ATO

CEET2005
Half-year Report

December 2000

Confidential

Consortium:
ATO
Carrier Transicold
P&O Nedlloyd
Ecofys
The Greenery International
Shell Solar Energy B.V.

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General

1.1 Work carried out

Summary

The last part of the project's second phase, i.e. implementation phase, has been focused on the accomplishment of individual targets per task. Even though the results per task are given in chapter 2-8, a summary of these results is given here:

- A relationship has been obtained between the oxygen uptake and carbon dioxide production versus temperature under both CA and air condition. The selected ranges for temperature, CA and air are chosen within container practice. Under similar circumstances, the effect of temperature fluctuations on respiration has been estimated. Both phenomena have to be under control in order to provoke energy reduction.
- The container macro model has been further tested on experimental data from the first large-scale experiment entailing 15 tons of apples. The model can predict the average product temperature and oxygen levels quite well. However, the prediction of humidity and carbon dioxide at low oxygen levels requires further optimization. This can be realized by further modeling of the cool-unit. Carrier Transicold is heavily involved in the modeling process.
- An energy model has been developed and tested in good agreement with experiments and manufacturers data. The results show that the power consumption of the compressor requires further modeling only.
- A laboratory test system has been developed for testing green chemicals under container conditions.
- Trans-2-hexenal is presently the most suitable plant volatile (green chemical) although experiments show that too high concentrations will lead to damage of the product (apples). Therefore, the most suitable range of concentrations where this volatile shows an anti-fungal effect must be determined.
- The largest bottleneck for the Oxygen sensor is its robustness. This problem can only be solved with a chemical modification of the sensor material. This expertise is not available at ATO. As a result, ATO is in negotiation with an external partner to solve this problem in order to bring this prototype to market.
- Two candidate hand held e-nose systems have been found which can meet the specifications for measurements in a container. It will be investigated whether these systems are suitable for the final container test at the end of the project.
- The concept of the cost/benefit model has been finished. The concept has been screened with simulated data and show that the focus should lie on energy reduction only, without affecting product quality. The final validation of the model with real data can only be done when this has been delivered by the different tasks. This will be after the final container test.
- The market introduction of the new container should focus on a continental reefer box only.
- The supervisory control system has been tested with simulated data and show that 1) significant energy savings are possible without harming the product quality and 2) product quality improvement is possible by gradually decreasing the O_2-setpoint at the beginning of the journey.

Furthermore, preparations have been started for the third phase: integration of all individual tasks. This will lead to a final container test including 15 tons of apples. This test will provide the most realistic estimation for energy reduction of the new container.

Introduction

The focus of the CEET2005 project is to substantially reduce energy within the transport sector, according to EET theme 4. In order to realize this aim for containerized transport of agricultural products, an innovative stand-alone intermodal container will be developed and sustainable energy will be applied where possible. Key tasks are maintenance of product quality, optimal climate conditioning, energy savings, application of green chemicals, integration of climate and product sensors, logistics and overall system control. The results presented in this report are obtained by the work carried out in the implementation phase. In the integration phase, all information from the individual tasks will be coupled. Therefore, a careful preparation is ongoing to facilitate this complicated task. Due to the size of the project, the results per task are described in chapters 2-8.

Project layout

The work plan for each task is described at the end of this report. The following persons have made contributions to the work carried out in this report:

Carrier Transicold:	M. Griffin, C. McHugh	
P&O Nedlloyd:	P. Eekel, M. Wildemans	
The Greenery International:	J. Smits	
Ecofys:	H. Opdam, J. Schoonderbeek, R. Heller	
ATO-DLO:	W. van den Broek	M. van Ooijen
	J. Sillekens	J. Ruijsch van Dugteren
	M. Strous	M. Sanders
	H. Peppelenbos	R. Veltman
	R. v.d. Sman	L. Lukasse
	P. de Leeuw	J. Snel
	R. van den Boogaard	F. Golbach
	G. van den Boogaard	G. Verdijck
	R. Moezelaar	G. Otten

Publications and PR actions

- R.G.M. van der Sman, Modelling air flow in vented box packed with produce, Murcia (see appendix 1).

1.2 Progress versus project planning

The work plan presents the results of the second half of phase 2: *implementation: conditioning of atmosphere and product response*. The results are in accordance with the project proposal.

Since the coming phase 3 entails the integration of all individual tasks, a planning has to be made for the integration. In phase 3, an independent test is planned with a 15 tonne container loaded with apples. All benefits of the new container must be tested in this experiment. Since the combined execution of all tests (originating from all other tasks) is complex, a procedure will be started to apply for an extension of the project end date.

Another reason for this extension is that the new season for apples will be around August/September. This period is too late for the present time scale. If extension is not possible, the test has to be performed with stored produce from one year before.
The individual planning for each task is given in the individual task description.

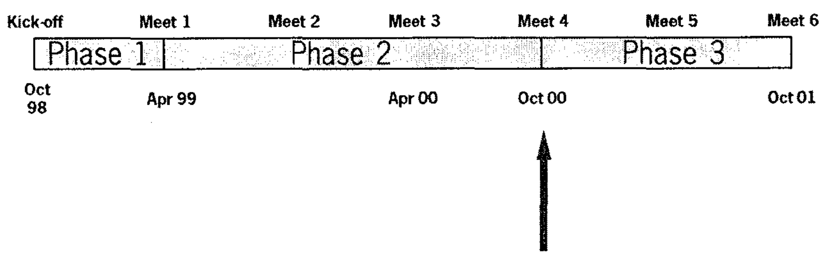


Figure 1: Phasing of the CEET-project and present situation. Phase 1 is *preparation*, phase 2 is implementation phase and phase 3 is *integration of all tasks.*

1.3 Realization project aims

The April 2000 project report describes a special chapter for the realization of the project aims. In chapter 3 of this report: *description of the new container: configuration*, a complete description is given of the 3 container configurations. For each configuration, the consequences for the EET-targets are given. In this project phase, the decision has been made to focus on the second configuration. This is the configuration that is planned as a deliverable.

1.4 Bottlenecks

The project is still facing one technical bottleneck. This bottleneck is about the communication protocol between the computer and the control system of the container. For the final container testing, this problem should be solved. However, Carrier has been notified and tries to solve the problem. This problem must be solved before the final testing takes place.
An alternative way to solve this problem is the acquisition of a new software package. This will solve the communication problem with certainty, but is an expensive solution.

1.5 Milestones

Milestones are identified later on in the project (end of phase 3). The first phase has been successfully ended. The third phase will end in October 2001. However, ATO is intended to apply for an extension of 3 additional months (see progress vs project planning).

1.6 Evaluation parameters

The evaluation parameters are mentioned in the individual task descriptions

2 Task 1: Optimisation of product quality under varying conditions

2.1 Contribution of ATO

Introduction

The main focus of task 1 is to assess quality of fresh products in a changing environment. Storage of fresh products until now has always requested storage conditions with minimal fluctuations in climate conditions (T, O_2, CO_2 and relative humidity). Because energy costs were not considered this often led to over dimension of cooling capacity and ventilation capacity.

When fresh products can be stored without quality loss in a climate with fluctuations (temperature and O_2 levels), it will decrease the energy demands during transport. However little or no knowledge is available how fresh products behave under changing climate conditions. To be able to compare fresh products in a changing climate it is necessary to know how products behave in a well-defined microclimate. In the last period research focussed on storage of fresh products (apple and tomato) in "steady state" climate conditions (T and O_2). The results for apples (cv. Elstar) are shown in the next paragraphs.

Aims

To guarantee the quality of fresh products and be able to reduce energy demands during transport the research will focus on the next aims:

- Boundary climate conditions where product quality remains acceptable: optimal temperature, temperature range, gas conditions
- Relation between respiration rates and ethylene production in response to temperature, CA conditions and temperature changes
- Relation between respiration rates and quality changes
- Quantification of advantage of CA over low temperature in terms of extension of storage life

Results

A. Boundary climate conditions

Normal storage conditions of model products (apple, green bean and tomato) during transport are given in table 1. These static conditions are maintained during transport to guarantee optimal quality of fresh products.

Table 1. Boundary climate conditions for the model products (apple, green bean and tomato).

		Apple	Green Bean	Tomato
T optimum	(°C)	4.4	7.2	10.0
T range	(°C)	4.4 - 5.6	4.4 - 7.2	10.0 - 11.1
O2	(%)	2 - 3	2 – 3	3 - 5
CO2	(%)	1 - 2	5 - 10	0 - 3
R.H.	(%)	90 - 95	90 - 95	90 - 95
Air exchange		High	Moderate	Moderate

B. Temperature control and product temperature

In an experiment 3 storage cells were set at 10 °C and different temperature boundaries (± 1, 2 or 3°C). Cooling was regulated by means of an on-off control. Figure 1 shows the temperature patterns of these cells when regulated on air temperature.

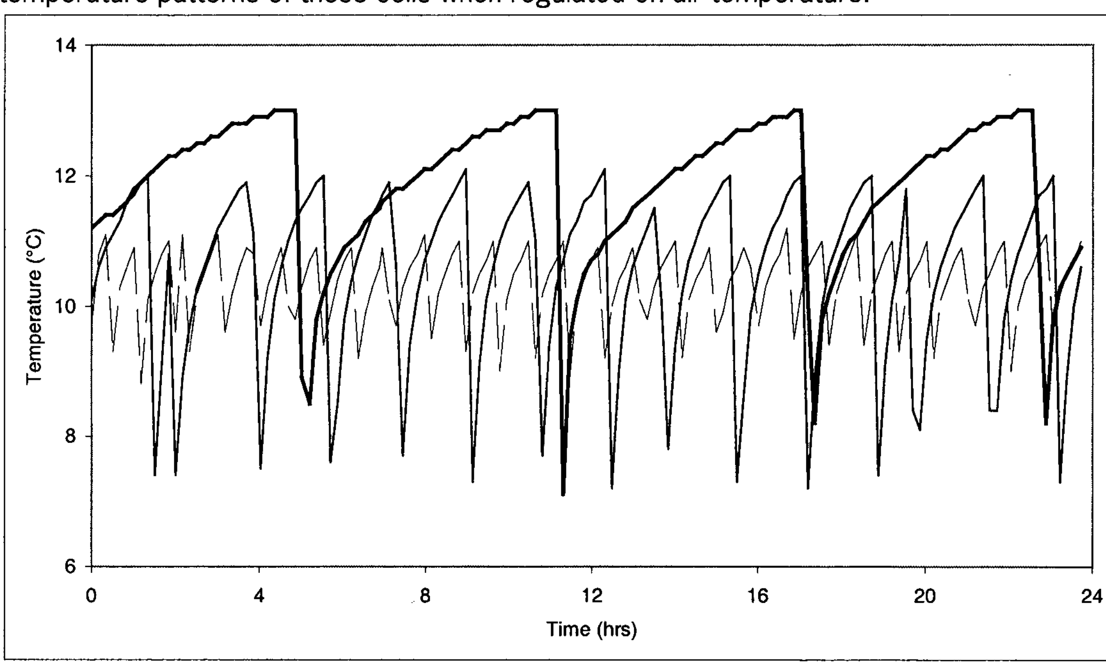


Figure 1. Room temperature set point 10 °C with different temperature boundaries.

In a second experiment temperature settings were not changed, but the temperature sensors were placed in a product (tomato). When temperature regulation is based on internal product temperature the cooling frequency is lower (decreased energy consumption).

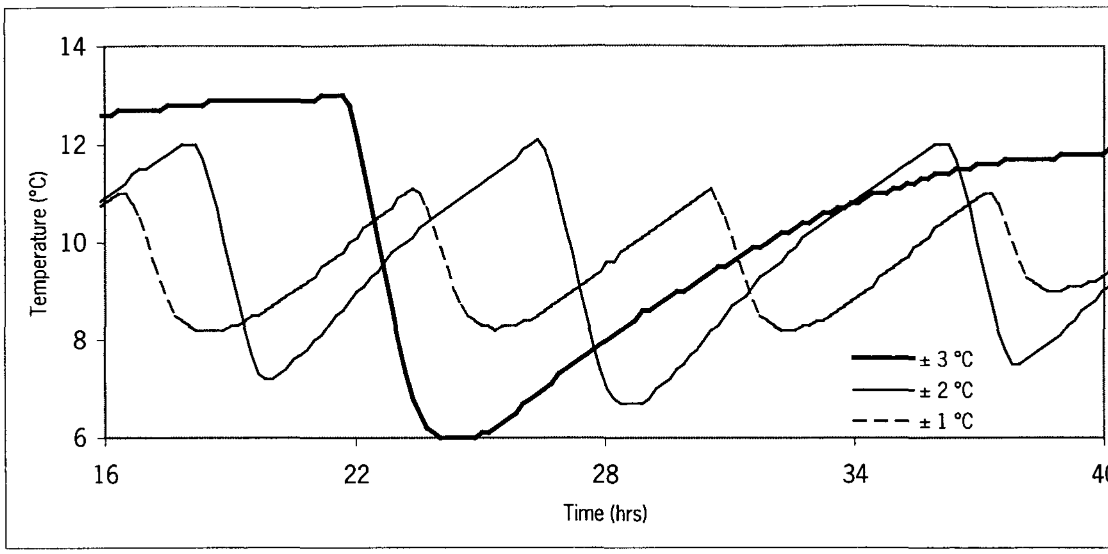


Figure 2. Internal temperature of tomato stored at set point 10 °C with different temperature boundaries.

C. Respiration rates in response to temperature and CA

In figure 3 O_2-uptake of apples (cv. Elstar) stored under air and CA conditions (1.2 % O_2 and 2.5 % CO_2) is plotted against the product temperature (average temperature during measurement). In this experiment the temperature was increased each day directly after respiration and ethylene measurements. The O_2-uptake at each temperature is an average of 10 measurements.

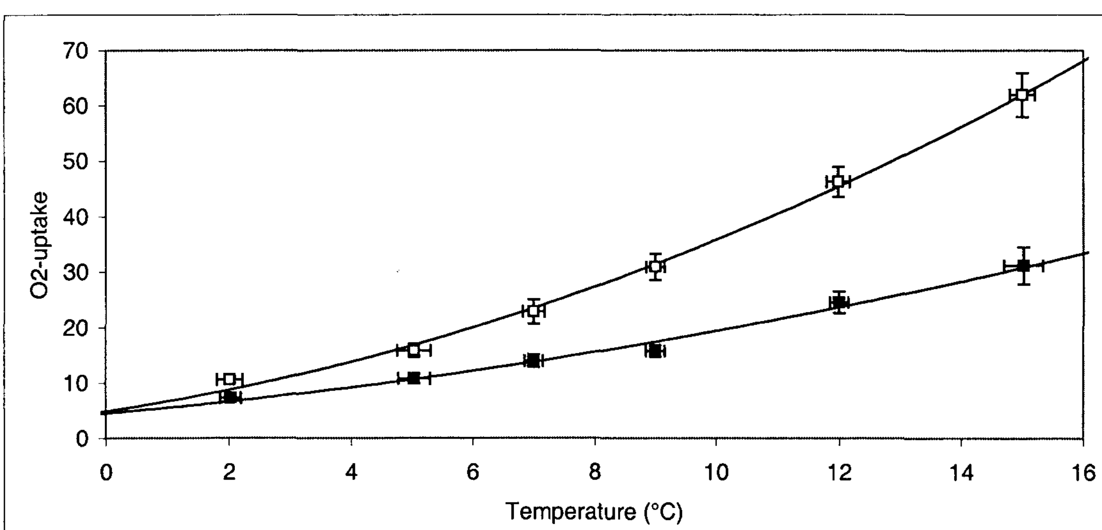


Figure 3. O_2-uptake (nmol/kg.s) of apple (cv. Elstar) vs product temperature. □ = CA stored □ = Air stored.

Maximum O_2-uptake is measured at the air stored products. The minimum O_2-uptake is reached at optimal CA conditions. When fresh products are stored at lower O_2- levels the product start to ferment. Comparable respiration rates for CA stored products are found at higher temperatures. If quality can be described as a function of respiration rate it is interesting to investigate whether products can be stored at higher temperatures (and CA) to reduce energy demands during transport.

All O_2-uptake and CO_2-production data were fitted with different models (tables 2 and 3) according to Zwietering et al (1991).

Table 2. O_2-uptake (nmol/kg.s) of apple (cv. Elstar) vs T (K)

		Value	Std	Value	Std
Air	r2	94.8		94.8	
	Standard Error	1.91		1.91	
	F-stat	1280		1278	
	a	-2.63 E+02	5.86 E-01	2.338 E+11	2.172 E+14
	b	2.29 E-01	6.70 E-03	7.097 E+05	2.200 E+03
CA	r2	98.0		97.5	
	Standard Error	2.52		2.81	
	F-stat	4394		3525	
	a	-2.67 E+02	2.71 E-01	2.15 E+17	1.49 E+17
	b	3.77 E–01	6.08 E-03	8.56 E+04	1.64 E+03

Two models [Ratkowsky $y=((x*b)-(a*b))^2$; Arrhenius $y=(a*\exp(-b/(8.314*x)))$] with both 2 parameters gave best correlation for O_2-uptake and CO_2-production. Arrhenius equation is often used to describe temperature dependent processes, for respiration rates of apple Ratkowsky's empirical equation seems to be more reliable (smaller standard deviation in parameters).

Table 3. CO_2-production (nmol/kg.s) of apple (cv. Elstar) vs T (K)

		Ratkowsky		Arrhenius	
		Value	Std	Value	Std
Air	r2	95.0		94.4	
	Standard Error	3.87		4.09	
	F-stat	1773		1589	
	A	-2.70 E+02	3.99 E-01	4.92 E+19	6.28 E+19
	B	4.01 E-01	1.06 E-02	9.89 E+04	3.03 E+03
CA	r2	98.1		98.6	
	Standard Error	1.42		1.21	
	F-stat	3620		4971	
	A	-2.69 E+02	2.83 E-01	1.30 E+19	9.04 E+18
	B	3.06 E-01	5.59 E-03	9.69 E+04	1.65 E+03

D. Ethylene production in response to temperature and CA

In this experiment ethylene-production was also measured (figure 4). Large deviations in ethylene production are found in air stored apples, standard deviation increases with temperature. During CA storage ethylene production is lower; the enzyme involved in ethylene production requires O_2.

