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Unit Load Devices with conditioning capabilities (a feasibility study)

Final report

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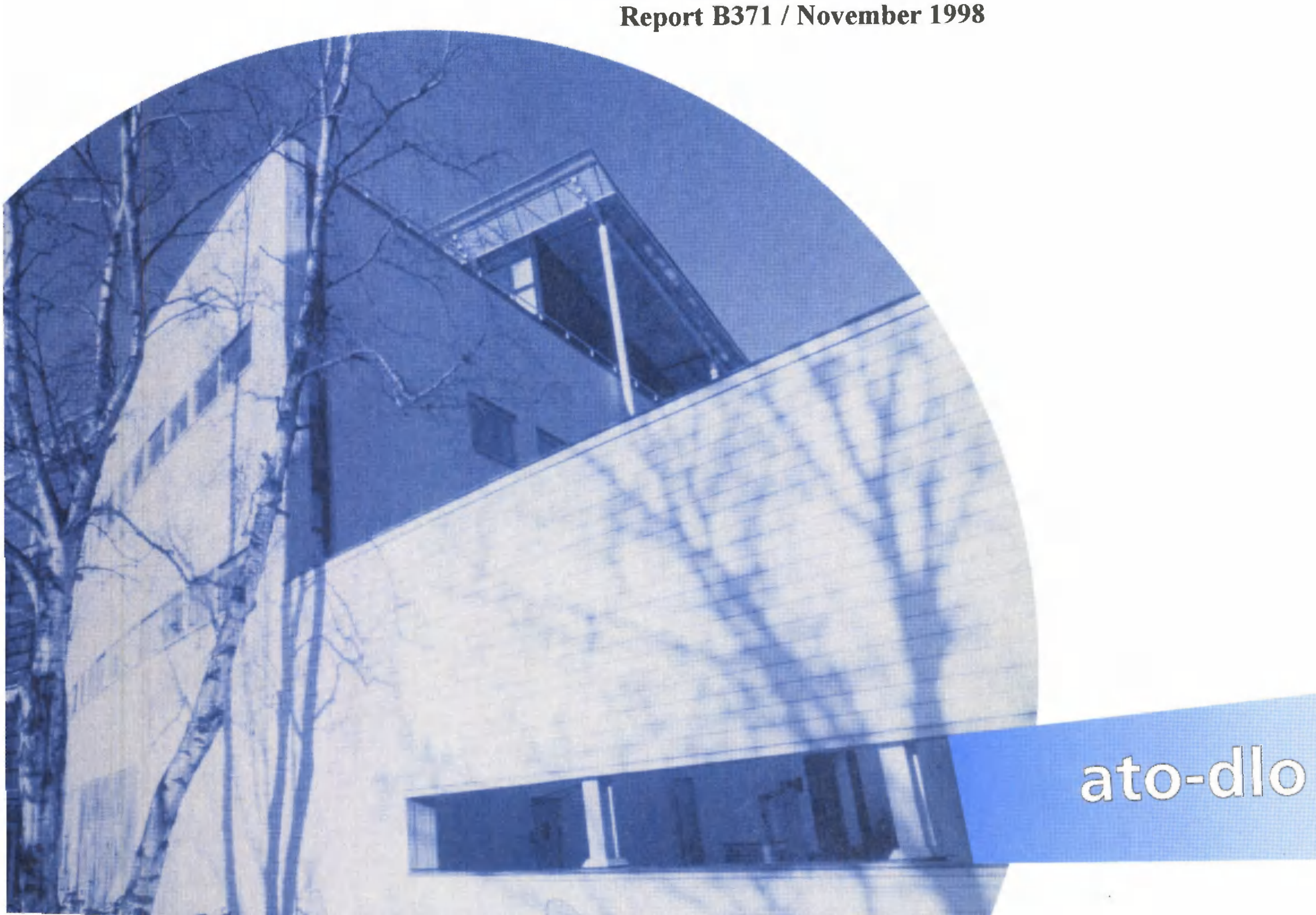
Report B371 / November 1998



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Summary

KLM has expressed to ATO-DLO the desire to monitor and control the process of transporting perishables by air. Therefore over the past two years the Coolmate system has been developed by the cooperation of KLM PMC perishables and ATO-DLO. From this project, in which perishable condition was recorded, it became clear that the conditioning capabilities in the present air transport chain are not sufficient. By performing the feasibility study 'Unit Load Devices with conditioning capabilities' the current solutions and future possibilities of conditioning Unit Load Devices (ULDs) for perishables have been investigated and evaluated. This study therefore forms the base of the development process of a well functioning and easy to use conditioning ULD.

In the previous report [1] an evaluation matrix has been developed consisting of several groups of perishable conditioning criteria on the vertical axis and three concepts clusters on the horizontal axis. The evaluation matrix has been developed as an aid in the design process to systematically analyze the perishable criteria and design possibilities. An overview of the matrix is printed in Figure 1. This final report amongst others elaborates on the criteria that influence perishable condition and the fulfillment of the evaluation matrix.

