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# CEET2005
# Management Report

## June 2000

Confidential

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

**ATO B.V.**
**Agrotechnological Research Institute**
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WAGENINGEN UR

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# Contents

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# 1 General

## 1.1 Work carried out

### *1.1.1 Summary*

Within the first half of the second phase, i.e. implementation phase, the work has been focused on the accomplishment of each target per task. Even though the results per task are given in chapters 4-10, a summary of these results is given here:

- The first experiments have been carried out where product behaviour has been quantified under expected conditions of the new container. The results indicate how the product shall behave under the regime of the new controller.
- The first experiments with a completely loaded container have been carried out and results have been interpreted.
- The macro model of the container has been extended with the dynamics of the gas conditions in the container.
- Decanal and E-2-hexanal have been selected as green chemicals candidate. They are presently tested for their efficiency.
- A prototype oxygen sensor has been built and is now undergoing robustness testing.
- A prototype cost/benefit model to quantify the effect of the new container in the distribution chain.
- The design for the complete control structure of the new container has been made.

Furthermore, preparations have been started for the third phase: integration of all individual tasks.

### *1.1.2 Introduction*

The focus of the CEET2005 project is to substantially reduce energy within the transport sector, according to EET theme 4. In order to realise this aim for containerised 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. Chapters 2 and 3 give general project information for the preparation of the integration phase. In the integration phase, all information from the individual tasks will be coupled. Therefore, a careful preparation has been started to facilitate this complicated task. Due to the size of the project, the results per task are described in chapters 4-10.

### *1.1.3 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 | |
| Shell Solar Energy B.V.: | J.W. Hendriks, Jan van Vlerken | |
| 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 | E. Smid |
| | R. van den Boogaard | G. Otten |
| | F. Golbach | S. Tromp |
| | G. van den Boogaard | G. Verdijck |

### *1.1.4 Publications and PR actions*

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)

Jeroen Kok, Reefer containers in maritime chains (in Dutch), Wageningen UR

To be organised by ATO: CA2001, a conference on Controlled Atmosphere and related subjects. The conference will be held in Rotterdam in July 2001.

G.J.C. Verdijck, Integration of quality evolution models for fruits and vegetables in model-based climate control, IIR Post harvest Refrigeration Conference, Oct. 2000 Murcia, Spain

R. van der Sman, Modelling heat transfer processes in packed beds of fresh food products at pore and macro-scale, IIR Post harvest Refrigeration Conference, Oct. 2000 Murcia, Spain

## 1.2 Progress versus project planning

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

Since phase 3 entails the integration of all individual tasks, a start has been made with the preparation for this. Chapter 2 and 3 (*Description of a new container: information flow*

and *configurations*) give a description of the new container. The last part of phase 2 will be used to realise a complete planning among all tasks to realise container configuration 2 and to make preparations for configuration 3.
The individual planning for each task is given in the individual task description.

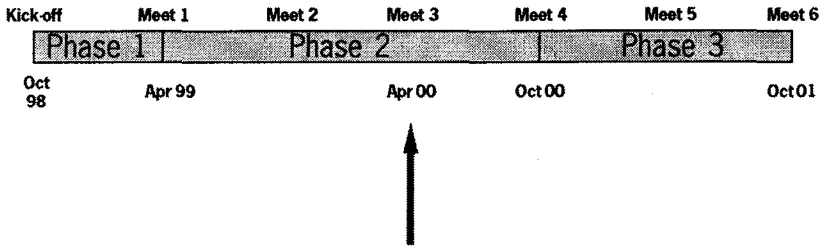


**Figure 1:** Phasing of the CEET-project and present situation. Phase 1 is *preparation*, phase 2 is implementation phase and phase 3 is *integration of all tasks.*

## 1.3 Realization project aims

There is a special chapter devoted for the realisation of the project aims. In chapter 3: *description of the new container: configuration*, a complete description is given of the container configurations. For each configuration, the consequences for the EET-targets are given.

## 1.4 Bottlenecks

The project is facing one technical bottleneck. It is about the communication protocol between the computer and the control system of the container. For final testing of the container, this problem should be solved. However, Carrier has been notified and tries to solve the problem. In the short term, this problem will not lead to a delay of the whole project.

## 1.5 Milestones

Milestones are identified later on in the project (end of phase 3). The first phase has been successfully ended. The present phase (phase 2) will end in October 2000.

## 1.6 Evaluation parameters

The evaluation parameters are mentioned in the individual task descriptions.

# 2 Description of new container: information flow

Before the new CEETainer can be introduced onto a given market some extensive research is required on forehand. The research can be market oriented or container oriented. This document focuses on container oriented research only. To perform such a study, it must be understood how the information flow within and beyond the CEETainer is structured. An overview of the information flow is given in figure 1. A description of each component is given below. A description of the container configurations (used in the figure) can be found in the accompanying document.