To reduce energy use, the ventilation rate required to reduce ethylene levels could be regulated as a function of temperature and the O_2-level.

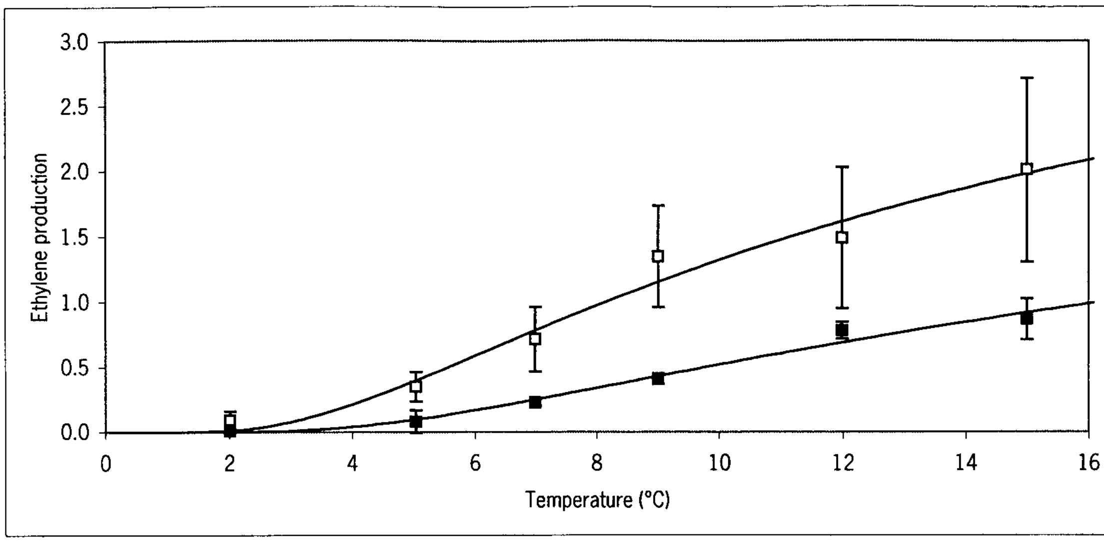


Figure 4. Ethylene production (pmol/kg.s) of apples (cv. Elstar) at different storage temperatures (°C)
□ = CA stored □ = Air stored.

E. Relation between respiration rates and quality changes

Are respiration rates of fresh products directly related to (or can it predict) the product quality? Respiration rates can be influenced by the following factors: time of harvest (ripening stage), adaptation of harvest products to the climate, storage conditions (T, O_2, and relative humidity) and ripening of the product.

During ripening of fruit ethylene production is increased. In fresh products there is a close relation (fig 5.) between the O_2-uptake curve (fig. 3) and ethylene production (fig. 4).

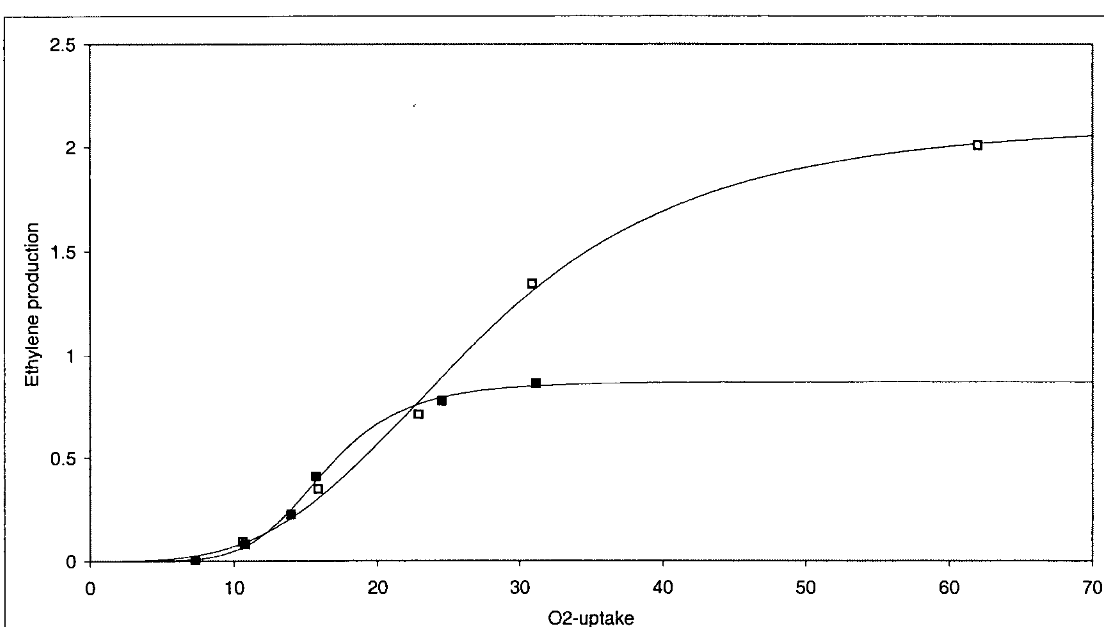


Figure 5 Relation between O_2-uptake (nmol /kg.s) of apple (cv. Elstar) and ethylene production (pmol/kg.s) can be described by a logistic dose response function $y=a/(1+(x/b)^c)$, □ = CA stored □ = Air stored.

Whether respiration rates during ripening increase and can be correlated to quality parameters will be examined in next experiments.

Deliverables
A relationship has been obtained between the oxygen uptake and carbon dioxide production versus temperature under both CA and air condition. The selected ranges for temperature, CA and air are chosen within container practice. Under similar circumstances, the effect of temperature fluctuations on respiration has been estimated. Both phenomena have to be under control in order to provoke energy reduction.

Requirements from/interactions with other tasks
Task 2. Data about the characteristics (flow rates, temperature profiles, O_2 profiles, CO_2 profiles) of the CA unit are required. This will give more insight about actual fluctuations in temperature and oxygen concentrations.

Task 4. Green chemicals are tested on the model products on an experimental scale. These experiments will be continued during the next period. Effects of these chemicals on the micro-organisms and model products will be monitored.

Evaluation parameters
The dynamic experiments give evidence about the possibility to be less strict in the climate conditions. Based on first experiments there seem to be three possible ways to reduce energy demands and maintain product quality:

- allowing larger temperature fluctuations,
- regulating air exchange based on temperature and O_2 levels,
- storing products at higher temperature and compensate for quality loss by applying CA condition.

Time schedule
In the next period further experiments will be carried out to determine the effects of temperature fluctuations on the quality and respiration of the three model products (apple, tomato and green beans).
Direct after harvest and after 3-month CA storage two transport simulation experiments were carried out. Apples were stored at 2, 5 and 9 °C under air and CA-storage. This experiment will be repeated after 6-month CA storage. Based on the experimental data an RQ-model (respiration + quality) for apples (cv. Elstar) will be build.
Additional experiments are required to determine the response of respiration to changes in O_2 concentrations and temperature, because the respiration model used in the algorithm of the control-unit is based on a "steady state" respiration.

2.2 Contribution of The Greenery

The activities of The Greenery in in this period were limited to delivering products (mainly apples) and forwarding information of one of the exporting groups to the experts of the ATO. The results of the research at ATO so far could not be implemented in the organisation so far. The goals and expected results as reported in a earlier stage remain unchanged.

3 Task 2: Optimisation of climate control under energetic and quality constraints

3.1 Contribution of ATO

Aim

This task models the physical transport phenomena in the container (airflow, heat, vapour and gas transport) and the working of the refrigeration/controlled-atmosphere unit. This task will eventually deliver a simple model for use by the supervisory control algorithm, to be developed in task 7.

In this task we take a dual approach: a top-down approach delivers a rough template for the final model, which is to be used by the supervisory control algorithm. By a bottom-up approach the final model is constructed from reliable models having a more detailed description of the physics in the container. The bottom-up approach will validate and refine the 'crude' model obtained by the top-down approach.

Former situation

The macro-level model has been further developed, and incorporates also the dynamics of the gas conditions in the container, including the operation of the CA-unit. Furthermore, experiments with a container loaded with 15 tons of apples have been performed, and analysed with the model.

At the micro-level a model is developed, describing the air flow resistance of a packaging filled with products in the situation of air being vented via holes through the packed bed of product. The model has been validated with data in literature.

Present situation

Experiments on the container with apples have been continued, and have been analysed by means of the macromodel. Experimental data shows that the model can predict quite accurately the average product temperature, and oxygen levels. The model does not yet have a good prediction of the humidity levels and the CO_2 levels at low oxygen levels. The humidity level is strongly coupled to the dehumification of the cool-unit, which also needs further modelling.

Furthermore a first prototype of the model describing the energy consumption of the cool-unit. The model shows a good agreement with experiments and manufacturers data. At one point, the power consumption of the compressor, the model have to be more accurate and generic.

Next activities

New container experiments with apples are planned for the fall of 2000. The experiments will be oriented on the airflow and temperature distribution inside the container. These results will be used for further refinement of the macro model. The energy-model will be developed further in close co-operation with Carrier. The model will be made more generic, and will incorporate also the CA-unit.

Finally, experiments will be done on pallet scale, oriented on the airflow and heat exchange between a pallet with boxes and the airflow flowing along the pallets.

Overview scientific activities

Macro-model

We are developing a macroscopic model, which describes the change of the average product temperature, humidity and gas conditions inside the cargo space. The cargo is represented by a single heat capacity (node) in the model, as shown in figure 1. The refrigeration unit is also roughly modelled, with its dynamics represented with logical control rules.

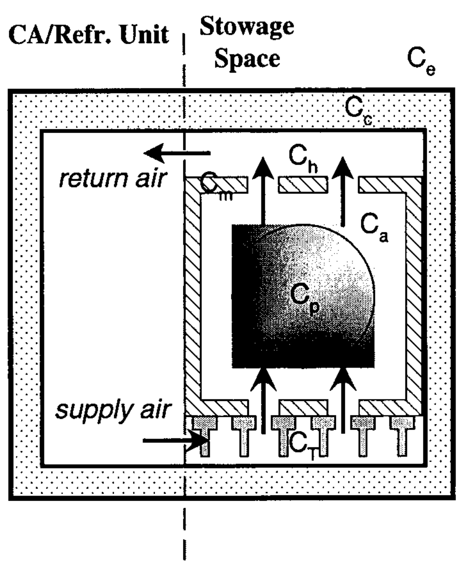


Figure 1. Schematic diagram of representation of heat capacities in the macro-model.

The model is still under development. A complete description will be given in a later report. Below in figures 2-3 we show some simulation results of the model, as compared to experiments performed with a reefer filled with 20 tons of apples. From figure 1 can be concluded that the temperature prediction is satisfactory, but the prediction of the relative humidity is too low. The value of the RH is strongly dependent of how much moisture is removed by the refrigeration unit. This piece of the model is still under development, and needs further adjustment. The moisture removal is part of the model describing the energy consumption and the operation of the refrigeration unit, which is described below.

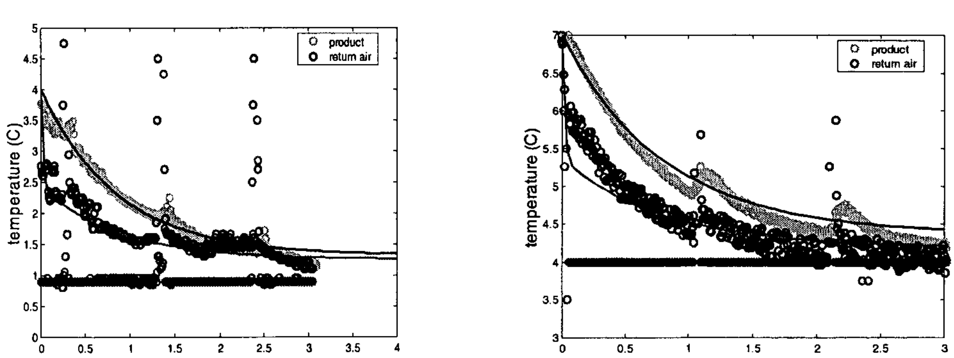


Figure 2. Prediction of (average) product and air temperature inside the cargo space, according to experiment (symbols) and macromodel (lines). In fig 2a) data is obtained from a cooling experiment from 4°C to 1°C, at high fan speed, and fig. 2b) data is obtained from a cooling experiment from 7°C to 4°C, at high fan speed. Ambient temperature is 4°C.

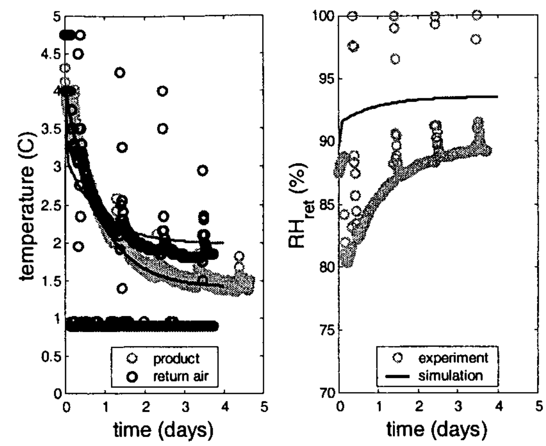


Figure 3. Prediction of (average) product, air temperature and relative humidity inside the cargo space, according to experiment (symbols) and macromodel (lines). Data is obtained from a cooling experiment from 5°C to 2°C at low fan speed.

The performance of the model in predicting the gas conditions is shown in figure 4. While the oxygen prediction is okay, the CO_2 prediction is a bit off. This is probably due to an inaccuracy of the model in the prediction of anaerobic respiration. This part of the model will be further improved.

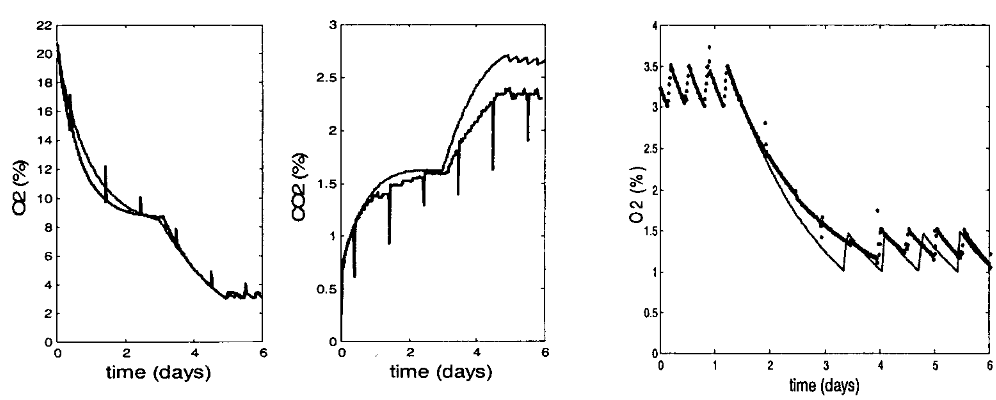


Figure 4. Prediction of gasconditions as measured during CA-experiments. In blue the experimental data and in red the numerical predictions. O_2 predictions are okay.

We have built a first prototype of the energy model, estimating the power consumption of the cool unit. In figure 5 one sees the experimental data and the predicted data for a single experiment. The prediction of the model of several experiments is satisfactory. But, for a few experiments, the prediction error is a bit off, due to inaccuracy of the submodel describing the power consumption of the compressor (which is quite dependent of ambient condition, conditions of return air and setpoints). Hence, in the further course of the project we will build a detailed, physical model of the refrigerant circuit. This model will predict the power consumption of the compressor and also will predict the climatic conditions (T and RH) over the supply air.

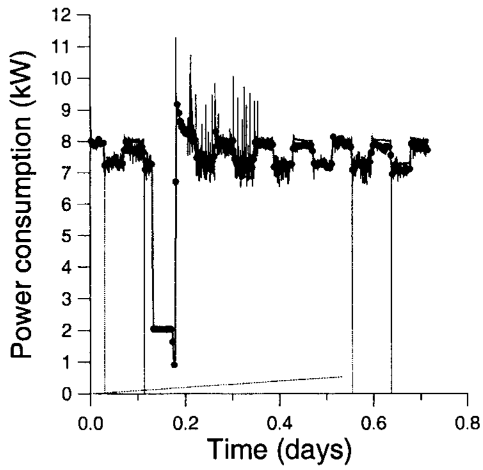


Figure 5 Power consumption of the cool unit, according to experiment (symbols) and numericla model (lines).

Furthermore, we have developed a model predicting the airflow resistance of a packaging with vent holes. The model is formulated using the Finite Element Method. In figure 6 one can observe the used meshing and the pressure field as a result of the numerical calculation. From the detailed pressure field we have extracted the total pressure drop versus the volumetric flow rate through the box. These results we have compared to experimental data found in literature. This comparison is shown in figure 7.

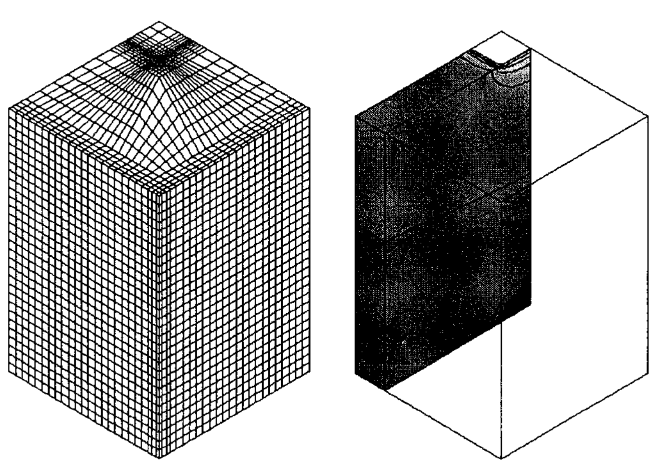


Figure 6. Finite element model of airflow in a package filled with tomatoes or mandarins. The box has a square hole in the middle. In the figure on the right one can observe a calculated pressure field. The largest pressure drop in near the vent holes.

