ATO

CEET2005
Management Report

October 2000 – April 2001

Confidential

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

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WAGENINGEN UR

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Contents

page

General

Summary

The work described in this report focuses on the first part of phase 3: Integration of all tasks. In this phase, the results and deliverables from all tasks will be combined. At the end of this phase, a final container experiment is planned. This experiment should give an answer to practical feasibility of the new container configuration (e.g. how much energy can be saved in the new container?). The description of this container has already been given in EET-report June 2000 and is filed as configuration 2. A copy of the container configurations is given in the appendix of this report.
This report is organized in such a way, that the deliverables and time-schedule are given per task. An overall summary for all tasks is given here:

- The response of gas exchange rates to changes in gas conditions has been quantified.
- Gas exchange rates of apple (cv. Elstar) and tomato (cv. Evident) have been quantified as function of oxygen concentration and temperature.
- A linear relation was found between the parameters, which describe gas exchange rates and temperature. This makes it possible to calculate gas exchange rates at other transport temperature.
- Gas exchange rates, ethylene production rates and firmness of apples have been quantified in relation to transport temperature, transport conditions (air and optimal CA), transport time and transport period
- Model simulation of container climate results are compared with (averaged) experimental data, and gave satisfactory results.
- The model is able to predict the change in average product temperature, relative humidity, and gas (O_2 and CO_2) conditions.
- Furthermore a model is developed predicting the airflow resistance of a vented package. The model is compared to experimental data, and agrees well.
- A system model has been developed that predicts energy consumption of the refrigeration unit.
- Model calculations show that the K-value for the wall isolation can be reduced by 25 % when a new foam technique is used. This will be tested in practice.
- Solar cells are not expected to be applicable to containerized transport.
- More energy savings are expected from improvements of the following components: heat recovery after the condenser and the use of cold outside air in cool climates.
- A pilot system has been developed for evaluating the effect of constant levels of volatile plant oils on fungal development and product quality. This system is also suitable for testing the delivery system for green chemicals inside the container.
- The oxygen sensor requires a redesign to operate autonomously.
- The costs of a complete container trip from New-Zealand- Rotterdam have been estimated by the cost/benefit model. Savings were estimated at ± $ 7000 per trip for a 300 slot vessel.
- There is potential for intermodal transport of new maritime reefer containers
- There is potential for intermodal containerised concept for continental transport of perishables cargo
- Tests have been performed that show possibilities to measure/estimate on-line the level of respiration in container transport of agro-material

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 integration phase. In the integration phase, all information from the individual tasks will be combined.

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:	Michael Griffin, Suresh Duraisamy	
P&O Nedlloyd:	P. Eekel, L. van der Lugt, F. Waals	
The Greenery International:	J. Smits	
Ecofys:	H. Opdam, R. Heller	
ATO-DLO:	W. van den Broek	G. van den Boogaard
	M. Strous	H. Peppelenbos
	R. van den Boogaard	R. v.d. Sman
	M. Sanders	H. de Wild
	L. Lukasse	H. Timmer
	P. de Leeuw	R. Moezelaar
	D. Somhorst	J. Slotboom

Publications and PR actions

- Sillekens JJM and Govaert KAY. CEET2005: towards an improved conditioning for agro-produce, at reduced energy levels. Proc. Intermodal 2000, Genova, Italy.
- G.J.C. Verdijck, G. van Straten, H.A. Preisig, A control methodology for product quality control in climate controlled operations involving agro-materials-with an application to controlled atmosphere container transport of agro-materials, ESCAPE 11, Kolding, Denemarken
- Leo Lukasse, Gerwald Verdijck, *Beheersing van kwaliteitsverloop van AGF-producten tijdens geklimatiseerde opslag en transport,* Koude & Luchtbehandeling, vol. 94, no. 4, 32-38.
- Leo Lukasse, Riki van den Boogaard, Mark Sanders, Gerwald Verdijck, Ruud van der Sman, Gerard van den Boogaard en Herman Peppelenbos, *Koelcontainers: stand van zaken en nieuwe ontwikkelingen,* Koude & Luchtbehandeling, vol. 94, no. 6, 22-27.
- R. van der Sman: Lecture modeling at Carrier Transicold, Syracuse USA.

Progress versus project planning

The work plan presents the results of the first half of phase 3: *integration of all tasks*. The results are in accordance with configuration 2 as described in EET report June 2000.