**Indicator level**

**Product info**
The indicator *product info* provides information about the state of the product. The information is either received from outside or inside the container. Information from outside is received when operators give in specific information about the origin of the product, the type of product or possible initial quality. Information from inside the container is received via sensor measurements of e.g. respiration, deterioration or alteration.

**Climate inside**
The *climate inside* indicator shows the climate condition inside the container. The information is obtained via sensor measurements such as e.g. $O_2$, $CO_2$, T, RH, dew point, pressure, air flow and air speed.

**Climate outside**
The *climate outside* indicator shows the climate condition outside the container. The information is obtained via sensor measurements, electronic connection with weather stations or manually via operators. Most important measures will be: T, RH and pressure.

**Route info**
The *route info* indicator gives information about the duration of the route and about stand-alone periods where the container has no connection to any power supply or control mechanism.

**Energy free**
The *energy free* indicator expresses the amount of energy available at the present time and expected availability in the future. Furthermore, it indicates the energy source.
It can be used to determine whether specific demands on the container can be granted with the available energy. Do the solar cells provide sufficient energy to make the required journey? Is the power of the battery sufficient to guide the container properly along the journey?

**Market info**
This indicator reveals the required market information for the given container gives information about the product quality expected by the (potential) consignee. This information can be used to change the set points of the control unit. For example, if a certain consignee prefers a ripe product. Market information entails the price of the product, distribution ability, alternative market openings, container availability,

## Resource level

### Local controls
The control resource unit entails all possible hardware controls required to take physical action. Actions are destined to achieve the setpoints obtained from the control algorithms. Examples of controls are: fan, heat exchanger, cool unit, green chemicals dispersion unit, condenser.

### Models
The model unit contains two different models: climate model and the product model. The climate model is subdivided in a thermodynamic model and a model for the CA-unit. The thermodynamic model describes the heat entrance and heat flow within the container. Heat can enter the container from outside via the walls or by air exchange. Inside the container, an induced air flow causes temperature homogeneity.

The CA model simulates the behavior of the CA-unit inside the container. This model is used to control the oxygen, carbon dioxide, relative humidity and optionally the ethylene or ethane concentration.

The product model describes the behavior of the product inside the container. The model describes internal product processes such as respiration, heat production and sensitivity of the product to temperature fluctuations.

### Database
The database contains all static information required to regulate any process in the container. The information can be classified in the following groups:
*Thermodynamic info:*
Energy usage of container components, model parameters
*Product info:*
Type of product, product specific setpoints and settings for climate and CA conditions, model parameters, product price and green chemicals applicability
*Container info:*
Isolation coefficients, geometry of container, model parameters
*Route info:*
Location of departure and arrival, location of intermediate stops, duration of route, duration of stops, energy availability
*Market info*
Product quality level required by consignee

### Control algorithm
The control algorithm operates at two levels: the long term and the short term level. The long term level receives information from the indicators. After processing this information, the long term control level directs both the short term control level and the local control unit. The latter is the control unit of the present container. The short term control level receives also information from the indicators and determines the short term control strategy of the local control unit. The local control unit directs the controls in the cool unit of the container.

The output of the algorithm is an estimation of the present product quality and the accompanying amount of minimal energy required to bring the actual product to the location of destination.

**CEETainer KPI**

There are three container KPI's (Key Performance Indicators) defined: Operational and Investment costs, product quality and minimal energy required.

**Cost/profit model**

This model uses the container KPI's to estimate the cost/profit performance of the container for a given route, with a given product under specific conditions. The model can be used to obtain insight in the effect of changes in the following model parameters: type of container, type of product, transport duration, extension of shelf-life per transport day, financial profits per day shelf-life extension, exploitation costs, write-off costs, operational costs, energy reduction