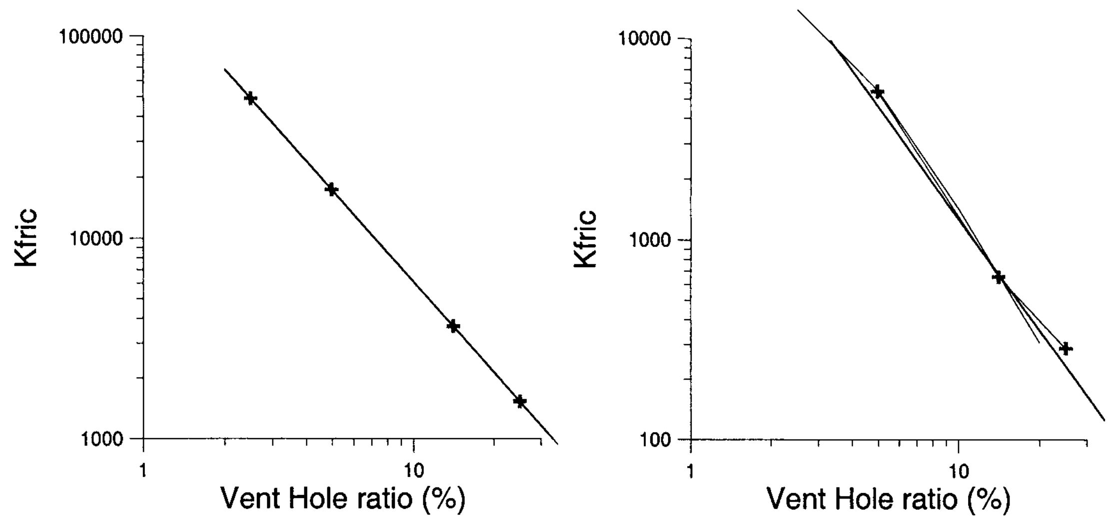


Figure 7. Prediction of the friction coefficient $K_{fric} = \Delta p_{tot}/u^2$ versus vent hole ratio O, according to experiment (symbols) and model (lines).

From the modeling work we have deduced a simple relation between the pressure drop over the box (Δp), the airflow velocity (u) and the vent hole ratio (O) (surface area of holes divided by surface area of side of the box). This relation will be used in the macro model, predicting the airflow distribution in the container. More details on the model one finds in the scientific paper, as presented in a scientific conference in Murcia Spain, and reprinted in appendix 1 of this report.

3.2 Contribution of P&O Nedlloyd

The aim of this project is to develop a Container with a much better K-value then the present Reefer Containers. In this way we need less power to keep the cargo temperature controlled which is contributing to the total power saving.

At the moment we have no concrete results regarding actual testing however some calculations proved that the K-value can be reduced by some 30% to 35% of the present value when we decide for a new foam technique.

We are discussing with a Chinese Container manufacturer and a European foam manufacturer's the possibilities for a new special foam technique.

At the moment the Manufacturer is preparing some drawings which we will discuss during a visit to this manufacturer in February 2001. Also we asked the manufacturer to make computer simulations regarding the k-value of the panels and we are looking to the possibility to prepare some test panels that can be tested afterwards.

In case there is a positive outcome we have to make decision if we actually build one test container with this concept. Also we need a serious look to the cost aspect of this matter before we decide to build a test container.

3.3 Contribution of Carrier Transicold

Overview
Carrier Transicold has continued its support of the tasks outlined in the project proposal in several specific areas. Results are discussed below.

EverFresh Controlled Atmosphere Unit
Beyond system improvements to improve CO_2 control, Carrier has begun development, with its compressor supplier, of a new air compressor. Our objective in this development is to improve the compressor air flow rate to allow further improvements in CO_2 control with high respiring cargo. We believe that improvements in compressor efficiency will also be realized.

Carrier will continue working closely with ATO to solve problems related to communicating with the Carrier EverFresh system controller. This effort is aimed to aid in the development of dynamic control algorithms.

Planned Efforts
In the coming months, Carrier will continue to provide the necessary support to ATO to allow external control of the controlled atmosphere system to aid in the research of dynamic atmosphere control. A visit to Carrier's Syracuse facility by ATO staff to investigate system modeling techniques will be supported.

Automatic fresh air vent
Two field trial systems are in place to evaluate in service use. The system controls delay opening of the vent until temperatures approach set point. In addition, the vent will automatically close if a frozen set point is entered. Reduced loading on the evaporator is expected to reduce overall unit poser consumption.

Planned Efforts
The field trials of the systems are expected to take place over the next six months. This will expose the system to a range of ambient and operating conditions. Further development effort is planned to evaluate use of an airflow sensor to control the vent position.

Variable Speed Motors
Carrier has initiated development of variable speed motors for use in its compressors.

Planned Efforts
Further development work is expected to take place on a variable speed compressor motor designs in late 2000 and through the first quarter of 2001.

Scroll Compressor Unit
The completion of the 65 unit field trial has lead to the successful release on the Carrier scroll compressor container unit. Limited production quantities are available to customers that are interested in the reduced weight, higher capacity, and lower power consumption that this unit provides.

Planned Efforts
Initial production units will be closely monitored when placed into service to ensure that system reliability is demonstrated to be equal to or better that the current reciprocating design.

Humidity Control System (Development of slow release systems for green chemicals)
Further development work has been completed on both ultrasonic and nozzle based water atomizing systems. Ultrasonic systems of both a submersible and horn type have been evaluated in conceptual prototype arrangements.

Additional information has been gathered on alternate nozzle based systems as well. Our prior findings had not revealed a nozzle based system that would work effectively with out clogging. However, work with an alternate supplier has uncovered a simple nozzle based system that appears to function quite well.All systems have the potential to reduce water droplet size by more than 50% to assist in the dispersion of green chemical through out the cargo space.

Planned Efforts
Additional development work is necessary through the balance of 2000 and into 2001 to conclude the testing necessary to allow the selection of the type of atomization system to proceed with. Consideration of both cost and system reliability will be thoroughly researched for each of the systems under study.

Further discussion with ATO is necessary to define requirements of a sample needed for testing of green chemical delivery.

4 Task 3: Development of a robust integrated sustainable energy system

Introduction

The focus of Task 3 of the CEET2005 project is to develop an energy supply system for a simple stand-alone reefer (configuration 2). In order to increase the number of optional supply systems the energy demand of the reefer container needs to be reduced. Therefore Ecofys has been investigating both the power supply of possible energy supply systems and ways to reduce the energy consumption of the refrigeration unit. In this last respect the focus is on the hardware of the unit (since software is tackled in task 7). Collaboration with ATO will start to integrate ideas with the developments in task 2.

Aim

To develop an energy supply system for a simple stand-alone reefer.

Results

From the qualitative survey of several – sustainable and non-sustainable - energy supply systems (reported on in the previous management reports) it was concluded that in the case of marine transport, efforts to improve the efficiency can turn out favourable, but will not take effect on the containers installation. Transportation on trains or trucks involves a per-container energy supply, which offers possibilities for photovoltaic cells, fuel cells or absorption heat pumps. A need for the container to run autonomously, favours the use of a maintenance-free or fuel-less system such as photo-voltaic cells (see Table 1).

Table 1 Criteria applied to energy systems. ++ suitable/cheap, - - unsuitable/expensive, 0 not applicable, ? unknown

	Diesel genset	Electricity	PV	Fuel Cells	Electric buffer	Thermal buffer	Bio-diesel genset	H2/LPG/NG	Absorption heat pump
Power	++	++	≤2.2 kW	++	-	- -	+	++	+
Autonomy	+/-	- -	++	+/-	+	+	+/-	+/-	-
Availability (fuel source)	+	ship ++	+	-/+	++	++	some regions -	some regions -/+	transport ++
Reliability	+	++	++	?	++	++	+	+	+
Sustainability	-	-	+	-/+	-/+	-/+	+	-/+	+
Investment cost	-	++	- -	-	- -	+	-	-	- -
Maintenance cost	-	++	++	+	+	+	-	-	?
Fuel cost	+	++	0	-/+	0	0	+	-/+	++
Built-in	-	- -	-	+	+	+	-	-	++
Availability technology	++	++	++	- - >2005	++	++	+	++	-

A quantitative assessment of the technical feasibility of a solar cell system was conducted. In collaboration with task 6 (P&O Nedlloyd (Eteca) and ATO) a choice of several specific cold-chains was made in order to define specific climatological and logistical information (see figure 1).

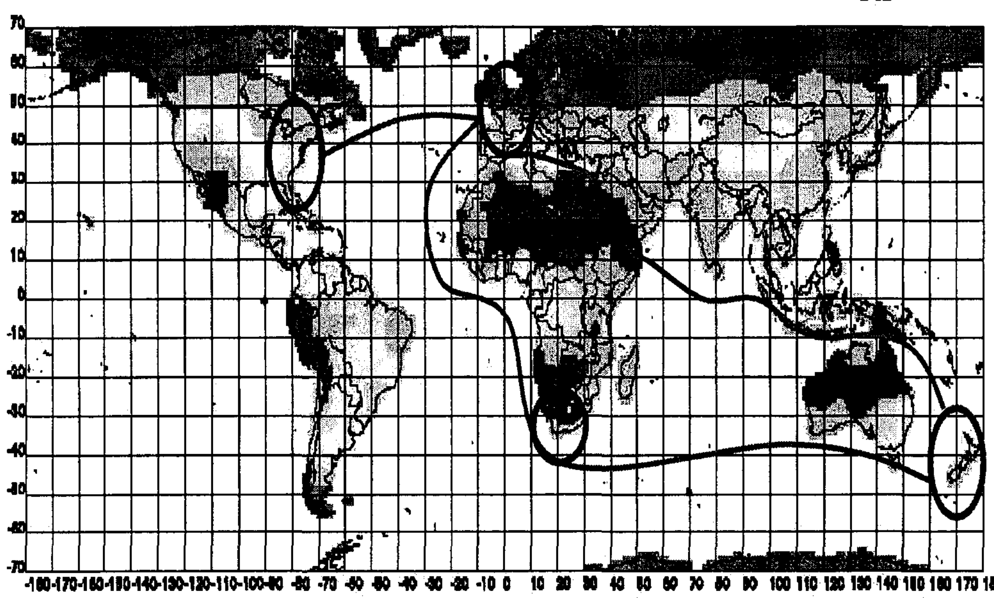


Figure 1 Annual irradiation chart of the world with selected trajectories: Apples from New Zealand or South Africa to Holland and bell pepper from Holland to the United States

The energy demand of the current container was first estimated with a model on the respiration characteristics of the product and the heat dynamics of the container, the electrical components of the cooling system and the climatological data. Measurements conducted by ATO on a test reefer (located at ATO) showed that the reefers cooling systems power requirements are as estimated in the model. With the data on the cold chain and the energy demand the actual potential of a solar cell system covering the roof of a container was investigated for several locations in the cold chain. From this analysis it was concluded that reduction of the containers power consumption by a factor 4-5 is necessary to cover the total demand with power generated by the solar panels (see figure 2).

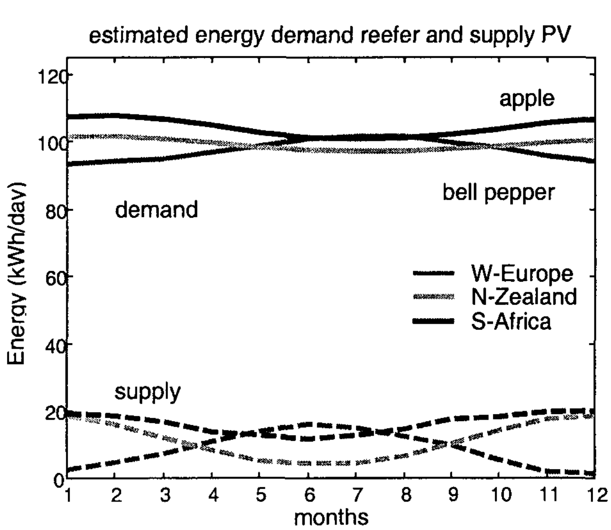


Figure 2 Estimated energy demand of the reefer in several climates (bold line) and energy supply of solar panels mounted on the top of the reefer (dashed line) during the year.

Although premature, the current estimations of power saving reachable (with hard and software) are not in this range yet. Therefore, Ecofys started collaborating with ATO on the power reduction options in the hardware of the cooling unit. From the measurements on the test reefer it became clear that the high power consumption is caused by the compressor, the heater and the evaporator fans. The following power reduction options considered are targeted to tackle these problem components:

- *Heat recovery after condenser*

The installation dehumidifies the container air by compressing and cooling the air so vapour can be removed. An electrically powered resistance heater reheats the air to obtain the desired temperature in the container. A modification to this configuration would be to use the heat of the condenser to reheat the air (see figure 3). This can be done by placing a heat exchanger in the outside airflow that cools the condenser. This could reduce the power needed to cool the condenser and reduce the power consumed by the heater.

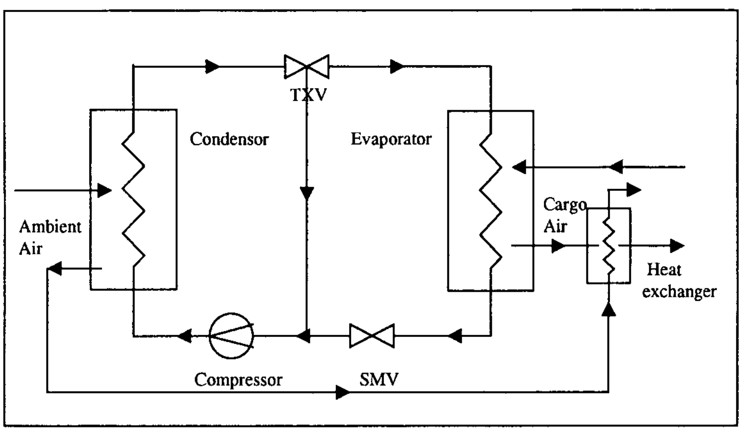


Figure 3 Schematic representation of refrigeration unit with heat recovery

- *Dehumidification with desiccant wheel*

Dehumidification could also be done by means of a desiccant wheel (see Figure 4). This could make the heater redundant and also reduce the demand for cooling. The temperature increase caused by the compressor would reduce the demand for heating the air before it is supplied to the filter. Possibly the heater would be redundant too. Warm air from the main condenser fan can be used to dry the desiccant wheel.

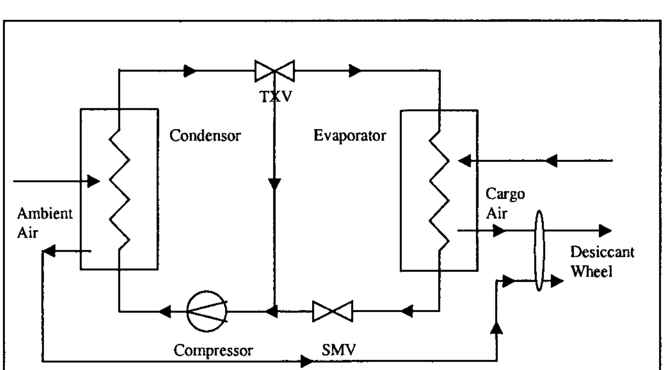


Figure 4 Schematic representation of refrigeration unit with desiccant wheel

- *Air recycling*

In the right (cold) climate, the outside air can be used to condition the container. This air can be mixed with container air directly, or its cold can be used to cool the container via a heat exchanger (see figure 5). In order to do this, outside temperature and humidity need to be monitored. This is not envisioned in the current configuration of the system.

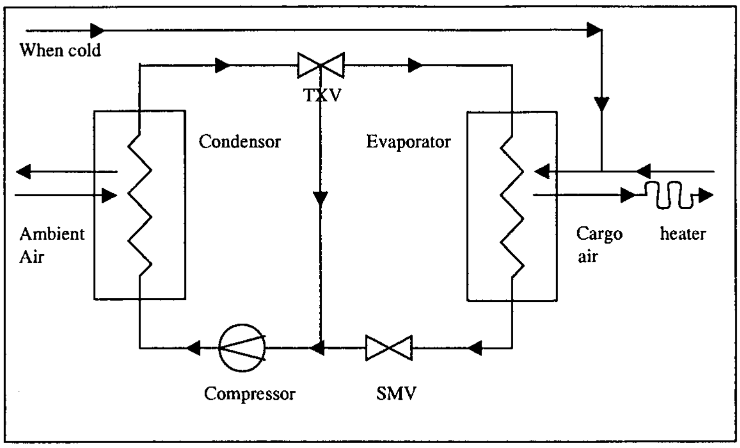


Figure 5 Schematic representation of refrigeration unit with air recycling

With the model developed in task 2 these options will be analyzed for their power saving potential in several climates.

Deliverables
Analysis of energy supply options in terms of technical and economical feasibility. Analysis of mentioned energy saving options in terms of technical energy saving potential.

Resources
Technical and economical data of energy supply systems and cooling and dehumidification systems. Model developed in task 2 to evaluate energy saving options.

Requirements from/interactions with other tasks
To design a stand-alone power supply the power requirements of the cooling unit should be known under various circumstances. This was investigated by ATO in task 2 during the period of April-September 2000. The results are used in the analyses of the possible energy supply systems. In order to achieve the power reduction required Ecofys will start to collaborate with ATO on energy saving options in the hardware of the refrigeration unit. Cost aspects of these options will be evaluated and delivered to task 6.

Evaluation parameters
Energy reduction is the main goal of the CEET2005 project. The reduction of energy costs is a direct result of this (economy). In task 3 the possibilities of a more efficient and possibly sustainable energy supply system are investigated (ecology).

Time schedule
Until April 2001 the resulting options of the energy reduction systems will be thoroughly studied together with ATO with respect to technical feasibility.

5 Task 4: Development of slow-release systems for green chemicals

Introduction

From an agro-industrial point of view, plants are a very obvious source natural antimicrobial and are known to contain antimicrobial or medicinal metabolites. In many instances, these compounds play a role in the natural resistance or defence against microbial or other diseases. A wealth of literature exists describing their favourable properties and identifying the active components. In general, herbs and spices and several of their active ingredients have been Generally Recognised As Safe (GRAS), either because of their traditional use without any documented detrimental impact or because of dedicated toxicological studies. Their application in postharvest crop protection may be facilitated by this feature although appropriate toxicological evaluations cannot be passed-by in any legislation.

