AGROTECHNOLOGY & FOOD INNOVATIONS
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QUEST

Quality and Energy Efficiency in Storage and Transport of agro-materials

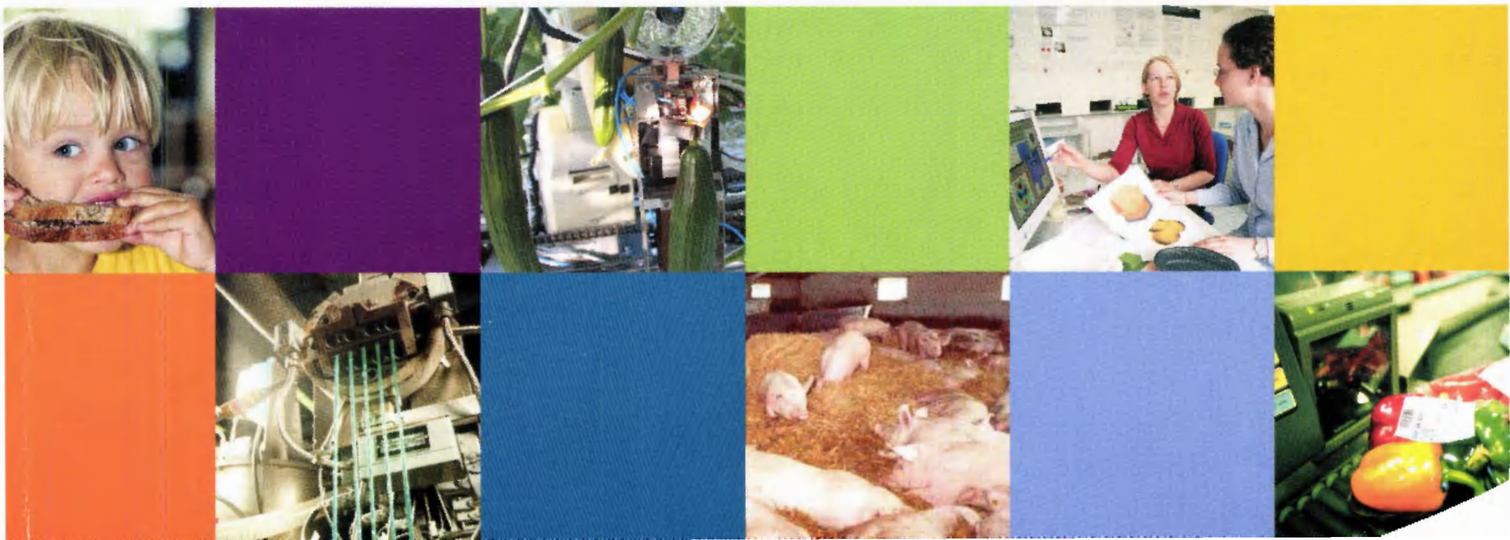
Progress report

March 2005 - August 2005

Consortium

Agrotechnology & Food Innovations
P&O Nedlloyd B.V.
Carrier Transicold, Container Products Group, Division of Carrier Corp.
Carrier Transicold Ltd.
The Greenery B.V.
Frugi Venta
Haluco B.V.
R&R Mechatronics B.V.

Report 555



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Content

1 Progress

1.1 Activities in relation with planning last half year

The main activities in the different tasks in the third half year of the Research phase were the following:

1. Selection of products and markets

In the summer of 2005 PONL was acquired by AP Moller. PONL will be incorporated in the AP Moller company Maersk Sealand (Maersk lines). Maersk is active as container shipper; it is the biggest company in the market. At the start of the summer of 2005 this was causing customers of PONL to be very conservative to participate in trails with PONL. They would rather wait until the incorporation of PONL in Maersk organization was complete. It is the intention to test and use the in Quest developed techniques together with Maersk. For this an addendum is signed by all partners to make this possible.

2. Market introduction strategy

No actions until successful trail

3. Predictive models

a. Climate models

In this half-year the distribution model is calibrated, the coupled models are validated. After that a series of simulations are run to predict temperature and humidity distribution throughout the container. Also, the microclimate model will be extended to a complete pallet, and will be incorporated in the coupled model in the last part of the project.

In the last half year the calibration of the network model was finished. The results obtained from the model are now comparable with the experimental results within the limits of accuracy. Calibration was done by changing various parameters in the model within the reasonable limits, to obtain the best possible results. Also, a sensitivity study was done to investigate the influence of changes in various parameters to the model output.

The combined unit- and network model was tested and the first result of these test also look quite well. In the last period both models will be validated, using another dataset.

Microclimate model: a coarse-graining methodology has been developed to transform a very detailed model on the level of a single product inside a packaging, to a coarse model for a complete pallet consisting of a multitude of packaging with produce – essentially containing a single *ordinary differential equation* describing the evolution of temperature and humidity inside the pallet. The coarse-graining is based on the local volume-averaging method, as frequently used in porous media theory. As the mathematics as very involving these results are not shown here, but are available in various theses of Masters of Technological Design, Mathematics department, University Eindhoven (N. Nishchenko, 2004; Botha & Rychahivskyy, 2004; Babych & Kopinga, 2004).

In essence at each next hierarchical level of i) packaging, ii) pallet-layer, and iii) complete pallet – the system is approximated as a porous medium. Via this coarse-graining methodology there is a direct relation between physical parameters (like product diameter, heat capacity, airflow rate, vent hole opening, packaging material etc) and the heat and mass transport. Only a few assumptions have been made, and the coarse-grained models have been tested against detailed CFD-models as much as possible. In the coming period the coarse-grained model will be incorporated in the network model, describing the macroclimate inside the whole container. As the models builds upon several levels of coarse-grained models, and a few assumptions the model has to be validated – also an action for the coming period.

b. Product regular tests

In the third avocado experiment and in the first banana experiment energy saving as well as improving product quality by application of fluctuating temperatures, was investigated.
For avocado all tested fluctuations were applicable, providing savings in energy expenditure, and in several cases immediately after transport leading to some quality improvement (less colour and less loss of firmness). A longer transport time was possible with fluctuations and it was also possible to store the avocados at a lower constant temperature (3.0 °C or 0.5°C) for a period of up to 6 weeks, without development of more internal problems than observed at the standard condition (5.1°C).
For banana's the standard transport temperature is 13°C. A transport simulation at fluctuating temperatures with an average of 13°C caused slightly negative effects on the product quality after 2 and 5 days of shelf life. Simulations with or without fluctuations lower than 13°C may have negative effects on quality parameters at the start of shelf life or during shelf life. In the next experiment concerning banana's the effect of fluctuating temperatures above 13°C will be involved.

c. Avocado ripening model

The avocado ripening model part that describes the ethylene response to time and temperature was calibrated on the ripening data collected from the batch experiments with Spanish avocados. Reasonably good fits could be found, using a single set of precursor parameters (Ep0 and Ep20) for all four different temperatures and a linear or Arrhenius dependent function of the rate parameters (ke and ke2). Currently, comparable fits are made on the data of South African avocado's which had a longer transport time.

4. Monitoring system

Last half year the respiration system is updated with a gas chromatograph (GC). The GC is specially calibrated for ethylene and is able to take samples with a frequency of 0.0033Hz (every 5 min one sample). The GC measures the ethylene concentration parallel with the 'popular' ethylene sensor, for fundamental research high quality measurements are important for validation and predictions of the product model.

5. Control system

For controlling the ripeness of avocado two controllers have been designed:
1. a controller which uses one temperature for the entire horizon and
2. a controller which can realize a custom trajectory for the firmness.
The first controller was discussed in the progress report for EET of March 2005. The second controller uses optimal control strategies to manipulate the temperature to realize a custom firmness trajectory. Both controllers are model based end use a conservative first model. When a better model comes available, the controllers will be validated by simulations and implemented in the respiration setup.

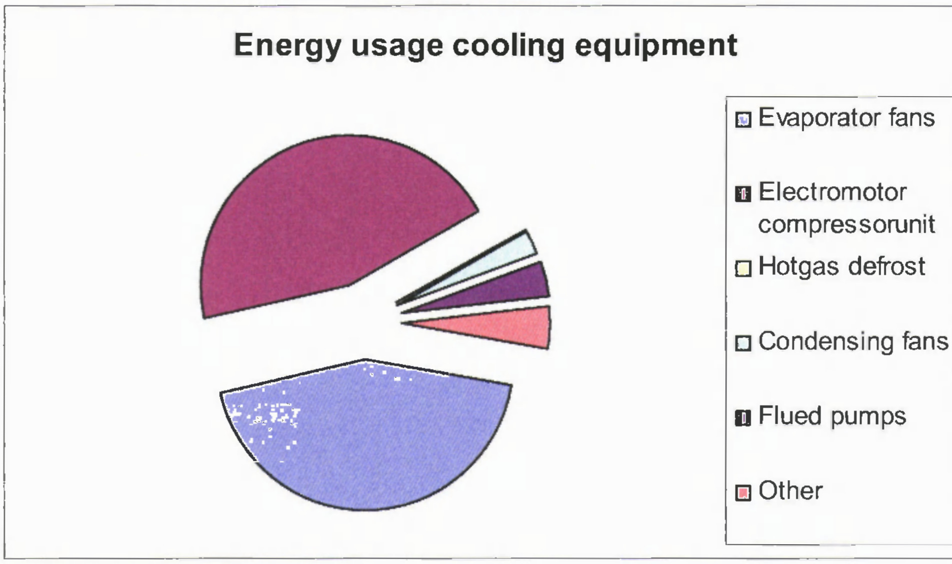
Carrier has implemented the Quest Regular protocol in their embedded control software. Various tests were performed in-house, for functionality and interaction with other control options. Also, the software was given to A&F on a data stick. A&F was able to easily download the software on the reefer unit. Various settings were tested, above and below 0°C. All settings performed well and the necessary data could be stored and read. Data from A&F sensors and the unit sensors were comparable. Results were discussed with Carrier and it was decided to make the following improvements:

- Setting 'pdlim' would also be made functional in case it is set higher then the low boundary for return temperature.
- Default values will be added, which are a function of a chosen normal operation setting of the setpoint, but can be adjusted by the user.

