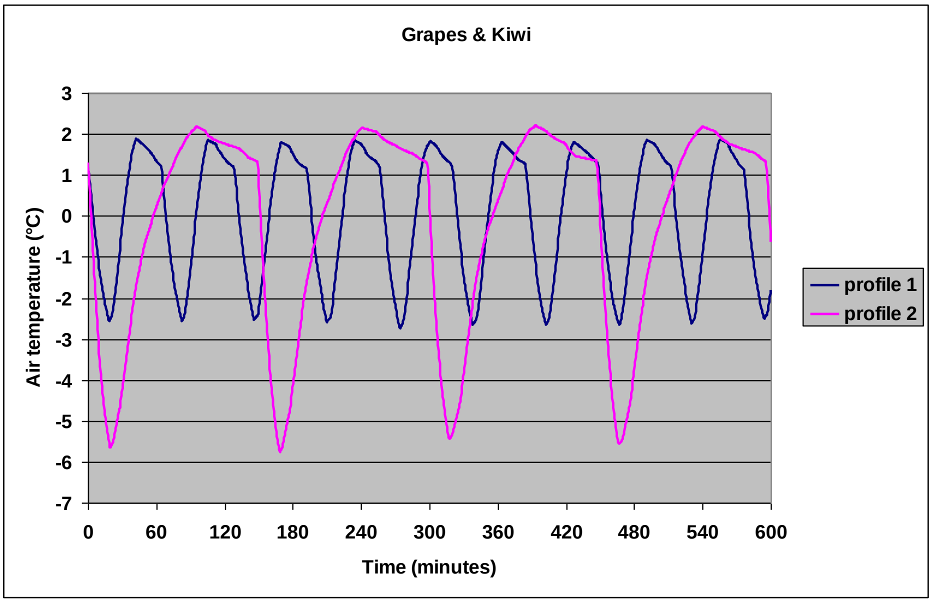

Fig. 8. Temperature profiles during shipping simulations of grapes and kiwis at fluctuating temperatures.

In the two climate rooms with temperature profiles the cartons are stacked. To mimic the propagation of supply air temperature variations in reefer containers as realistically as possible, an upward air flow of about 2.5 m/s (approximate average air velocity in air slits between and around cartons) is forced through the stack. This air flow is maintained by mounting a fan with adjustable air flow rate underneath the stack, and taping plastic around the fan outlet and the stack. The cartons at the top of the stacks are covered with open crates, in order to get as much as possible the same conditions for all cartons in the stack (Fig. 9). In the three constant temperature climate chambers the cartons are placed in one layer on empty crates (to avoid direct contact with the cold concrete floor), the cartons are covered with empty crates in order to prevent extreme dehydration (Fig. 10).

Obviously in this experimental setup the air flow rate through the cartons in the two temperature profile rooms is stronger than in the three constant temperature rooms. The reason for not building the temperature-profile setup in all five climate rooms is practical: only two fans were readily available and only for fluctuating temperatures air flow through the stacked cartons was regarded critical for enforcing the realistic propagation of supply air temperature variations into the cartons. All simulations were done in climate rooms (length 3.00 m, width 2.00 m, height 3.00 m) with abundant fresh air exchange and an air cooler (Fig. 11).

Fig. 9 Experimental set-up at temperature profiles.

Fig. 10 Experimental set-up at constant temperatures.

Fig. 11 Air cooler in climate room.

Typical registrations throughout the experiment:

- In each room: temperatures are measured in air, at fruit surface and inside some fruits.
- At start of transport simulation: destructive and non-destructive initial quality aspects of a representative sample from the batch.
- At end of transport simulation per temperature regime:
  - non-destructive quality aspects of all fruits, or a representative number of them.
  - destructive quality aspects of a representative number of fruits, at most of 50% of all fruits.
- At end of shelf life simulation per temperature regime:
  - non-destructive quality aspects of all remaining fruits, or a representative number of them.
  - destructive quality aspects of a representative number of fruits, at most of all remaining fruits.