Figure 1: overview of evaluation matrix

Evaluation matrix	Conditioning cluster	Construction cluster	Materials cluster
Criteria perishable condition	I		
Logistics and aircraft capacity load criteria	II	II	II
Other criteria (handling, cleaning, maintenance/ repair, legal aspects, applicable trajectories)	III	III	III

In order to search for an optimal conditioning ULD the evaluation matrix needs to be filled in. The information entry of Section I will be collected and filled by ATO-DLO. The focus of the information entry of Section II will be by KLM. Section III of the evaluation matrix will not be focussed on in this stage of the project. The gray sections are not relevant and will therefore not be evaluated. Two groups of aspects were taken into account during the filling in of this matrix by ATO:
1. The optimal perishable condition
2. The environmental conditions

As example perishable roses, tomatoes, raw salmon and strawberries have been chosen. Adequately conditioned air transport has high added value on these perishables and their transported volume or potentially transported volume is high. Considering the conditioning of the example products a significant difference can be seen. While during transport of fruit, vegetables and flowers most attention needs to be paid to the fact that they produce heath and alter gas concentrations due to respiration, fish does not respire but is very sensitive to microbiological susceptibility. All criteria these products require have been regarded in the filling of the matrix. The environmental conditions during a flight from Curaçao to Amsterdam have been taken as the reference trajectory and are printed in Table 13.

From the filling of section I the main conclusion was that temperature is by far the most important aspect to focus on when preserving optimal perishable quality. The temperature very much influences

the processes leading to quality decay. Obviously this implies that in general other factors play a less important role if temperature is inside the optimum range. At non-optimal temperatures additional processes are initiated inside the product leading to much faster quality decay. It is therefore not surprising that especially at non-optimal temperatures additional conditioning capabilities like altered gas concentrations, condensation removal etc. play an important role.

To preserve perishables active cooling is needed. Ventilation and circulation increase efficiency of conditioning. Ventilation can both positively and negatively influence R.H. dependent on the environment conditions. For agricultural perishables ventilation positively influences O_2/ CO_2 and C_2H_4 (ethylene) concentration and smell. Usually strong smell is removed from the ULD by ventilation. Circulation improves a uniform distribution of temperature, R.H. and O_2 and CO_2 concentrations inside the ULD. To preserve fish and meat on the other hand only cooling and maintenance of relative within its limits is needed. Therefore a fully isolated ULD may be appropriate for fish and meat. Heating, which can be applied independently, is only needed if the environment temperature is below the optimum temperature of the perishables. Heating lowers R.H. as well. Application of absorbers and scrubbers is used take up water, water vapor, gasses like O_2 and CO_2 and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water. Conditioning control improves temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations. Adequate packaging prevents bruising of especially strawberries.

From the matrix it follows that the construction cluster aspects and material cluster aspects only influence the perishables condition in a very limited way (see gray area in Figure 1. To this end optimal conditioning concepts can be chosen independently from construction and material concepts). At the same time construction and material concepts can be chosen independently to optimally suit the logistics, aircraft capacity and other criteria. For verification of the producability of an ULD concept the feasibility matrices in Table 18 and Table 19 of Appendix D that opposed the conditioning, construction and materials clusters against each other can be used.

As a result of the partially filling of the matrix five different ULD concepts have been developed. The concepts vary in degree of condition control, reverse logistics, flexibility, multi-modality and control system. The two extreme concepts are a simple insulating bag and on the other side a sophisticated foldable multi-modal cooling module.

In two brainstorms with KLM clients opinions were asked about the conditioning and transporting of perishables and about the five conditioning concepts. The invited clients consisted of a group from South America and a group from the Netherlands. The opinion fell out into two extremes. One group favored the simple insulating bag, as this would suffice when the perishables were properly pre-cooled at the airport. The other group preferred the foldable multi-modal cooling module because this system can be used from grower to retailer while it fits into a road truck, is foldable and conditioning is fully performed by the ULD. Clients appreciated that attention was paid to their opinions.

An additional orientating study has been performed on the thermodynamic aspects of existing ULDs. ULDs studied ranged from non-insulating to insulating devices with both a coolant and some kind of circulation. Non insulating ULDs can not preserve perishable quality while the products warm up very quick because of the high environmental temperatures. Insulation lowers temperature rise. Additional coolant and finally air circulation limits temperature rise in the best way.

After performing this feasibility study it can be concluded that a tool for evaluation of design concepts has been successfully developed. The matrix makes the design and decision making process clear and understandable. The tool has helped to ease this process of developing a conditioning ULD for perishables that meets the criteria and can with small changes be applied in other developing processes as well.

The development of a conditioning ULD by KLM is an important marketing instrument, which can be used to approach clients. However, further research is needed to successfully develop a conditioning ULD for perishables. To complete the matrix and the evaluation part II and possibly part III should be fully filled as well.