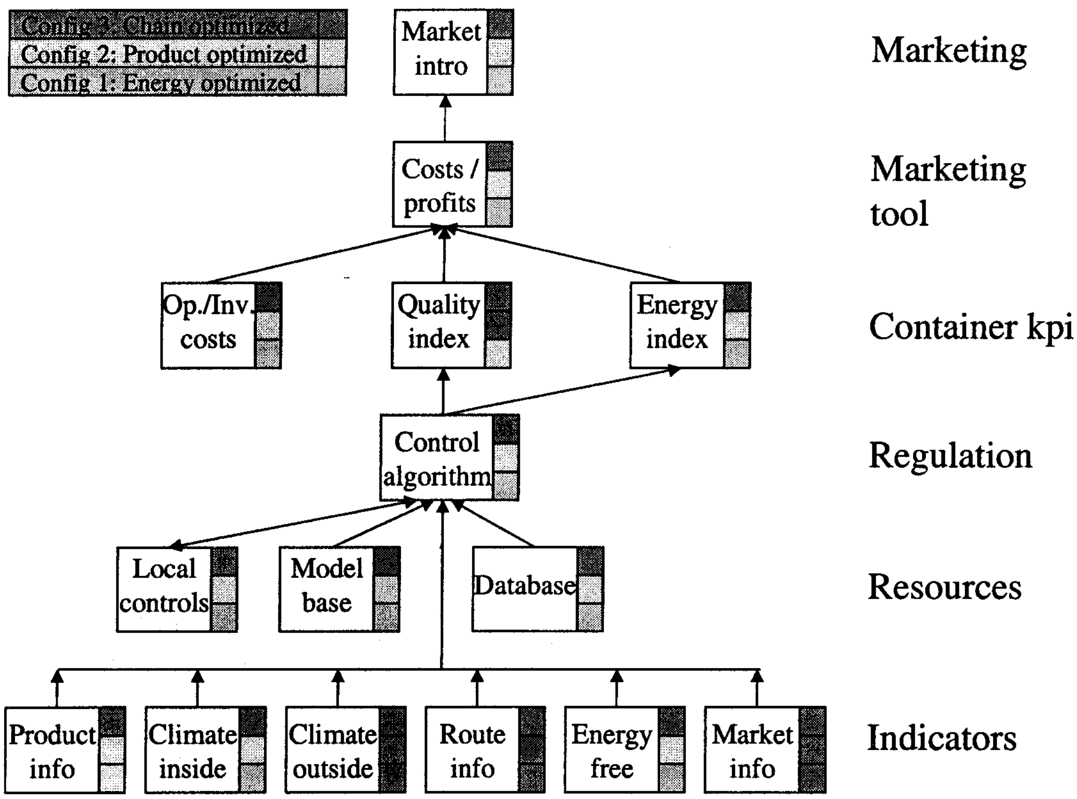


**Figure 1**: Information flow inside the container

# 3 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).

## 3.1 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.

## 3.2 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.

## 3.3 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 $\Delta T$ 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)

## 3.4 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 ($R = f(T,RH,O_2,CO_2)$)
- 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
- $CO_2$ and/or $O_2$ 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 $O_2$ or $CO_2$ 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)

## 3.5 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.**

# 4 Task 1: Optimisation of product quality under varying conditions

## 4.1 Contribution of ATO

**Introduction**

The project is focussed on quality optimisation 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 so far:

- The metabolic rate of apples reaches a new steady state within 6 hours after a major change in temperature (dT = 10$^{0}$C).
- Sources of variation in metabolic rates of apples have been quantified (cultivar, grower, type and duration of storage before transport).
- Metabolic responses of apples to different temperature profiles have been quantified.

**Deliverables**

- Optimal conditions (temperature, gas composition) for transport.

**Requirements from / interactions with other tasks**

This task closely interacts with task 5, where a sensor will be developed for monitoring metabolic rates of the transported product.

**Time schedule**

The planning for the next year is:

- Quantification of metabolic responses of tomato and green beans to temperature strategies.
- Assisting the implementation of the $CO_2$ sensor.

## 4.2 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 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 CEET- 2005 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.

**Results**
Two interviews were given by Greenery-experts to the researchers of Eteca. Information was forwarded concerning the decision making process as it comes to airfreight versus seafreight.
The delivery of 25 pallets of Elstar-apples was prepared.

**Resources**
From 01/10/99 till 31/03/99 19 hours were invested in the project.
It is expected that in the next period an equal amount of time will be invested. ATO will be supplied with the necessary products.

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

## 5.1 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**
In the former period a crude macro-level model has been developed and delivered to task 7. In addition an experimental design for the measurement of respiration and transpiration has been set up and delivered to task 1.

**Present situation**
In the last period the macro-level model has been further developed. It now also incorporates the dynamics of the gas conditions in the container, including the operation of the control-unit.

Furthermore, experiments with a container loaded with 15 tons of apples have been started. During the experiments the response of the product and the climate conditions on steps on the setpoints and ambient conditions is measured. The experimental results will be used to validate the macro-level model, and for estimation of the energy demand of a refrigerated, and filled container.

At the micro-level a model is developed, describing the airflow 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.

**Next activities**
In the coming period the experiments on the container with apples will continue. In the summer experiments with the container filled with tomatoes are planned.
The macro-level model will be validated on these experimental results and will be extended further. It is planned that the model is able to give an estimation of the distribution of climate conditions (temperature e.g.) inside the container.

Furthermore, a first prototype of the model estimating the energy demand will be developed. The model should be able to explain the energy use of the container during the last experiments and to make predictions of the energy demand in the logistic scenarios developed in task 6.

