AGROTECHNOLOGY & FOOD INNOVATIONS
WAGENINGEN UR

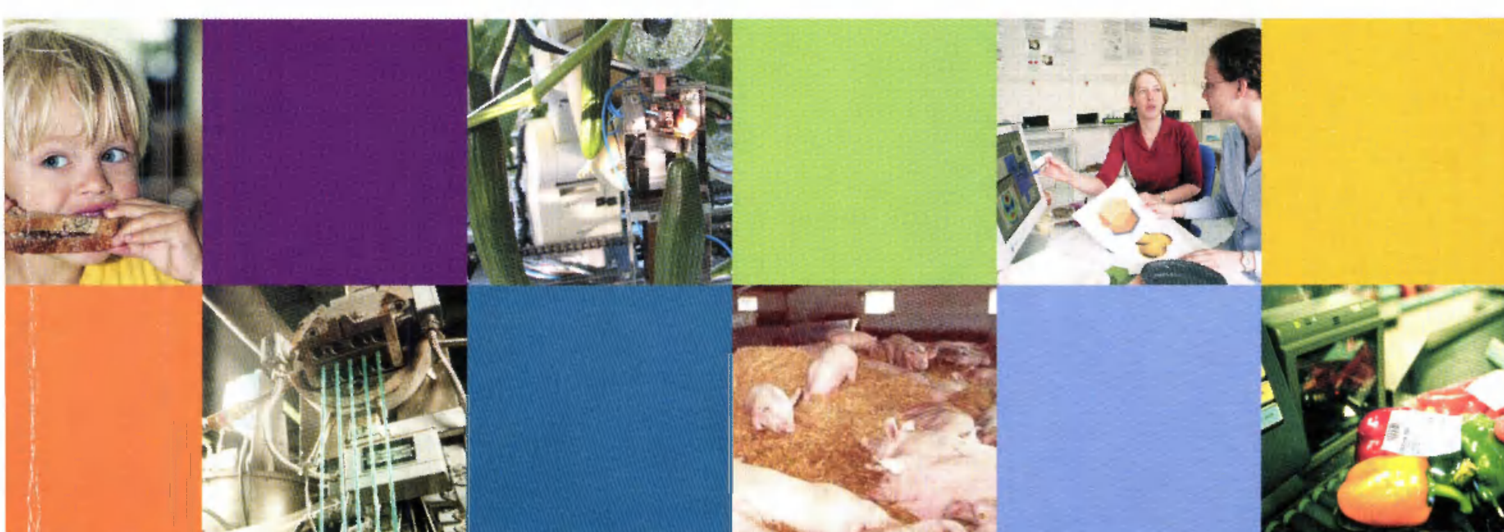
QUEST

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

Progress report
March 2003 – August 2003

Ref.nr. OPD 01/350/060503

Confidential



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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.

Agrotechnology & Food Innovations
Bornsesteeg 59
P.O. Box 17
6700 AA Wageningen
The Netherlands
Tel: +31.317.475024
Fax: +31.317.475347

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1 Progress

1.1 Activities in relation with planning last half year

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

1. Selection of products and markets

Conducting a full-scale test with QUEST-regular was not possible in the summer season of 2003 due to quality problems in bell pepper and tomatoes on the vine. Therefore it was decided to postpone the test to October.
For QUEST-pro it was decided to work on avocados as most interesting product for all partners.

2. Market introduction strategy

PON and ERBS have decided that the market introduction research as described in the discussion document 'QUEST Selection of products and markets, and market introduction strategy, discussion document', will proceed after one or more successful pilot-tests with QUEST-regular.

3. Predictive models

A model of the air- and temperature distribution in climate controlled sea containers carrying fruits and vegetables is being developed and has been tested. First, the airflow distribution will be described using a network-resistance model and secondly, the temperature distribution will be described.

A classification has been made that divides products in categories, which can be stored under identical temperature conditions (mean product temperature, and a minimum and maximum return air temperature). The selected products cover a wide range of products currently shipped with reefer containers. The products were divided in 3 categories, i.e. temperature range, ventilation rate, and transport and volume and value. From all categories, a product has been chosen for further research on QUEST Regular. A workplan has been made for QUEST Regular products. For the selected products it will be investigated if the cycling control regime is possible without higher quality losses or higher quality variations compared to standard storage conditions.