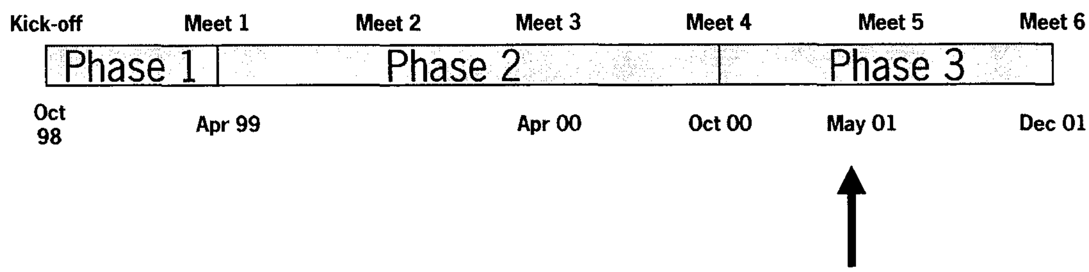

Figure 1: Phasing of the CEET-project and present situation. Phase 1 is *preparation*, phase 2 is implementation phase and phase 3 is *integration of all tasks.*

Realization project aims

The outcome of a quantitative assessment of the feasibility of a solar system showed that usage of a solar system is only beneficial when the energy demand can be reduced by 75/80%. Since the present estimations for power reduction are in the range of 30-50%, it is not likely that the required reduction can be achieved for solar systems. Therefore, the presently used gensets are chosen for further experimentation.

Bottlenecks

The communication protocol for communicating between computer and refrigeration unit, mentioned as a bottleneck in the management report of December 2000 has partly been solved. The communication has been accomplished. It only has to be tested how to instruct this unit with adjustments as calculated by the control unit.

The main bottleneck now is the availability of resources at ATO. At the end of last year, two specialists (modeling and control) have left ATO and one project member suffered an illness for 4 months. ATO has not been successful in acquiring substitute expertise. In first instance, ATO has applied for a project extension of 3 months. However, it is expected that new expertise will not be available in short time. Therefore, it will be difficult to finish the project at January 1st 2002. If the required personnel will not be available in the current year, it will be necessary to extend the project for another 6 months.

Milestones

Milestones are identified later on in the project (end of phase 3). The third phase will end in December 2001.

Evaluation parameters

The evaluation parameters are mentioned in the individual task descriptions.

1 Task 1: Optimisation of product quality under varying conditions

1.1 Contribution of ATO

Introduction

The project is focussed on optimisation of quality of fresh commodities in transport containers with a reduction in energy costs. Current data on optimal storage conditions is generated under controlled laboratory conditions, and is not always relevant to be used in practice. These optimal conditions are also based on unlimited energy resources. Additional data must therefore be generated on product responses to fluctuations in climate conditions normally appearing in containers. When such fluctuations are used to minimise energy costs, the impact on product quality must be known.

Aim

The aim of this task is to provide other tasks with relevant product information. Therefore the focus is on quantifying:

- the relation between temperature control and CA strategies within containers and quality changes.
- the relation between metabolic rates and quality changes: how to use metabolic rates as a tool to interactively control climate conditions.
- the relevance of CA: how long should a product be stored under CA conditions to gain one day of shelf-life.

Results

In short, the next results have been obtained thusfar:

- $O2$ uptake and $CO2$ production rates decrease similar to the decline in internal apple temperature.
- The response of gas exchange rates to changes in gas conditions has been quantified.
- Gas exchange rates of apple (cv. Elstar) and tomato (cv. Evident) have been quantified as function of oxygen concentration and temperature.
- A linear relation was found between the parameters, which describe gas exchange rates and temperature. This makes it possible to calculate gas exchange rates at other transport temperature.
- Gas exchange rates, ethylene production rates and firmness of apples have been quantified in relation to transport temperature, transport conditions (air and optimal CA), transport time and transport period

Deliverables

- Optimal conditions (temperature, gas composition) for optimal transport strategies.
- Relevance of CA during transport (see figure 1).
- Gas exchange rates, ethylene production rates and firmness data of apples to develop the product model.

		Transport time (days)		
	T (°C)	**7**	**14**	**28**
CA				
AIR				

Figure 1. Firmness of apples (cv. Elstar) after 7 days shelf life and transport (days) at various storage temperatures (°C), for transport period Janauary. ▒ = > 50 N; = 45 – 50 N; ■= < 45 N.

Requirements from / interactions with other tasks

This task will participate with the following tasks:

- Task 2, with the measurements of gas exchange rates on container scale.
- Tasks 3 and 7 in the last large-scale container experiment, which will be carried out in September – October.
- Task 7 in the development of the product quality model. This model describes quality (firmness) of apples as function of gas exchange rates during transport.