Aim

The aim of task 4 is to implement the use of green chemicals in the climate control system of the container. In principle this is an energy efficient means of preventing deterioration of the perishable product, since the requirements for temperature and humidity control can become less strict.

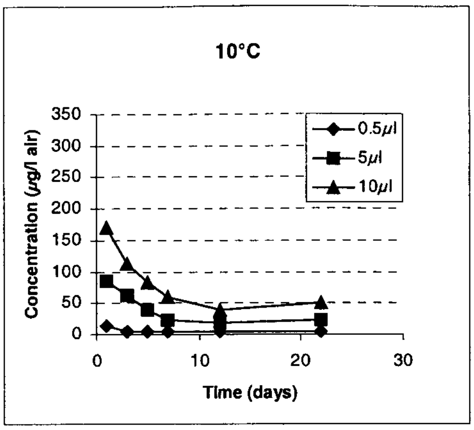
Results

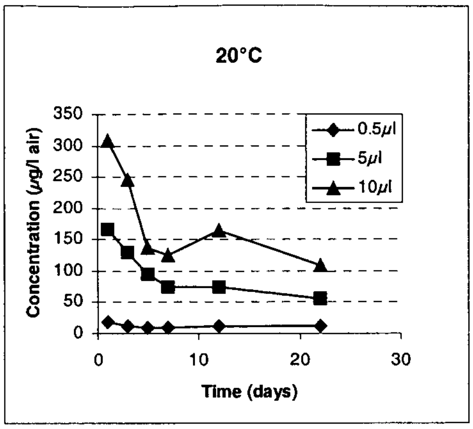
Previously, several volatile plant oils were evaluated *in vitro* for antifungal activity against four postharvest pathogens. Trans-2-hexenal which showed the highest degree of antifungal activity against all four target strains, was selected for further research. In the reporting period, *in situ* efficacy and phytotoxicity of trans-2-hexenal was studied during storage of apples. *Penicillium expansum* was used a a target organism.

1. Determination of the head space concentrations in *in vitro* experiments

In the *in vitro* system the headspace concentration of the oils was varied by adding different volumes of oil to the petridishes but the actual headspace concentrations were not determined. In the reporting period the corresponding headspace concentrations of three dosages of trans-2-hexenal in similar petridishes were analysed by gaschromatography. Headspace concentrations were linearly proportional to the volumes added and decreased in time according to first order kinetics (figs 1 and 2). Since the petridishes were not inoculated with organisms, this decrease must be caused by chemical oxidation or leakage. As a consequence, *in vitro* efficacy could only be related to a broad concentration range.

It was estimated from fig. 2 that a dosage of 2 µl trans-2-hexenal, which inhibited *in vitro* development of spores of *Penicillium expansum* at 20°C, corresponded to a headspace concentration of *ca* 80 µg/L.



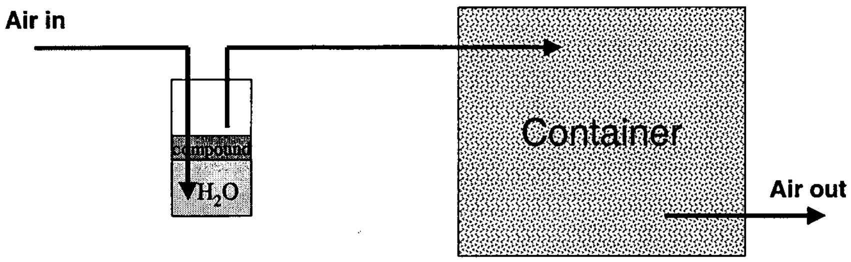


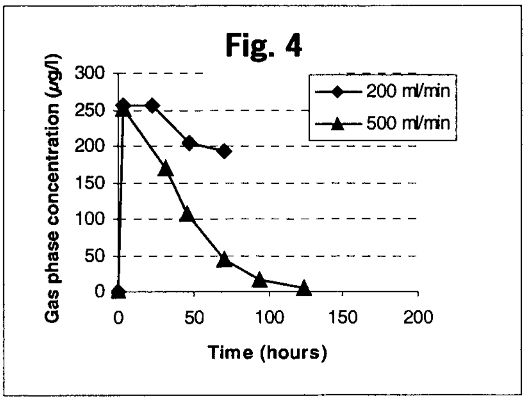
2. Development of a test system

For evaluation of *in situ* efficacy and phytotoxicity, we set out to develop a test system in which the headspace concentration could be kept constant. Also, this system would have to allow combined application of volatile plant oils with conventional modified gas atmospheres. A stainless steel container with a continuous supply of humidified air was taken as a basis. Two ways of delivery of trans-2-hexenal were evaluated:

1. Trans-2-hexenal was added to the washing bottle (fig. 3). With this delivery system, no constant headspace concentration was obtained in the container (fig. 4).

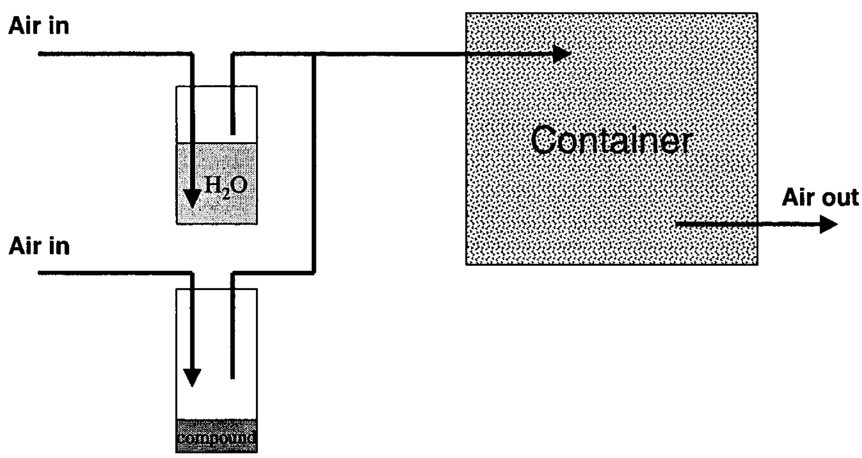
Fig. 3





2. The airflow into the container was split. One flow was humidified by passage via the washing bottle while the other flow was saturated with trans-2-hexenal by passing it over trans-2-hexenal into the container (fig. 5). With this delivery system, a relatively constant headspace concentration was obtained (fig. 6). By varying the ratio of both gas flows, the headspace concentration in the container was altered. This system was used in further studies.

Fig. 5



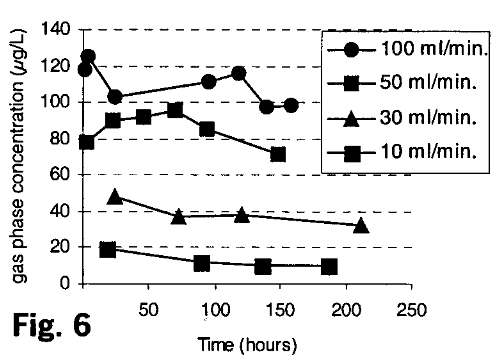


Fig. 6

3. *In situ* efficacy and phytotoxicity of trans-2-hexenal

Using this system, the effect of three concentrations of trans-2-hexenal on apples was studied. A control (no trans-2-hexenal) was included. Storage was two weeks at 5°C. Three concentration ranges were applied: 10-20 µg/L (low), 37-48 µg/L (medium), and 97-126 µg/L (high). At all concentrations, a considerable part of the trans-2-hexenal (50-90%) was metabolized by the apples. No fungal development nor product damage was observed after storage. However, when the apples were subsequently stored for 6 days at 18°C, damage was observed on apples that had been exposed to the highest concentration. Since no fungal development was observed on control apples, no conclusions could be made about the antifungal efficacy. When apples were artificially infected with *Penicillium expansum* spores, development of this fungus was observed irrespective of the presence of trans-2-hexenal. It should be noted that these apples had been severely infected.

Future research

Evaluation of both *in situ* and *in vitro* efficacy of trans-2-hexenal under constant headspace concentration will be continued. Focus will be on more accurate determination of the threshold concentrations for antifungal and phytotoxic activity.

Deliverables

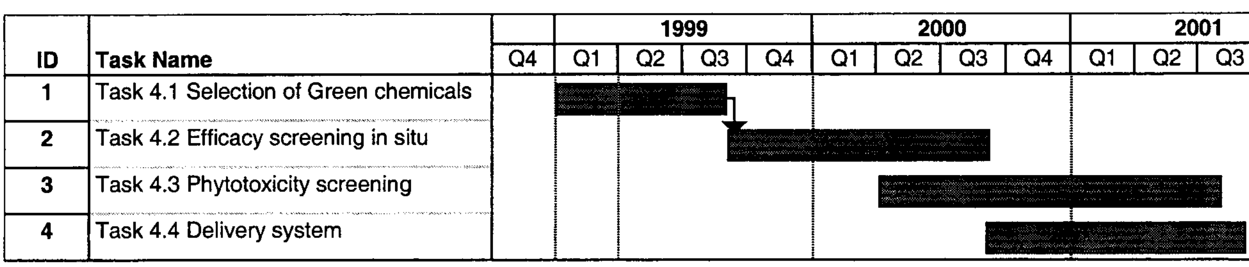
A test system has been developed for continuous administration of volatile plant oils.
Apples metabolise trans-2-hexenal which results in lower working concentrations.
Depending on the concentration applied, trans-2-hexenal may result in damage of apples.

Requirements from / interactions with other tasks

When storage experiments are conducted on container-scale, input of Carrier Transicold may be required for implementation of a delivery system.

Time schedule

Due to extensive *in vitro* screening of selected volatile plant oils (task 4.1), other tasks have been delayed. In order to avoid further delay, tasks 4.2.and 4.3 were combined and was research restricted to one volatile plant oil and one crop.



6 Task 5: Monitoring the surrounding environment and the product response

Introduction

Task 5 is concerned with monitoring product traits and the product environment. These measurements should provide the necessary information to control metabolic rates of the transported product. For obvious practical reasons, direct measurements on the product are inappropriate. Consequently, focus is on developing gas analysers that meet the requirements of sensitivity, selectivity, stability, robustness, size and longevity, as well as being cost effective. For the current application, the method of choice is an array of gas sensors. In common terminology such an array is denoted as an electronic nose, in short e-nose.

Aim

The aim of the conducted research was twofold, namely to:
(1) gather insight in the volatiles profile (flavour and off-flavour) emitted by the most important model product, i.e., apples and
(2) determine the best candidate among the currently commercially available e-noses.
These aims have been achieved through an extensive search in the scientific literature and the internet. It turns out that the most promising e-noses have become available during the last year.

Results

Volatiles profile

It is well known that ethylene is the volatile that supplies most information on the stadium of ripeness. Unfortunately, the detection of ethylene at the interesting level (low ppm) yields a difficult analytical problem, because other volatiles (e.g. butyl and hexyl acetate) exceed this level by two orders of magnitude. Preliminary experiments have been conducted with the e-nose presently used at ATO, i.e., the eNOSE 4048 (EEV Chemical Sensor Systems). The results show that differences in volatile composition of the headspace of apples can be measured, but only if there are clear differences in ripeness.

Candidates for prototype e-nose

An overview of commercially available e-noses is given in Table 1. The 'best' instruments (especially in terms of stability) are based on existing analytical instrumentation, i.e., GC (zNose) and MS (HP 4440A and Smart Nose-300). Their applicability is limited here because of size restrictions (as well as price). The most promising e-noses are both hand-held sized. One is based on conducting polymers (Cyranose 320), while the other works with metal oxyde semiconductors (KAMINA). The manufacturers claim a high stability as well as reproducibility between sensors. These claims need to be tested. It is likely that software must be developed to handle drift.

Sensors

The goal of the task

Task 5 is mainly concerned with sensors. This includes measurement of physical properties for climate control and estimation of product status. For practical reasons direct measurements on the product itself are not considered, but as much information as possible should be obtained from environmental measurements.

Aim of research for the past period
Improving the stability of the oxygen sensor, and working towards a commercial product. Monitoring other interesting gas sensor developments for use in fruit storage and especially container transport.

Former situation
An oxygen sensor has been developed with integrated optical detection system. Signal processing software has been integrated for linearization and temperature and air pressure correction. Tests have shown that sensitivity and accuracy of the device is good, but the stability of the sensing layer needs to be improved. A suitable, but still a bit expensive CO_2 sensor has been ordered and tested.

Present situation
For the oxygen sensor development, we joined forces with a small external company specialized in analytical chemistry. They already developed a prototype carbon dioxide sensor and are helping us now to solve the stability problems with our oxygen sensor. We agreed to bundle our products into one cheap device for measuring both oxygen and carbon dioxide. To stabilize the chemical probe for oxygen detection we already made some improvement by encapsulating the dye in another polymer.

Future realizations
For stabilizing the optical oxygen sensor, we will look for and screen other, more stable probes. Besides that we can optimize the measurement system to reduce average light exposure of the probe and therefore extend sensor lifetime. We are planning to integrate the CO_2 and O_2 measurement into a single device.

Actual comments on the evaluation parameters
We are working towards a commercial sensor product for simultaneous oxygen and carbon dioxide measurements. This sensor consumes a tiny amount of power. An accurate measurement of climate and product status allows for larger variations in climate regulation, which saves on energy for the cooling system. The oxygen sensor is a good alternative for the accurate but heavy, fragile and expensive paramagnetic oxygen analyzers. Competing technologies deploying the same photochemical effect for oxygen detection, use remote fiberoptic sensing and are more complex and much more expensive. The combination of both O_2 and CO_2 sensors in one cheap device is a major advantage compared to using separate sensors.

The sensor knowledge and experience gained by the CEET project greatly accelerated other sensor developments in our institute. For example, we have developed a prototype ethanol sensor with a detection limit of 50ppb for use in fruit storage, controlled by the ATO patented DCS system. This system regulates the oxygen concentration by measuring the ethanol production of the fruit. The system is designed to increase storage time and preserve fruit quality.

Deliverables
E-nose that functions under the conditions present in a container. This implies that it should be equipped with software that enables self-calibration to counter potential drift. The key word is lifelong calibration, which is usually not guaranteed by standard software.

Resources

In the past period, 563 hours were invested in the project. It is expected that in the next period an equal amount will be required.

Requirements from / interactions with other tasks

Before testing the e-nose prototype we need input from Task 1 and Task 4 about the strategy for sensor testing with respect to the product. From Task 7 we need information of how the e-nose should be connected with the control unit.

Evaluation parameters

Economical:
1. energy saving and
2. improvement of economical lifetime of product.

Ecological:
1. saving of product loss,
2. increase of lifetime and quality of the transported products and
3. energy saving resulting in reduced CO_2 emission in the Netherlands and world-wide with respect to 1998.

Technological:
1. potential applications in other areas (quality control in the entire food production chain, with emphasis on the early detection of spoilage),
2. technological spin-off (dependable self-calibrating gas analysers) and
3. technological lead and added value (food safety).

Proposed experiments and time schedule

Proposed experiments

While providing a proof of principle, the previously conducted experiments clearly imply that additional trials are required. The currently proposed experiments should comprise the following aspects:
- the gas samples should also be analysed using gas chromatography with mass spectral detection (GC-MS). The use of GC-MS, which is the standard reference method, will enable the identification of the volatiles that are subject to the largest concentration changes. This information can be used to select the sensors for the e-nose,
- headspace samples should be measured for apples infected with mould (and for a control group),
- headspace samples should be measured for isolated mould cultures and
- quality control samples should be measured over a long period to quantify potential drift and test the adequacy of drift correction software.

Planning for the next year

				4th Quarter			1st Quarter			2nd Quarter			3rd Quarter			4th Quarter			1st Q
ID		Task Name	Duration	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1		**Task 5 Volatiles sensor**	**150 days**																
2		Experiments	28 days																
3		Software development	20 days																
4		Validation	20 days																

Table 1. Overview of commercially available electronic noses

Manufacturer	Product	Technology
WMA Airsense Analysentechnik GmbH	PEN	10×MOS
Alpha M.O.S.	FOX 2/3/4/5000	6/12/18/24×MOS, CP, QCM
Bloodhound Sensors Ltd.	BH114	14×CP, DLC
Cyrano Sciences Inc.	Cyranose 320	32×CP
Element Ltd.	FreshSense	MOS
Environics Industry Oy	MGD-1	Imcell™ (IMS)
Electronic Sensor Technology	zNose	GC-SAW
Forschungszentrum Karlsruhe	KAMINA	40×MOS
	SAGAS	8×SAW+1 reference
HKR Sensorsysteme GmbH	QMB6/HS40XL	QCM, MS
	HS40/MS	QCM, MS
Hewlett Packard	HP 4440A	MS
Lennartz Electronic	MOSES II	8×QCM, 8×MOS, calorimetric, electrochemical
EEV Chemical Sensor Systems	e-Nose 5000	CP, MOS, QCM
Microsensor Systems, Inc.	Vaporlab	SAW
Motech Sensorik, Netzwerke und Consulting GmbH	VOCmeter	QCM, MOS, electrochemical
Nordic Sensor Technologies AB	NST 3210/20/20A	MOSFET, MOS
Osmetech plc	Multisampler-SP (A32S)	32×CP
	Core sensor module	48×CP
Daimler Chrysler Aerospace RST Rostock	Sam	QCM, SAW, MOS
Smart Nose	Smart Nose-300	MS

CP = conductive polymer, DLC = discotic liquid crystal, GC = gas chromatography, MS = mass spectrometry, IMS = ion mobility spectrometry, MOS = metal oxide semiconductor, FET = field effective transistor, QCM = quartz crystal microbalance, SAW = surface acoustic wave.

7 Task 6: Chain optimisation and marketing opportunities

7.1 Contribution of ATO

Introduction

This task will result in the description of market opportunities and marketing and logistical concepts for the agro-container. Participants in task 6 are P&O Nedlloyd (task 6b) and ATO (task 6a). P&O Nedlloyd has outsourced a considerable amount of work to the Erasmus University through Erbs bv (former Eteca bv).

Aim

Task 6a will quantify the effects of using the new agro-container within a certain distribution chain by developing a cost/benefit model that will give a better insight in the present logistical chain of climate controlled goods.

Results

The cost/benefit model will be built in 4 stages: 1) concept development 2) concept screening with simulation and real data 3) Implementation 4) model validation and 5) documentation.