For QUEST Pro the product under investigation to apply controlled ripening is avocado. The idea is to control ethylene production and respiration rated by adjustments of gas conditions and/or temperature..

4. Monitoring system

For the monitoring system, work of the previous project on estimation of respiration rates is continued. A presentation has been given at the conference 'Quality In Chains', An Integrated View on Fruit and Vegetable Quality, in Wageningen on 8 July 2003. The presentation and accompanying article (published in the conference proceedings) deal with monitoring produce quality in reefer containers by estimation of respiration.
A feasibility study on the development of an ethylene sensor and weight loss sensor is carried out.

The set-up for lab scale testing of interactive control using a monitoring system has been built and is being extended and improved. The leakrate was reduced significantly and a temperature control system was designed. This set-up will be used for testing the Quest-pro control principle.

5. Control system

For the first pilot planned to be done in July 2003 energy saving control software has been evaluated and improved. Control parameters were determined for shipments with bell pepper, apple, tomato on the vine, grapes and avocado, by using the macroclimate model. The required input-parameters, describing the products and packages were determined and estimated. A large number of simulations were done to determine the effect of Quest-regular, ventilation rates and circulation rates on the container climate and energy usage.
For Quest-pro the requirements and possibilities of the controller were discussed with the product experts.

6. Practical guidelines

For the development of practical guidelines a number of questions on type of information, form (web-site, table etc.) and the use/users of the information needs to be answered by the commercial partners The discussion about the practical guidelines will be continued throughout the project. It will be a summary of all knowledge which is important to work successfully with reefer containers.

7. Chain information and technology transfer

The technical inventory at the different locations of The Greenery is finished. A specific type of room that is present on most of the Greenery locations is chosen, which allows a a comparison between locations. Of these rooms several climate condition parameters as well as energy consumption will be monitored. A comparison between the Quest regular control and the onland facilities will be made and the possibilities to apply Quest regular will be investigated.

8. Testing and integration

An extensive report was made of the first full-scale test of Quest regular. Preparations were made for the first full-scale test in real transport in July: a shipment of bell peppers from Rotterdam to New York. Due to insufficient quality of the produce because of an early and hot summer, preparations were also made for transport of tomatoes on the vine but ultimately the pilot has been postponed. PONL made a container with up-to-date cool unit available at A&F. The control unit of the Quest Regular pilot container has been prepared and tested at A&F in co-operation with Carrier. An industrial computer, logging devices and a kWh-meter were built in. To have the required voltages available, additional electronic equipment was necessary. Also, the software had to be adapted to the new cool unit version. A plan was made for the execution of the pilot, including the placement of the sample boxes and the temperature and relative humidity sensors.

1.2 Costs in relation with planning last half year

The costs realised in the period from 1 March 2002 to 1 September 2003 are €565,587 and the requested subsidy is € 298,248. This is exclusive of the costs made by Carrier Transicold US and Frugi Venta. These expenses will be submitted in March 2004, after the next half-year period. R&R Mechatronics has not made costs in this period.

In total approximately 20% of the total costs of the project has been realised. A&F has realised approximately 35% of its total budget. It is expected that in the course of the project the relative contribution of the companies to the project will increase.

1.3 Milestones next half year

The milestones for the next half-year are:

1. Selection of products and markets
   - partners for pilot test
2. Market introduction strategy
   - will proceed after successful pilot tests
3. Predictive models
   - Quest Regular: validation for wide range of product
   - Quest Pro: Ripening models for controller
   - validation of macro climate model
   - spatial variation/effects of stowage and packaging: validation, simulation
   - humidity distribution network model
4. Monitoring system
   - labscale monitoring ready
5. Control system
   - Quest-regular control in the unit controller; after first pilot test
   - Quest pro control prototype ready
6. Practical guidelines
   - Definition
7. Chain information and technology transfer
   - Inventory completed, indications for improvement, comparison with reefer
8. Testing and integration
   - Tests Quest-regular container scale with Dutch produce
   - Test Quest-regular container scale with foreign produce
   - Test Quest-pro lab scale (at A&F)

2 Results

2.1 Main results

2.1.1 Predictive models

Climate modelling

Introduction
Air and temperature distribution in climate controlled sea containers are crucial to the quality (distribution) of fruits and vegetables in long distance transportation. Climate distributions also impact proper control, as representative set-points are difficult to establish, the control behaviour may be unstable and the greater part of the container is likely to be off set-point. The ability to predict – and possibly correct – climate non-uniformities is therefore of great importance.