1 Introduction

Over the past two years the Coolmate system has been developed by the cooperation of KLM PMC perishables and ATO-DLO. In the CoolMate project perishable temperatures and relative humidities were recorded, and compared to optimal perishable conditions. In almost all transports studied, recorded data were far from optimal from a perishable point of view. As a result of the project it has become clear that the conditioning capabilities in the present air transport chain are not sufficient to maintain the optimal microclimate for perishable agricultural products. Therefore the feasibility study 'Unit Load Devices with conditioning capabilities' has been set up in order to develop a well working and easy to use conditioning ULD.

This report reflects the activities performed in phase two, ULD evaluation matrix, of the feasibility study. The activities in this phase consist of defining and describing several representative perishables for air transport, filling in several sections of the evaluation matrix and finally defining and evaluating some interesting conditioning concepts. The concepts have been discussed during two external seminars with clients of KLM from both South America and the Netherlands. Finally an orienting study has been performed on the thermodynamics of existing ULDs. As well an additional study on the thermodynamics of existing ULD types is performed while temperature appears to be of major importance in perishable quality maintenance.

As has been stated in the first phase, the evaluation matrix is an instrument to make the development process transparent and to ease decision-making as far as possible. The list helps in preventing costly mistakes, which can happen if minor though important aspects are not taken into account. 'Less important' criteria might proof to cause (very) high costs or might even appear to be fatal at the end of the development process or after the market introduction. Therefore, the list of criteria combined with a systematic list of features concerning a conditioning ULD concept is a very good instrument to present a clear overview of the development process and give clear insight inside choices and decisions to make. Furthermore the matrix and the information it contains is used during the development and evaluation of several ULD concepts. The matrix therefore seems to be very valuable during this study as well as in future projects.

2 Perishables characteristics and conditioning

In this chapter the perishable characteristics and the influence of conditioning concepts on these characteristics are described. After a general introduction these aspects are elaborated for four example perishables.

2.1 Introduction

In the previous report [1] the evaluation matrix has been developed consisting of several groups of criteria on the vertical axis and three design clusters on the horizontal axis. An overview of the matrix is printed in Figure 2.

Figure 2 : overview of evaluation matrix

Evaluation matrix	Conditioning cluster	Construction cluster	Materials cluster
Criteria perishable condition	I		
Logistics and aircraft capacity load criteria	II	II	II
Other criteria (handling, cleaning, maintenance/ repair, legal aspects, applicable trajectories)	III	III	III

The field perishable conditioning criteria vs. conditioning cluster part of the evaluation matrix has been filled by ATO for a set of assumed environmental conditions. The environmental conditions have been chosen as determined from measurements in the Cool Chain Control project [8]. The assumed environmental conditions as well as other assumptions used can be found in appendix A along with the filled in matrix. The Logistics and aircraft capacity load criteria will be filled in by KLM. In this report the outcome of the study performed by KLM on the optimal dimensions of the ULD will be summarized. The fields of other criteria will not be filled in this report. Grayed out fields are not relevant.

Several factors play an important role in good perishable storage and transportation. Perishable quality can be very much influenced by the conditions in the transport facility. Depending on the type of perishable e.g. fruits and vegetables, flowers or fish the perishable decays because of specific characteristics. Fruits, vegetables and flowers are respiring products. They continue to respire, grow and develop and ripen and senesce after harvesting. To minimize deterioration of agricultural perishables respiration should be minimized because this process uses up stored reserves and food value. The processes taking place in agricultural perishables are schematically shown in Figure 3. Fish and meat on the other hand do not respire after 'harvesting'. In these products other processes, like growth of microorganisms should be suppressed in order to minimize deterioration.

As the factors that determine perishable quality very much influence each other a strict ranking of the importance of each factor can not be made. However, studying the processes that take place in both respiring as well as non-respiring perishables it can be concluded that all these microbiological and physiological processes are highly dependent on the perishable's *temperature*. Therefore a distinction will be made for two situations during transport:

1. The perishable temperature is within an appropriate range.
   The simplest and most powerful technique to minimize respiration and/or deterioration is to cool the perishable to the lowest temperature it tolerates without getting injured. At low temperatures deterioration is very much slowed down. In this situation the factors influencing perishable quality, listed in the lower half of Table 1, do still influence the perishable quality, but in a limited or at least controlled way.

2. The perishable temperature is outside its optimal range.
   If the temperature gets in one way or another above its optimal range all other kinds of biological processes causing deterioration will increase in speed. In this situation not only temperature should be lowered but all other perishable processes should be managed as well in order to get the produce as soon as possible back to its optimal storage conditions. Only by actively controlling both the temperature and the factors listed in lower part of Table 1, decay will be minimized. It should be noted however that a too long exposure to both too low and too high temperatures could by itself cause injuries to perishables (respectively. chilling injury and high temperature injury). Furthermore almost all deterioration processes are dependent on the perishable's temperature. It is therefore very hard to slow down, or at least control, these processes in case of an uncontrolled temperature. The first goal should therefore always be to obtain a controlled and constant temperature.