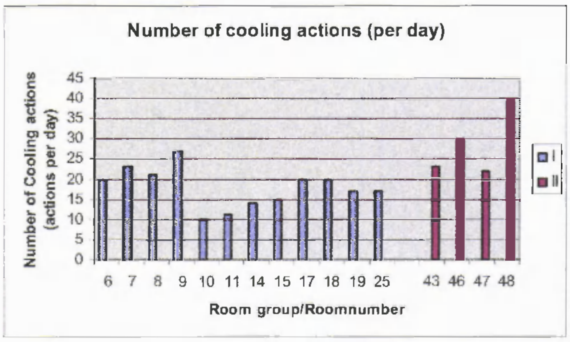
Also, Carrier is considering adding power data instead of just voltages and amperages, by using the necessary phase shift measurements. Finally, we are considering on how to handle high heat loads which could cause the unit to keep cooling on the low inlet air setpoint, since the lower boundary is not reached.

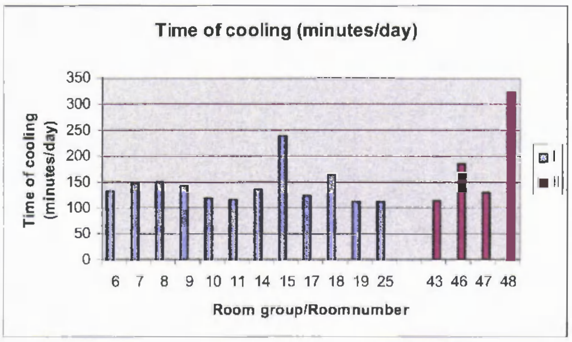
6. Practical guidelines
No actions until successful trail.

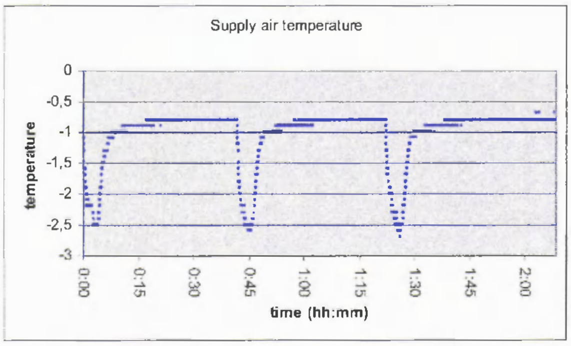
7. Chain information and technology transfer
In the last half year most work of part is done as a deskstudy. Measurements for aircirculation combined with specific energy use measurements will be done at different locations in the next months. We expect that depending on the location and the way of controlling the aircirculation an enormous energy reduction can be reached. To show the importance of the energy use of several parts of the Greenery cooling equipment the below figure is made.

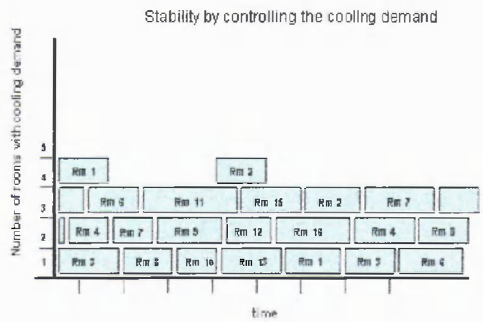


At one Greenery location a study of the number and time of cooling action is made. Because of the different systems at this location some difference in numbers as well as time of cooling actions is measured.









To find some comparison with reefer containers a study is made of the supply airtemperature in a Greenery storage facility. With the on-off cycling we find a difference in supply air showed in the below graph.

To lower the energy consumptions we have studied the possibility to stabilize the pressures in the central cooling equipment by controlling the cooling demand. The aim is to optimise the stability of the pressures by realising a stable number of cooling actions and cooling time on any moment.

1.2 Cost in relation with planning last half year

The costs realized in the period from 1 March 2005 to 1 September 2005 are € 271.299,-- and the requested subsidy is € 158036,--.

1.3 Milestones next half year

The milestones for the final 3 months of the project are:

Predictive models

- Quest Regular
  - Extended research on set-points for banana
  - Microclimate stack model development & testing
  - Combined model validation, simulations & conclusions
- Quest Pro:
  - Develop ethylene path estimator
  - Validate and extend avocado ripening model
  - Testing of Lab-scale setup and ethylene path estimator with avocado

Monitoring system

- Testing and use of ethylene measurements of the GC in the lab-scale setup

Control system

- Avocado ripening controller testing
- Simulations with controllers using the new model
- Implementation and testing of avocado ripening controller, using GC measurements

Testing and integration

- Pilot organization after project
- Test Quest-pro lab scale (at A&F)

2 Results

2.1 Main results

2.1.1 Product research

2.1.1.1 QUEST Regular

In this section the results of the third avocado and the first banana experiment are reported.

The experimental set-up as described in EET report 448 (every product is subjected to at least the following treatments: i) normal storage temperature, ii) temperature below the normal storage temperature, iii) temperature above the normal temperature, iv) fluctuating temperature with which extra energy savings are to be expected (profile 1). Furthermore cycling conditions were chosen aiming at optimisation of the deep cooling cycling regime (profile 2 and 3), while leading to potential quality improvement of the product, with respect to longer storageability. The constant temperature above the normal temperature was not applied.

In these treatments temperature refers to the temperature of the air around the product. After the chosen storage periods the product's quality was examined and examination was repeated after a shelf life period. The temperatures in the experiments were based on expert knowledge and model simulations on container scale. The model predicts the climate in the load, headspace and T-bar floor, based on specific temperature ranges, package and product. From these values an estimate for the temperature fluctuations was made.

The first avocado experiment described in Progress Report 448 indicated that application of temperature fluctuations might lead to some quality improvement, and in the second avocado experiment it was investigated whether these improvements were lying in an extension of the shelf life period. In the third avocado experiment (described below) it is investigated if the possibility for prolongation of the transport time exists.

Avocado 3

The third avocado experiment was performed with the cultivar Hass as well. The product was transported from Spain (just as was the case in the second avocado-experiment) by van. The experiment was started within 5-6 days after picking. Harvesting began late November, and the avocados we used were harvested in April. This is a late harvest and we were informed that the quality was not optimal anymore. A 23–44 days transport simulation was performed. Sampling took place immediately after 3, 4, 5 and 6 weeks of transport simulation, each of which was followed by 4 days of shelf life after which sampling took place again. Standard storage temperature was 5.1°C.

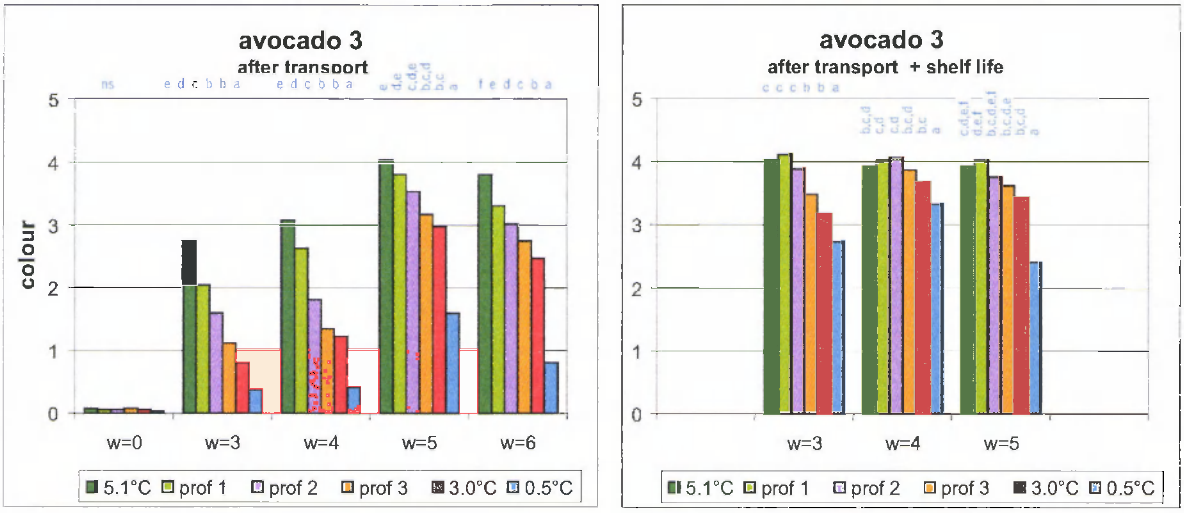
Three cycling experiments were performed:
a) cycling between 7.0°C to 1.6°C; with 30 min(utes) cooling of which 5 min constant at 1.6°C, followed by switching the cooling off for a period of 100 min (profile 1);
b) cycling between 6.8°C to 0.1°C; with 75 min cooling of which 20 min constant at 0.1°C, followed by switching the cooling off for a period of 170 min (profile 2);
c) cycling between 6.8°C to 0.1°C; with 245 min cooling of which 185 min constant at 0.1°C, followed by switching the cooling off for a period of 295 min (profile 3).
Furthermore transport simulation at 3.0°C and 0.5°C was performed.

The following quality parameters were examined: colour (class 0-5, with 0 is green, 5 is brown), firmness (class 0-5, with 0 is hard, 5 is soft), internal discolouration (grey discolouration which can be a result of low temperature injury, and browning).
The temperatures that were reached during the various transport simulations are presented in Table 1.

Table 1. Temperature of the air around the product, as recorded by Escort dataloggers, during transport simulation.