Objective
We aim to construct a validated model of the air- and temperature distribution in climate controlled sea containers carrying fruits and vegetables. Having obtained such a model, we may study the potential impact of e.g. type of pallet, "openness" of the boxes, stowage pattern/height, inside ventilation rate and outside temperature on the climate distribution and the temperatures of the cargo.

Method
Firstly we obtain the airflow distribution based on a network-resistance model. In this network, all open passages present underneath and between the stow of a fully loaded container are properly connected at nodes, while flow resistance formulae yield the pressure drop over each passage. When solved simultaneously, both the airflow and the pressure distribution are obtained.
Secondly we establish the temperature distribution, using the air distribution from the flow model. The temperature model employs enthalpy balances around the nodes of the flowmodel and appropriate heat transfer correlations in the flow passages.

To validate and tune both models, validation measurements will be carried out. For the flow model these involve extensive static and dynamic (and hence velocity) pressure measurements in the T-bar floor, the palletspaces, the vertical air gaps and the headspace. As a first validation of the temperature model, representative stow and air temperatures (for selected pallets: palletspace, stow and headspace) in a fully loaded container will be monitored during a trial run involving tomatoes on the vine.

Results
- A beta version of the airflowmodel incorporating both 2-way and 4-way europallets has been developed. Changing dimensions of the T-bar floor, channel roughnesses, the vertical air gaps and the headspace, this model yields plausible results (*Figure 1*, left).
- Based on preliminary simulations critical parts of the airflow model have been identified, and required locations to measure air velocity and pressure during validation using empty boxes have been established.
- Pressure and velocity measurements in the T-bar floor using a custom built pitot-tube/slider carriage arrangement show the feasibility of the network approach.

- The enthalpy balances of the static temperature model have been implemented and a preliminary version was run. Currently this model is undergoing extensive testing and debugging.
- At three critical points (parts of the T-bar floor, the palletspace and the headspace) a detailed flow analysis using the CFX Finite Volume package was carried out (*Figure 1*, right).

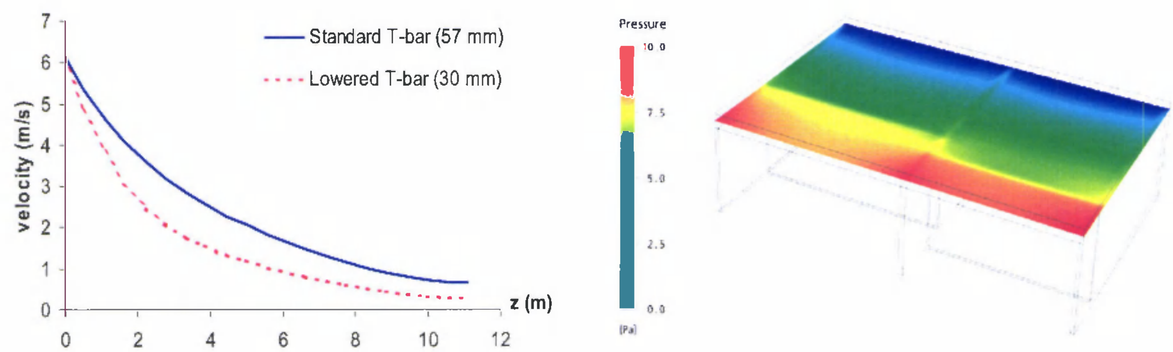

Figure 1 *Velocity through the T-bar floor as a function of profile height (left), and the pressure distribution in the headspace obtained using CFX (right).*

The influence of Quest regular on various products

Introduction

The energy-saving control mechanisms will be applied on various reefer-shipped products. Therefore, it is important to test and validate the mechanisms for a wide range of products. The products show a more or less complicated behaviour under storage, resulting in the division in 'regular' and more advanced products ('pro'). As a result, also the product research is divided in these two categories.