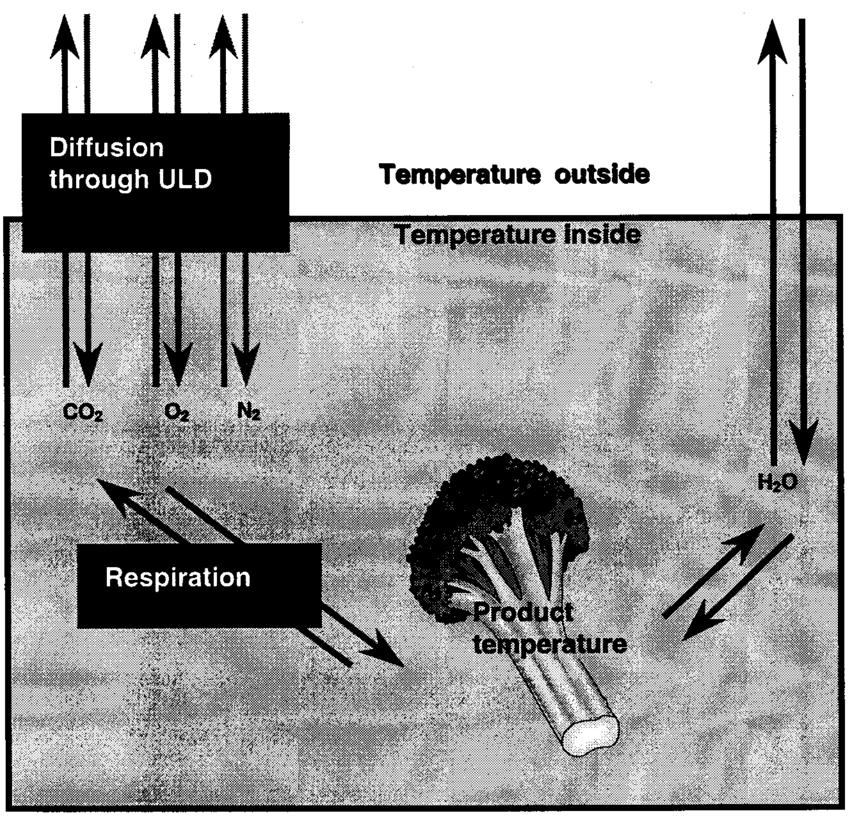


Figure 3: interaction of perishable and its environment

The list of factors influencing perishable quality as shown in Table 1 will be used as criteria for the design of ULD concepts. The criteria have been split into two groups. The upper half representing the situation when temperature is within an appropriate range (situation 1), and the second half describing aspects that are especially important when temperature is above its optimum (situation 2).

Table 1: Most important factors influencing perishable quality

Criteria perishable condition
Temperature
Product temperature
Maintenance within limits
Equal temperature throughout ULD
Air temperature
Maintenance within limits
Equal temperature throughout ULD
Relative humidity
Condensation removal
O_2/ CO_2 concentration
Ethylene production
Ethylene sensitivity
Microbiological susceptibility
Bruising
Smell uptake

Relative humidity. All perishables lose water after they are harvested. Water and hence weight loss is a major cause of deterioration during marketing. Some loss is unavoidable but excessive losses that lead to shriveled, wilted or tough products should be avoided. Optimum temperature and humidity levels will reduce water loss. On the other hand if relative humidity is high and the temperature is fluctuating condense may occur. For many perishable products like flowers, fruits and vegetables condensation will stimulate the growth of all kinds of moulds. Summarizing, the relative humidity should be as high as possible, but especially at sub-optimal temperatures condensation should be avoided.

Gasses. Perishables are used to growing and surviving in normal atmospheric conditions of approximately 21% O_2 and 0,03% CO_2. However, for respiring products altered gas conditions (decreased O_2 and increased CO_2) may reduce respiration and consequently reduce quality decay. For non-respiring products like fish and meat altered gas may reduce the growth of microorganisms. In this way quality decay may be reduced. For both respiring and non-respiring products the optimal gas concentrations strongly depend on the type of product. Care must be taken that the right gas conditions are applied, as only with the right gas conditions the shelf life can be increased. In case of too extreme atmospheres, both too high and too low levels of specific gasses, injuries may occur.

Ethylene (C_2H_4) is one of a number of natural plant hormones. It discriminates itself from the other hormones because ethylene is gaseous and easily exchanges with surrounding air. Even at very low concentrations ethylene has effects on growth, development and ripening of especially fruits and flowers. After harvesting these perishables may be exposed to ethylene unintentionally as the gas is produced by the crop itself, by other perishables, by micro-organisms and as it is available as a component of air pollution. The production and uptake of ethylene can be very much regulated by lowering temperature and minimizing injury and avoiding infections by careful handling. Ethylene production and ethylene sensitivity varies with the different agricultural perishables. Roses, for example, are not sensitive and ethylene is absent in meat and fish products.