The micro-level model, concerning the airflow through packaging with vent holes, will be validated experimentally and with other data from literature. The model will be extended to regimes where the current model is proven to be invalid. The model will also be extended to the level of a pallet. It should also be able to make predictions of the change in temperature during cooling or warming of the pallet.

## 5.2 Contribution of Carrier Transicold

**Overview**

Carrier Transicold has continued its support of the tasks outlined in the project proposal in several specific areas. Progress has been made in the areas of controlled atmosphere system improvements, power consumption reduction, green chemical delivery system development, and future technology evaluations. Results, progress and planned efforts for the coming period are discussed below.

**EverFresh Controlled Atmosphere Unit**

Carrier has made progress in both improving sensor reliability as well as improving system control algorithms. An improvement to sensors has been focused on improving reliability of the current carbon dioxide sensor from adverse conditions that exist in the container environment. Improvement to wiring seals better protects against moisture ingress, which has led to premature failure of the $CO_2$ sensors. In addition, significant progress has been made in the ability to control $CO_2$ with high respiring cargoes.

The two-purity nitrogen injection system discussed in the prior half-year report has been implemented and found to provide improved control of $CO_2$ for high respiring cargo. The system has been applied in the field at this point with several shipments of Cox apples from New Zealand. Results have revealed improved control versus last year's performance with the single purity system.

To assist in developing dynamic control algorithms, Carrier has been actively working with ATO to provide communication links to the Carrier EverFresh system controller. This effort is aimed to aid in the development of dynamic control algorithms. The EverFresh unit provided to ATO for these experiments has been upgraded to include the most recent design modifications discussed above.

*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. Also, during the second half of 2000, Carrier will work with its air compressor supplier to develop a new compressor with improved efficiency and performance. Samples are expected from the supplier in September and field trials are planned to commence by the end of the year.

**Automatic fresh air vent**

Further progress has been made on the development of the automated fresh air exchange mechanism. Initial control software has been completed and two installations are to be made in June for a series of field trials. Five additional installations are expected by end of July.

Control of the vent position is determined by a mode selection entered by the user via the keypad. If set in automatic mode, the vent will remain closed until a preset temperature condition is established or after an elapsed time of 50 hours takes place. Once this criteria is satisfied, the vent will open to a preset amount. If a frozen set point is entered, the vent will automatically close.

*Planned Efforts*
The field trials of the seven 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. Preliminary evaporator motors have been designed and tested in the Syracuse laboratory. Results support the expected power savings opportunity. Our analysis concludes however that application of variable evaporator fans in the container application currently presents a high risk to cargo temperature control. This is due to effects of variable stowage and packaging conditions. Additional research is necessary to understand the opportunity for changes in cargo temperature control prior to application of variable speed evaporator fans.

*Planned Efforts*
During the second half of 2000, further development work is expected to take place on a variable speed condenser and compressor motor designs.

**Scroll Compressor Unit**
Significant progress has been made in the development of the R134a scroll compressor unit. Field trials have been completed on 65 machines. The system has an increased COP at all rating conditions, provides more frozen cooling capacity and reduces power consumption for perishable conditions by 15%.

*Planned Efforts*
Carrier plans to build up to 600 scroll compressor units during the second half of the year. These 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)**
Carrier has successfully used a spinning disc atomizer for container humidity control for a number of years. It is felt however, that this system will not be effective for distribution of green chemicals within the container. Alternative atomization techniques were to be explored.

During the past period, Carrier has researched the type of atomization systems that are commercially available for humidity control. This has included both mechanical nozzle systems and ultrasonic systems that would provide lower droplet size. Our analysis concluded that the nozzle systems were unable to perform at the low atomization rates necessary for the container application. Carrier is currently pursuing the feasibility of an ultrasonic system.

*Planned Efforts*

A concept prototype using a number of ultrasonic atomizers is to be constructed and tested in Syracuse during June and July of this year. Further discussion with ATO is necessary to define requirements of a sample needed for green chemical delivery.

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

## 6.1 Contribution of Ecofys

**Objectives**
To develop an energy supply system for a simple stand-alone reefer (configuration 2).

**Previous results**
In 1999 a qualitative survey of several – sustainable and non-sustainable - energy supply systems for the CEET2005-reefer was made. These systems were evaluated according to criteria of power, autonomy, fuel availability, reliability and costs. Combined with the modalities in the cold chain (marine or continental transport, or storage) this generated a list of potential energy supply systems (see half-year report September 1999). It was concluded that in the case of marine transport, efforts to improve the efficiency can turn out favorable, 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 favors the use of maintenance-free or fuel-less systems such as photo-voltaic cells or absorption heat pumps.

**Current period**
In the past half year a quantitative assessment of the technical and economical feasibility of these energy supply systems was started as was planned.