Objectives

To avoid having to do research on all possible reefer-suitable produce, a classification of produce was made. From this classification, combined with economic importance, a number of products were chosen for further research. The research necessary for QUEST Regular products was set up with a specific objective in mind: can the product bear the climate resulting from the cycling control regime without higher quality losses or higher quality variations compared to standard storage conditions?

For QUEST Pro the research set up is more innovative. The objective is to understand the product's ripening mechanisms, to be able to measure the status of the product, and to intervene with the ripening during storage.

Realisation

Classification

The goal of the classification is to divide the products in categories, which can be stored under identical temperature conditions (mean product temperature, and a minimum and maximum return air temperature). The selected products must cover a wide range of products currently shipped with reefer containers. Therefore, the products were divided in 3 categories, i.e. temperature range, ventilation rate, and transport and volume and value. This resulted in the classification in table 1.

Table 1 Classification of products

Temperature	Ventilation	Product
Low (-1° to 4°C)	High*	*Apple* Apricot Cabbage Cauliflower *Kiwi fruit* Lettuce
	Medium*	Asparagus Cabbage Nectarine Peach *Pear* Plum Spinach
	Low* to very low	Artichoke Carrot Cherry Fig Garlic *Grape* Mushroom Onion Strawberry
Medium (8°-10°C)	High	Avocado
	Medium	Cucumber Grapefruit Green bean Mango Olive *Orange* Tomato (breaker)
	Low to very low	*Bell pepper* Eggplant *Pineapple*
High (> 12°C)	High	Banana
	Medium	Lemon Papaya Tomato (green)
	Low to very low	

*High = 125-250 m^3/h; Medium = 65-85 m^3/h; Low to very low = 25-35 m^3/h.

QUEST Regular

The italic products in Table 1 investigated further in QUEST Regular. Based on this classification one can apply, with low risks, a tested and suitable profile for a certain product to another product in the same category.

The profiles for the different products result from model calculations combined with expert knowledge (chapter 2.1.3). In short, the experiments consist of a comparison of the effect of the current transport conditions and a limited number of sub-optimal conditions on the product quality. Depending on the product and package properties the sub-optimal conditions are temperature profiles with smaller or bigger fluctuations in time. The sub-optimal conditions represent areas in the container where the average product temperature is above or below the standard / mean product temperature.

For grape a first experiment with cycling profile conditions has been performed. The results showed that the product quality declination under cycling conditions was normal compared to the standard storage conditions.

QUEST Pro

The product under investigation to apply controlled ripening is avocado. The idea is to control ethylene production and respiration rated by adjustments of gas conditions and/or temperature.

Further plans

In the coming year experiments with the products for QUEST Regular will be continued and more insight will be gained in some specific risks present in the application of cycling. Upon finishing all experiments for QUEST Regular each class in the classification will be extended with settings for the cycling regime control applicable to all products in the specific classes.

Research on QUEST Pro will result in insight on the ripening process of avocado and selection of the most promising control parameter. Together with the monitoring task research will be performed on testing the possibilities to control the ripening to desired profiles.

2.1.2 Monitoring system

An extensive search has been performed for commercially available sensors for measuring ethylene gas in low concentrations. Because a good sensor is not available at the moment, A&F has also done some development work. The results are described below.

Amperometric combustible gas sensors
These generally consist of an electrochemical cell filled with liquid electrolyte and a constant voltage applied between a platinum sensing electrode and a counter electrode. The target gas diffuses through a permeable membrane and oxidizes on the catalytic platinum surface, generating a measurable electric current between the electrodes. These types of sensors are relatively cheap, but are sensitive to a large number of gasses like carbon monoxide and ethanol. In scientific literature, a version has been described that uses gold instead of platinum for higher selectivity towards platinum. The gold is deposited directly onto a solid electrolyte Nafion® membrane, eliminating the limitation of a polymer diffusion layer to make it more sensitive. Good results have been obtained with this sensor, but it has never been commercialized because of the difficult membrane preparation. This is tried as described in the article, but it has not been successful yet. The difficulty is the gold deposition onto the membrane by chemical reduction of chloroauric acid. The goal is to produce an even, electrically conductive layer of gold with a high active surface area that is tightly integrated with the Nafion.

Infrared gas analyzers
These detect gasses by their specific spectral absorption properties in the infrared. They are bulky, complicated and hugely expensive when ppb levels of ethylene need to be detected.