Microbiological susceptibility. Microbiological decay of perishables can be caused by moulds, bacteria and yeasts. Microbial decay can be caused by the micro-organisms themselves growing exponentially and by the toxins that some of them produce. Microorganisms are present in the product, on its skin and in the surrounding air. Decay by micro-organisms can amongst others be minimized by lowering temperature, altered gas conditions and careful handling to avoid bruises and punctures where micro-organisms can attack the product and packaging.

Bruising. Bruising of perishables may cause changes in shape, texture color and flavor. Careful handling, adequate packaging and common sense is the most important way to reduce mechanical injury.

Smell uptake. Fatty products like fish and meat are very well able to take up smells. Agricultural perishables take up smell as well. The odor taken up may be caused by perishables stored nearby or from polluted air.

Four perishables have been selected as example perishables for determining the influence of conditioning concepts on the perishable condition: roses, tomatoes, raw salmon and strawberries. These four products have been selected from four product groups and cover a considerable area of perishable characteristics. Additional selection criteria are their high added value and volume. The four perishables and their boundary conditions will be described in the next paragraphs according to their characteristics as listed in Table 1.

Next, the conditioning concepts that best fit the perishable characteristics will be described. The conditioning concepts as shown in the evaluation matrix in Appendix A have been regarded. An overview matrix of the influence of conditioning concepts on perishable criteria is printed in Table 2. Perishable conditioning will be described according to the aspects printed on the vertical axis.

Table 2: Influence of conditioning concepts on perishable criteria (Group1)

Legend *Influence of concept on criterion:* *++ = very positive influence* *+ = positive influence* *empty = no influence* *- = negative* *-- = very negative influence* **Criteria perishable condition**	**Conditioning cluster** **Cooling/ Coolant**	**Ventilation** (in - out)	**Circulation** (inside module)	**Heating**	**Absorbers/ scrubbers**	**Conditioning Control**
Air temperature						
Equal distribution						
R.H.						
O_2 /CO_2 concentration						
Ethylene production						
Ethylene sensitivity						
Microbiological susceptibility						
Bruising						
Smell uptake						

2.2 Roses

2.2.1 Characteristics

Regarding rose quality transportation on water is normally best. This is sometimes done when roses are transported in road trucks. In air planes however flowers are always transported dry because of weight and volume reduction. For the same reason roses are very densely packed in air transport packages.

Table 3: summarizing the transport characteristics of roses

Roses		
Temperature		
Product temperature T	0-10 °C	
Storage temperature	**If 0 < T < 10 °C**	**If T > 10 °C**
heat production	Low respiration	High respiration
Relative Humidity [%]	90-100	80-90
Optimal O_2/ CO_2 Concentration [%]	Air	Air
Ethylene production	Negligible	Low: 0,3 µl/kg.h
Ethylene sensitivity	Not sensitive	Moderate sensitive
Microbiological susceptibility	Sensitive	Very sensitive
Bruising	Sensitive	Sensitive
Smell uptake	Sensitive	Sensitive

Temperature. The consumer likes to buy roses at a state of minimum bud opening. Bud opening during distribution can be prevented by storing the roses between 0 and 10 °C. Furthermore the amount of bud opening can be decreased by reducing the transportation time from grower to retailer. At too high storage temperatures roses become very sensitive for temperature instabilities. Storage below freezing point will damage roses as well. Dry storage of roses is possible for 7 days at 0 °C followed by a sufficient vase life at the consumer's. Storage life of roses shows a sharp decrease with increasing temperature. For instance at 10 °C the storability is only two days.

R.H. While roses are transported dry during air transport, R.H. should be high. A high relative humidity prevents roses from dehydration. However, generally the storage conditions are far from optimal: product temperature is above the optimum and R.H. in the cargo deck is far below the optimum. In these climate conditions the roses will dehydrate which will significantly shorten their vase life. Because roses are very densely packed in air transport packages and (local) temperature fluctuations often occur, the occurrence of condensation is likely. Especially when temperature is above the optimum condensation should be prevented because at elevated temperatures condensation forms an excellent medium for moulds.

Gasses. Altered gas concentrations do not have a positive influence on the quality of roses. Roses are therefore transported under normal air conditions. Roses have high respiration, causing high heat production. The best measure to decrease respiration is therefore a decrease of temperature.

Ethylene sensitivity and ethylene production of roses varies with the different cultivars but is in general not very high [2]. When the rose bud is fully developed ethylene sensitivity is higher. This stage is not a common situation in airfreight. Therefore roses are generally not described as ethylene sensitive.