Transport at	mean temperature (°C)	standard deviation (°C)
5.1°C	5.2	0.7
profile 1	4.6	1.5
profile 2	4.2	2.0
profile 3	3.1	2.2
3.0°C	3.1	0.3
0.5°C	0.5	0.1

Figure 1–3 show the colour and firmness development of the avocados as well as the occurrence of grey and brown discolouration inside the avocados.
Colour development is presented in Figure 1, and as expected avocados became browner when transport time increased. Not surprisingly there was also a temperature effect visible: colour development was slower at a lower temperature. Immediately after transport simulation all applied fluctuations showed less colour development than observed at the standard condition After shelf life only small differences were visible in colour development, in all cases (except for transport at 0.5°C) the final colour was between 3 and 4.

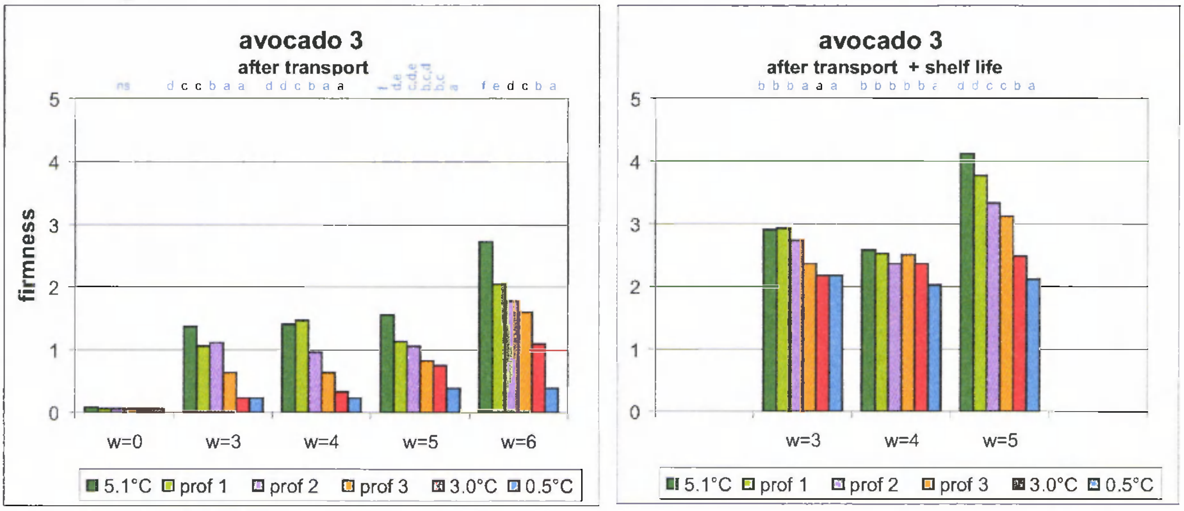


1a. Colour development after 3, 4, 5 and 6 weeks of transport simulation (w=0: colour at start of transport simulation)

1b. Colour development after 3, 4 and 5 weeks of transport simulation, each followed by 4 days of shelf life

Figure 1 Changes in colour as a result of transport and shelf life simulation using avocados as a test product. Bars with different letters (within one sampling time) are significantly different at a 5% level.

Changes in avocado firmness as a result of transport simulations are presented in Figure 2. Avocados became softer when the transport time increased. In firmness there was also a temperature effect visible: softening was slower at a lower temperature. Immediately after transport simulation avocados from all applied fluctuations were less soft (or equally soft) compared to the avocados stored at the standard condition After shelf life only minor differences in firmness were observed. This indicates (together with colour development after shelf life) that ripening proceeded well after application of the temperature fluctuations, or after storage at a lower temperature.

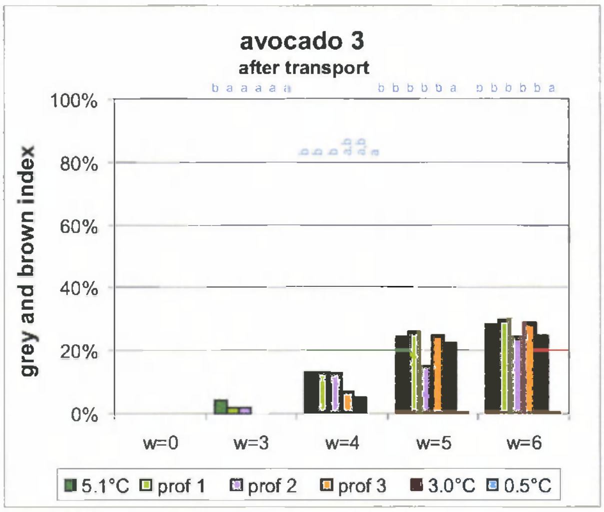


2a. Firmness development after 3, 4, 5 and 6 weeks of transport simulation (w=0: colour at start of transport simulation)

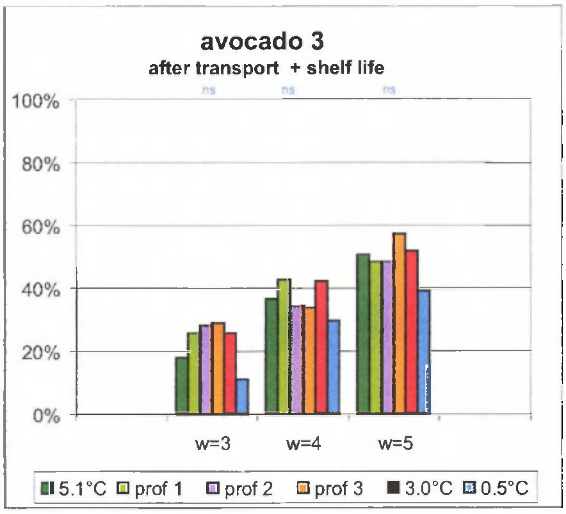
2b. Firmness development after 3, 4 and 5 weeks of transport simulation, each followed by 4 days of shelf life

Figure 2 Changes in firmness as a result of transport and shelf life simulation using avocados as a test product. Bars with different letters (within one sampling time) are significantly different at a 5% level.

Figure 3 shows that after 3 weeks of transport simulations a minor internal grey and brown discolouration was observed at 5.1°C and with profile 1 and 2. This was not observed at the lower temperatures and profile 3. The problem increased at prolonged transport time and after shelf life. After 4 weeks of transport simulation the grey and brown discolouration in avocados receiving the applied fluctuations did not differ from the standard temperature, only avocados stored at 0.5°C had significant less problems. After shelf life differences were not significant anymore.



3a. Internal grey and brown discolouration after 3, 4, 5 and 6 weeks of transport simulation (w=0: colour at start of transport simulation)



3b. Internal grey and brown discolouration after 3, 4 and 5 weeks of transport simulation, each followed by 4 days of shelf life (ns= not significant)

Figure 3 Changes in grey and brown discolouration as a result of transport and shelf life simulation using avocados as a test product. Bars with different letters (within one sampling time) are significantly different at a 5% level.

There were hardly any differences in colour and firmness development immediately after transport simulation and after shelf life. Application of temperature fluctuations resulted in a slower colour and firmness development, this was associated with lower temperature. After 4 days of shelf life differences in colour and firmness were smaller or had disappeared. Internal discolouration was observed, which increased in time, and was not visible during transport at 0.5°C. After shelf life the problem was visible in all treatments. It is not sure whether the observed internal grey and brown discolouration is a result of chilling injury or not. It might be due to the fact that late season avocados were used.

Therefore, all tested fluctuations were applicable for avocado, providing savings in energy expenditure, and in several cases immediately after transport leading to some quality improvement (less colour and firmness). A longer transport time was possible with fluctuations and it was also possible to store the avocados at a lower constant temperature (3.0 °C or 0.5°C) for a period of up to 6 weeks, without development of more internal problems than observed at the standard condition.

Banana 1

The first banana experiment was performed with the cultivar Giant Cavendish. The product was transported from Panama by boat. The banana's were transported at 13°C. The experiment started 18 - 22 days after picking. A 14 days transport simulation was performed. Standard storage temperature was 13.1°C. Two cycling experiments were performed:
a) cycling between 14.6°C to 11.1°C; with 75 min(utes) cooling of which 20 min constant at 11.1°C, followed by switching the cooling off for a period of 120 min (profile 1);
b) cycling between 13.2°C to 9.6°C; with 70 min cooling of which 20 min constant at 9.6°C, followed by switching the cooling off for a period of 110 min (profile 2);

Furthermore transport simulations at 13.1°C, 11.5°C and 8.0°C were performed. After the transport simulations the banana's were ripened during 6 days. After 7 days of ripening the banana's that were stored at 13.1°C (standard temperature) were in colour stage 4-5, which is the optimal colour for the start of shelf life. After ripening the banana's were exposed to a 5 days' shelf life.

The following quality parameters were examined.

- External:
- Colour (class 2-6: 2 is green, 6 is yellow),
- Grey discoloration, dull kind of grey (grey-index 0 – 1: 0 is no grey discolouration, 1 = > 75% of surface discoloured) and
- Sugar spots (0-7, 0 = no sugar spots, 7 = > 60 sugar spots per banana.
- Internal:
- Discolouration under the skin (one banana per cluster, before ripening).

The temperatures during the various transport simulations are presented in Table 2.

Table 2. Temperature of the air around the product, as recorded by Escort dataloggers, during transport simulation.

Transport at	Mean temperature (°C)	standard deviation (°C)
13.1°C	12.9	0.5
profile 1	12.8	2.3
11.5°C	11.5	0.2
profile 2	11.3	2.6
8.0°C	8.4	0.6

Grey discolouration under the skin

After the transport simulations (before ripening) grey discolouration under the skin of all banana's was determined. This parameter is an indicator for chilling injury. It was also determined in the banana's stored at 13.1°C.

<u>Colour development</u>

Before the transport simulations the banana's were green according to stage 2. Colour development during transport simulation and shelf life is shown in Figure 4.