Gas sensing by luminescence with ozone
This device contains an ozone generator and destructor, a reaction chamber and a photo-multiplier tube (PMT) for luminescence detection. When ethylene reacts with ozone the emitted light is proportional to the ethylene concentration. Two companies have been found that sell gas analyzers of this type. Both are relatively expensive ($8000-$10000). In the future one device will be bought or borrowed to evaluate its performance and investigate if such a device could be built more cheaply.

Other options
A Dutch company called LioniX has developed a micro Mach-Zehnder interferometer chip. They claim that in combination with a gas specific absorbent material it can be used as a highly sensitive gas sensor.

A concentrator can be used with all the above methods to pre-concentrate ethylene to obtain a higher sensitivity and selectivity. For example, ethylene 'sticks' to a silver surface. This has been tested successfully by concentrating the gas with silver-coated active carbon. Upon heating the ethylene is released, resulting in an increased concentration. In a flow-through system that periodically heats the trap, ethylene peaks are produced that can be measured and integrated by software. This greatly increases sensitivity and selectivity of the sensor.

2.1.3 Control system

For a number of products model simulations were done to determine the control parameters for Quest-regular and to see the effect of various control schemes. Here an example will be given for the results of the tomato on the vine calculations. First of all, the mean climatic conditions on the pilot route for October were studied (*Figure 2*). From the following figures (see http://www.cdc.noaa.gov/cgi-bin/Composites), it was concluded that on the ship the unit will not suffer worse conditions then 18°C and 85% RH.

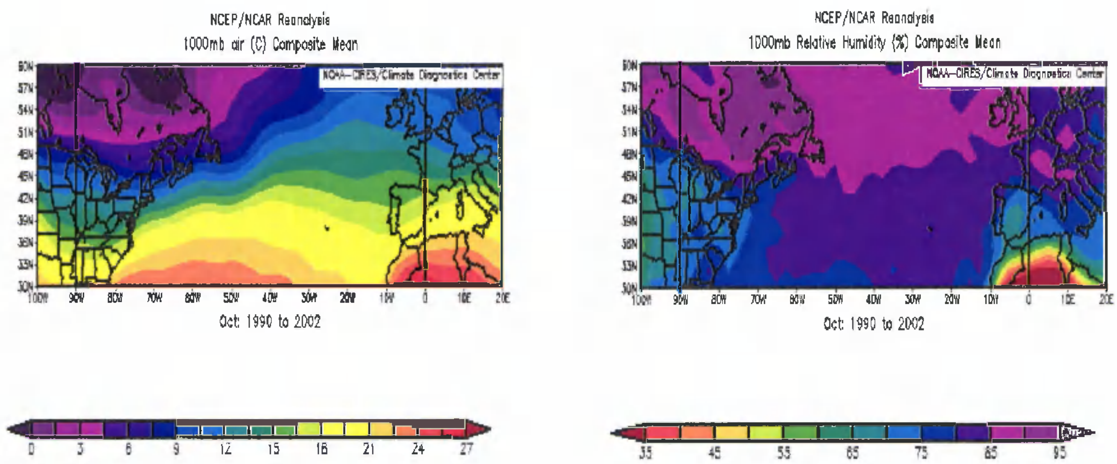

Figure 2. Temperature and relative humidity on Atlantic Ocean during October

With 10 m^3/h ventilation, an outside air temperature of van 18°C and a RH of 85% the model calculations for tomato on the vine for Quest Regular are given in *Figure 3*