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. This also enables an unambiguous economical evaluation of the cost-effectiveness of the reefer concept in a later stage of the project. For this purpose the transport of apples from New Zealand or South Africa to the Netherlands and bell pepper from the Netherlands to the United States were chosen. The energy demand of the current container was estimated with a model on the heat dynamics of the product and container, the electrical components of the cooling system and the climatological data. From measurements on the test reefer located at ATO a more detailed picture of the energy demand will come available from task 2 in the next few months. With the data on the cold chain and the energy demand the actual potential of a solar cell system for the energy supply of the reefer 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.

**Time schedule**
Until September 2000 the resulting options of the energy systems will be thoroughly studied with respect to technical and economical feasibility and validated with the logistic chain studies of task 6.

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

## 7.1 Contribution of ATO

**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.

**Former situation**

Completion of the large screening programme has been the main focus of all activities till now. The main deliverable for this phase is underpinning of a selection of product derived aromatic volatiles with anti microbial activity against the major post harvest pathogens of apple, tomato and chicory.

**Present situation**

The screening programme including 9 natural antimicrobials has been completed for *Botrytis cinerea*, *Rhizopus stolonifer* and *Penicillium expansum*. We investigated the inhibition of germination of conidia and the delay in linear growth of the mycelial mat at different doses of the selected compounds. Decanal and E-2-pentenal were found to be the most potent antifungal agents towards *B. cinerea* and *P. expansum*. E-2-hexenal was also the most active inhibitor of *R. stolonifer*. However, the latter fungus was relatively insensitive towards decanal. Microscopic analysis revealed that R. *stolonifer* forms special survival structures in response to exposure to decanal. For the second phase, E-2-hexenal and decanal are selected for further research.

The effect of exposure of conidia of *Botrytis cinerea* to decanal administered via the gas phase was investigated in more detail. Decanal (approximately 35 µg/l) was found to reduce the viable count of *Botrytis* conidia by 1 log cycle in 20 minutes. This observation indicates that decanal act as a fungicidal agent on *Botrytis* conidia.

Long-term growth studies have shown that the inhibition of mycelial growth of *B. cinerea* is complete for at least 18 days at 8°C. AT 18°C however, full suppression is observed for only 8 days. This can be explained by the oberservation that decanal is sensitive for chemical oxidation (oxygen) and bioconversion by *Botrytis cinerea*. Both processes lead to a drop in the headspace concentration of decanal resulting in decreased antifungal activity.

Finally, the effect of gas-phase exposure of decanal on survival of the bacterium Pseudomonas marginalis has been studied.

**Next realized**

The next 6 months, attention will focus on task 4.2 and 4.3. More specifically, we will study the in situ activity of the selected plant derived anti-fungal compounds. In addition, we assess the phytotoxical side effects these compounds may have on the tested products.

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

## 8.1 Contribution of ATO

**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**
The aim was obtaining suitable sensors that conform to the requirements of other tasks in the project. This could be accomplished partly by buying suitable sensors, but where no suitable sensors are available, some development should be done. This means not developing completely new sensor technologies, but adapting existing measurement methods to the project's specific needs. Development needed to be done for inexpensive and accurate oxygen measurement and characterization of product status by odor and volatiles.

**Former situation**
Former research in the past period was mainly focused at which properties need to be measured and what type of measurements are feasible in terms of sensor cost, durability and usability.

**Present situation**
For the oxygen sensor a circuit board has been developed with an 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.

For a more sophisticated climate control, some product feedback is needed. In particular the respiration rate of the product is an important parameter in the control algorithms being developed in task 7. By measuring the $CO_2$ concentration accurately, this respiration rate can be calculated in an early stage of transport. A suitable sensor has been found and ordered.

An electronic nose is an electronic olfactory sensor capable of discriminating between several classes of odors. Initial experiments with a commercial e-nose have shown that it is possible to separate healthy apples from infected apples and to discriminate between two types of moulds.

**Future realizations**
Improving the stability of the oxygen sensor.
Finding out which odor components are representative for product quality and by which e-nose type these components can be detected.
In the future we may get involved in development of an application method for green chemicals inside the container.

**Actual comments on the evaluation parameters**

Sensors consume a very low 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 physical effect for oxygen detection use remote fiber optic sensing and are more complex and much more expensive.

# 9 Task 6: Chain optimization and marketing opportunities

## 9.1 Contribution of ATO: Logistics

The effect of using the new container within a certain distribution chain is being quantified by developing a cost/benefit model. The following cost types have been defined:
- 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.

The following benefit types have been defined:
- Shelf life of the product after discharge
- Internal product quality
- Product loss
- New trade lanes or modalities because of shelf life extension

We assume that a shipper will make a comparison between these benefits and the potential higher tariff of the new container compared to a 40ft high cube reefer (non CA). In practice we see that external factors may influence this decision. For example at the time of writing this report the supply of climate controlled containers in Europe was low. This means that a shipper doesn't really have a choice between different types of climate controlled containers. He will be even glad if he can have a standard reefer.