Time schedule

The planning for the next year:
- Verification of the effect of temperature fluctuations on gas exchange rates, ethylene production rates and quality parameters.
- The development of the product model will require more time than expected (see task 7).
- Additional research will be required to validate the product quality model. This research can not be performed within the present time schedule.

1.2 Contribution of The Greenery International

Introduction

The Greenery International as internationally operating marketing and sales organisation for fresh fruits and vegetables is importing and exporting fruits and vegetables per a.o. reefer container and by air. There is an ongoing interest to cut on costs e.g. by replacing airfreight in reefer transport and to win on product quality e.g. by more optimal atmospheric conditions during boat transport.

Furthermore The Greenery is committed to sustainable production and distribution.
In the above-mentioned perspective CEET2005 is an important and strategic project for The Greenery International.

Aim

The aim for the Greenery is to implement new technology and new tools in order to save on transport costs, to save on energy-input and to improve on product quality.
In this project The Greenery is supplying fruits and vegetables for quality assessments by ATO. Furthermore The Greenery is delivering information on experiences with container shipments, product quality information and quantitative information about export and import of fruits and vegetables.

Deliverables

- Meeting for information exchange about logistics with ERBS (Larissa van der Lugt).
- Delivery of 15 ton apples for container experiment.
- Delivery of produce for laboratory experiments.
- Contributing project meeting at May 21th 2001.

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

2.1 Contribution of ATO

Introduction

In the CEET project a model-predictive control algorithm will be developed. The models will predict energy consumption, climatic conditions in the container and the product quality. Using these predictions the control algorithm tries to minimize energy, while keeping product quality at a acceptable level.

Aim

The aim of Task 2 of the project is: the development of models for predicting energy consumption and climatic conditions inside the container.

Results

In earlier parts of the project a simple model for the prediction of climatic conditions is developed. In this model we assume that the climatic conditions are uniformly distributed in the cargo space. Simulation results are compared with (averaged) experimental data, and gave satisfactory results. The model is able to predict the change in average product temperature, relative humidity, and gas (O2 and CO2) conditions. Furthermore a model is developed predicting the airflow resistance of a vented packaged, under the condition that air flows through the box. The model is compared to experimental data, and agrees well.

In the last period of the project, we have finished the model predicting the energy consumption of the cool unit. It is compared to experimental data from our lab and from the manufacturer, and gives reasonable results. In the later stage of the project the model will be coupled to the climate model, mentioned above. Furthermore, new ideas from the project partners on energy saving components in the cool unit will be incorporated in the model.

The major activities of Task 2 in the last stage of the project will be:

- Development of an airflow model, indicating the distribution of air in the cargo space
- Decomposition of the climate model, in a bulk, cold and hot spot areas, using results of the airflow model.
- Development of a model predicting heat and gas exchange of vented package if air flows across the vented faces of the box. The model will be based on the previous model on airflow through the box.
- Coupling of the model to product quality models, and the model-predictive control algorithm.
- Final experiment testing the coupled energy and climate model, and control algorithm with compressor cycling.

Deliverables

The aim is to deliver a model with a limited number of degrees of freedom, for usage in the model-predictive control algorithm. Model will be able to predict energy consumption and product quality of product in bulk, cold and hot spot areas. If possible, characteristics of packaging will be an input to the model.

Resources
Human resources, with experience in modeling is needed for the development of models. Given that the project will end this year, and the amount of available manpower, it is conceivable that not all models will be completed or fully tested.

Requirements from / interactions with other tasks
Task 2 will interact intensively with Task 1 and 7, to make the couplings to the product quality models, and the control algorithm. Furthermore, inputs from the partners Carrier and Ecofys are welcome for incorporation of new energy-saving components into the energy consumption model. With Carrier the energy consumption model will be further tested.

Evaluation parameters

Economy and Ecology
First simulations with the coupled energy-consumption and climate model indicate a potential of 25-50% energy reduction. This maybe overestimated, because risks of condensation in cold spot areas have not yet been evaluated.

Technology
The intended SOC-algorithm will use weather forecasts (and when not available weather averages), 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
Below we have tabulated the amount of time allocated to the various activities in Task 2, as described above.