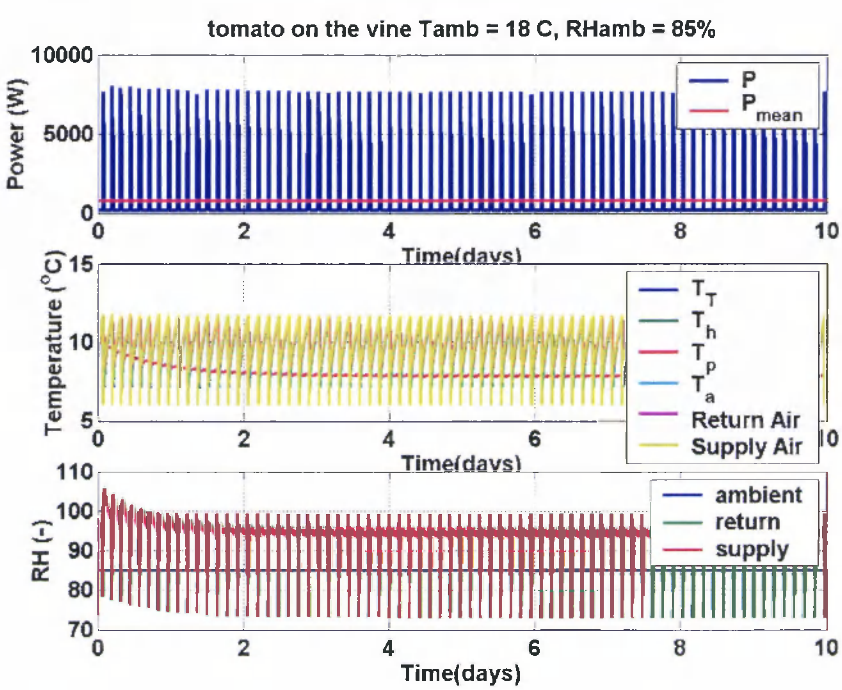

Figure 3. Model calculations of Power consumption, temperature and relative humidity in Quest regular container

The peaks in the RH during cycling are model uncertainties, the mean RH should be taken into account. These peaks also influence the amount of predicted mass loss and therefore temperature drop of the tomatoes. The real temperature could be somewhat higher, comparable to that during normal transport. For normal transport under the same circumstances see *Figure 4*.

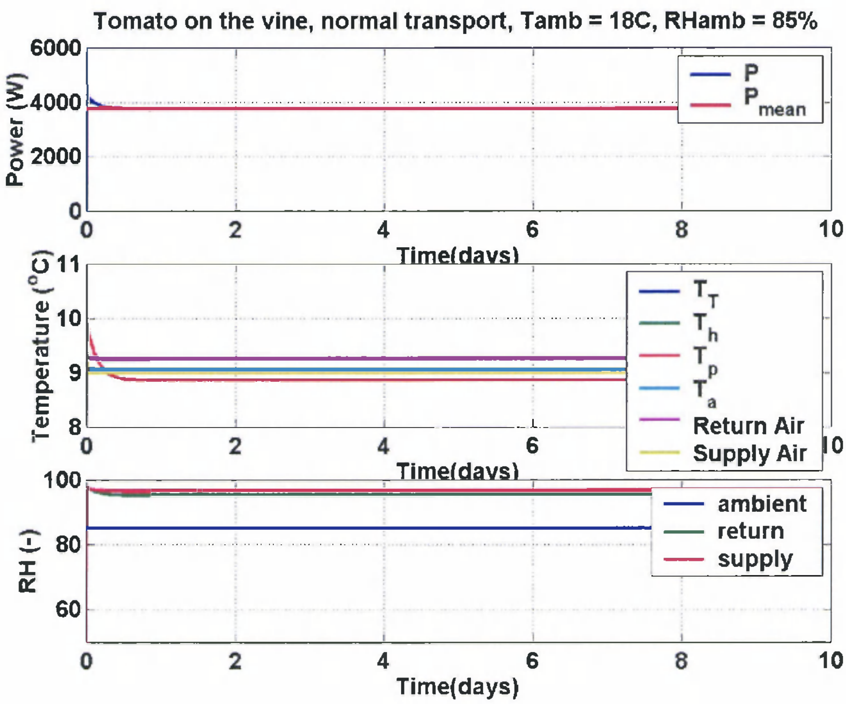

Figure 4. Model calculations of Power consumption, temperature and relative humidity in standard container

The RH values are comparable, for higher ventilation rates a too high RH would be reached using Quest regular with constant ventilation rate. Other results of simulations for 60 Hz, 480 V power draw are summarised in *Table 2*. Here QR stands for Quest regular, HS for fans on high speed, LS for fans on low speed, two ventilation numbers for ventilation cycling and HS/Ls for fan speed cycling.