In relation to the cost/benefit model we defined the following cost types:
- Container provision
- Maintenance & repair
- Energy use

The value of these cost types added to the profit margin of the carrier will result into a certain tariff.

Assuming that the new container would be able to raise the product quality and extend shelf life we had defined -in relation to the cost/benefit model- the following benefit types:
- Shelf life of the product after discharge;
- Internal product quality;
- Product loss;
- New trade lanes or modalities because of shelf life extension.

We assumed that a shipper would make a comparison between these benefits and the potential higher tariff of the new container compared to a 40ft high cube reefer (non-CA).

We quantified these benefit types by interviewing exporters, importers and the shipping company's. On the basis of the current market situations, government regulations and (price) data of the transported products and used fuels we learned the following.

The first conclusion is that regarding to product quality in general the container is not the bottleneck. Besides the most occurring cause of product loss is 'human error' and also not the container. Thus using the agro-container will only prevent a small number of claims (product loss, wrong climate / low Q-in). Moreover, it will probably induce new ones because of its high-sophisticated appearance.

In addition, when you are able to extend the shelf life of the product within the same supply chain -by using the new container- you are not able to make money out of it. A certain level of quality must be achieved and additional shelf life is not paid for. Shelf life extension seems only interesting if it creates new possibilities (new supply chains or a modal shift within the same chain). However in regard to the first, the replacement market is small (< 0,5 % of global reefer market) and stable product prices are required but not often realistic. So, there is a potential market for a CA+ container in particular to make a modal shift possible.

We also learned that the shipping company's want to maximize their energy savings because actual energy cost is substantial. When the new container is able to reduce the energy consumption essentially compared to the conventional reefer box the shipping companies are willing to use this new container. Of course the cost of the new container must not exceed the energy savings and the quality of the product must be at least equal to the minimal product quality required by the market.

Combining these findings we can conclude that the main benefit of the new container is to enable a product quality that is at least equal to the minimal required product quality by the market, while using a minimal amount of energy transporting these products (**Min E such that Q ≥ Qmin**)

Initially we expected the main possibilities of the new agro-container to lie within the fields of less product loss, better internal product quality or longer shelf life. However, research showed that the main benefit of the new container is energy reduction. The conclusions show that the new container can be used to minimize the energy consumption without affecting the (minimal) product quality the market demands.

Therefore for the further development of the cost/benefit model we focus on energy savings. Furthermore the goals for next year will be:
- Calculate cost reduction for different configurations;
- Comparison between different container configurations;
- Possibility to quantify the advance in a trip.

Next we will -in close co-operation with Erbs- look into the possibilities of continental use of the new agro-container. We will focus on the energy savings due to the use of the new container and a possible modal shift.

Deliverables
The development of the model concept including almost all simulation testing has been finished. The final deliverables of the cost/benefit model have the following capabilities:
- To give insight how much it will cost to use the agro-container for transporting a certain product along a certain distribution chain;
- To give insight what will be the energy use during transport;
- To give insight what will be the door-to-door lead time of transporting the product;
- To be able to compare these results with the results of making use of other (more conventional) containers.

Resources
Existing market studies, literature studies, and interviews with the main actors in the reefer industry.

Requirements from / interaction with other tasks
Task 1 (Product quality)
We expect support in translating a higher product quality into possible benefits such as a longer possible transporting time (modal shift) and larger market area.

Task 6b/P&O Nedlloyd and Erbs (Market development)
We expect a quantification of the reference container.

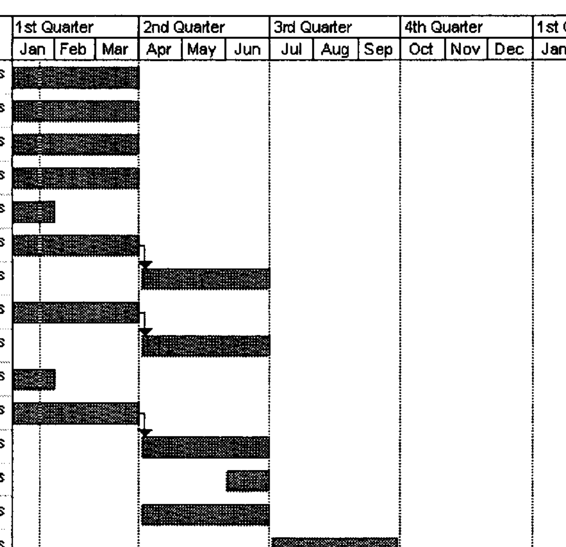
Evaluation parameters EET
The cost/benefit model will give insight into the following parameters:

Economy:
- Modal shift from air transport to sea transport and/or from road transport to rail transport or inlandshipping;
- Acceptation of the new container by the market;
- Development of the cost price of the product related to other containers;
- Savings on energy cost.

Ecology:
- Savings on waste
- Increase in product shelf life and quality

Time schedule
The MS Project Gantt will give some more insight in the planning.

ID	Task Name	Duration
1	1.1 Kwantificeren houdbaarheidsverlenging voorbeeldpr	130 days
2	1.2 Kwantificeren energiebesparing	130 days
3	1.3 Kwantificeren operationele kosten	130 days
4	1.4 Kwantificeren afschrijvingskosten	130 days
5	1.5 Kwantificeren referentiecontainer	218 days
6	2.1 Kwantificeren continentaal transport (container)	65 days
7	2.2 Kwantificeren energiebesparing	65 days
8	2.3 Bepalen randvoorwaarden modalshift	65 days
9	2.4 Kwantificeren energiebesparing a.g.v. modal-shift	65 days
10	3.1 Beschrijven model functionaliteit	153 days
11	3.2 Implementatie software tool	65 days
12	3.3 Analyses uitvoeren	65 days
13	3.3' Update model	21 days
14	3.4 Schrijven documentatie	65 days
15	4.1 Eindrapportage	65 days



7.2 Contribution of P&O Nedlloyd: Logistics

1. Introduction
The third half-year report of the team responsible for task 6a, will summarize our findings in respect of the maritime market or maritime container as referred to in our second briefing. The intra-European market will be evaluated during the coming period.

In the course of our research we have come across a variety of trends that influence the design, investment and consequently technological requirements in a reefer container.

2. Aim

Over the last period, it was our aim to summarize the general trends like 'Global Orientation', 'Industry Consolidation' and 'Horizontal Integration' will cause a shift of power within the cold chain. Looking at the perishables industry, retailers have confirmed their interest in global souring. At present pilots are being set up in Europe, where retailers buy their produce straight from selected growers in Southern Europe and commit to a full season's program. Through Mergers & Acquisitions retailers in future will have the purchasing power to source the range of produce from Europe as well as other Continents. We strongly believe that in future decisive power when it comes to shipping will be at the import rather than at the export side of the market as well, which does not necessarily mean that the retailers themselves will decide on their logistics service providers, but they will appoint a dedicated party that will act on behalf of the retailer only.

The retailer will strive to accomplish two goals: cost reduction and quality improvement. On a micro economic level, a focus on Finance has become number one priority again. Over the last decade companies have moved from a focus on Production, to a focus on Marketing and Sales, and only recently this focus has shifted towards Finance again. The key areas are cost control and process costs reduction, which again explains the strong interest in ICT solutions. Retailers, most probably through a selected service provider, will – in future - purchase their produce on FOB rather than CIF basis and consequently gain over-all cost control in the cold chain. The 'Order to Build'-concept seems unlikely to ever take place in the produce industry, 'just-in-time' management will certainly be introduced. Order quantities decrease, whereas the frequency rises, causing less storage points, less storage costs and fresher produce in the shelves. Value added services that can be moved upstream, will be moved upstream.

The next and probably most interesting development is quality improvement and control. The total amount of fruit per capita in Europe will stabilize or decrease, however the consumption of exotics will increase. There has been a rise in the consumption of organic vegetables and fruits. Consumers more and more expect fruit and vegetables to be available on a year-round basis. Recent incidents like BSE and sickness of Dutch pigs have caused a decrease in consumption of meat and an increase in the consumption of fish. Due to these problems, health inspection in Europe has become stricter.

Looking at the cold chain, we have seen a movement of decisive control towards the retailer, whom aims on reducing logistics costs, however not to the detriment of the quality of the produce (market pull factors). Due to an increased demand for a larger variety of produce we foresee a larger variety of reefer equipment in future, equipment that will fit the increased commodity complexity. Looking at the ownership of the equipment, we expect the owner to be different, depending on the complexity of the product shipped. Shipping companies will own standard equipment, like 20ft, 40ft and 40ft HC, whereas combined ownership will be chosen for CA boxes. When looking at chemical products, we expect to see only shipper's owned boxes. In our opinion the commodity will be the starting point, from where the type of box and its ownership will be determined.

As an example frozen commodities do not require complicated technological features other than a reefer plant with the ability to take frozen products and keep them in frozen condition. An interesting development has been the introduction of the super freezer that has the ability to take products at a level of minus 60 dgrs. The super freezer was build in order to move tuna to Japan. It is interesting to see that all over the world, tuna and swordfish are being moved in regular reefer containers and conventional ships. For this reason we would like to look upon the super freezer as a luxury good rather than a necessity.

Contrary to the frozen segment, the fresh segment contains quite some commodities that have and will benefit from the technological development of reefer equipment. In general we have seen that most of the bulk products can be moved in regular reefers, however depending on the product protocol and value of the cargo CA/MA techniques have proven to be successful and consequently any technique that manages to control/influence the atmosphere in a reefer box could be beneficial. The reason for stressing product protocol and value of the cargo is because CA/MA conditions when applied to products with a long protocol, the market situation might work to the detriment of the effects of CA/MA.). The value of the cargo has to be as such that it can bear the costs of CA shipments.

We would like to discuss box design in some more detail. Market research has shown an interest of shippers for any cost reduction measurements like lighter equipment (aluminum vs. steel boxes), adoption to the equipment that will increase handling speed (two levels), increased box capacity due to a reduction of the engine size and insulation walls. In respect of quality control, we can observe a technology push when it comes to remote control. Shippers are very interested in learning what the status of their produce is during its voyage. With this information they can play the market. Most of the shippers however, are reluctant to the remote control experiments, the most important reason being the liability for transport. If shippers control the contents of a reefer from shore, they will be liable rather than the shipping company for any damage to the cargo, due to wrong/changed temperature settings.

The spin-off of the introduction of a larger variety of reefer equipment will be a shift from air to sea (for relatively valuable reefer commodities with a relatively short product protocol) and moreover, the ability of shippers to reach markets, which they haven't explored due to the fact that logistics costs were to high (for instance flower exports from Holland to countries around the Mediterranean).

As per the last half-year report, the aim of task 6 of CEET2005 is meant to smoothen the market introduction of the CEETainer and describe her market opportunities. In order to reach this goal, Task 6 will result in the description of the markets of supply and demand of perishables, determining the shipper of the future. Moreover the our study will give a better insight in the present logistical chain of climate-controlled goods and the existing bottlenecks. The next step is to provide feed-back on container design for both the maritime and the continental container and a market introduction plan that aims on optimizing the use of the CEETainer and avoiding existing logistical bottlenecks.

3. Results

The team responsible for task 6a, have come up with two reports. The first report describes the cold chain, the actors in the cold chain, the shift in decisive power in the cold chain - or in other words: the determination of the shipper of the future. The second report focuses on the traditional box owner (the carrier), the way the carrier operates in the reefer segment at the moment and the way the carrier can or will position themselves in future. Both reports are focused on the maritime container, rather than the continental container. Besides two reports on the GDR sessions, organized to prove our concept, are available upon request.

In 2001 the team responsible for task 6 will come up with a report focusing on the continental container, including a market analysis of continental reefer flows, possibilities of containerizing these carg flows and design and technical capabilities of the continental reefer box.

4. Deliverables
A market analysis of the maritime and the continental markets, a definition of the shipper of the future and their requirements and demands as to the design and technical capabilities of the a new to be developed reefer container and an implementation and marketing strategy for the CEETainer.

5. Resources
Existing market studies, but mostly interviews with the main actors in the reefer industry. We have held interviews with the various actors in the cold chain. A group decision room session has confirmed trends and scenarios as described by us. Secondly we have held interviews with the main leasing companies and container carriers (the 'traditional' box owners) and organized a group decision room session in order to verify client criteria and performance of the container and specialized reefer carriers. For the continental part, again we will make use of market studies and interviews. We are also in the middle of linking with existing initiatives based on the European transport of perishables, being it in truck, train or barge.

6. Requirements / Interactions with other tasks
In general we would like to be closely updated by the over-all project leader on eventual boundaries/assumptions that might have been formulated in order to proceed in a more focused way. Moreover we would like to stress to the consortium to focus on developing generic applicable techniques, so that these techniques can be used in various type/size of containers.

Task 1 (Product quality)
We are interested in receiving feedback on the effect of CA/MA or ULO conditions on perishables as to the extension of product life. Moreover we are interested in the effect (shock) or brining perishables back into normal atmosphere. Can perishables be brought in and out CA/MA/ULO conditions more than once in a supply chain? Lastly we would like to be kept updated on the additional investment necessary to move perishables in CA/MA or ULO conditions.

Task 2 (Climate control)
The maritime market has already confirmed that any type of energy reduction will be extremely important. Our question remains: what is the consequence of a new energy source on the perishables inside the container and can the reduction in energy consumption be quantified?

Task 3 (Energy supply)
We expect a quantification of the cost (both investment cost and operating and maintenance cost) of energy supply devices (all alternatives that are being investigated).

Also we would be interested in the weight and volume of the alternative energy supply devices (most of all since it was mentioned that we could talk about more than one supply source).

Task 4 (Green chemicals)
We would like to receive a quantification of the cost of green chemicals and appending devices. We also would like feedback on the effect of green chemicals on perishables (health!).

Task 5 (Sensors)
We would like to receive a quantification of the cost of the sensors. We would also like to receive output reports/temp logs and information that is provided.

Task 7 (Control system)
We expect a quantification of the cost of the control unit.

8 Task 7: Development of integrated dynamic control strategies

Introduction
In the CEET 2005 project Supervisory Optimizing Control algorithms (SOC-system) will be developed. These algorithms take product dynamics into account in the optimization of a specific transport. This additional layer will improve the transport of agro-material by conditions to guarantee optimal quality against lowest possible cost.

In this chapter the modeling approach and the control structure with respect to the main module will be presented in Section 2. Different algorithms are tested in simulation studies. The results of these studies are shown.

Aim
The aim of Task 7 of the project is the: Development of a model-based Product Quality Control algorithm for container transport of agro-material".

Results
The results of Task 7 are in modelling, development of control structure and development of a short-term controller. Different models are developed, compared with measurement data and analysed in simulation studies. The models are used in the controllers and/or act as "real" world (plant) in simulation studies. A control structure is developed consisting of different control levels and components. Current research is focused on the use of model predictive control algorithms in the short-term controller.

Deliverables
The aim is to deliver a Supervisory Optimal Control algorithm that will optimize the CA/refrigerator setpoint trajectories. This optimization will take into account both product quality preservation and energy consumption. On the basis of first (simulation) results (using results from productexperiments) the impressions are that:
- significant energy savings are possible without harming the product quality by allowing minor temperature variations
- product quality improvement or a limited decrease is possible by gradually decreasing the O_2-setpoint at start of the trip and also gradually increasing the O_2-setpoint to ambient conditions at the end of the trip.

Resources
In the near-future experiments are needed to test the algorithm. In these experiments the available 40 ft container from P&O will be used. To enable manipulation of the external climate around the container it is positioned inside an ATO store with climate-control. The container will be loaded with apples/tomatoes put available by the Greenery. Software for communication with the CA/refrigerating units is put available by Carrier and should be in operation conditions very soon.

Requirements from / interactions with other tasks
The SOC will be the part that at the end of the day performs the overall optimization. Therefore it combines inputs from all other tasks.

Evaluation parameters

Economy

The SOC-algorithm will allow for better product quality preservation, by improved control of the climatic conditions *around the product*. Control of climatic conditions *around the product* comes natural in the SOC-algorithm by computation of setpoints for supply air on the basis of measurements in both supply and return air, and possibly in the cargo-hold's headspace. An effect is that more mature harvesting becomes possible, which will allow higher yields for farmers and improved flavor for consumers.

Putting the algorithm to the market can be quick, as it just concerns a piece of software. Parts of the SOC-algorithm will be applicable to any refrigerated storage facility.

First impression is that more efficient operation of the CA/refrigerating-units will result in significant energy savings, by just exploiting favorable ambient conditions. Simulation studies show that 20-40 % energy reduction using the control algorithms should be possible. It is important to note that this number is not including the cooling down of the product to the desired operation point as in this period no significant energy reduction can be achieved.

Ecology

First impression is that more efficient operation of the CA/refrigerating-units will result in significant energy savings, by just exploiting favorable ambient conditions.