We have started to quantify the benefit types by interviewing exporters and importers. The objective is to let the shipper value the potential benefits. For example, what is the value of a shelf life extension of a few days? And what is the value of decrease in product loss of 50%, for example. These interviews are primary focussed on the export of bell peppers from the Netherlands to the US and secondary on the import of apples from New Zealand to the Netherlands.

At the same time, we started to interview shipping companies. We found that in some cases the cost of product loss turns out to be paid by the shipping company. Although legally the company may not be responsible, it feels responsible 'commercially'.

Valuing the benefits of less product quality loss turns out to be very difficult. Several cost types are involved. We have identified the following ones:
- Sorting and handling
- Profit loss because of having to sell the product on an alternative market
- Dumping cost
- Production and distribution cost of having an alternate product

First we have to know which cost type occurs how often. For example, how often a product is dumped? Second, we have to obtain the 'tariffs' for each cost type. For example, how expensive is dumping a product? Hereafter, we can calculate the cost of having product loss. Having these costs, we finally know the value of having a container that will decrease product loss with e.g. 50%.

After having valued the benefit types, we will ask the 'box developers' to asses the hardware cost, the maintenance cost and the energy savings. Moreover, we will ask them to assess the potential shelf life extension and other benefit types. In this way, we expect to converge to a quantified cost/benefit analysis. The final step will be to 'automate' this analysis in a software tool. This tool can be considered as being a basis for developing a decision support system for a potential user of the container to be developed.

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

Economy
- Modal shift from air transport to sea transport
- 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

## 9.2 Contribution of P&O Nedlloyd: marketing

**Introduction**
The second briefing of task 6 will show a change in approach by the team members involved in task 6. At first the intention has been to perform a market analysis that was supposed to be ready by the end of January 2000. To do this, the trends in the cold chain have been investigated to determine the 'shipper' of the future. This description is used to determine the needs and demands of these shippers and incorporate this into the design and functional features of the new reefer container. We realized that, as we are talking about a time-span of app 5 years, a difference has to be made between a maritime container and a continental (intra-European) container.

First of all the characteristics of the maritime world, as we described it are bulk products, long protocol, large quantities, whereas the continental reefer cargo flows are characterized by smaller quantities, a much larger variety in produce and a short protocol. For this reason we have identified two boxes for the two different worlds, a maritime and a continental box.

Based on this result, our feed back to the consortium is for them to focus on developing generic applicable techniques. These techniques should be applicable to various container sizes.

**Aim**
Since the last half-year report, the aim of task 6 is meant to smooth 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 a cost model that 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.

**Results**

Two reports will be finalized in June this year. Due to the fact that the approach of task 6 has changed over the last months, we haven't distributed our definition and market analysis yet, however we will distribute two reports in June. The first report will describe the cold chain, actors in the cold chain, decisive power in the cold chain and the way this is changing, or in other words: whom will be the shipper of the future? The second report focuses on the traditional box owner (the carrier and leasing companies), the way they operate in the reefer segment at the moment and the way they will position themselves in future.

Both reports are focused on the maritime container, rather than the continental container. The continental container will be described in more debt in the second half of 2000.

**Deliverables**

A market analysis, which consists of a broad description of the cold chain, definition of the shipper of the future, definition of the owner of the future and description of the optimal box/owner combination and feed back on box design. Secondly task 6 shall result in a cost model and a customer/market database. Thirdly task 6 shall describe the marketing and implementation strategy for the CEETainer.

**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. Several group sessions have confirmed trends and scenarios as described by us.

**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.

Task 1 (Product quality)

We expect feedback on which conditions per commodity provide least damage and loss of the value of agricultural produce. The next step is the support of the Greenery and ATO members involved in this task to translate a higher product quality into possible benefits. Possible benefits are a longer possible transportation time (modal shift), higher price, less waste, less claims, larger market area, extended shelf life of the product (how much longer).

Task 2 (Climate control)

Based on the discussions we have had at the meeting of the 27th of September at Ato, we would like to be kept closely updated on the consequence of energy reduction on reliability. In case an interesting source of energy reduction will be found, we would be interested in knowing the boundaries of this source and receiving a quantification of the possible energy reduction.

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). In case sun panels will be used, we would like to receive feedback on weight, position on the box and possibility to approach sun panels as a clip-on.

Task 4 (Green chemicals)
We expect a quantification of the cost of green chemicals and appending devices. We also would like feedback on effect of green chemicals on other commodities (the whole range: fruit/frozen/deciduous/etc) and consequences of the use of green chemicals on dry cargoes stowed in the new CEETainer.

Task 5 (Sensors)
We expect 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.