Table 2 Summary of simulations with tomatoes

Freq. [Hz]	60								
Mode [-]	**NORMAL HS**		**QR HS**	**QR LS**			**QR HS/LS**		
V [m³/h]	**10**	**50**	**10**	**10**	**30**	**50**	**10/10**	**50/0**	**100/0**
P_{mean} [kW]	3.8	4.1	2.3	0.9	1.0	1.1	1.37	1.35	0.9
T_p [°C]	8.9	8.8	7.0	7.7	7.5	7.6	7.9	7.85	7.6
Min, max T_T [°C]	9.0	9.0	6.7 11.9	7.5 11.5	7.2 11.5	7.3 11.7	7 11.5	7.0 11.5	7.2 11.6
Min, max T_h [°C]	9.2	9.2	7.6 11.7	8.9 11.6	8.9 11.6	8.6 11.7	8.6 11.5	8.2 11.5	8.5 11.6
RV_{ret} [%]	95	94	84	87	90	93	89	89	84
RV_{sup} [%]	96	96	84	89	92	91	89	88	85
Cyc: on [min]:off	-	-	18 78	20 140	24 150	24 120	12 150	15 155	24 150
T_{sp} [°C]	9.0	9.0	6 20	6 20	6 20	6 20	-	-	6 20
$T_{high\,B}$ [°C]	-	-	11.5	11.5	11.5	11.5	11.5	11.5	11.5
$T_{low\,B}$ [°C]	-	-	9.5	9.5	9.5	9.5	9.5	9.5	9.5

The following conclusions can be drawn from *Table 2*:

- The power rises with the amount of ventilation.
- QR with LS gives a large power reduction, varying for the product type.
- The CO_2–level stays within acceptable range.
- Ventilation cycling helps to prevent taking in warm and humid outside air and has no negative effect.

For the product research the temperature dynamics of the container air are important, therefore plots are made of the expected paths (*Figure 5*).

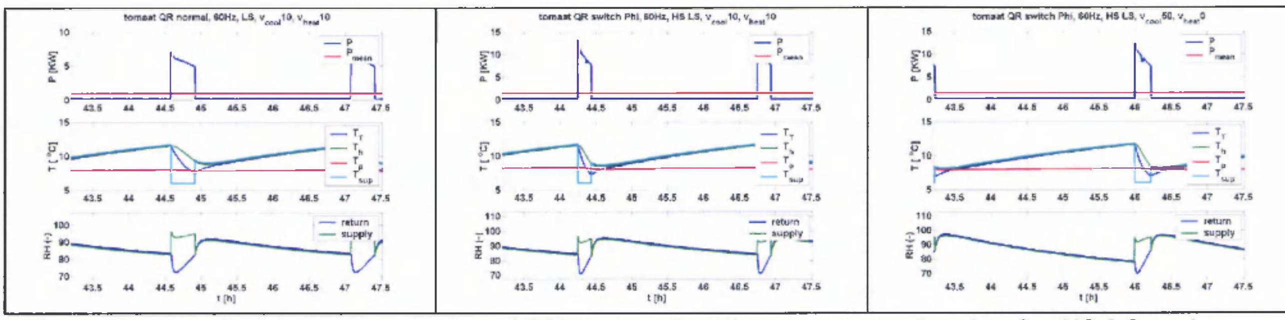

Figure 5. Power, temperature and RH in container for tomato on the vine for HS/LS and ventilation on/off

The complete results can be found in the internal report on this subject (Product simulations).

2.1.4 Chain information and technology transfer

This part of the project started with a technical inventory at the different storage locations of The Greenery. Other than 40 Ft Reefer containers, cold stores on land differ very much in capacity, technical cooling system, dimensions etc. Even within storage locations several types of technical equipment, capacity and energy consumption can be found. A good evaluation of these differences is most important. With an inventory of the techniques the right choices can be made in comparing different locations.

Recently, the choice was made to examine a specific type of room that is present on most of the Greenery locations, instead of the total cooling equipment on every Greenery location. This way a comparison between locations is possible. The most important technical difference between the locations will be described. Besides the technical evaluation of the different rooms, these rooms will be followed for several condition parameters and the global energy consumption.

Because of the basic difference in controlling temperature in on land storage facilities and reefer containers, we will examine the practical difference between the Quest regular control and the on land facilities control. With this knowledge, hopefully the Quest regular can be incorporated in the on land facilities to make them more effective.

For the coming months the inventory of the chosen rooms will be completed with a summary of the main differences and the possibilities of improvements. A comparison between the technical equipment of the reefer container and the 'on land equipment' will be made.