Table 2: Time schedule of task 2

Subtask	Timing (months)
Air distribution model	1,5
Model decomposition	1,5
Vented box model	3
Coupling to quality model and controller	2,5
Final experiment	1,5

2.2 Contribution of Carrier Transicold

Introduction
The focus of this project is to optimize product quality & minimize energy consumption during a containerized reefer transport of fresh produce. In order to formulate the optimization logic, inputs such as product quality (initial & ongoing), metabolic rate, transportation route, product tolerance to temperature & gas composition are required. The use of green chemical may further aid in energy consumption reductions, without compromising product quality.

Aim

- Assist in the development of a refrigeration system model that predicts the energy consumption of a perishable product at varying cargo & ambient temperature conditions.
- Improve system components' efficiencies, in order to achieve lower energy consumption during transportation of product.
- Assist ATO in CA testing of apples by providing updated everfresh CA container unit.

Results

- Using the system component models, a working system model that predicts energy consumption with reasonable accuracy has been developed.
- A higher efficiency air compressor has been proposed for the CA container unit.
- Alternate means of effectively dispersing moisture into the container are being developed.

Deliverables

Obtain power consumption reduction/savings while transporting containerized produce by employing optimum transport conditions (temperature, gas composition).

Requirements from/interactions with other tasks

This task will interact with the next task, which is the development of sensor to monitor metabolic rates of the transported product.

Time Schedule

The following activities are planned for the rest of the year:

- Assist ATO with verification of the container power consumption model at various load conditions.
- Continue qualification testing on the new high efficiency air compressor for CA unit.
- Continue development of moisture (& green chemical) delivery system using ultrasonic crystal oscillators.

2.3 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 25% 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.

The Manufacturer is preparing some new drawings which we will discuss during a visit to this manufacturer in June 2001. Also we asked the manufacturer to make computer simulations regarding the k-value of the panels. Also we are under discussion with the European foam supplier to have smaller panels in order to avoid big k-value losses in case of damages.

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

3.1 Contribution of Ecofys

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.

Aim

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

Results

From the qualitative survey of several energy supply systems 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 photo-voltaic 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.

A quantitative assessment of the technical feasibility of a solar cell system was conducted. With 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. 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. Although premature, the current estimations of power saving reachable are not in this range yet. Another drawback for the use of solar cells in the total chain of marine and continental transport is that the containers are stacked on top of each other on the ship and in harbors which makes the solar cells very vulnerable to damage.

To further decrease the power used by the container, Ecofys started collaborating with ATO on power reduction options in the hardware of the cooling unit, especially compressor, heater and evaporator fans. The following power reduction options are considered to tackle these problem components:

- *Heat recovery after condenser*
- *Dehumidification with desiccant wheel*: this involves new technology development
- *Use of cold outside air*: this could give an energy saving of 3-8% in Dutch climate.

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. The results are used in the analyses of the possible energy supply systems. In order to achieve the power reduction required Ecofys will 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 December 2001 the resulting options of the energy reduction systems will be thoroughly studied together with ATO with respect to technical feasibility. The present planning causes no problem to accomplish the aforementioned deliverables.

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

4.1 Contribution of ATO

Introduction

From an agro-industrial point of view, plants are an obvious source of natural antimicrobials and are known to contain anti-microbial 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

The test system and protocols for evaluating the effect of a continuous overflow of volatile plant oils on fungal development and product quality has been refined. Potential causes of the observed variation of the headspace concentration of trans-2-hexenal and the gradual decrease of the steady state concentration of trans-2-hexenal have been identified and adaptations have been introduced to minimize variation:

- Temperature variation of the liquid trans-2-hexenal (which affects the evaporation and hence the concentration in the container) has been minimized by insulated the washing bottle by a water jacket.
- The procedure for taking gas samples for analyzing the concentration of the plant volatiles and the gaschromatographical analysis have been reviewed, adapted and protocolized. These adaptations have resulted in a decrease of the analytical variance.
- The gradual decrease of the trans-2-hexenal headspace concentration has been eliminated by replacing the airflow through the washing bottle by nitrogen.

The effect of constant levels of trans-2-hexenal during storage on fungal development and on product quality has been studied. While the experiments were conducted as described previously (2 weeks storage at 5°C, followed by 7 days exposure to ambient conditions at 18°C), the procedure for damaging and infecting the apples (in this case with Penicillium expansum) was refined and recorded in a protocol. Storage in the presence of trans-2-hexenal decreased the number of infected apples (by up to 70%) and decreased the rate of Penicillium development (by up to 60%). Typically, these effects were not visible immediately after storage but became evident in the week after. The applied concentration of trans-2-hexenal (140 µg/L) did not induce damage of the product.
A cost estimation of the use of trans-2-hexenal has been made. In the experiment described above, the costs of trans-2-hexenal were 0.11 €/m3/day.