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

**Future realizations**
The following activities are planned for next period:
- Analysis of the intercontinental maritime based reefer market
- P&O Case study
- Determination of the market potential for intermodal use

# 10 Task 7: Development of Supervisory Optimising Control algorithms

## 10.1 Contribution of ATO

In the CEET 2005 project Supervisory Optimizing Control algorithms (SOC-system) will be developed for transport of agro-materials (apples, chicory and tomatoes) in a container. The goal is to monitor and optimize product quality and cost in the container by calculating desired setpoints for the climate/product conditions.

**Introduction**
The current control system of the container receives setpoints not from a SOC-system but directly from the user. In current operation the setpoints are determined only once in the beginning of the transport. The additional layer that will be developed in this project will improve the transport of agro-material by conditions to guarantee optimal quality against lowest possible cost. The system is illustrated in Figure 1.

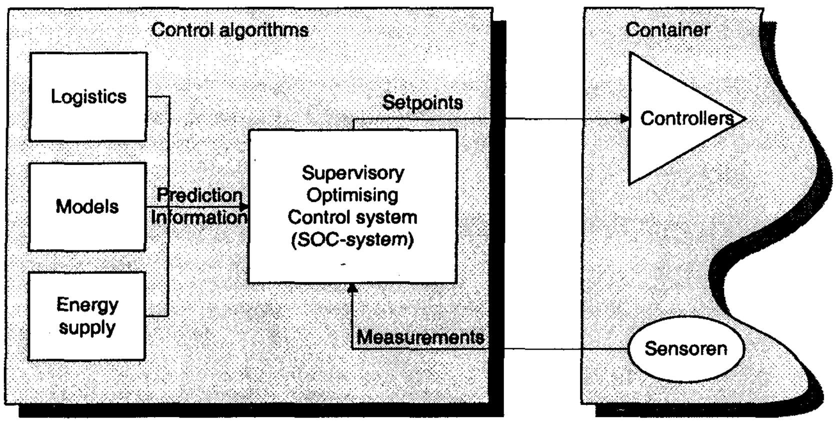

Figure 1: Global control structure

The SOC-system uses:
- monitoring information about product quality and product behaviour (Task 1, 4 and 5),
- information on energy supplies (Task 3),
- information about the trajectory of the container (Task 6).

For more details the reader is referred to the documentation on the configurations (chapter 3). The 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 try to reach and maintain these setpoints in the container.

**Recent work**
The SOC-system consists of three modules:
- the Main module,
- the Estimator module and
- the Check module.

In the time period July-December 1999 the main focus of this task was on the main module. The objectives of the main module are to determine those setpoints for the local control level that guarantee optimal efficiency of the transport process in economical and ecological terms. A badly designed control system leads to a non-optimal operation of the controller and the process. There are several aspects of importance in the design procedure, but the most important in processing agro-materials are:

- Boundary conditions in the design procedure;
- The time scales of the (sub)-processes in the operation;
- The information about the process and product and the quality of this information;
- The effect of the controlled input on the process.

For more details on these subjects is referred to Verdijck et al. (2000). A simulation study was performed using linear control models (in the Model Predictive Controller) while the effect of the control outputs were calculated/simulated using non-linear models. The objective of the simulation study was to test the potential linear control techniques in CEET and to attain the final structure for the controller (and its components). The status of the different components in the control structure as presented in the management report of 1-4-99 till 1-10-1999 is:

*Measurements*

- current (configuration1): temperature, RH, temperature differences, $O_2$, $CO_2$, actions of cool unit
- nearby future (configuration2): estimation of respiration level
- future (configuration3): ethanol/ethylene/...

*Trajectories from long-term controller ($u_l^{ref}$)*

- in nearby future not fixed (configuration2): respiration, temperature and temperature differences
- future (configuration3): bacterial/microbial activity

*Setpoints long-term controller ($u_l^{set}$)*

- in nearby future (configuration2): RH, $CO_2$
- future (configuration3): use different energy resources, Rough estimates of energy usage and "product quality"

*Setpoints short-term controller*

- current: temperature, $O_2$
- nearby future: dT (effect on flow)
- future: energy resources, green chemicals

*Local control actions*

- current: on-off fans, cooling, heater, (de-)humidification
- nearby future: continuous control of fans and cooling devices (extra temp. fluctuations)

In the simulation studies the reference trajectories were generated by the user (long-term controller not implemented) with respect to respiration, temperature, $O_2$, temperature difference, (bacterial/microbial concentration), as illustrated in Figure 1. The temperature and $O_2$ setpoint from the short-term controller were calculated using linear models with MPC-techniques. The local controllers were assumed ideal and moisture balances were not yet included in the models. Simulations were performed with and without CA (CA=1 or

0) and with and without Product Quality Control (PQC=1 or 0) as is illustrated in the Figures 2 and 3.