2.1.5 Testing and integration

General

A full scale Quest Regular pilot to the USA with either bell peppers or tomatoes on the vine was planned and prepared in July. Due to insufficient quality of the produce because of an early and hot summer the pilot has been postponed to October 2003.

Aim pilot

- Test in practice the energy savings of a reefer unit through the adapted control logic
- Test in practice the effect of the adapted control logic on the quality of bell peppers or tomatoes on the vine
- Test in practice the effect of the adapted control logic on the temperature and RH distribution in a reefer container
- Test in practice pressure drop in a loaded container

Partners involved

The Quest partners that will be actively involved in this pilot are:

- A&F
- Haluco and it's receiver Merex in Yonker (New York)
- P&O Nedlloyd
- Carrier Transicold

Set-up of the pilot

Two P&O NL 40 ft reefer containers loaded with either Dutch bell peppers or tomatoes on the vine will be shipped through Haluco to New York with a PONL vessel in order to test the application of the adapted control of the Quest regular reefer container. One of the 2 reefer containers will have an adapted control (through an industrial vehicle computer), the other reefer container will be the conventional control container.
Prior to the pilot shipment the control unit of the Quest Regular pilot container will be prepared and tested at A&F in co-operation with Carrier Transicold. In addition other technical preparations of the Quest Regular container needed for the pilot will be realised at A&F.
Both containers will be fully loaded with export quality Dutch bell peppers or tomatoes on the vine. Sample boxes will be marked at strategic spots in both the containers. At these strategic spots temperature and relative humidity will be recorded (escort dataloggers) and the quality of the bell peppers from these boxes will be measured before and after shipping. Carrier will supply USDA approved sensors for additional temperature and relative humidity data loggings. In addition the Voltage and ambient temperature will be logged. The places of the sample boxes as well as the sample origin (grower, variety, colour, grade, harvesting date, package) will be exactly the same for both containers. The rest of the load does not necessarily have to be the same for both containers (but as much as possible preferably), as long as the bell peppers or vine tomatoes have the required export quality.

Planning coming months (end 2003)

- Execution of full scale pilot in October/November

2.2 Difficulties and solutions

Product quality during the summer of 2003 did not meet the required standards for shipment to the USA. For this reason the pilot shipment was postponed.

2.3 Internal reports

The internal reports and presentations are available on request submitted to the project manager R. 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

Papers

- Product choice QUEST, discussion paper (A&F)
- Opportunities for energy savings for refrigerated containers, discussion paper (A&F)
- A preliminary classification of fresh products based on transport conditions, discussion document (A&F)
- Preliminary classification including import/export volumes, discussion document (PON)
- QUEST Selection of products and markets, and market introduction strategy, discussion document (ERBS)
- Product simulations (A&F)
- Summary avocado properties (A&F)

Presentations

- Kick-off QUEST, 31 October 2002
- Milestones QUEST, November 2002
- Energy Savings, Progress meeting 30 January 2003
- Product Classification, Progress meeting 30 January 2003
- Practical Guidelines, Progress meeting 30 January 2003
- General Progress, Management Meeting 27 March 2003
- Container test March, Management Meeting 27 March 2003
- Control System, Progress meeting 22 May 2003
- Monitoring System, Progress meeting 22 May 2003
- Pilot and Product Selection Quest Pro, Progress meeting 14 August 2003

2.4 External reports

Automatic produce quality monitoring in reefer containers, L.J.S. Lukasse, M.G. Sanders, J.E. de Kramer. ATO, Wageningen, The Netherlands. Abstract. Quality In Chains, An Integrated View on Fruit and Vegetable Quality, Third International And Multidisciplinary Conference, Wageningen, 6-9 July 2003

3 Conclusions

3.1 Project realisation

The first full-scale test with a partially loaded container with bell pepper showed that product quality after storage was equal to product stored at optimal conditions. The energy use for climate conditioning was reduced to 50%. The first full-scale test in real transport will be carried out in the Research phase of the project. Currently, preparations are being made 2 pilot shipments, one dealing with export of Dutch produce, the other with import of foreign produce to the Netherlands. If this technology can be made suitable for a wider range of products, it is very likely that the project goals will be met.