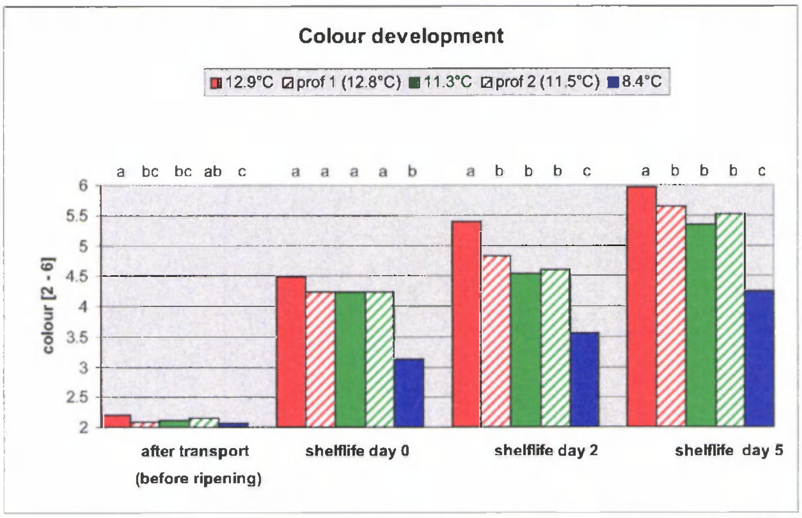


Figure 4 Banana experiment 1. Colour development (2 – 6) before and after ripening and after 2 and 5 days of shelf life.

It is shown that after transport there are some small significant, but not very relevant differences. After ripening (shelf life day 0) only transport at 8.4°C shows less colour development. After two and five days of shelf life all simulations show less colour development then the standard simulation; transport at 8.4°C shows less yellowing than all other simulations.

<u>External grey discolouration</u>

External grey discolouration was not observed before ripening. During ripening a dull kind of grey appeared on the banana's. Figure 5 shows the results before and after 2 and 5 days of shelf life.

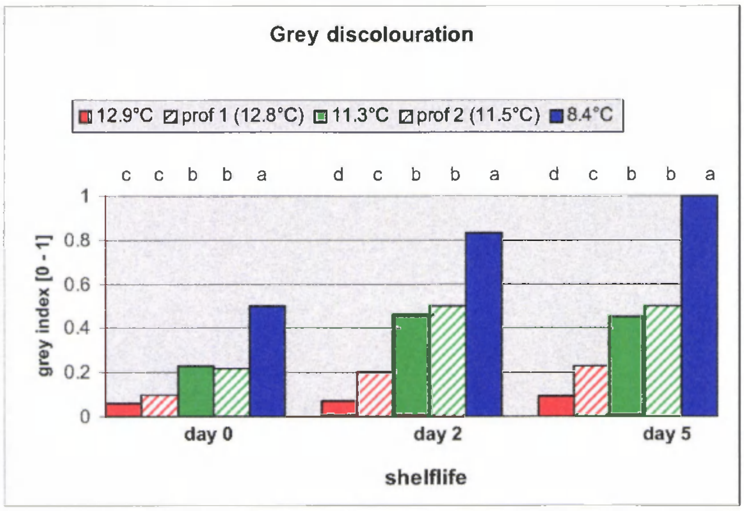


Figure 5 Banana experiment 1. Grey discolouration index (0-1) after ripening and after 2 and 5 days of shelf life.

It is very clear that there is more grey discolouration due to storage at a lower average temperature. After 2 and 5 days of shelf life, application of fluctuating temperatures (profile 1: average 12.8°C) caused more grey discolouration than storage at the constant same average temperature (12.9°C). No difference was found between storage at profile 2 (average 11.3°C) and the constant same temperature (11.5°C). Storage at 8.4°C caused more grey discolouration than all other simulations.

<u>Sugar spots (Figure 6)</u>

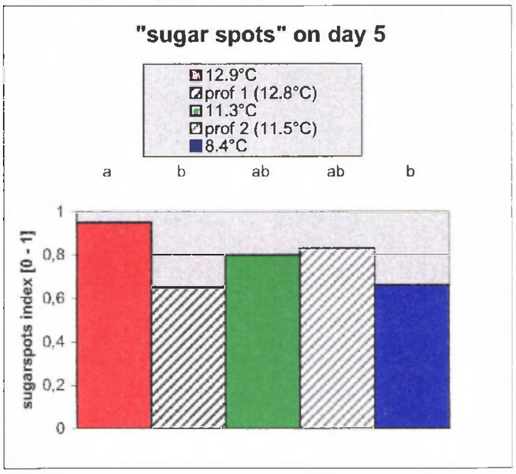


Figure 6 Banana experiment 1. Sugar spots on day 5 of shelf life.

Figure 6 shows some differences in the amount of sugar spots, however no relationship between temperature and sugar spots was found. It is clear that the amount of sugar spots does not depend on the colour stage of the banana's.

<u>In conclusion</u>: a transport simulation at fluctuating temperatures with an average of 13°C or with or without fluctuations lower than 13°C may have negative effects on quality parameters at the start of shelf life or during shelf life.
<u>Next experiment</u>: in the second experiment concerning banana's the effect of fluctuating temperatures above 13°C will be involved.

Simulation results

To validate the QUEST results simulations have been made over the most common temperature regime [1.5°C - 14.5°C]. To generate the data for the temperature regime the following products were used: apple (1.5°C), avocado (5.5°C), bell pepper (9.0°C) and banana (14.5°C). Each product was simulated twice for each set point temperature, one with a fluctuation of 1°C and one with a fluctuation of 2°C, a polynomial function was plotted trough these points. The ambient temperature was kept constant at 20°C and the container was feed with a tension frequency of 60Hz, see the left graph of figure 7.

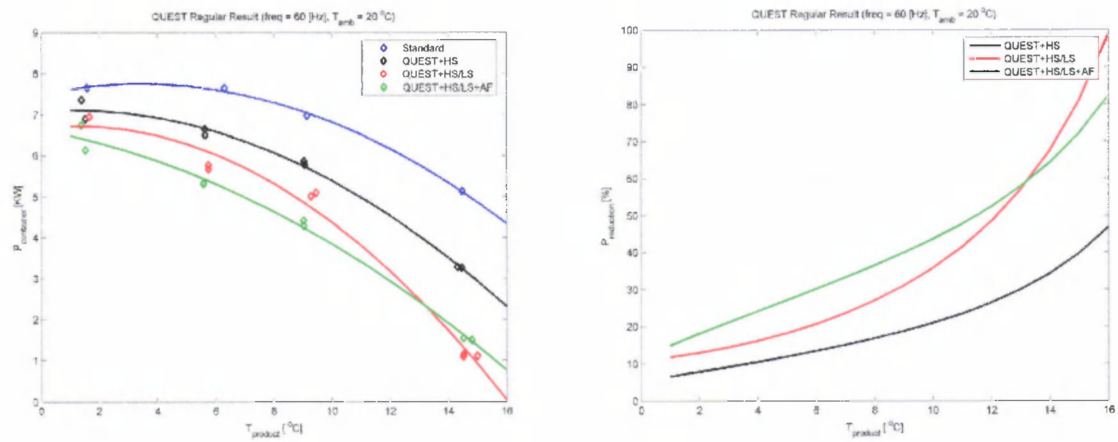


Figure 7 Figure 1: results QUEST regular, left: power consumption [kW], right: power reduction [%]

In the left graph of figure 1 the mean consumed power [kWh], during a steady state of one day, with a full container, is plotted versus the operation temperature [°C]. The different lines represent the different modes that are possible with a QUEST controlled container. The blue line in the graph shows how much power gets consumed during standard control (now-a-days temperature control) and is used as reference to compare with the QUEST solutions.
The comparison between QUEST and standard control is plotted in the right graph of figure 7. This graph shows the energy consumption reduction [%] of the different QUEST controllers in comparison with the standard control (positive means les energy than standard control) versus the operation temperature [°C]. From the figures can be concluded that the higher the setpoint temperature of the container is the more energy can be saved by using a QUEST controller. For bananas up to 80%.

2.1.1.2 QUEST Pro

2.1.2 Experiment setup

Experiment 1

Avocados (cultivar Hass) were harvested in September 2004 in South Africa and transported by CA-reefer to the Netherlands. Avocados were ripened individually at 15°C (21% O_2; RH ≥ 95%). After different ripening times (3, 4, 5, 6, 8 and 10 days) at 15°C, avocados were placed at 5°C Ethylene production of each individual avocado was measured daily. Ethylene levels were measured before and after an accumulation period. The ethylene production (pmol/kg.s) was calculated from the difference in ethylene level, the weight of the avocado and accumulation time. Quality parameters (firmness by hand and colour) were measured daily after the ethylene measurements. Firmness scale 0-5; were 0 = firm and 5 = soft. Colour scale 0-5; were 0 = 0% brown and 5 = 100% brown.

Inhibition of ripening on individual level

Ethylene production at 15°C and subsequently at 5°C is shown in figure 8. The effect of temperature decline on ethylene production is very clear during the complete ripening phase. Ethylene production can be reduced even after the maximum ethylene production (=climacteric peak) has been reached (10 days).