Microbiological susceptibility. The mould *Botrytis* is one of the main causes of quality decay of roses. When roses are stored outside the optimum temperature range they become sensitive to *Botrytis.* It easily grows in humid conditions especially where free water is available. When condensation occurs it should be removed within several hours by ventilation or by using water absorbents. Hence the best measure to control the growth of Botrytis is lowering the temperature or avoiding condensation.

Bruising. Roses are sensitive to bruising. Especially the leaves can be damaged easily. In practice most leaves at the lower end of the stem will be removed before putting them on the vase.

Smell uptake. Roses are sensitive for smell uptake of surrounding products that have a strong odor.

2.2.2 Conditioning of roses

Coolant. A coolant must be used to lower air temperature inside the ULD for roses. Both wet ice and dry ice can be used for active cooling. These coolants should not be in the same space as the roses because of available free water for microorganisms and gas injury. Instead a heat exchanger should be introduced. Active cooling can both positively and negatively influence relative humidity. Microbiological susceptibility is increased by active cooling with wet ice due to the presence of free water.

Ventilation can both positively and negatively influence R.H. depending on the environmental conditions. O_2/ CO_2 concentration and smell are positively influenced by ventilation. Usually strong smell is removed from the ULD by ventilation. In case ventilation increases R.H. in the ULD, condensation should be avoided to minimize microbiological decay. Ventilation increases temperature inside the ULD.

Circulation works positively on air temperature and equalizes temperature differences. Effective circulation minimizes R.H., O_2/ CO_2 fluctuations and microbiological susceptibility as it avoids locally high concentrations.

Heating. If the outside temperature is too low heating is needed to establish the right temperature. Heating can be both positive and negative for R.H. and is positive for microbiological susceptibility.

Absorbers/ scrubbers. Various absorbers/ scrubbers can be used to take up water vapor, gasses like O_2 and CO_2 and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water.

Conditioning control is advantageous for temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations.

2.3 Tomatoes

From an economic point of view tomatoes are one of the largest horticultural products of the Netherlands. Tomatoes and especially tomatoes on the vine are transported by air in large quantities to the USA (annual turnover NL-USA: $32*10^6$ kg, 1997 [3]) and to a lesser extend to the Far and Near East.

2.3.1 Tomato characteristics

Temperature. Optimal storage temperature of tomatoes is between 8° and 15 °C. Because tomatoes can be injured by either too low (chilling injury) or too high temperatures, proper postharvest handling and storage methods are essential for maintaining acceptable quality and storage life. Chilling injury is cumulative and is a function of both temperature and exposure time and shows in tomatoes as a delayed coloration (failure to ripen), taste problems and reduced shelf life. Storage at too high temperatures results in high temperature damage. Storage life of red tomatoes under optimal conditions varies from 14 up to 20 days. At 12 °C heat production is low (40 Watts/1000 kg), heat production doubles when storage temperature is >20 °C.

Table 4: summarizing the transport characteristics of tomatoes

Tomatoes		
Temperature		
Product temperature T	8-15 °C	
Storage temperature	**If 8 < T < 15°C**	**If T > 15°C**
heat production [W/t]	40 (low)	90 (20 °C)
R.H. [%]	90-100	80-90
Optimal O_2/ CO_2 concentration [%]	5/ 5	5/ 5
Ethylene production [µl/kg*hr]	Varies per type 0,2 –10	0,2-10
Ethylene sensitivity	Not sensitive	Sensitive
Microbiological susceptibility	Moderate sensitive	Sensitive
Bruising	Sensitive	Sensitive
Smell uptake	Not sensitive	Not sensitive

R.H. Tomatoes are best stored at a R.H. of 90-100% under optimal temperature and at 80 to 90% when the temperature is above the optimum. At higher temperatures extra care must be taken to prevent condensation, therefore R.H. should not exceed 90% at these temperatures. Condensation is a source of mould growth mainly on the calyx and other green parts (tomatoes on the vine). The calyx is used as a freshness indicator. For marketing reasons it is not removed. Therefore at low relative humidities precautions for dehydration should be taken. Dehydration also causes early softening.

Gasses. Altering the gas conditions inside the ULD can lower the respiration rate of tomatoes. Storage life of tomatoes can be increased significantly by a modified atmosphere. Care should be taken in the choice of the altered gas conditions. A combination of 5% O_2 and 5% CO_2 filled up with 90% N_2 will give optimal effects. Lower O_2 levels and higher CO_2 levels can produce off-flavors.

Ethylene production and sensitivity. Ethylene production of tomatoes varies per type from a low production to a high production. Sensitivity to ethylene of red tomatoes however is low.

Microbiological susceptibility. Tomatoes have a moderate sensitivity for microorganisms. Tomatoes especially suffer from mould growth at the calyx. Sensitivity increases as the storage temperature gets above the optimum and if free water is present.

Bruising. Tomatoes are sensitive for mechanical damage. Sensitivity does not increase with temperature.

Smell uptake. Tomatoes are not sensitive for smell uptake, neither in the optimum temperature range nor in the non-optimum ranges.