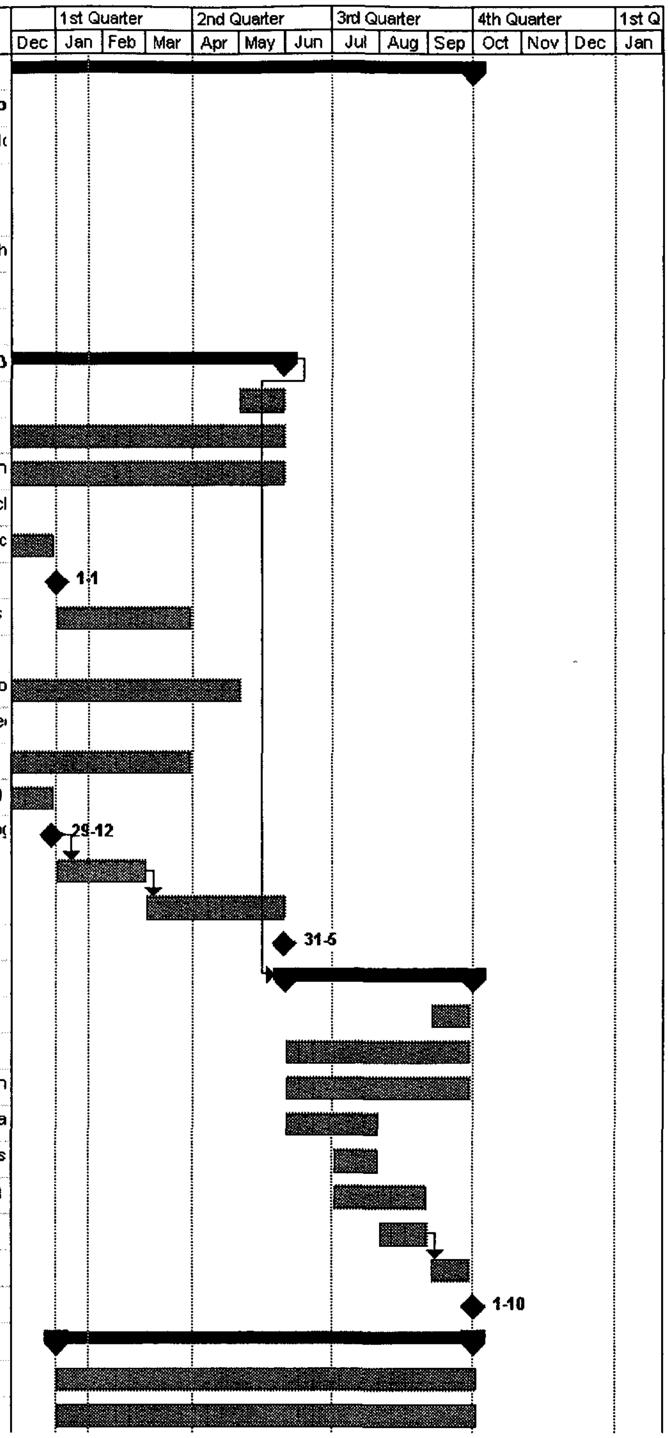
Technology

The intended SOC-algorithm will use weather-forecasts, an estimate of the remaining duration of the trip, market-prices of the transported product. To feed this information to the container requires communication of the container's microprocessor with the outside world. This communication is technically feasible, but not available in current reefer transport.

Time schedule

In the oncoming half-year the nonlinear short-term controller will be further developed. The objective is to test the algorithm both in simulation and in experiments. Special attention will be drawn at the identification of mass flows of air inside the container and the on-line measurement of the level of respiration by the product.

ID	Task Name
47	**Task 7**
48	**Part 2: Linear control: secondaryco**
49	Investigation local controllers, flo
50	Product measurements
51	Experiments for respiration
52	Development first adaptive mech
53	Experiments
54	Simulation program finished
55	**Part 3: Nonlinear control: secondary**
56	Report
57	Meetings
58	Investigation product information
59	Development product rules checl
60	Updating dynamical product moc
61	investigate flowpatterns
62	Determine reference trajectories
63	Experiments
64	Improving and implementation lo
65	Development of the nonlinear se
66	Update adaptive mechanism
67	Controller simulation and tuning
68	Nonlinear control simulation prog
69	Implementation
70	Testing
71	Nonlinear control implemented
72	**Part 4: Total product qualitycontrol:**
73	Report
74	Meetings
75	Investigation product information
76	Development of primarycontrol a
77	Indication on adaptive mechanis
78	Controller simulation and tuning
79	Implementation
80	Testing
81	Total controller implemented
82	**Evaluation and project follow-up**
83	Evaluation
84	Project proposal follow-up



Appendix 1: Scientific contribution Task 2

MODELLING AIR FLOW IN VENTED BOX PACKED WITH PRODUCE

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ABSTRACT

In this paper a numerical model is presented, which describes the airflow through a vented box packed with horticultural produce. By assuming the packed bed of produce to be a porous medium, we are able to predict experimental data with good accuracy. By analysing the simulation results we have been able to validate the hypothesis of Yun et.al. (1996), who have proposed a correlation between the total pressure drop over the vented box with produce and the vent hole ratio.

INTRODUCTION

For the quality conservation of packed horticultural produce the control of heat, moisture, and gas exchange with the environment is of great importance. An important tool for controlling these processes are vent holes in the packages (van der Sman, 1999). Through these holes air flows in and out of the package, thereby enhancing the exchange with the environment.

Most studies in literature concerning vent hole design are empirical studies (Chau,1983), (Haas,1976), (Wang & Tunpun,1969). An early attempt to develop a numerical model is by Talbot (1988), though he has not been successful in predicting the airflow through the package correctly. Later, when sufficient computer power came available, van der Sman has developed numerical models which are able to describe the natural convection in a vented box of seed potatoes (van der Sman, 1999) and forced convection through a vented box with oranges (van der Sman, 1998) successfully. Both models have predicted accurately the experimental data, by Chau, (1983) and van der Sman (1999) respectively.

The model presented by van der Sman (1998) has concerned packages with a constant vent hole ratio. In the present paper this model is tested further against experimental data by Yun et.al., (1996), who have investigated packages with a whole range of vent hole openings.

The numerical study presented in this paper is part of a larger research programme aimed at the development of a numerical model describing the physical transport of heat, moisture and respiration gases inside a refrigerated container stowed with pallets of packed horticultural produce. The final objective of this programme is to use this numerical model in a model-based control algorithm for the refrigeration/ controlled atmosphere unit. This algorithm requires a model with a restricted number of degrees of freedom, which we derive from numerical model describing subsystems at a more detailed level. A vented box is such a subsystem, for which a more averaged description of the airflow resistance than the Finite Element model is desired. For such an averaged description one might use the hypothesis proposed by Yun et.al. (1996), relating the total pressure drop, average flow rate and the vent hole ratio. Hence, the goal of this study is to verify this hypothesis by the presented numerical model.

THEORY

In the numerical model the usual assumption is used that the packed produce can be considered as a porous medium (Barker-Arkema, 1969). The airflow is described by the Darcy-Forchheimer equation. For flow though a packed bed in an enclosure, such as a vented box, the Darcy-Forchheimer equation is extended with the Brinkman term, which is required for the description of the flow near a solid-porous media boundary:

$$-\nabla p = \frac{\mu}{\kappa}\vec{u} + \beta \rho u \vec{u} - \mu_{eff} \nabla^2 \vec{u} \qquad (1)$$

The coefficients in the Darcy-Forchheimer equation can be computed for near spherical products, using the Ergun relations, which is shown to hold for bulks of agricultural produce (Van der Sman, 1998).
For packed beds of smooth spheres the Ergun relations are:

$$\frac{1}{\kappa} = \frac{K_1(1-\varepsilon)^2}{d_{eff}{}^2 \varepsilon^3}, \text{ and } \beta = \frac{K_2(1-\varepsilon)}{d_{eff}\,\varepsilon^3} \qquad (2)$$

In the numerical model Eq.(1) together with the continuity equation is solved using the Finite Element Solver FIDAP. In the scheme trilinear isoparametric elements with 8 nodes are used. The grid is densified near the walls of the package and near the vent holes, as shown in figure 1a. The Finite Element equations are solved iteratively by a conjugate gradient solver. The pressure field is discretised explicitly using a discontinuous pressure approximation.

The boundary conditions at the vent holes are prescribed as constant pressures across the complete area of the in- and outlet vent holes. The pressure at the outlet is defined as zero, and the pressure at the inlet is defined as Δp_{tot}.

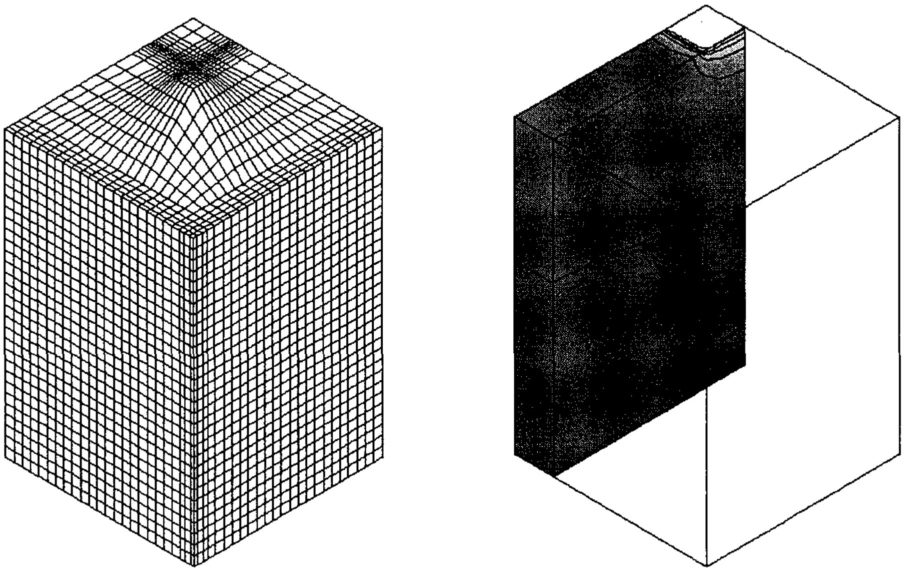


Figure 1. a) Example of mesh used in FEM model of a vented box with horticultural produce. b) Typical simulation results of the distribution of pressure field in the vented box. Contour lines are spaced at a 10 Pa interval.

EXPERIMENTAL DATA

The experimental data, against which the numerical model is tested, are gathered by Yun et.al.(1996). In that study the total pressure drop versus the average flow rate is determined for packaged produce with the vent hole ratio in the range of 2.5 to 20%. The products used are mandarins (with an average diameter of 4.9 cm and a porosity of 0.29) and tomatoes (with an average diameter of 6.4 cm and a porosity of 0.44). A staggered stacking pattern is used. The products were placed in a square enclosure (with a cross section 40 cm by 40 cm) having at the front and the back two steel plates, spaced $\Delta l = 30$ cm apart. Each plate has 1 rectangular vent hole at its centre, with a vent hole ratio of 2.5, 5, 10 or 20%.

By analysing their experimental data Yun et.al. (1996) have hypothesised that the total pressure drop Δp_{tot} over the system of packed produces and plates with vent holes can be described as:

$$\Delta p_{tot} = \Delta p_{holes} + \Delta p_{bulk}\, O^{-1.5} \qquad (3)$$

Here O is the vent hole ratio (vent hole area divided by the steel plate area), Δp_{hole} is the pressure drop over the empty package, and Δp_{bulk} is the pressure drop over the bulk of produce.

The pressure drop over the bulk of produce Δp_{bulk} is measured using the same experimental setup, only now without the front plates (i.e. $O = 100\%$). Because the tomatoes and mandarins are nearly spherical, it is expected that Δp_{bulk} follows the Ergun relations, Eq.(2), which has been established already for oranges and potatoes (Van der Sman,1998), (Chau,1983). However, the experimental data by Yun et.al. (1996) have shown *not* to follow Eq.(2). A possible cause is that the air flow channels along the walls of the package, where the porosity is known to be considerably less than in the centre of the packed bed (Talbot, 1988). Because of this uncertainty over the accuracy of Δp_{bulk} from the data set of Yun et.al.(1996) we estimate this factor numerically.

For both mandarins and tomatoes the contribution of Δp_{holes} to the total pressure drop is less than 10%. Hence, only the validity of the last term in Eq.(3) is analysed with the numerical model.

NUMERICAL ANALYSIS

Mandarins

Using a test simulation for a box with a 5% vent hole ratio, it is estimated by linear regression, using Eq.(4) as a model, that Δp_{bulk} for mandarins follows $\Delta p_{bulk}/\Delta l = 1283\, u^2$. In subsequent simulations the vent hole ratio (25%, 15%, 5%, and 2.5%) and the total pressure drop (Δp_{tot} = 40 .. 200 Pa) are varied. A typical simulation result is shown is figure 1b. As one can see the main pressure loss is near the vent hole, where the airflow strongly diverges or converges.

From the simulation results the average velocity (u) in the box is computed. As the quadratic term in Eq.(1) is dominant over the linear term in the flow regimes considered, we can state that the total pressure drop is quadratic with the average velocity: = $\Delta p_{tot} = K_{fric}\, u^2$. Here K_{fric} can be considered as a friction coefficient. For each vent hole ratio the friction coefficient is determined by applying linear regression between Δp_{tot} and u^2. In figure 2a the estimated friction coefficient K_{fric} is plotted against the vent hole ratio (O). This figure shows that the total pressure drop indeed scales as $O^{1.5}$, as hypothesised by Yun et.al. (1996).

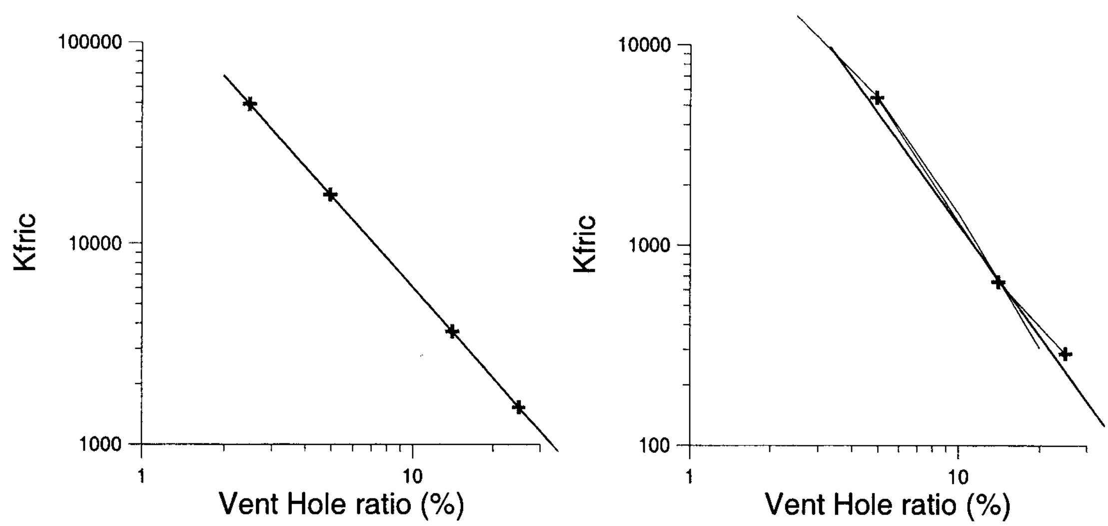


Figure 2. Friction coefficient K_{fric} of a vented package with mandarins (a) or tomatoes (b) versus the vent hole ratio (O). The solid line is according to the hypothesis of Yun et.al., Eq.(4), which states that K_{fric} scales with $O^{1.5}$. The crosses are according to the numerical results.

Tomatoes

For the pressure drop over the bulk of tomatoes it is estimated by means of the numerical model that $\Delta p_{bulk}/\Delta l = 222\, u^2$. Likewise for mandarins the friction coefficient is estimated for several vent hole ratios. These results are also shown in figure 2b.

Eq.(4) states that the total pressure drop Δp_{tot} over the filled package with vent holes is linear with Δp_{bulk}. Hence, simulations are performed for various values of the parameter (β) of the Forchheimer term in Eq.(1), and keeping the vent hole ratio constant. In figure 3 β is plotted versus the friction coefficient K_{fric} for a package with a vent hole ratio of 5%.

From these results one can conclude that the total pressure drop is linear with the bulk pressure drop.

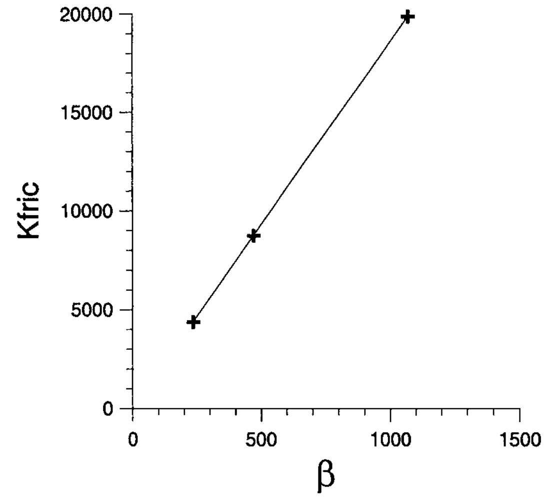


Figure 3. The friction coefficient K_{fric} of a vented box packed with horticultural produce and a vent hole ratio of 5%, versus the Forchheimer coefficient β of the packed bed of produce.

CONCLUSIONS

In this paper a numerical model, describing the airflow through a vented box packed with horticultural produce, is validated against a data set for boxes packed with tomatoes or mandarins, gathered by Yun et.al. (1996). In their experiments they have varied the range of vent hole ratios. After reestimation of the pressure drop over the bulk of produce, a good agreement is found between the numerical model and the experimental data by Yun et.al. (1996).

In a previous paper, (VanderSman,1998), we have also found good agreement between our model and another dataset concerning vented boxed packed with oranges, for which the vent hole ratio was kept constant, but the diameter and the stacking pattern of the packed produce was varied. In the same paper we have also shown that the experimental data of the pressure drop over the bulk of produce does follow the Ergun relations.

Based on the results presented in this paper and a previous paper (van der Sman,1998), one can state with confidence that the numerical model is valid for describing the flow rate / pressure drop correlation a for a broad range of vented boxes. However, it remains to be investigated whether the model is valid for boxes with holes near the walls or where the pressure drop over the empty box (Δp_{holes}) is in the same order as the second term in Eq.(4): $\Delta p\ O^{1.5}$.

The numerical model can be further refined for a better description of the airflow inside the vented box. As suggested by Talbot (1988) and experimentally established by Tanner (1998), the airflow can channel along the walls of the package because of the increased porosity of the packed bed near the walls. For the total pressure drop and the average flow rate this effect is not significant, as the vent holes at most times are not located near the walls of the box. However, Talbot (1988) noted that the channelling might effect the exchange of heat and moisture of the packed product and the environment. Hence, in a subsequent paper the effect of channelling will be investigated.

Finally, it is noted that the numerical model confirms the hypothesis by Yun et.al. (1996), that the total pressure drop over the vented box packed with produce (Δp_{tot}) is linear with the –1.5 power of the vent hole ratio ($O^{1.5}$) and linear with the pressure drop over the bulk of produce (Δp_{bulk}). This simple expression for the airflow resistance of a vented box is very useful in simplified numerical models described airflow through a collection of these boxes, as one finds in storage and transport of packed horticultural produce.

REFERENCES

Bakker-Arkema F.W.; et.al. 1969. Static Pressure-Airflow Relationships in Packed Beds of Granular Biological Materials such as Cherry Pits, *Trans. of ASEA* 12,134-137

Chau K.V.; et.al. 1983. Resistance to airflow of oranges in bulk and in cartons. *ASAE paper* 83-6007

FIDAP 1993. Theory Manual v7.0. Fluid Dynamics International, Evaston, Ill.