Resources
In the course of the research it has become evident that the number of man months originally allocated to task 4 is not sufficient to complete the research plan. Resources from task 1 have assisted in research activities of task 4.

Deliverables
A pilot system has been developed for evaluating the effect of constant levels of volatile plant oils on fungal development and product quality. This system is in agreement with container configuration 2, as described in EET-report June 2000.
Using this system, a concentration range has been identified where trans-2-hexenal inhibited the development of Penicillium on apples without causing product damage.
Delivery of trans-2-hexenal (and structural analogs) into the container via an airflow resulted in oxidation which can be prevented by applying nitrogen instead.
A delivery system for the green chemicals will be tested in the pilot setup. The distribution of the green chemicals can not be tested in the container setup. The expected distribution of the green chemicals is explored in task 2.

Requirements from / interactions with other tasks
The above results have been obtained in close collaboration with task 5. In the next 6 months, this collaboration is continued. Input from task 2 is required in order to estimate the distribution of green chemicals during storage of fresh produce in the test system.

Evaluation parameters
Application of the green chemical trans-2-hexenal during storage decreased the number of apples infected with fungi by up to 70%.

Time schedule
Most of the research described above is related to the combined tasks 4.2 and 4.3. More knowledge is required about the interaction between the green chemical and the produce. Therefore, more time is required for tasks 4.2 and 4.3 and task 4.4 will be focused on preparation of the distribution of the green chemicals inside the container only.
The time schedule to accomplish configuration 2 is in agreement and causes no difficulties.

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

5.1 Contribution of ATO

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 analyzers that meet the requirements of sensitivity, selectivity, stability, robustness, size and longevity, as well as being cost effective. For monitoring of the environment an oxygen and carbon-dioxide sensor was developed. For monitoring product traits we have investigated the use of an array of gas sensors, denoted as an electronic nose.

Aim
The aim of the research in the past period was to improve the stability of the oxygen sensor and work towards a commercial product.

Results
We have tried to stabilize the oxygen-sensitive dye we were using in the oxygen sensor. As stabilization was not satisfactory, we have decided to use another dye. This dye poses other requirements on the optical and electronic parts of the sensor. We are currently working on re-designing the sensor to make it suitable for use with the new dye.

Deliverables
Results in the coming period should show if the approach with the new dye for the oxygen sensor proves to be successful.
A feasibility report is delivered for the application of an enose system inside the container.

Resources
The planned work on the e-nose was not carried out due to capacity problems.

Requirements from/interactions with other tasks
The work on the oxygen sensor and e-nose is carried in close cooperation with task 1, product quality.

Evaluation parameters
The oxygen sensor we are developing 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 fiber optic sensing and are more complex and much more expensive. The combination of both $O2$ and $CO2$ sensors in one cheap device is a major advantage compared to using separate sensors.
An accurate measurement of climate and product status allows for larger variations in climate regulation, which saves on energy for the cooling system. Proper climate control during storage and transport minimizes the risk of product loss.

Time schedule

The electronics of the oxygen sensor will be re-designed for use with the new dye. In the coming period the work on the e-nose will be continued. The time schedule for this will not lead to delay of the accomplishment of configuration 2.

6 Task 6: Chain optimization and marketing opportunities

6.1 Contribution of ATO: Logistics

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 focus on quantifying the effects of using the new agro-container within a certain distribution chain. To achieve this a cost/benefit model is developed that will give an insight in the present logistical chain of climate controlled goods and the effect on cost caused by using a CEET 2005 container.

Results

In relation to the cost/benefit model we focused on the energy use of a standard 40ft high cube reefer container and compared this with preliminary estimations of the savings of a CEET 2005 container. For testing the model the cost/energy saving on a trip, New Zealand – Europe with apples during the main production season in New Zealand were calculated. Only costs/benefits affected by using a CEET 2005 container were taken in account. Savings were estimated at ± $ 7000 per trip for a 300 slot vessel. Experts of P&O Nedlloyd were consulted for information used in the model and evaluation of the results.

Deliverables

Task 6a will develop a cost/benefit model having 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 3 (Energy supply)
We expect a quantification of the costs of energy supply devices.

Task 5 (Sensors)
We expect a quantification of the cost of the sensors.

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 inland shipping;
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

6.2 Contribution of P&O Nedlloyd: marketing

Introduction
This document describes the activities and results of the period October 2000 – March 2001 of task 6 of the CEET2005 project. During this period the maritime market research part was finished and the continental study was started. A short summary of the results of the maritime part and listing of intermediate steps of the continental part are given below, followed by a planning for the next period.