2.3.2 Conditioning of tomatoes

Coolant. A coolant is needed to store tomatoes at an appropriate temperature. Coolants like wet ice and dry ice should not be in the same space as the tomatoes. The water and CO_2 that comes from these coolants may damage the perishables if they are not adequately removed. It is advisable to introduce a heat exchanger. Active cooling can both positively and negatively influence relative humidity. Cooling has a positive effect on the ethylene concentration inside the ULD as it lowers the tomato's ethylene production. In case outside temperature is lower than the appropriate product temperature heating should be available.

Ventilation cleans the inside of the ULD by exchanging O_2, CO_2 and C_2H_4 and smell with outside air. However, by exchanging inside and outside air, other smells might be introduced into the ULD that will be taken up by the tomatoes. Ventilation increases the temperature in the ULD. R.H. may be both positively and negatively influenced by ventilation, dependent on environmental conditions. In case R.H. increases to 100%, microbiological decay is likely to occur because of condensation.

Circulation distributes temperature, gasses and vapor equally throughout the ULD. Microbiological susceptibility is reduced.

Heating. As tomatoes should not be stored below 8 °C heating may be an aspect of attention if the outside temperature is too low heating is needed to establish the right temperature. Heating can be both positive and negative for R.H. but is beneficial to avoid condense and therefore microbiological susceptibility is reduced.

Absorbers/ scrubbers. Various absorbers/ scrubbers can be used to take up water vapor, gasses like O_2, CO_2 and C_2H_4 and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water.

Conditioning control. Finally conditioning control is advantageous for temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations.

Adequate primary packaging can prevent bruising of tomatoes.

2.4 Raw Salmon

2.4.1 Characteristics

Fish is a very delicate and complex and therefore very perishable product that should be taken care of well in the supply chain to retailers and consumers. In contrast with other fresh products from land, with fish the first and most important information concerning the quality only becomes available at the moment of 'harvest'. Harvested fish also differs from products like fruits, vegetables and flowers in the area of respiration. Respiration processes in fish stop from the moment it has been 'harvested' while agricultural products continue respiring and producing heat after harvest

Table 5: summarizing the transport characteristics of raw salmon

Raw Salmon		
Temperature		
Product temperature T	0-3 °C	
Storage temperature	**If 0 < T < 3°C**	**If T > 3°C**
heat production	No respiration	No respiration
R.H. [%]	100	100
Optimal O_2/CO_2 Concentration [%]	0/ 60-100	>0/ 60-100
Ethylene production	Not relevant	Not relevant
Ethylene sensitivity	Not relevant	Not relevant
Microbiological susceptibility	Sensitive	Very sensitive (toxin)
Bruising	Sensitive	Sensitive
Smell uptake	Sensitive	Very sensitive

Temperature. Only with a strict control of climate and temperature an extension of the shelf life of fish is possible. A thorough control of temperature (0-3°C) is essential. Temperatures above 3 °C should be avoided because of growth of dangerous bacteria. Stored on ice storage life of fish like raw salmon ranges from 3 to 10 days.

R.H. of raw salmon should be 100% to prevent dehydration. At temperatures above the optimum relative humidity should be lower to avoid condensation. Bacteria can easily develop if condensation is available.

Gasses. Contrary to roses, tomatoes and strawberries raw salmon does not respire. Consequently heat production is zero. Only a small amount of CO_2 is absorbed by the fish because of biochemical reactions. Lowered temperature in combination with a modified atmosphere offers the right conditions for a maximal and sensible extension of the shelf life while growth of food spoiling bacteria is prevented. When properly applied altered gas conditions can significantly increase the shelf life with

10 days. The concentration of CO_2 is limited, especially at low temperatures. A too high concentration of CO_2 may result in adverse organoleptic changes like coarsening of the texture of the tissue and undesired color changes and it may affect the water holding capacity of the tissue of the fish leading to excessive loss of water.
With fresh uncured salmon oxygen has to be excluded, because fatty fish develop rancid off-flavours and odours due to oxidation. Salmon is suitable for storage in the absence of oxygen which leads to a relatively long shelf life compared to other fish. It has to be stressed that during storage without oxygen a strict control of temperature is essential. At temperatures above 3 °C. anaerobic bacteria will start producing toxins.

Ethylene production and sensitivity is not relevant for raw salmon.

Microbiological susceptibility. Even perfectly healthy fish offer a nearly optimal medium for the growth of bacteria that are always available in the fish, on its skin and in the water surrounding it. Raw salmon is very sensitive to microorganisms. At temperatures higher than optimal raw salmon becomes very sensitive to bacteria. A thorough control of temperature is essential. At temperatures above 3 °C. production of toxins by anaerobic bacteria of the species *Clostridium botulinum* may cause a severe danger for public health.

Bruising. Salmon is sensitive for bruising like shocks and bruises.