Table 4, overview of which commodities are tested at which reference temperature

reference temp. [°C]	**produce**
-1.5 °C	lily bulbs (3 cultivars), lamb shoulder cuts
+0.5 °C	kiwi, iceberg lettuce, grape
+6.5 °C	pineapple
+13.5 °C	banana

Table 5 and Table 6 list the quality aspects evaluated for all commodities included in the labscale produce research.

Table 5, overview of quality aspects analyzed for each produce (fruit/vegetable)

pineapple	**kiwi**	**iceberg lettuce**	**grape**	**banana**
External colour			Stem colour	External colour
Weight loss	Weight loss	Weight loss	Weight loss	
	Stem-end rot	Decay + wilting	Decay	
	Other decay			
Soluble solids	Soluble solids		Soluble solids	
Firmness	Firmness			
Internal color (discoloration / glassiness)	Internal glassiness			
Cut surface (fungal growth)		Cut surface (colour)		
External glassiness			Fruit abscission	Sugar spots
Visual quality of foliage			Dried fruits	Chilling injury (grey (under)peel)
Fungal growth on fruit			Cracked fruits	
			Frozen fruits	

Table 6, quality aspects analyzed for chilled lamb meat and lily bulbs.

Lamb meat	**lily bulbs**
Firmness	Plant length (mean)
Smell	
General impression (esp. color)	Plant length (variance)
Drip	
pH	Number of buds
Texture	Aborted buds
Colour	Leaf damage (freezing)
Rancidity	
Microbial counts for total Aerobic mesofile bacteria, Lactic acid bacteria, Enterobacteriacae and Pseudomonas spp.	Malformed leafs Burnt leaves

5 Overview of labscale produce research results

The tables in this section summarize the quality evaluations of the labscale research. Each table presents the quality analysis results for one commodity performed at the end of simulating transport and the subsequent shelf life conditions. Each row shows the results for one quality aspect.

The meaning of all colours in this section's tables:

green = no statistical difference as compared to reference temperature.
red = statistically significantly worse than reference temperature.
bright green = statistically significantly better than reference temperature.
yellow = not included in experimental setup
white = quality aspect not measured

Table 7, banana quality after simulation of transport + shelf life.

after shelf life simulation	**reference -3 °C**	**profile 1**	**profile 2**	**reference+3 °C**
Chilling injury (dull grey)				
External colour				
Sugar spots				

Table 8, pineapple quality after simulation of transport + shelf life.

after shelf life simulation	**reference -3 °C**	**profile 1**	**profile 2**	**reference+3 °C**
External colour				
weight loss				
soluble solids				
firmness				
internal colour (discoloration / glassiness)				
cut surface (fungal growth)				
external glassiness				
visual quality of foliage				
fungal growth on fruit				

For iceberg lettuce, grape and kiwi the quality aspects are not scored for the *reference* -3 °C temperature treatment. Reason is that these produces suffered distinct freezing injury at *reference* -3 °C (Fig. 12). This is sufficient evidence that transport at reference – 3 °C would be completely unacceptable for those commodities.

Fig. 12, transport simulation at reference temperature (upper row) and reference - 3 °C (lower row) with clear freezing injury.

Table 9, iceberg lettuce quality after simulation of transport + shelf life.

after shelf life simulation	**reference -3 °C**	**profile 1**	**profile 2**	**reference+3 °C**
weight loss				
cut surface (colour)				
decay + wilting				

Table 10, grape quality after simulation of transport + shelf life.

after shelf life simulation	**reference -3 °C**	**profile 1**	**profile 2**	**reference+3 °C**
weight loss				
decay				
stem colour				
fruit abscission				
dried fruits				
cracked fruits				
frozen fruits				

Table 11, kiwi quality after simulation of transport + shelf life.

after shelf life simulation	**reference -3 °C**	**profile 1**	**profile 2**	**reference+3 °C**
weight loss				
firmness				
stem-end rot				
other decay				
soluble solids				

internal glassiness				

For lamb meat the reference – 3 °C temperature treatment was excluded from the experiment. The motivation is that it was known in advance that only a little below -1.5 °C meat will start to freeze, resulting in unwanted quality loss due to drip. Firmness is used as an indicator of freezing, obviously after shelf life simulation the meat is not frozen. That's why firmness is only measured after transport, and not after the shelf life simulation.