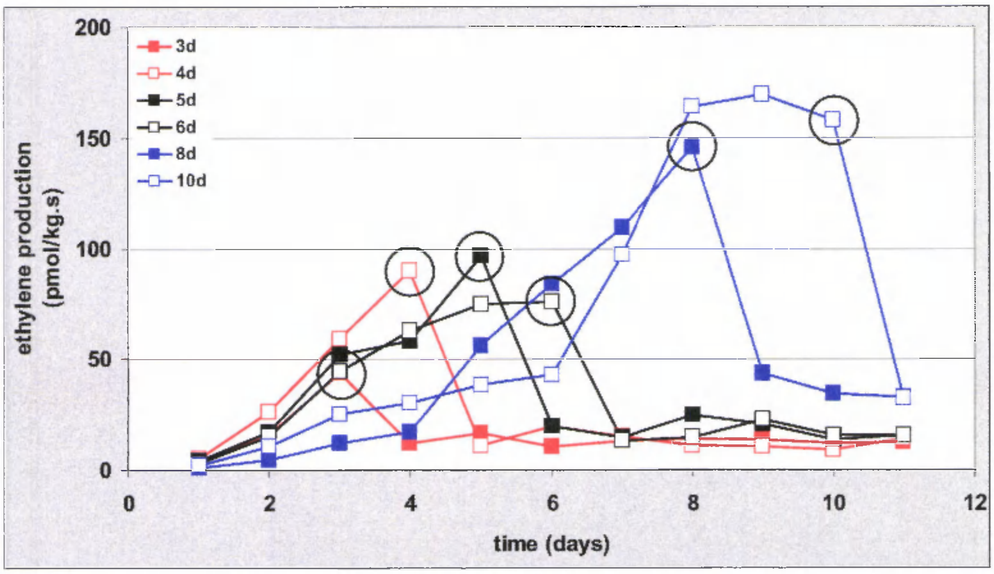


Figure 8 Average ethylene production (pmol/kg.s) of 30 avocados. Ripening was initiated at 15°C and inhibited at 5°C at various time points (days).

Firmness loss can be very effective inhibited during the first 8 days ripening at 15°C (figure 9), which is the period before maximum ethylene production is reached. No ripening data is available after 11 days. Therefore it is unclear whether a temperature decline after the climacteric peak had a large effect.

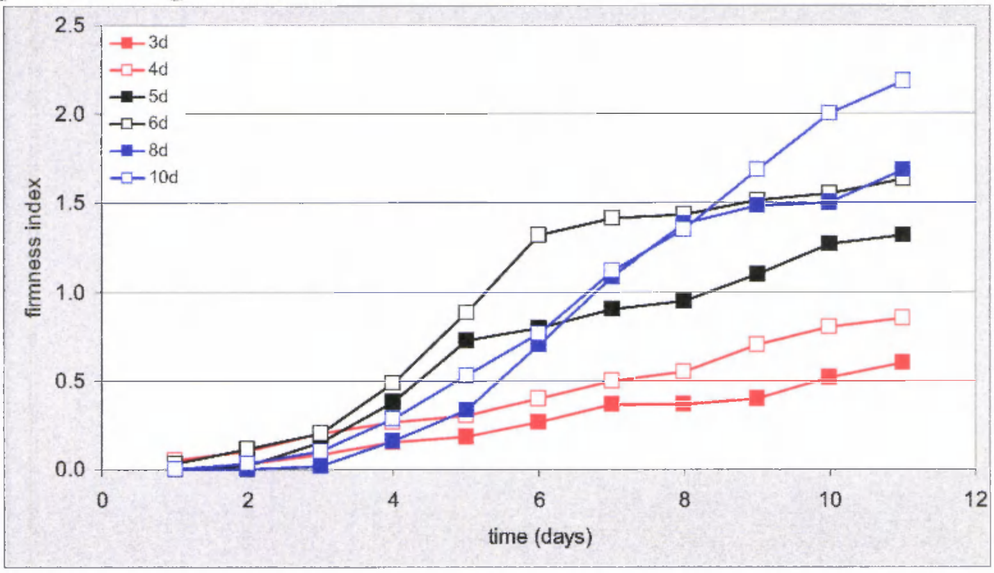


Figure 9 Average firmness development of 30 avocados. Ripening was initiated at 15°C and inhibited at 5°C at various time points (days).

Colour development was also inhibited by declining storage temperature (figure 10). However, after ripening was initiated at 15 °C colour development could not be stopped at 5°C.

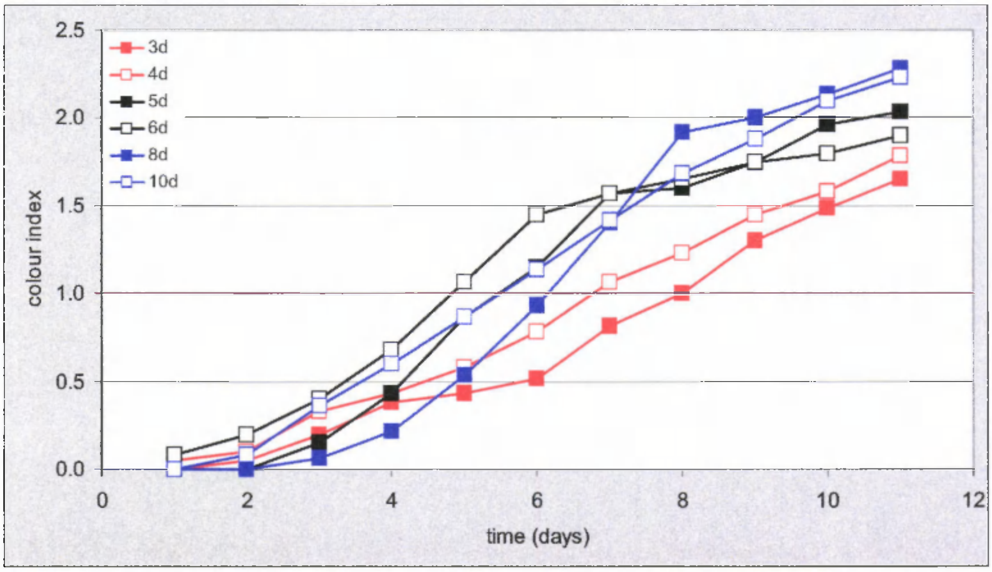


Figure 10 Average colour development of 30 avocados. Ripening was initiated at 15°C and inhibited at 5°C at various time points (days).

Experiment 2

Avocados (cultivar Hass) were harvested in January 2005 in Spain and transported by cooled truck to the Netherlands. Avocados (60 fruits per container) were ripened in 65-L containers at 5, 10, 15 and 20°C (21% O_2; flow rate 500 ml/min, RH = 95%). All ripening experiments were performed in duplicate. Ethylene levels of each container were measured using a small flask, which was placed at the outlet of each container. Ethylene levels were measured in a flow-through system 2-3 times a day (flow and CO_2 levels were monitored). Ideal gas law was used to calculate the ethylene production (pmol/kg.s). Quality parameters (firmness by hand and colour) were measured at different intervals depending on the ripening temperature.

Data from this experiment was used to test, whether the ripening model (based on data from individual fruits) could also be used to describe ethylene production and ripening (firmness loss and colour development) on batch-scale. In an additional experiment avocados, which were stored for 3 weeks at 5°C, were subsequently ripened at 20°C.

Batch ripening at 20°C

Ethylene production at 20°C rapidly increased after 24 h and reached a maximum level of about 900 pmol/kg.s in 3 days (figure 11). CO_2 levels sharply increased directly after transfer to 20°C, maximum level was reached in 2 days. The following decline in CO_2 levels was sharp and could easily be detected. Avocados ripened at 20 °C were ready to eat (firmness index = 3) in about 6 days.

Colour and firmness development of batches seem to give a good correlation, however on individual fruits this correlation is poor. For example, on individual fruit level a brown avocado (colour index 5) can still be firm (firmness index 1). In addition firmness loss can still develop while maximum colour is already reached (colour index 5).

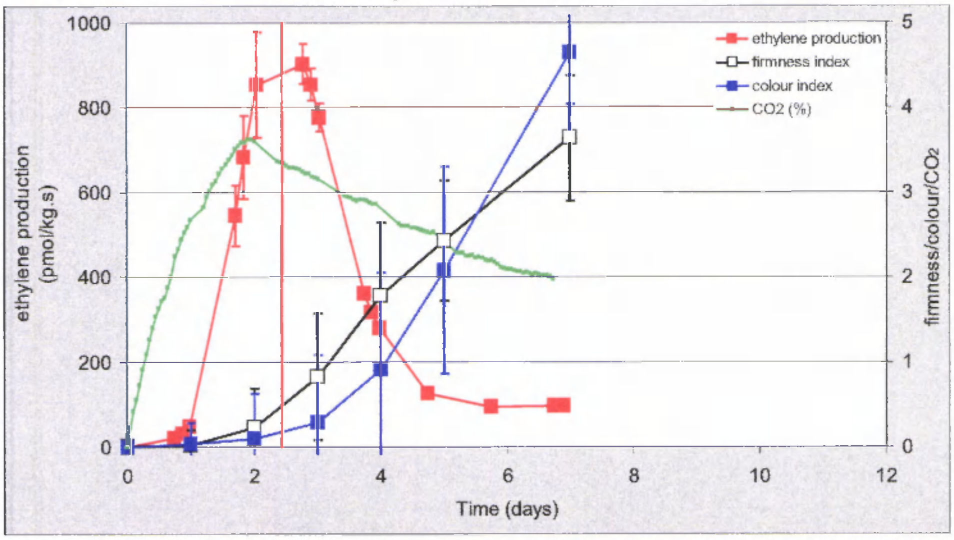


Figure 11 Average ethylene production (pmol/kg.s), CO_2 levels (%), firmness development and colour development of 2 batches avocados during ripening at 20°C.

Batch ripening at 15°C

The increase in ethylene production at 15°C started after 24 h and reached a maximum level of 800 pmol/kg.s in approximately 3.5 days (figure 12). CO_2 levels increased directly after transfer to 15°C, the maximum level was reached in 3 days and remained at this level the next 3-4 days. The decline in CO_2 levels at 15°C started several days after the maximum ethylene production has been reached in contrast to the decline in CO_2 levels at 20°C. Avocados ripened at 15°C were ready to eat in about 9 days. Average colour development preceded the average firmness development.