Haas E.; et.al., 1976. Factors affecting resistance to airflow through packed fresh fruit. *ASHRAE Transactions* 82(2), 548-554

Sman, R.G.M. van der, and Sillekens, J.J.M. 1998. Air flow in vented packaging systems for agricultural products. *Proc. AgEng'98.* Oslo, Norway, 1998.

Sman, R.G.M. van der, 1999. Solving the vent hole design problem for seed potato packages with the Lattice Boltzmann scheme, *Int. J. Comp. Fluid Dyn.* 11 (3-4), 237-248.

Tanner, D. 1998. Mathematical Modelling for design of horticultural packaging. *Ph.D. Thesis.* Massey univ. Palmerston, New Zealand.

Talbot M.T. 1988. An approach to better design of pressure-cooled produce containers. *Proc. Fla. State Hort. Soc.* 101, 165-175

Yun, H.S., et.al. 1996. Resistance to air flow of fruits in bulk and in a carton. *Proc. ICAME'96,* Korea.

Wang J.K.; Tunpun K. 1969. Forced-Air precooling of tomatoes in cartons. *Trans. ASAE* 12, 804-805

Appendix 2: Scientific contribution Task 7

Introduction

Climate controlled container transport of agro-materials is a common way to get products at their desired location. During this transport the product quality changes due to time and transport conditions like temperature, relative humidity and concentrations of oxygen, carbondioxide and ethylene. The current control system of the container receives setpoints directly from the user. In current operation the setpoints for temperature, and sometimes RH, 0_2 and CO_2 are determined only once in the beginning of the transport. Furthermore, the user sets fan speed. Changing product states are not noticed and no appropriate action is taken, such as changing the settings for the local controllers.
In the CEET 2005 project Supervisory Optimising Control algorithms (SOC-system) will be developed. These algorithms take product dynamics into account in the optimisation of a specific transport. This additional layer will improve the transport of agro-material by conditions to guarantee optimal quality against lowest possible cost.
The SOC-system uses:

- monitoring information about product quality and product behaviour (Task 1, 4 and 5),
- information on energy need, supplies and limitations (Task 2 and 3),
- information about the trajectory of the container, e.g. lead times (Task 6).

This information is used to determine the optimal container settings. The main difference between the existing and the new structure is the direct use of product, logistic and energy information in determining the optimal setpoints for the hardware controllers. The existing hardware controllers in the cool unit try to reach and maintain these setpoints in the container.
The SOC-system consists of three modules as discussed in the Half-year Report 1-4-99 to 1-10-1999. These modules are:

- The Main module,
- The Estimator module and
- The Check module.

In this document the modelling approach and the control structure with respect to the main module will be presented in Section 2. Different algorithms are tested in simulation studies. The results of these studies are shown.

2. Aim

The aim of Task 7 of the project is the: Development of a model-based Product Quality Control algorithm for container transport of agro-material".

3. Results

The results of Task 7 are in modelling, development of control structure and development of a short-term controller. These different subject will be discussed in the next subsections.

3.1 Modelling

The different model components that can be recognised in these processes are:

- Primary states,
- Direct environmental states,
- Indirect environmental states.

The primary states consist of the chemical and/or biological components in the product that are subject to reactions that change the quality of the product. As a first step for the direct control on product properties and quality, the focus will be on the level of respiration and, perhaps to some extend biological activity. The direct environmental states are those states that are not subject to the reactions inside the product, but directly influence reaction speeds. This environment consists of the physical states of the product, such as temperature and moisture, and of the direct product surroundings, such as temperature, humidity, O_2, CO_2 and ethanol of the air. The indirect environment are the remaining process states that do not directly influence the primary states and consists of air conditions in e.g. the headspace, T-bar and space between the packaging material in case of packed product.
This model structure is focused on the control purpose of the model. It captures the characteristics of the transport operation. With this separation the dynamics (time scales, non-linearity's) can be located in different process components. This, more detailed information will be useful in the selection of the control structure and, eventually, for the development of control algorithms.
All these components may exhibit non-linear dynamics and will interact with each other. In Figure 2.1 the relations between the different components of the model structure are shown. In most modelling approaches a separation is made between climate and product, while in this case the process is separated in product quality states and its environment. This is closer to the process and its control objectives.

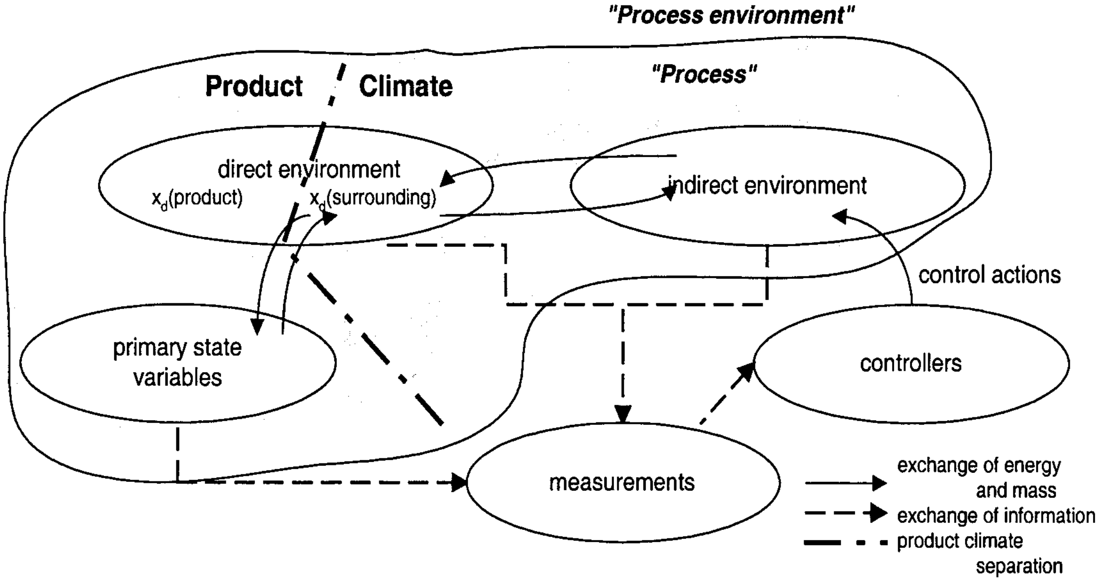


Figure 3.1: Relations between the model components

Each process component can be modelled separately. The modelling starts with the formulation of the conservation laws for mass and energy. This results in differential equations in the extensive variables mass and energy. After a translation the differential equations for the intensive variables, such as temperature and concentration are deduced for each subsystem in the process.

Only measurements of the indirect environment are available. From these measurements the state variables in the direct environment have to be estimated. With respect to the primary state variables additional indirect measurements can be performed, such as actions of the cool unit, temperature rise in a time interval, and the change in the O_2

and/or CO_2 concentrations. These measurements have to be related to the respiration of the product.

3.2 Control structure

Improving process control involves: the formulation of the control objective, building the necessary models, selection of the control structure, design of the selected controllers, validation of the control system and implementation of the controller. The selection of a control structure is an important step, although this step is often not given much attention. It determines the inputs and outputs of the control components, the objectives of the different control components and the control performance.
The control structure is, certainly for these type of processes, not a trivial choice as there are different time scales, uncertain information and practical constraints present in the design procedure. A non-optimal control structure results in a non-optimal control design and, therefore, a non-optimal operation of the controller and the process. The selection of a control structure can be seen as an optimisation problem where the objective is to determine or select the control structure.

In general each time scale should be controlled on its own control level. This is illustrated in the illustration on the left of Figure 3.1. Due to the available information and the level of uncertainty the control structure may be simplified for a specific process by reducing the control components, as illustrated in the illustration on the right of Figure 3.2. The control structure selection for a specific process is subject to practical constraints, furthermore, the complexity, of the control structure must be as low as possible without loss of performance. This includes the aspect of time scales that may occur in the process and the separation of time scales, if possible. Also the availability and uncertainty of the information has to be considered in the selection of the control structure. These different aspects will be discussed in the next subsections on time scales and information availability.

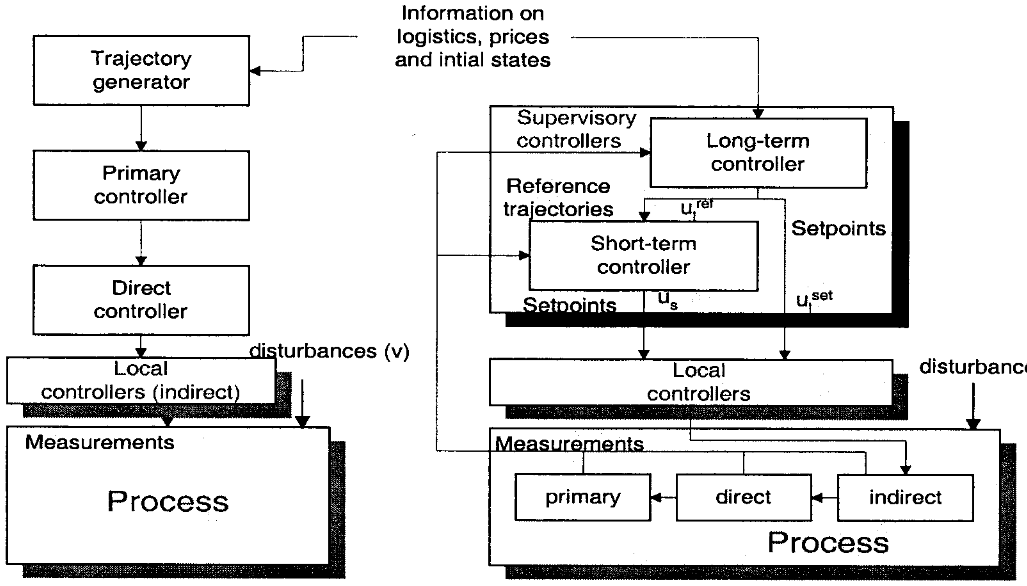


Figure 3.2: Total control structure

In short, the local controllers control the indirect environmental state variables. The short-term controller controls the primary and direct environmental state variables. The long-term controller performs an economical optimisation resulting in reference trajectories,

u_l^{ref}, and settings, u_l^{set}, for variables that are not controlled on the short-term level. In Section 4 the objectives of the different control components will be discussed briefly.

3.2.1 Practical constraints

At present, the climate during transport of agro-materials is controlled on a relatively low control level with local controllers. Setpoints for process conditions like temperature and humidity are determined before transport. These setpoints are fixed or adjusted manually and are not automatically adapted to changes in incoming product or variation in product behaviour.

Often in an industrial environment, practical constraints are imposed on the control structure. The model-based (supervisory) controllers may not control directly the process quantities of interest, but only by means of the settings of the local controllers. The advantage of this approach is that, in case of control system failure, the operator can return to the existing low level subsystems. Of course, the drawback of this is that the local control dynamics often can not be changed and must be taken into consideration in the development of the supervisory controllers. In the class of operations that is discussed in this paper, this boundary condition is often present.

Constraints are included in the controller algorithm. These constraints consist of Local controller performance possibilities, the product, outside weather and the process capabilities.

3.2.2 Time scales

Characteristic in operations that involve agro-materials are the different time scales of the (sub)-processes. In Table 1 time scales are presented that are representative for transportation of agro-material.

Table 1: Time constants of the subprocesses in transportation of agro-material

Subprocess (τ)	time scales
Product (τ_p)	hours/days
Direct environment (τ_d)	hours/days
Indirect environment (τ_i)	seconds/minutes
Hardware controllers (τ_h)	seconds

These different time scales enable the development of a decoupled control structure. The fast dynamics in the process can often be ignored by assuming a pseudo-steady state, while studying slow dynamic behaviour. This is a valid approximation in the presence of slowly fluctuating inputs. In this approximation the time for the fast dynamics to settle in the pseudo-steady state is ignored and the different time scales are decoupled. However, in presence of fast fluctuating inputs this will give rise to non-optimal control performance. If time scales can be decoupled this reduces controller complexity. This improves understanding and insight in the controller and the process by the end-users.

In container transport of agro-material the controlled inputs are constrained to relatively slowly changing values to prevent product stress. In transport the expected disturbances often are the outside weather conditions that may change rather fast. However, due to insulation fast outside disturbances only affect the inside conditions with slow dynamics. This motivates the choice for a decoupled control structure. As the primary and direct environmental state variables have dynamics with more or less the same time scales, they are controlled on the same level. This choice is also motivated by the information availability as will discussed in the following subsection. This simplifies the control structure. The fast dynamics of the local controllers and (part of) the indirect environment are dealt with on the local control level.

3.2.3 Information availability

On the supervisory control level the relatively slow dynamics of the product and its direct environment are controlled by determining the setpoints of the local controllers, thereby manipulating the indirect environment. In general, this control level consists of different sub-controllers: a long-term and two short-term controllers. The long-term controller optimises the long-term economical objective of the process using e.g. the weather averages over several years. This controller uses information that would not be usable in a short-term approach. The outputs of the long-term controller are either used by the short-term controller as reference trajectories, u_l^{ref}, or are directly used by the local controllers as setpoints, u_l^{set}

$$u_l=[u_l^{ref} \quad u_l^{set}]^T.$$

The short-term controller deals with the main controlled inputs that control the most important aspects of the product. The two short-term control components for these variables can be combined to one short-term controller as discussed in the former subsection.

The different control components require process and product information. There are essentially two types of problems regarding the availability of information in processing agro-material. The first type of problems is that necessary information is not always available or is rather uncertain. For example, exact information on the outside weather conditions is only available at the actual time, predictions are available for five days at most and only averages over several years are available for long-term objectives. The second type of problems is that the influences of the different system inputs (with respect to climate conditions) on product quality are not known with equal accuracy.

The first type of problems is solved by the separation in long-term and short-term control components. The second type of problems are solved by the use of the long-term controller outputs directly as setpoints for the local controllers, or as reference trajectories for the short-term controller. The choice whether or not the selected inputs should be controlled at all and by which controller is difficult to quantify. For uncertain systems robust analysis may answer this question. However, in the transport of agro-material, often more information is available then only unmodelled dynamics. The model structure is often known and uncertainty is mostly located in the model parameters. The selection of the controlled inputs for the controller components on the supervisory level is determined by the effect a candidate input has on the desired control objective. In this selection there is the constraint of controllability of the system as a whole. The effect of an candidate input, in presence of parameter uncertainty, can be calculated with

$$\frac{\partial y}{\partial u}\Big|_{u_0, p_0+\Delta p} \Delta u$$

where Δu and Δp are the spreads in respectively the input u and the parameter p. The effect of the input should be considered for the range of the parameter. A certain degree of robustness must be considered as there is a parameter uncertainty involved in the selection of the control structure. A specific input is controlled by the short-term controller, in u_s, if the effect $>\Theta$. Otherwise it is controlled by the long-term controller, in u_l, or stay fixed. The parameter Θ depends on the specific operation that is considered.

3.2.4 Control components

The different components in the control structure as shown in Figure 3.1 will be discussed briefly.

3.2.4.1 Long-term controller

The objective of the long-term controller is to optimise the overall performance of the process. Therefore, the desired trajectories of the states are calculated. The objective function can be written as

$$\min_{u_l} J = -P(Q)M + \int_{t_0}^{t_f} L(x_p, x_d, x_i, v, t)dt$$

where P is the price of the product that depends on the end-quality Q, M is the end-mass of the product and the integral represents the cost that are made to achieve the desired product quality states and direct and/or indirect product environment in presence of disturbances. This objective function tries to achieve maximum product quality (most likely this will mean minimise quality loss), minimum weight-loss and minimum cost to result in a maximum performance.

An important problem that is encountered is the amount of uncertainty in the information that is available to the control algorithm, e.g. product price.

In Table 2 the inputs and the reference trajectories, u_l^{ref} and setpoints (directly used by the local controllers), u_l^{set}, from the Long-term controller are given.

It will not be necessary to control the RH on the short-term control level as the temperature is not subject to fast changes that would lead to problems with respect to unwanted condensation. For the calculation of the temperature bandwidths and amount of ventilation additional information from Task 1, 2 and 3 is required. In future versions, that could be developed in additional project phases, dynamic logistic, market, weather and energy information could be incorporated in the long-term controller. In the current research project only information at the starting point of the transport is considered to be known.

Table 2: Inputs, setpoints and settings resulting from the Long-term controller

Version	Inputs	Current version outputs
Current	Logistic information (lead times)	Reference trajectory respiration
	energy supply	Temperature setpoint without PQC
	Energy prices	Oxygen setpoint with CA, without PQC
	Initial product state values	carbon dioxide setpoint with CA
	Product prices	RH setpoint
		temperature bandwidth
		amount of ventilation
Future	dynamic logistic information	
	dynamic market information	
	dynamic weather information (prediction)	
	dynamic energy information	

The long-term controller is not developped in this stage of the research. Research focuses on the short-term controller.

3.2.4.2 Short-term controller

The objective of the short-term controller is to reach and maintain the process at the desired trajectories with minimum cost. Undesired disturbances must be rejected. The controller must optimise between achieving the setpoint, inhomogeneity inside the container and cost (energy usage). This leads to a short-term objective function that can be written as

$$\min_{u_s} J = \int_t^{t+H} (W_x(x - u_l^{ref}) + \Delta u_s)dt$$

where W are the weighing factors that relate differences between actual and desired behaviour to control actions that should be limited. The time horizon of this controller is denoted with H. Most likely, there will be constraints on the quality attributes x_p direct product environment x_d (e.g. with respect to inhomogeneous conditions in the process),

$$x_p^{\min} \le x_p \le x_p^{\max}$$
$$x_d^{\min} \le x_d \le x_d^{\max}$$
$$x_i^{\min} \le x_i \le x_i^{\max}$$
$$u_s^{\min} \le u_s \le u_s^{\max}$$
$$|u_s| \le u_s^{\max}$$

indirect environment x_i and the short-term control inputs u_s,
The objective function is a quadratic function with constraints and this allows the formulation of a control problem in standard notation. This short-term controller is a MPC type controller with a horizon in terms of hrs. In Table 3 the setpoints that result from the Short-term controller are given.
In a future version it might be extended with temperature bandwidths as a result of short-term weather predictions.