Aim of the task
The aim of task 6 is to determine the potential market and set the logistics and commercial boundaries for the new agro-container. Task 6 is divided into a maritime/intercontinental and continental part, as supply chains differ significantly.

Results
The results of this phase of task 6 are:

- completion of the maritime part of the market and logistics analysis, by determining market potential and commercial and logistics requirements
- first steps in the continental part of the market and logistics analysis:
  - overview of continental transport market of perishables
  - supply chain structure and working of limited "case supply chains"
  - potential performance of intermodal containerised concept

In the *maritime part* potential clients are identified based on the confrontation for each actor in the supply chain of costs and benefits of the new reefer container and the willingness to pay for it. Table 6.1 gives an overview.

Table 6.1: Costs, benefits and willingness to pay of each actor in the supply chain

Actors	Direct costs	Direct benefits	Willingness to pay
Final customer	Higher product price	Better product quality	Maybe
Retail organisation	Higher product price due to higher logistical costs	Better product quality	Not
		Flexibility in buy pattern	Maybe
		Extension of supply	Yes
Importer	Higher product price, if delivery is CIF, higher transport costs if delivery is FOB	Better product quality	Not
		More flexibility in sales process	Maybe
		Reduction in damage	Maybe
		Reduction in transport cost by moving cargo from air to sea	Yes
Exporter	Higher transport costs if delivery is CIF	Opening of new markets	Yes
		Reduction in transport costs by moving cargo from air to sea	Yes
Logistics service provider	Higher sea transport costs	Better service to client	If additional price can be transferred to the client
Forwarder	Higher sea transport costs	Better service to client	If additional price can be transferred to the client
Carrier	Higher investment costs	Reduction in operational costs	Yes, if costs savings compensate for additional investment costs
		Better service towards client	Yes, if it is sure that sufficient clients are willing to pay more for service, so additional investment costs are compensated
		Opening up new markets by competing with air transport	Yes, if market is substantial
		Reduction in claims	Yes, if savings are substantial

Conclusions for market potential based on table:

- if energy cost savings more than compensate investment costs for the new technology, the container carrier is the first benefiting actor and the complete maritime reefer container market forms potential market. In 1999 about 2 million reefer TEU movements were counted globally, corresponding with about 400.000 reefer containers.
- quality improvements providing the possibility of a cargo shift from air to sea imply a very small potential market of specific flows (tomatoes on vine, bell peppers f.e.); the shipper, f.e. the exporter is then the first benefiting actor in the supply chain.

The main important logistics and commercial requirements are:

- One of the initial objectives for the development of the new reefer container was to develop a container with which the cold chain (the maintenance of the same conditions in the complete door-to-door chain) should not be broken. The market research has shown that there is not actually such a logistical requirement: reefer goods always have to be inspected at some points in the supply chain. In addition, the trend towards smaller parcel sizes and higher frequencies implies that value added services like labeling, repackaging move up-stream in the chain.
- Retailers or their logistics service providers, the shippers of the future, are not clearly willing to pay an additional price for investments solely aimed at the improved performance of the maritime reefer container.
- For a carrier the only real benefit of the new development can be the energy savings, leading to a reduction in operational costs: these savings should at least compensate for the additional investments to make it attractive for the carrier to invest. The benefit of potentially opening up new markets is only interesting for a

container carrier if the new market is significant in volume (which is not expected) and/or if the new market is willing to pay an additional price for the transport (which is still unclear).

- One actor alone in the chain should not invest in an advanced reefer container a priori. It is very likely that the other benefiting actors in the chain will not pay the initial investor sufficiently. Solutions are that the shipper itself invests in the container, or that investment are done in co-operation with different actors in the chain, or, finally, that firm and chain wide contracts are set up for use of the new reefer container against a acceptable price.

Results of *continental part* fall apart in two sections:

- potential for intermodal transport of new maritime reefer container
- potential for intermodal containerised concept for continental transport of perishables cargo.

Final results will be described in next management report

Remark: The trucking market in the transport of perishables is large. If the innovation for the control of the cooling machine could be applied to the trucking market as well, on the short term positive results in energy savings could be gained.