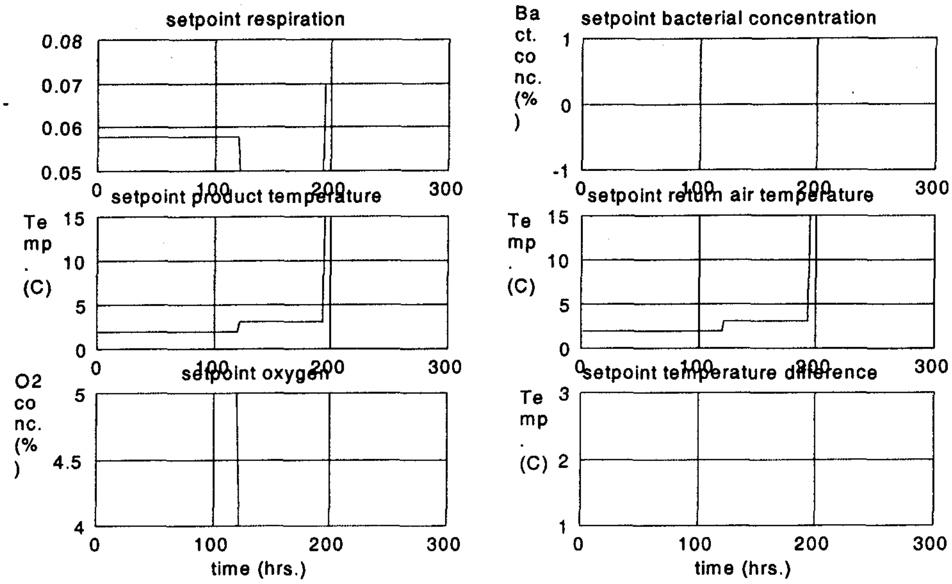


Figure 1: Setpoints simulation studies

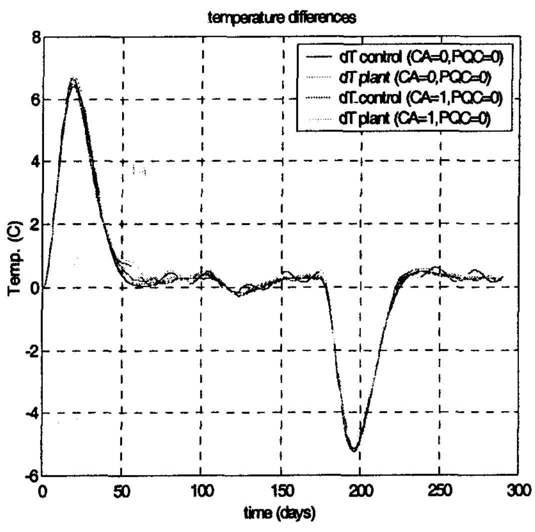


Figure 2: Temperature results simulation studies

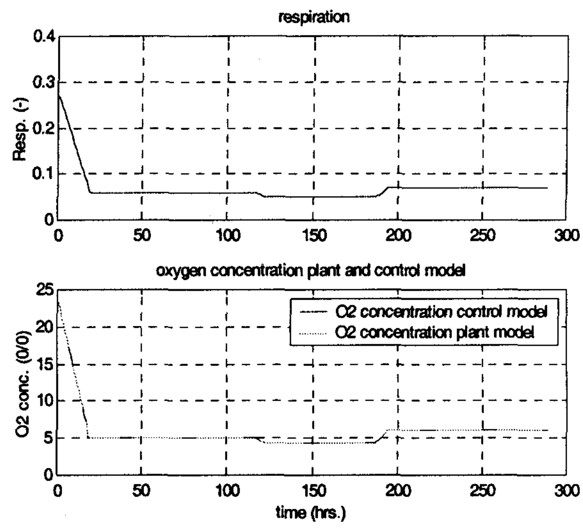


Figure 3: Respiration and oxygen outputs from the non-linear simulation model

Preliminary conclusions of the simulation studies are that the measurement information is essential and that linear techniques are not sufficient with respect to respiration.

**Future work**

Future work involves studies with and without CA and PQC (plain simulation) and investigation of the effect of a mismatch between initial conditions of the plant and model (stability and robustness). Furthermore, the linearization of control model will be studied together with the necessity of using non-linear control techniques, especially for the product models.

*Current and nearby future (configuration 1-2)*

The main research points of interest are:

- estimation of respiration level from available measurements,
- long-term optimization with fixed product prices, duration of transport, climate information, energy resources,
- use of non-linear control techniques,
- implement changed macro-model (from experimental results),
- implement adaptive identification of essential properties of specific container.

*Future (configuration 3)*

The foreseen items for further research are:

- use of logistic and climate information in long-term controller,
- active planning of energy resources,
- use of weather predictions in short-term controller,
- active use of green chemicals in control.