Table 3: Setpoints resulting from the Short-term controller

inputs	outputs
reference trajectories, constraints and weighing factors from the long-term controller	Temperature setpoint
actual state values from measurement information.	oxygen setpoint
	Flow setpoint (if controllable)

3.2.4.4 Local hardware controllers

The local controllers are PID and on-off type of controllers. The objective of the local hardware controllers is to minimise the error between the desired and actual product environment states. Inputs are setpoints and settings (e.g. bandwidths). Outputs are control actions that act upon the process. In Table 4 the list of current controlled variables are shown. In future the local controllers will most likely be improved and e.g. a continuous control of the fan speed will be applied.

Table 4: Setpoints and settings resulting from the local controllers

no.	Current version
1.	Fans
2.	Cool unit (e.g. heaters)
3.	CA unit (e.g. nitrogen separator)

3.3 Simulation study

The objectives of the simulation study are:

- Test the applicability of the developed short-term controller using linear MPC techniques;
- Concretise the inputs and outputs for the different components of the SOC.

In the simulation study different possibilities are tested. The short-term controller is tested on a macro model of the container. The long-term controller is not yet implemented in this simulation study. Output from this control component is fixed and chosen in a way that corresponds with realistic values. The behaviour of the local controllers is considered ideal. This means that the desired setpoints from the short-term controller are directly realised in the supply air that results from the local controllers.
As a first approach linear control techniques are used. Based on the results of simulation studies with these controllers the development of a nonlinear short-term controller has been started.

3.3.1 Linear control

The different possibilities that are considered are:
Case 1 is a simulation with the current controllers.
Case 2 represents a situation with the current controllers where airflow is controlled.
Cases 3 and 4 represent situations with the supervisory controller where airflow is respectively not included as manipulable variable and is included.
PQC involves the direct control on the level of respiration. The bacterial concentration is not yet used actively in the simulation. A simple (sub)-model is included in the controller and the simulation model, but is not yet used actively in the control, due to uncertainty in this model. The CA-unit enables the control and manipulation of the oxygen concentration in the container.

In Figure 3 an indicative energy usage comparison is presented for four different cases resulting from a simulation study. Case 1 is a simulation with the current controllers. Case 2 represents a situation with the current controllers where airflow is controlled.
Cases 3 and 4 represent situations with the supervisory controller where airflow is respectively not included as manipulable variable and is included. From these results can be concluded that for a reduction in energy usage manipulating the airflow can be interesting (as compared to current practice with continuous airflow). However, as control of airflow leads to larger temperature variation inside the container possibilities for energy reduction are limited by the acceptable temperature variation.

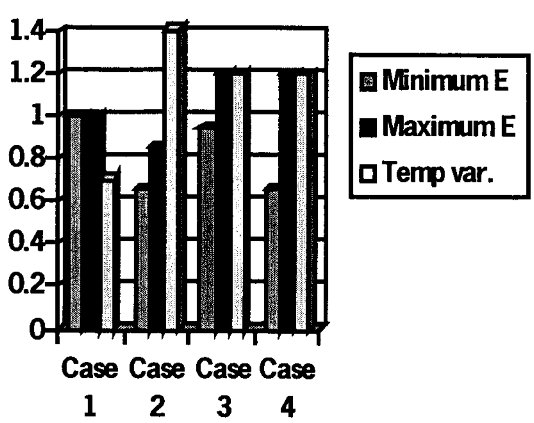


Figure 3.3: energy reduction

A special situation arises when, besides climate conditions like temperature, O_2, RH and CO_2, also airflow is controlled. In the simulation study this nonlinear control nonaffine problem is solved by linearisation. As such a control nonaffine problem is a typical control problem for the climate controlled processes discussed in this report possibilities to improve the controller are investigated. This is discussed in the next section.

3.3.2 Nonlinear control

The approach used for this control problem is based on the algorithm described in [3]. The steps followed to enable the use of this algorithm are linearising the minor nonlinearities, the formulation of the nonlinear control nonaffine problem, calculation of the relevant matrices and to perform (iterative) control. The main idea is to use a q^{th} order Taylor series approximation for the step response matrix, *S*, in the prediction equation

$$\hat{Y} = \sum_{i=1}^{q} \frac{S^{(i)}|_{u_0}}{i!} (\Delta U)^i + Y^{past} + \hat{D}, \qquad (5)$$

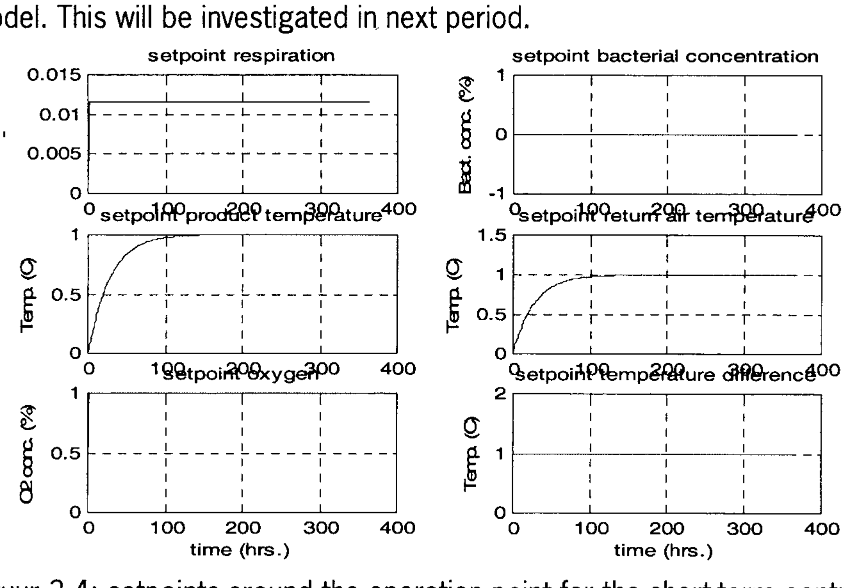
with

$$\hat{Y} = [\hat{y}(k+1|k) \ldots \hat{y}(k+p|k)]^T, \qquad \Delta U = [\Delta u(k)\,\Delta u(k+1) \ldots \Delta u(k+M-1)]^T,$$

$$\hat{Y}^{past} = [\hat{y}^{past}(k+1|k) \ldots \hat{y}^{past}(k+p|k)]^T, \quad \hat{D} = [\hat{d}(k+1|k) \ldots \hat{d}(k+p|k)]^T.$$

The step response matrix needs to be updated every iteration to reach the *optimal* solution for the control action. In the simulation study a first order approximation is used in the cases with controllable airflow. Higher order terms are currently added to the algorithm.

In the Figures 3.4 and further simulation results with this controller are shown. The operation point is 5 degrees Celsius and 5 % oxygen concentration. The controller uses a control model and is tested on a complicated plant model of the container with product (apples). The temperatures of this "realised" temperatures are absolute numbers whereas the respiration is around the "normal" operating point. From the temperature differences can be concluded that there still is a small mismatch between the control and plant model. This will be investigated in next period.



Figuur 3.4: setpoints around the operation point for the short-term controller

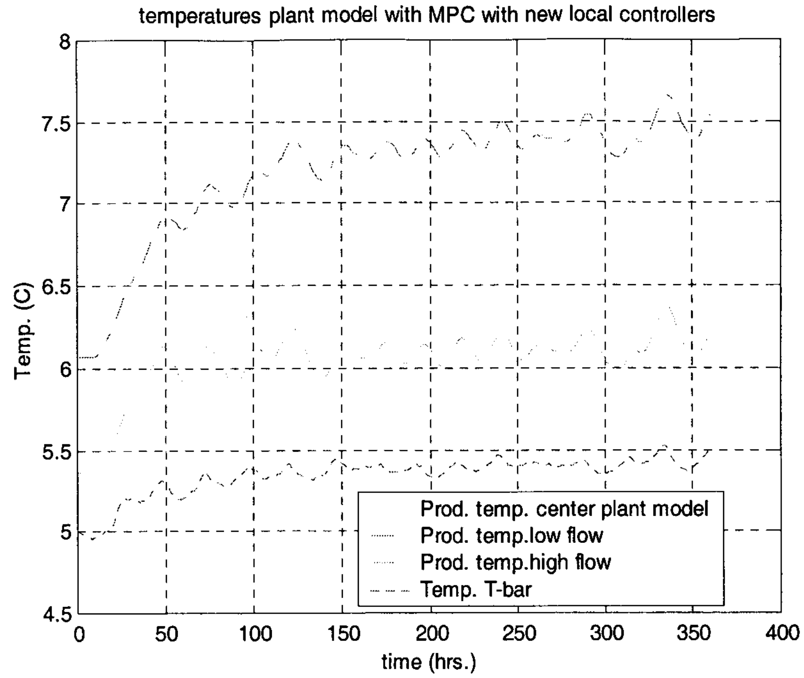


Figure 3.5: "Realised" plant temperatures

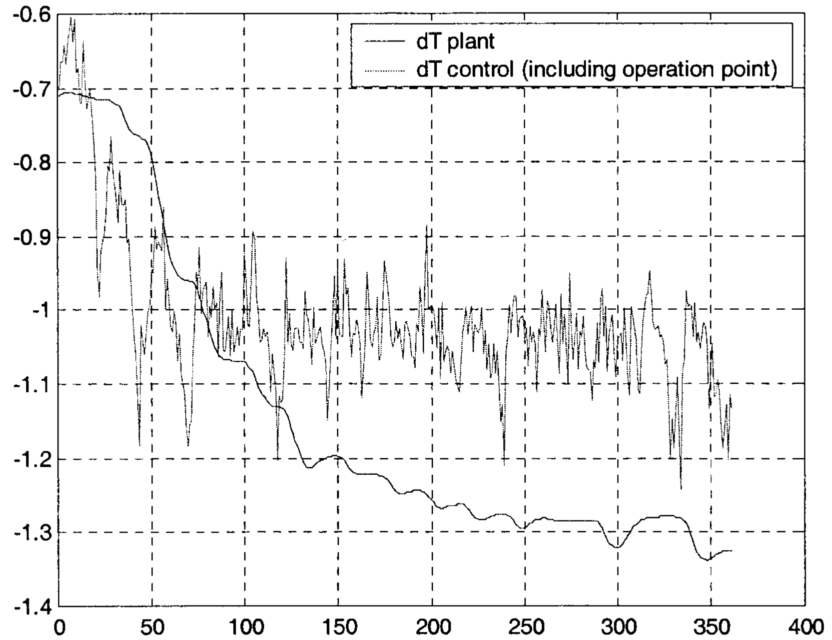


Figure 3.6: Temperature differences

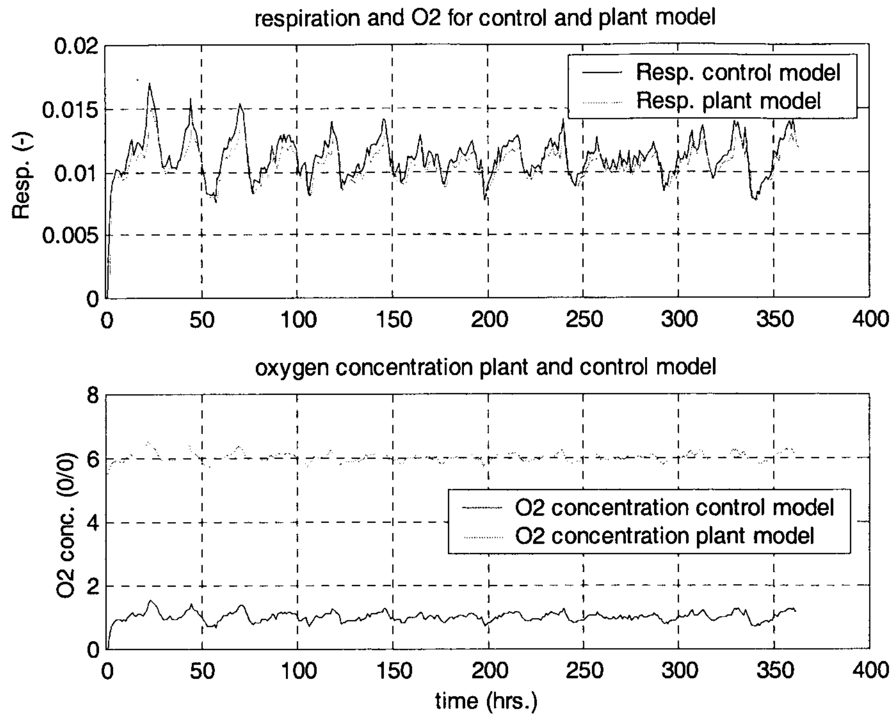


Figure 3.7: Respiration and oxygen concentration

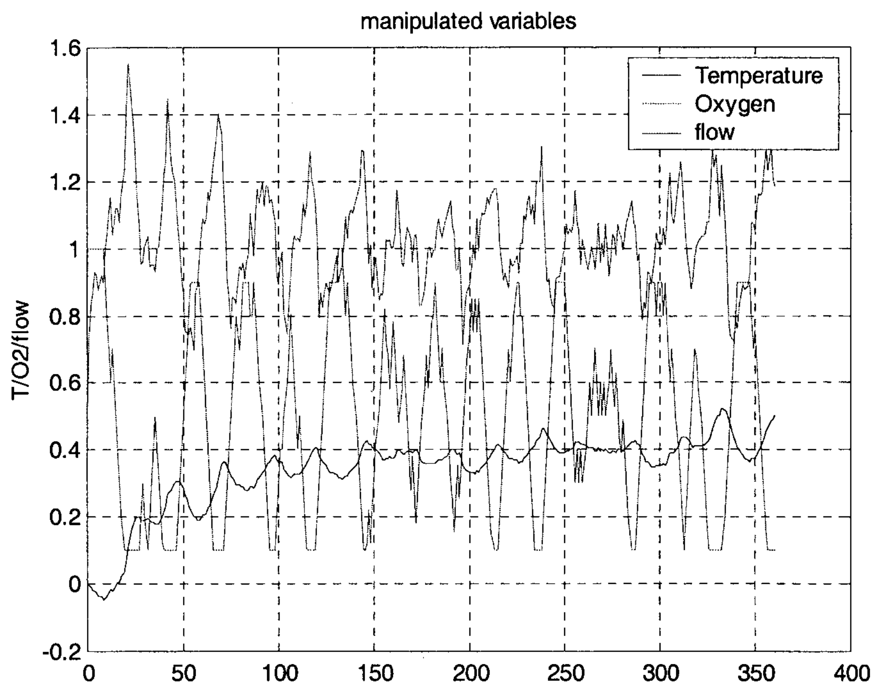


Figure 3.8: Inputs from the short-term controller to the container unit

From the figure with the controlled air flow can be concluded that it is possible to reduce the operation of the cooling and CA equipment by half around the operating point in this simulation. It is important to note that this number is not including the cooling down of the product to the desired operation point as in this period no significant energy reduction can be achieved.

3.4 Conclusions

In the control structure, product quality is directly incorporated in the controller to enable process settings that are more appropriate for the product that is processed. In the case study on refrigerated container transport quality loss will be reduced, as it seems to be possible to directly monitor (Figure 2) and control the quality evolution. Furthermore, energy usage may decrease by 20-40 % around the operation point by controlling airflow, as this reduces over-circulation and –ventilation. It is important to note that this number is not including the cooling down of the product to the desired operation point as in this period no significant energy reduction can be achieved.

4. Deliverables

The aim is to deliver a Supervisory Optimal Control algorithm that will optimize the CA/refrigerator setpoint trajectories. This optimization will take into account both product quality preservation and energy consumption. On the basis of first (simulation) results (using results from productexperiments) the impressions are that:

- significant energy savings are possible without harming the product quality by allowing minor temperature variations
- product quality improvement or a limited decrease is possible by gradually decreasing the O_2-setpoint at start of the trip and also gradually increasing the O_2-setpoint to ambient conditions at the end of the trip.

5. Resources

In the near-future experiments are needed to test the algorithm. In these experiments the available 40 ft container from P&O will be used. To enable manipulation of the external climate around the container it is positioned inside an ATO store with climate-control. The container will be loaded with apples/tomatoes put available by the Greenery. Software for communication with the CA/refrigerating units is put available by Carrier and should be in operation conditions very soon.

6. Requirements from / interactions with other tasks

The SOC will be the part that at the end of the day performs the overall optimization. Therefore it combines inputs from all other tasks (see table 1).

Table 1, required inputs from other tasks.

Task no.	required input
1 (product)	product quality models
2 (models/controller hardware)	models of CA-unit, refrigerating unit and cargo-hold
3 (energy system)	model of energy supply system
4 (green chemicals)	economics of e.g. exchanging less tight temperature control for green chemical usage
5 (sensors)	cheap, reliable, free-of-maintenance sensors (O_2, CO_2, ethylene, calorimeter)
6 (marketing/logistics)	knowledge of trip path/duration

From the simulation results that are presented in Section 3.5 it can be concluded that the use of linear techniques in the short-term controller will not lead to good control of product quality. Furthermore, large temperature differences inside the container can be expected. This should be validated with the results of the experiments that are being performed on different scales at ATO (especially interaction with Task 1).

In further research the macro-model that is used for simulation purposes will be updated with the experience resulting from the experiments. This especially involves interaction with the tasks 1,2 and 3. From this updated macro model the control models will also be updated. In the short-term controller non-linear techniques will be incorporated which will be focused on the product components in the models, because these exhibit the largest non-linearities. The other components in the control structure will be developed and tested, first in simulation studies and finally using a full-scale container.

References

G.J.C. Verdijck, L.J.S. Lukasse, J.J.M. Sillekens, Aspects of control structure selection in post-harvest processes, Agricontrol 2000, Wageningen, The Netherlands, (2000)

G.J.C. Verdijck, G. van Straten, H.A. Preisig, A Modeling and Control Structure for Product Quality Control in Climate Controlled Processing of Agro-material, Journal of Control Engineering Processing (to be submitted), (2000)

G.J.C. Verdijck, L.J.S. Lukasse
Control of quality evolution of agricultural products in climatised storage and transport using product quality evolution models, Journal A, submitted