Requirements from / interactions with other tasks

In this phase strong cooperation has taken place between Erasmus University and ATO concerning:

- input data for cost – benefit model for new maritime reefer container (EUR)
- product protocols for different continental supply chain cases (ATO)

For the final feasibility part for the new maritime reefer container the model set up by ATO with input from the EUR will play a key role. Additional information needed for the completion of the feasibility and the market introduction plan:

- potential market figures, divided by products and trades (EUR & P&ONedlloyd)
- energy savings (ATO / Ecofys)
- total investment and operation costs of new control mechanism (ATO)
- indication about risk for product quality deterioration of new control mechanism (ATO / Ecofys)
- costs of sensors (Carrier Transicold)

Evaluation parameters

Task 6 will give more insight in the parameters 'economy' and 'ecology' as defined by EET.

Time schedule

	Duration	2001							
TASKS		April	May	June	July	August	Sept	Oct	Nov
Completion of continental study									
Feasibility for the maritime reefer container									
Market introduction plan									
Writing of final report									

7 Task 7: Development of Supervisory Optimising Control algorithms

7.1 Contribution of ATO

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.

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

In earlier parts of the project a control structure has been designed largely based on a time scale analysis. The next was the development of the different components of this control structure (long-term, short-term and local controllers). The focus was on the short-term control development using model predictive controllers. First, available linear techniques and algorithms were used. This resulted in promising results with respect energy savings. However, as variable and controllable air flows contributed significantly to the savings this acted as a controllable input leading to a nonlinear control problem (control nonaffine). New algorithms have been implemented and are currently tested in simulation studies. Furthermore, a testing facility has been developed to test the estimation procedure that estimates the activity level of the product in terms of respiration. First tests have been performed that show possibilities to measure/estimate on-line the level of respiration in container transport of agro-material.

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 product experiments) the impressions are that:
- significant energy savings are possible without harming the product quality by allowing minor temperature variations,
- energy savings are possible by varying and controlling air flow through the container.

A pilot system for respiration measurements has been developed and is presently being tested. The results of these tests are used to incorporate in the container test as planned in September 2001.

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 put available by The Greenery. Software for communication with the CA/refrigerating unit has been put available by Carrier. The first communication has been accomplished. The overall testing is presently under construction.

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, but especially with .
Task 1: integration of product behaviour/dynamics in the control components,
Task 2 and 3: use of extended models for simulation studies and simplified control models including climate and energy models,
Task 6: use of logistic information.

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 (and when not available weather averages), 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 and transferred to enable real-time industrial testing. Special attention will be drawn at the identification of mass flows of air inside the container and the upscaling of the on-line measurement/estimation procedure of the level of respiration by the product. Furthermore, product models developed and adapted using the results of Task 1, need to be incorporated at the corresponding locations in the control components.
Two difficulties prevent the task objectives to be reached within next half year. First, the capacity problems of people involved in this task. Second, the modeling of product dynamics is more complex than could have been expected due to limited measuring possibilities in practical operations. This puts higher constraints on the model accuracy and robustness.

Below a time schedule is shown that can be achieved with present resource capacity. The results fulfill all requirements of configuration 2:

Table 7.1: Time schedule of task 7 *with present resource capacity*

Subtask	Time period
Upgrading respiration procedure (incl. different products)	June 2001-april 2002
Installing additional equipment for the experiment	June - August 2001
Integrating product models (including an approach for different products)	June 2001-april 2002
Finish simulation studies control nonaffine algorithms	June - September 2001
Perform experiment	September-November 2001
Integrating "final" climate and energy models	June 2001-december 2001
Development first approach to long-term control component	June 2001-april 2002

Appendix

Description of new container: configurations

The objective of the CEET 2005 project is to develop a system for the reefer/CA transport of agricultural products. This system should reduce the energy use and at the same time monitor and control product quality. Product quality is described by so-called quality attributes (firmness, color, shape, appearance, taste, smell). Changes in product quality will be modeled with quantitative product properties (respiration, fermentation, microbial load).

Objective of configuration description

To assess the market potential for CEET 2005, information will be collected on possible final configurations of the container in combination with costs and benefits.

System description

Three system configurations will be described. These system configurations represent three types of containers that could be realized by the project:
- The energy-optimized system. This configuration will be realized without any doubt. It represents the energy-optimized project result.
- The product-optimized system. This configuration is considered to be 'realizable'. It represents the expected project result.
- The chain-optimized system. This configuration is the one that meets all specifications (and more), which are and will be investigated according to the project proposal. It is not expected, however, that this container will be operational at the end of the project.