Table 12, lamb meat quality after simulation of transport + shelf life.

after shelf life simulation	reference -3 °C	profile 1	profile 2	reference+3 °C
firmness				
smell				
general impression (esp. colour)				
drip				
pH of drip				
texture				
colour				
rancidity				
Aerobic mesofile bacteria				
Lactic acid bacteria				
Enterobacteriacae				
Psuedomonas spp.				

For lily bulbs the experimental setup and moments of quality evaluation have been slightly different. The bulbs have been subjected to 4 weeks of transport simulation in our climate rooms, then half of them were planted in a glasshouse, the other half of them were stored for another three months and only than planted. Quality evaluation for both plantings has been done after about three months of growing, just before the plants start to flower. So in fact not the bulb quality was scored, but the quality of the plants grown from the bulbs. The results for the 2nd planting, believed to be the most critical one, are shown in the three tables below.

Table 13, lily bulb (cv. Simplon) quality after simulation of transport, followed by another three months storage and three months growing.

after 2nd planting	reference -3 °C	profile 1	profile 2	reference+3 °C
plant length (mean)				
plant length (variance)				
number of buds				
aborted buds				
leaf damage (freezing)				
malformed leaves				

burnt leaves				

Table 14, lily bulb (cv. Tiara) quality after simulation of transport, followed by another three months storage and three months growing.

after 2nd planting	reference -3 °C	profile 1	profile 2	reference+3 °C
plant length (mean)				
plant length (variance)				
number of buds				
aborted buds				
leaf damage (freezing)				
malformed leaves				
burnt leaves				

Table 15, lily bulb (cv. Conca d'Or) quality after simulation of transport, followed by another three months storage and three months growing.

after 2nd planting	reference -3 °C	profile 1	profile 2	reference+3 °C
plant length (mean)				
plant length (variance)				
number of buds				
aborted buds				
leaf damage (freezing)				
malformed leaves				
burnt leaves				

6 Discussion

Unsurprisingly, the produce quality results confirm that constant temperatures 3 °C below or above reference temperature have a distinct adverse effect on produce quality (see all the red fields in the left and right columns in Table 7 - Table 15). When transported at reference – 3 °C disastrous freezing injuries were observed for all commodities tested in the temperature segment around 0 °C (Fig. 12). For bananas serious chilling injury was observed for average temperatures below reference temperature.

It is interesting to observe that for pineapple, with reference temperature 6.5 °C, there is no adverse effect of 3 °C below reference temperature during the whole shipping simulation (Table 8), while there is a distinct adverse effect of 3 °C above reference temperature.

Not only too low temperatures harm produce quality, also 3 °C too warm temperatures have a well-noticeable negative impact (preventing warm temperatures is the reason for existence of refrigerated transport!).

6.1 Effect of temperature profiles

The extreme temperature profile has an adverse effect on pineapple in terms of firmness (Table 8) and on lily bulb quality in terms of burnt leaves in one of three cultivars in one of two plantings (Table 13).

Apart from weight loss the severe temperature profile has some positive effects and one negative effect. Though statistically significant these effects are too small to be relevant (not shown).

weight loss

The only consistently negative effect of the severe temperature profile is the increased weight loss (Table 8 - Table 11). What causes this increased weight loss:

1. The experimental set-up in which air flow through the cartons in the two temperature profile rooms is higher than in the other rooms?
2. Do the relative humidity variations induced by the temperature variations increase the weight loss?
3. Other factors?