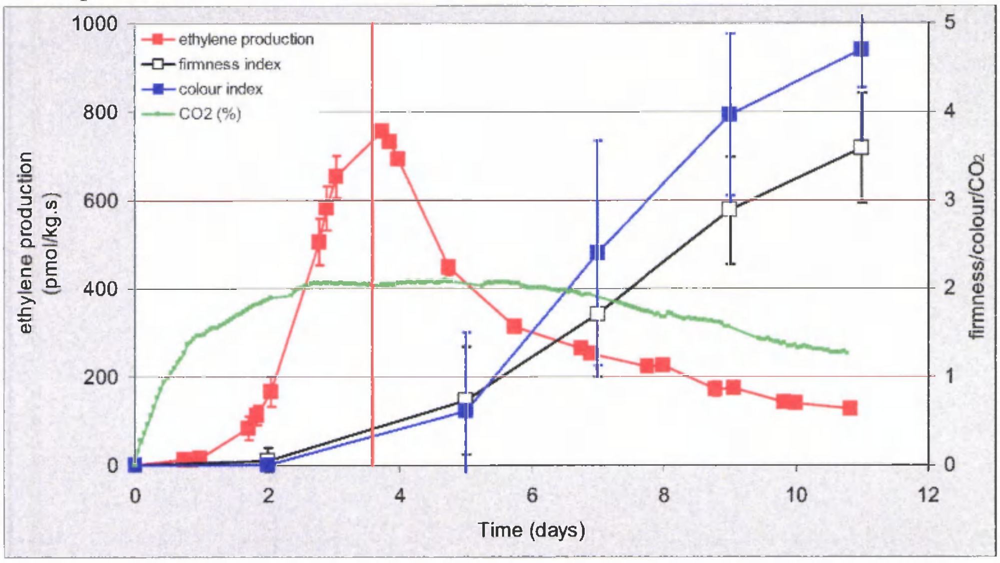


Figure 12 Average ethylene production (pmol/kg.s), CO_2 levels (%), firmness development and colour development of 2 batches avocados during ripening at 15°C.

Batch ripening at 10°C

The increase of ethylene production at 10°C was delayed compared to storage at 15°C and 20°C (figure 13). Ethylene production increased after 48h. The maximum ethylene production was reached after 6 days. The maximum ethylene production level is about 6 times lower compared to the maximum ethylene production 15°C. A sharp peak decline after the climacteric peak can not be observed. It is unclear, whether this can be explained due to a larger standard deviation in ripening of the individual avocados.

CO_2 increased at the start of ripening, but did not clearly decline. Therefore it is not possible to correlate the time at which the maximum CO_2 level is reached at 15°C to the time in which maximum ethylene production is reached. Avocados ripened at 10°C were ready to eat in about 17 days. Similar to 15°C, average colour development preceded the average firmness development.

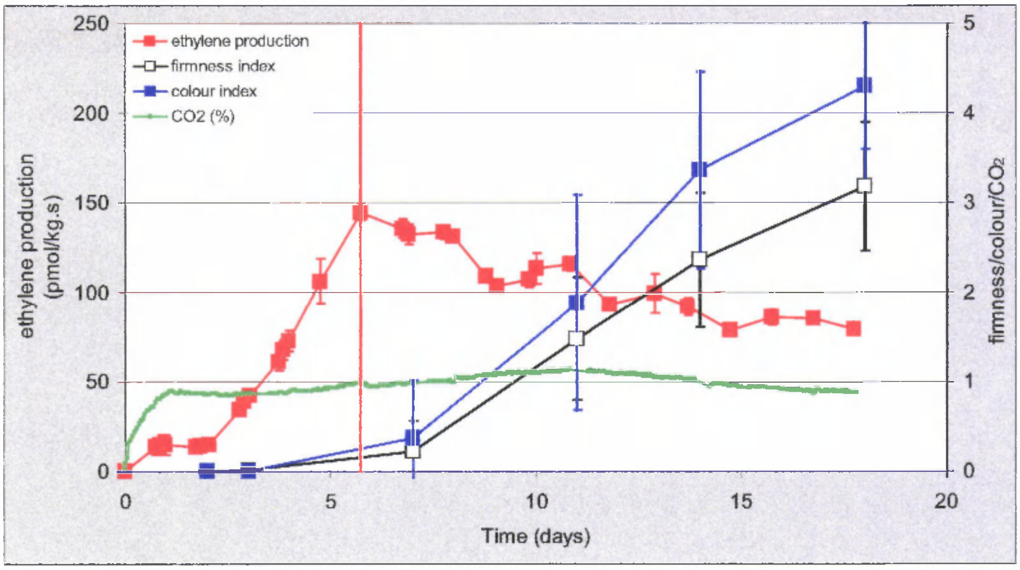


Figure 13 Average ethylene production (pmol/kg.s), CO_2 levels (%), firmness development and colour development of 2 batches avocados during ripening at 10°C.

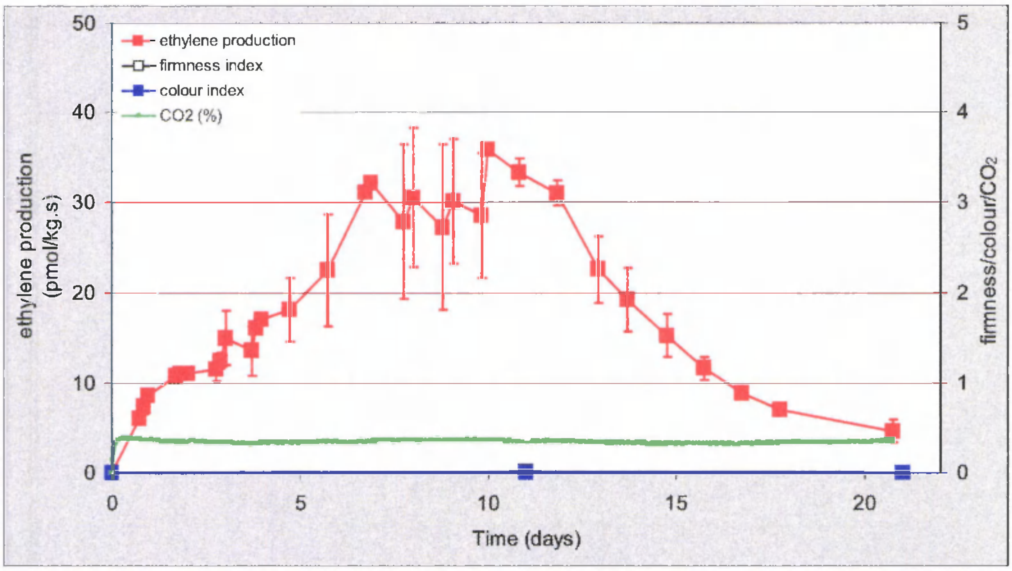


Figure 14 Average ethylene production (pmol/kg.s), CO_2 levels (%), firmness development and colour development of 2 batches avocados during ripening at 5°C.

Batch ripening at 5°C.

When avocados were stored at 5°C no colour development and firmness development could be observed (Figure 14). Maximum ethylene production was very low (40 pmol/kg.s). It seems likely that this level of ethylene production can not trigger the autocatalytic ethylene production. After 3 weeks storage at 5°C the level declined below 10 pmol/kg.s.

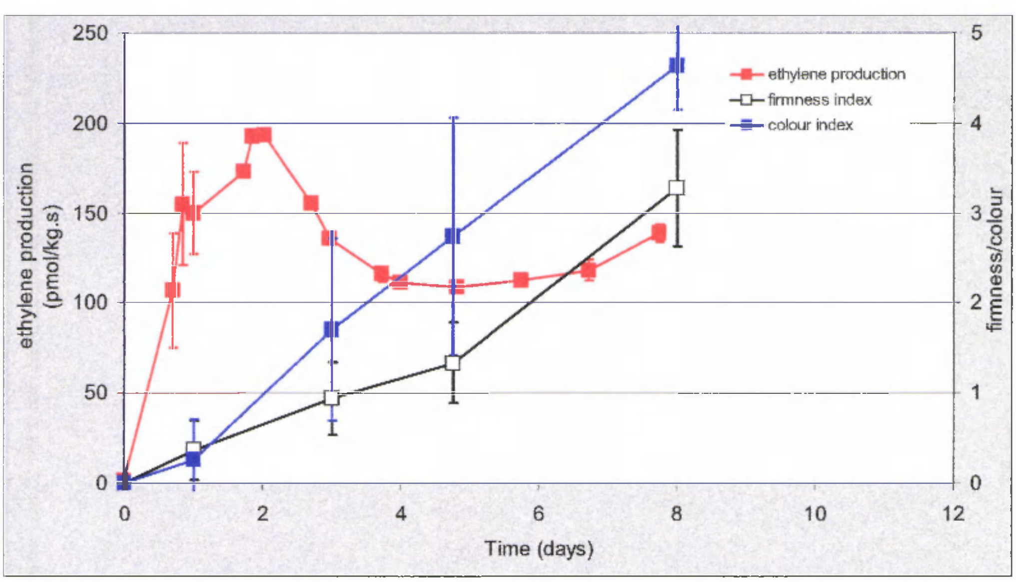


Figure 15 Average ethylene production (pmol/kg.s), firmness development and colour development of 2 batches avocados during ripening at 20°C. This batch was placed for 3 weeks at 5°C.

Although avocados do not ripen at 5°C, there is a large effect on ethylene production levels when the fruits are subsequently ripened at 20°C (figure 15). Ethylene production levels are 4 times lower compared to direct ripening at 20°C (see also figure 11). In contrary to direct ripening at 20°C colour development precedes firmness development.

Table 1. Ripening characteristics (maximum ethylene production (pmol/kg.s or days); 2nd increase in ethylene production (days); maximum CO_2 production (% or days); RTE = ready to eat (days)) of Hass avocados during ripening at various temperatures (°C).