Configuration 1: Energy-optimized System

Characterization
- product dependent tolerances around setpoints
- energy-optimized ventilation, circulation and cooling depending on product
- fixed setpoints for climate parameters (T,RH,O2,CO2) and fixed tolerances/bandwidths
- no on-line interactive climate control
- improved isolation of the container (P&O)
- energy saving components (Carrier)
- existing measurements

Nowadays tolerances around setpoints are not product dependent and quite small. It is expected that most products allow larger tolerances.

Consequences

EET
- energy reduction possible by applying larger tolerances (regarding product quality), improving isolation and implementing energy saving components
- reduction of product quality loss not expected

Implementation in practice

- easy to implement/current state of art
- scientific support of setpoints and tolerances

Scientific issues

- determine fixed setpoints and tolerances
- determine which temperature should be used to control the climate in the container (cool unit in going, cool unit out going, product temperature)
- determine ΔT between in going and out going temperature, finding an optimum between product quality and cooling efficiency

Improvements versus present systems

- product dependent tolerances
- reduction of product weight loss
- energy savings
- monitoring realized climate conditions (already realized in modern present systems)

Configuration 2: Product-optimized System

Characterization

- fixed setpoints for climate parameters and product activity (e.g. respiration, humidity loss, heat production)
- on-line interactive climate control by optimizing between energy use and product activity
- no fixed tolerances (R = f(T,RH,O2,CO2))
- implementation a controlled release system for bio-preservatives in case of non operation control unit
- control unit may offer a functionality to "survive" a foreseeable stand alone / power off period
- CO2 and/or O2 measurements to measure product activity, probably sensors for pressure measurements

The control unit will try to reduce energy use on climate control (eg. less ventilation, less cooling) without increasing product activity dramatically. This is realized by on-line measuring product activity and controlling climate conditions.
Bio-preservatives are use during power off periods.

Consequences

EET

- considered to be within project objectives

Implementation in practice

- requires additional measurements (sensors) that must be integrated in the container design
- requires additional software to calculate the desired control actions

Additional scientific issues compared to energy-optimized system

- determine relationship between quality loss and product activity
- determine product property to measure (e.g. respiration by O2 or CO2 measurement, humidity loss, heat production)

- determine how to measure (which sensors)
- develop software that integrates sensor signals with product knowledge and generates adequate control of climate
- develop non-interactive controlled release system for the release of bio-fungicides in case of a non operating control unit
- (see appendix)

Improvements versus energy-optimized system
- Control on product quality loss (resulting in higher product value and reduced risk for loss of cargo)
- simple stand alone feature (resulting in reduction of handling cost)
- energy savings, because larger tolerances could be admitted (based on on-line measurements)

Configuration 3: Chain-optimized System

Characterization
- on-line interactive control of setpoints for climate parameters based on product activity
- on-line interactive control of tolerances of products to changes in climate parameters.
- implementation of an interactive controlled release system for bio-fungicides
- implementation of a solar system or other systems providing energy (stand alone) (Ecofys)
- (components of a) electronic nose

Depending on transport duration, different initial setpoints and tolerances could probably be used without causing product quality loss. Information on the actual value of the transported commodity could be used to control climate conditions, in order to meet a specific quality (ripening stage) at arrival. This requires information on the initial product quality. Outdoor climate information and predictions that may be used to decide on additional climate control (ventilation, cooling) are necessary.

Consequences
EET
- within project objectives

Implementation in practice
- requires additional measurements and software
- logistic and climate information (i.e. information on transport duration, congestion time, outdoor temperature and humidity) and market-price information must be made available to the software
- requires guidelines for using solar system in practice

Additional scientific issues compared to product-optimized system
- product: predictive tool (model) on product quality (6 weeks)
- determine long-term control system
- develop solar system
- develop interactive controlled system for the release of bio-preservatives (see appendix)

Improvements versus product-optimized system

- Energy savings, because higher setpoint may be allowed (by making use of trip duration information, climate information and market price information)
- Making use of sustainable energy
- Application of an energy system e.g. solar system (improving energy cost and stand alone possibilities)
- Incorporation of 'quality-driven logistics' (fine tuning of product quality regarding market demands)

Application mode	Variants	Equipment	Constraints	Configuration
During container transport	Non interactive	Slow release system, or pulsing	No mixed loads, longer shipping lanes, Finding the right feed back mechanism, High risks regarding overdoses	Chain-optimized system
	Interactive, on product response			
	Interactive, on climate response			
In case of a non operating conditioning unit	Predictable power off period	Slow release system, or pulsing		Product-optimized system
	Unpredictable malfunction			

Table 1: **The application of natural anti-microbials within CEET 2005.**