In the Quest II implementation there are not only supply air temperature variations, but also fan speed reductions once heat load reduces. These fan speed reductions are not simulated in the labscale produce quality experiments. Therefore, it was decided to measure weight loss in some of the field trials. In 12 containers (6 Quest II, 6 non-Quest) weight loss was measured in four cartons: 2 from the lower tier at the unit end, one from the centre of the stow and one from the top-tier at the door-end. In six banana containers at 13.5 °C the observed weight loss is around 0.5%, in two citrus containers at 6.0 °C the weight loss is around 2%, in 4 pineapple containers at 6.5 °C the weight loss is around 3.5%. In the pineapple and citrus containers a clear trend occurs: weight loss in the warmest cartons (upper tier at door-end) is two to three times higher than in the coldest cartons (lower tier unit-end). Unfortunately, after all the effort spent on this the differences between Quest II and non-Quest are inconsistent: in Quest II containers the weight loss is about 0.2% larger for bananas, 0.3% larger for citrus, but 0.4% smaller for pineapples. The available results justify the conclusion that the Quest II effect on weight loss might be positive or negative, but will in any case be limited.

6.2 Relating the produce quality results to the Quest II methodology

Avoid hot spots. For all investigated commodities a constant temperature of reference + 3 °C has a distinct adverse quality effect. Hence Quest II should only start to save energy on internal air circulation if heat load is low.

Fluctuating supply air temperatures. None of the commodities suffered any negative effect from the severe temperature profile (profile 1). Also, QUEST II stays on the safe side (Fig. 13). It uses shorter cycle periods than profile 1 and therefore its temperature profiles are milder than those imposed in the severe temperature profile. Quest II temperature profiles are not milder in terms of the temperature profile's amplitude, but in terms of frequency (faster cycles are better dampened by the packaging's thermal inertia).

<u>Coldest acceptable time-averaged supply temperature</u>. In some temperature segments chilling and freezing injury easily occur and/or have very strong effects. Therefore prolonged periods with supply temperatures below reference temperature are to be avoided in those temperature segments. In other temperature segments too warm temperatures seem more harmful than too cold. Based on these observations Quest II aims to control the average of supply and return temperature to the reference temperature, while obeying a set lower limit for time-averaged supply temperature. The time-averaged supply temperature will reduce to minimally reference temperature – 1 °C if return temperature is above reference temperature + 1 °C. However Quest II will not reduce time-averaged supply temperature below reference temperature if the reference temperature is below +1 °C or between +12 and +15 °C.

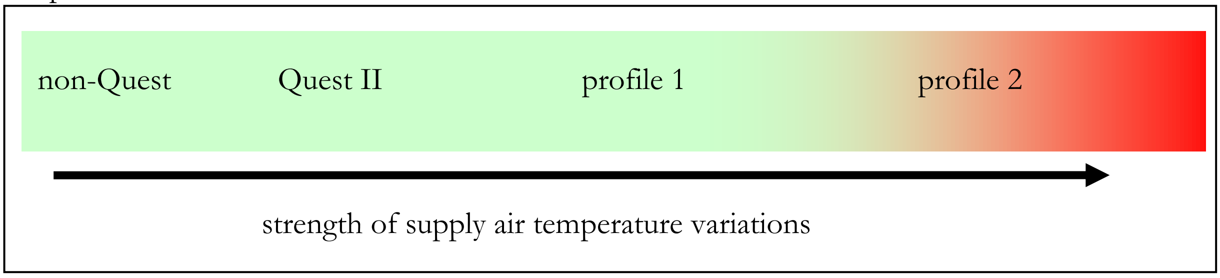

Fig. 13, classification of four different supply air temperature regimes (green = no harm to produce quality, red = produce quality harmed).

7 Conclusions

Extensive produce quality research inspires confidence to the safety of applying Quest II. The tests provided no evidence that Quest II might have an adverse effect on produce quality. Also, the limits found in the produce quality research, were used in the design of Quest II, in order to make sure that Quest II stays away from those limits.

8 References

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