	Ethylene production			CO_2 production		RTE
T (°C)	maximum level (pmol/kg.s)	maximum (days)	2nd increase (days)	maximum level (%)	maximum (days)	(days)
20.0	900	2.5	-*	3.6	2	6
15.0	800	3.5	-*	2.1	2-3	9
10.0	150	6	-*	1.2	10-12	17
5.0	30-40	low level	-*	0.4	1	>21

* no 2nd increase in ethylene production could be observed

Experiment 3

Avocados (cultivar Hass) were harvested in July 2005 in South Africa and transported in CA-reefer to the Netherlands. The time from harvest date to arrival in the Netherlands is on average 26 days ± 5 days.

Before the avocados were placed at the ripening temperatures, ethylene production of all batches was measured at 5°C. Afterwards avocados were ripened in 65-L containers at 5, 7.5, 10, 12.5, 15 and 20°C (21% O_2; flow rate 500 ml/min, RH = 95%). All ripening experiments were performed in duplicate. Ethylene production and ripening characteristics were measured as described in experiment 2.

The data was used to investigate the temperature dependency of the parameters for the ethylene production model (on batch-scale) and the ripening model (describing firmness and colour development on batch-scale).

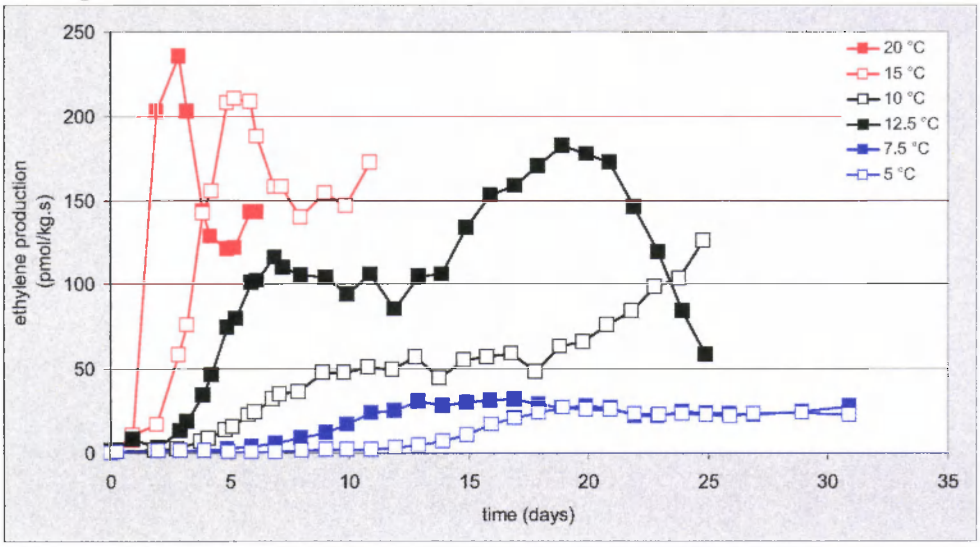


Figure 16 Average ethylene production (pmol/kg.s) of 2 batches avocados during ripening at various ripening temperatures (°C).

Ethylene production during ripening at various temperatures is shown in figure 16. As shown in figure 15 ethylene production at 20°C (after 3 weeks storage at 5°C) reached a maximum of approximately 250 pmol/kg.s. Sharp climacteric peaks are found at 15°C and 20°C. During ripening at 10°C and 12.5°C ethylene production is spread over a longer period. After the climacteric peak, ethylene production first declined and afterwards increased. Both at 10°C and 12.5°C ethylene production increased after a "plateau" ethylene production was reached, respectively after 19 and 15 days storage.

Average CO_2 levels of batches per ripening temperature are shown in figure 17. Clear maximum CO_2 levels are found at 20, 15 and 12.5°C (in contrary to experiment 2). Maximum CO_2 levels are reached after respectively 2.5, 5 and 6.5 days. Interestingly the times to reach maximum CO_2 levels are in close proximity to the times to reach maximum ethylene production of the 1st peak (2.5, 5 and 7 days).

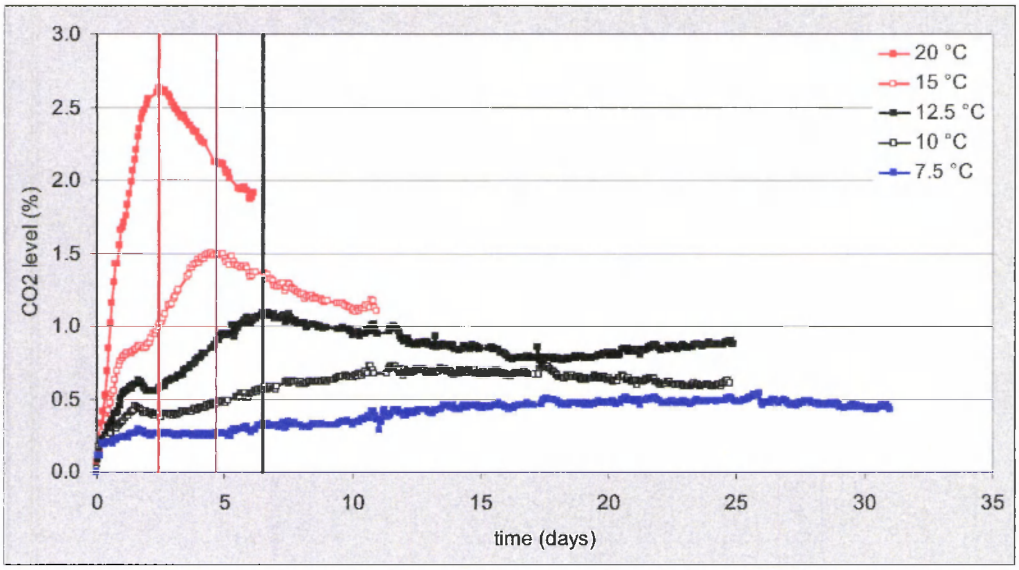


Figure 17 Average CO_2 levels of 2 batches avocados during ripening at various ripening temperatures (°C).

Avocados ripened at 7.5°C and 5°C did not reach the ready to eat ripening stage within 30 days (figure 18). Based on ethylene production patterns and firmness development controlled ripening could best be performed in the temperature range between 12.5°C and 20°C. Colour development preceded firmness development for all ripening temperatures.

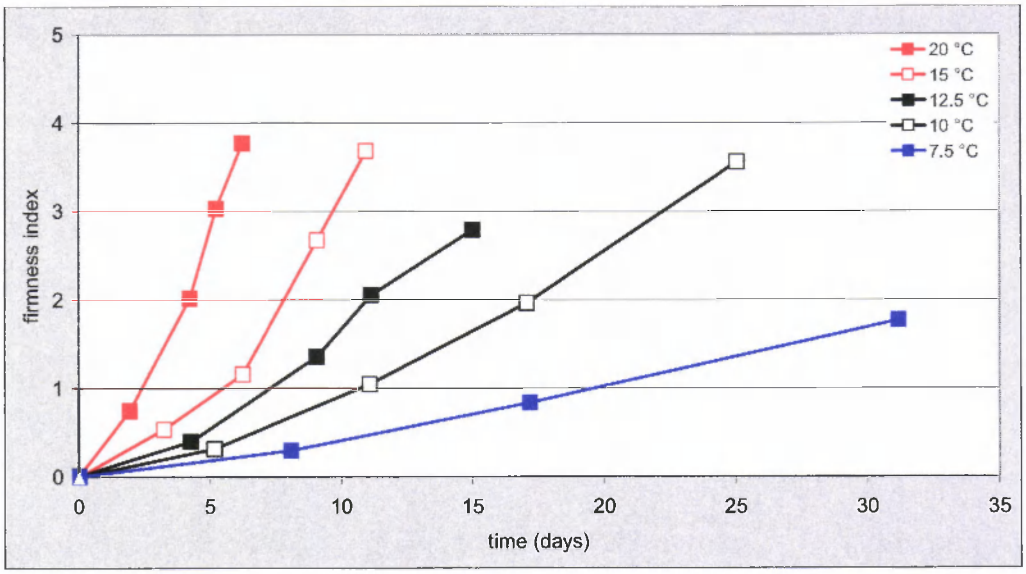


Figure 18 Average firmness index of 2 batches avocados (n=100) during ripening at various ripening temperatures (°C). (Firmness index 0 = hard; 3 = ready to eat; 5 = soft)

Table 2. Ripening characteristics (maximum ethylene production (pmol/kg.s or days); 2nd increase in ethylene production (days); maximum CO_2 production (% or days); RTE = ready to eat (days)) of Hass avocados during ripening at various temperatures (°C).

	Ethylene production			CO_2 production		RTE
T (°C)	Maximum level (pmol/kg.s)	maximum (days)	2nd increase (days)	maximum level (%)	maximum (days)	(days)
20.0	250	2.5	5	2.6	2.5	5
15.0	220	5	8-10	1.5	5	10
12.5	110	7**	14	1.1	6.5	15
10.0	50	11**	19	0.7	10-12	22
7.5	25	no top	no top	0.5	18	>30
5.0	25	no top	no top	no top	no top	>30

* RTE = ready to eat

** Time in which 1st peak is reached

Conclusions

- Firmness loss before maximum ethylene production has been reached (at 15°C) can be very effective inhibited by declining temperature to 5°C.
- Colour development during ripening at 15°C was inhibited by declining the storage temperature to 5°C, but could not be stopped.
- The time of storage at 5°C affected the maximum ethylene production levels during ripening.
- Maximum ethylene production during batch ripening is reached before avocados are ready to eat.

- Controlled ripening based on ethylene production levels can best be performed between 12.5 and 20°C.
- Avocado did not ripen at 5°C within 21 days

2.1.2.1 Coupled model validation

Validation of the distribution model

Sensitivity analysis of the model

After obtaining the first results of the model, a sensitivity analysis was done to get a clearer insight in the influence of the different parameters determining the temperature in the container. This sensitivity analysis leads to a number of parameters which are possible factors to be used in calibrating the model.

The main parameters found controlling the climate in the container are the following:

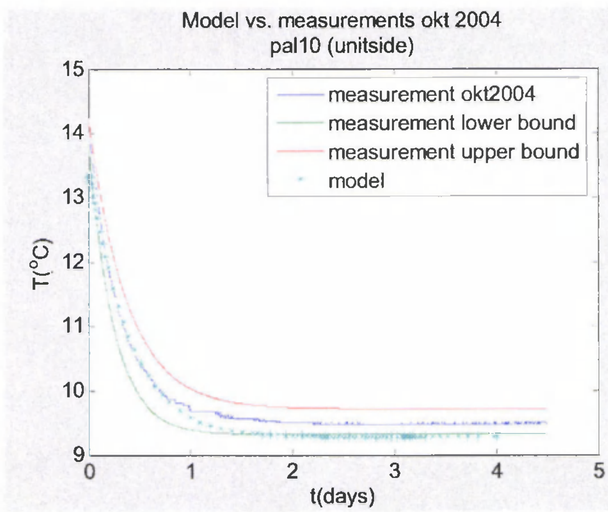
- Headspace height
- Middle slit width
- D'arcy constant
- Heat transfer coefficient of the load
- Respiration heat of the product

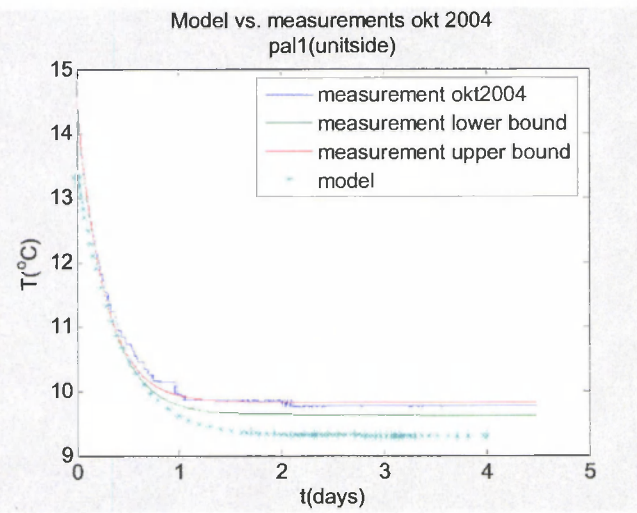
Calibration of the model

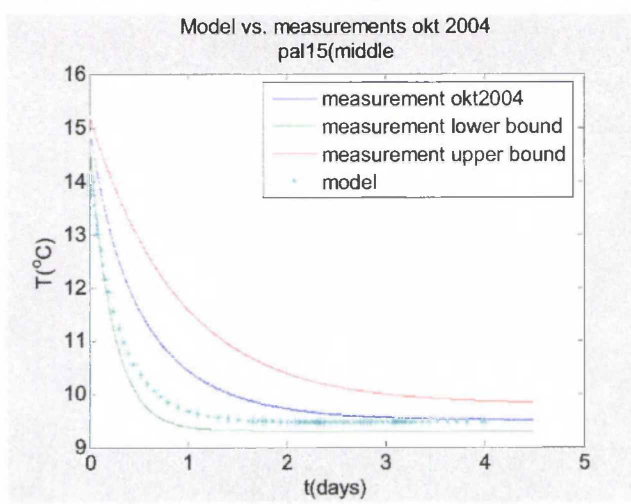
Not all factors found in the sensitivity analysis are used in calibration of the model. Headspace height for example is a factor which is known exactly from the measurements done.

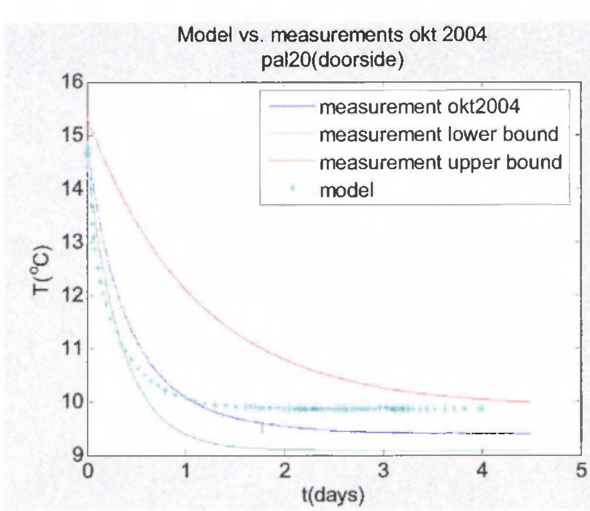
The rest of the parameters named above was varied to obtain the optimal solution.

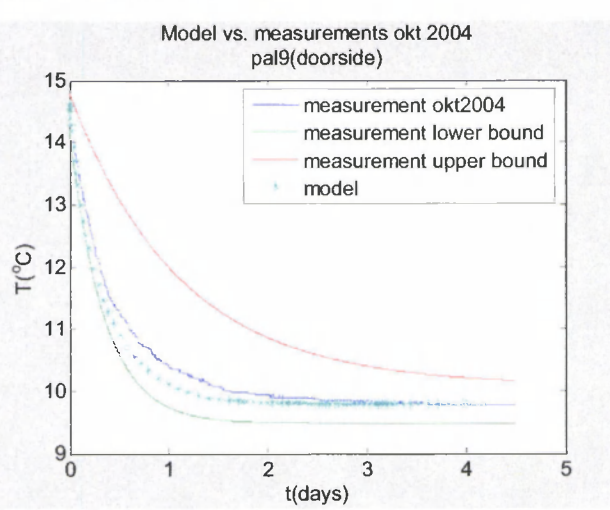
The following results were found:









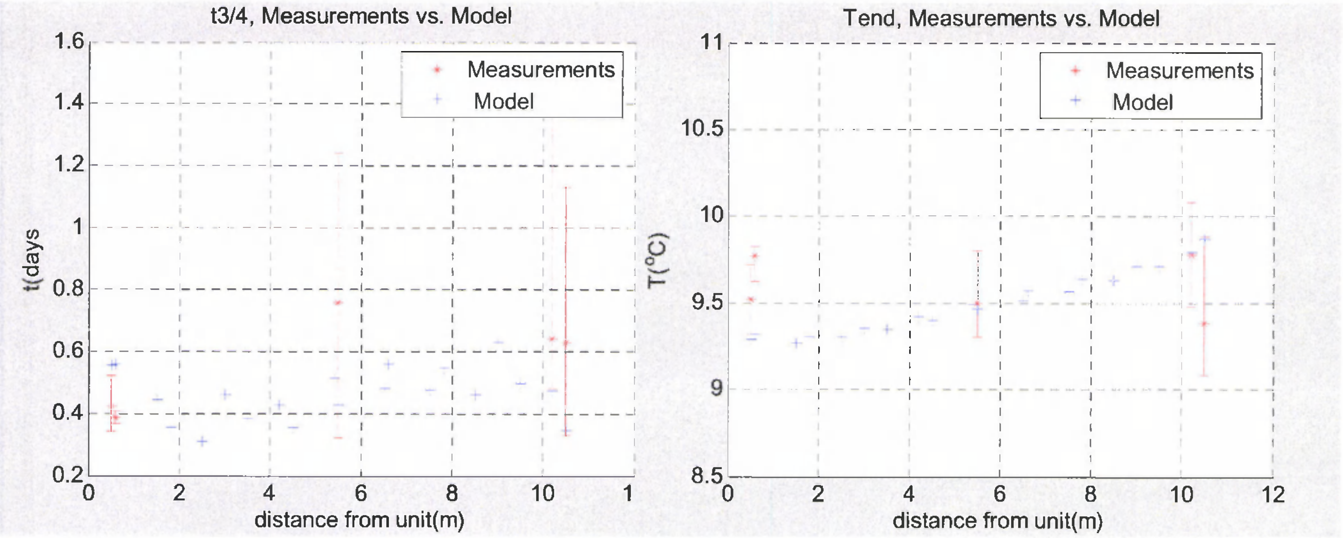


In the figures above the measurements and the model prediction for different pallets in the container are displayed.

In the upper two figures the two pallets near the unit are displayed.
The middle figure shows the pallet in the middle of the container.
The lower two figures show the two pallets near the door side of the container.

To analyse these results quantitatively two quality parameters were extracted out of these data:

- The ending temperature: this temperature gives an insight in the quality of the steady state situation.
- The cooling speed, expressed in the time to cool a measurement point for three quarters of the total cooling. This parameter gives better insight in the quality of the dynamic behaviour of the model



In the two figures below these parameters are shown for model and measurements.

From the figures above the following conclusions can be drawn:

- The modelling results generally fall within the accuracy of the measurements.
- Although this is the case, the trends in model and measurement tend to be slightly different. This will be subject to further investigation.

2.2 Difficulties and solutions

As referred in 1.1 organising a pilot is still difficult to organise. In this period PONL was merged with Maersk, PONL did not see any option to organise a trail in this period. In the future we hope to do trails with Maersk.

2.3 Internal reports

The internal reports and presentations are available on request submitted to the project manager G. van den Boogaard at A&F. For the participants of the projects some of these documents can be addressed via the web-site of the project: *http://www.ato.dlo.nl/quest/index.asp*

Reports

- Internal reports
- description GC and ethylene measurements (2X)
- Effect of temperature fluctuations on chilling injury and shelf life of Cavendish banana, Varit Srilaong and Wouter G. van Doorn, A&F

Presentations

Internal presentations:

- Avocado exp 3
- Banana exp 1

External presentations:

- poster presentation at the MODEL-IT conference from May 29 to June 2, 2005 in Leuven, Belgium (see also www.model-it-2005.be): "Airflow and Climate Distribution in Reefer Containers - a Network Model"