Smell uptake. Salmon is a type of fish that contains relatively much fat. This indicates that it is sensitive for smell uptake. Of all fatty fish species salmon is even more sensitive for smell uptake.

2.4.2 Conditioning of raw salmon

Regarding the characteristics of raw salmon only active cooling, in some cases heating, absorbers, scrubbers and conditioning control influence the salmon quality.

Coolant. A coolant must be used to lower air temperature inside the ULD for raw salmon. Both wet ice and dry ice can be used to cool raw salmon. Inside the appropriate temperature range salmon can be cooled with wet ice, as at these temperatures contact with water does not harm raw salmon. If dry ice is used it should be applied in combination with a heat exchanger because too high levels of CO_2 cause excessive water loss (drip). If a powered cooler is used care should be taken to prevent dehydration. Active cooling can both positively and negatively influence relative humidity concentrations. Microbiological susceptibility is negatively affected by active cooling with wet ice in case melting water is not adequately removed. If maintenance of the temperature within the appropriate temperature range can not be guaranteed for raw salmon a heat exchanger should be used.

Ventilation and circulation. Both ventilation and circulation are not necessary during the storage of raw salmon because of the absence of respiration. If the temperature gets above 3 °C condense should be avoided however, to avoid the anaerobic bacteria *Clostridium botulinum* from growing which toxin is very dangerous for humans.

Heating. If the outside temperature is too low heating is needed to establish the right temperature. Heating can be both positive and negative for R.H. and is positive for microbiological susceptibility.

Absorbers/ scrubbers. Various absorbers/ scrubbers can be used to take up free water, water vapor and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water.

Conditioning control. Finally conditioning control is advantageous for temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations.

Adequate primary packaging can prevent raw salmon from bruising.

2.5 Strawberries

Strawberries are very soft flesh fruits and highly sensitive for mechanical injuries or bruising. Therefore strawberries are extremely perishable and compared to other fruits have unusually demanding postharvest handling requirements. Storage life of Dutch grown strawberries in limited and as a result of that not exported to far markets. However, at this moment there is a high market potential in Japan for Dutch grown strawberries.

2.5.1 Characteristics

Temperature. Only under ideal conditions throughout the complete supply chain strawberries (1 °C) can be kept approximately 10-14 days. Storability shows a sharp decrease with increasing temperature. For instance at 10 °C the storability is five days. After harvest they must be cooled immediately to their lowest safe temperature of 1 °C to prevent over-ripening and decay.

Table 6: summarizing the transport characteristics of strawberries

Strawberries		
Temperature		
Product temperature T	0-5 °C	
Storage temperature	**If 0 < T < 5°C**	**If T > 5°C**
heat production [W/t]	45 (medium/ high)	290 (20 °C)
R.H. [%]	90- 100	90-95
Optimal O_2/ CO_2 Concentration [%]	5 / 15	5/ 15
Ethylene production	Negligible	Low
Ethylene sensitivity	Not sensitive	Not sensitive
Microbiological susceptibility	Highly sensitive	Extremely sensitive
Bruising	Highly sensitive	Extremely sensitive
Smell uptake	Sensitive	Sensitive

R.H. Strawberries are very sensitive to dehydration. If the air inside the storage room or transport medium is too dry, water will evaporate from the strawberries and they will become soft and shriveled [4]. Within the appropriate temperature range humidity should be approximately 90-100%. At temperatures higher than the optimum strawberries become very sensitive to microbiological spoilage. Relative humidity should be in the range of 90-95%.

Gasses. Altered gas conditions can increase storage life with a maximum of four days. To increase storage life oxygen levels should be lowered to 5 % and carbon dioxide levels should be increased to 15 %.

Ethylene production of strawberries is negligible and at the same time they are not sensitive to ethylene.

Microbiological susceptibility. Strawberries must be kept free of bruises and other injuries, as bruised strawberries are very susceptible to post harvest decay. Very careful handling and distribution is essential to maintaining quality. At too high product temperatures relative humidity should be lowered in order to prevent condensation. When condensation is present moulds will very easily grow on the thin and not smooth skin. The two most common types of decay for strawberries are gray mould, *Botrytis cinerea*, and *Rhizopus rot.* Even a small infection can quickly spread throughout an entire load. Strawberries that have been cooled and then allowed to re-warm, causing moisture to condensate on them, are extremely susceptible to decay.

Bruising. Strawberries are highly susceptible to bruising. This results in rapid decay, which readily spreads to other fruits.

Smell uptake. Strawberries are sensitive to smell and taste uptake. Especially at temperatures above the optimum the fruits very easily take up off-odors.

2.5.2 Conditioning of strawberries

Coolant. A coolant can be used to lower air temperature inside the ULD for strawberries. Both wet ice and dry ice can be used to cool strawberries as long as these coolants are not in the same space as the strawberries because of available water stimulates microorganisms growth and CO_2 may cause gas injury. Instead a heat exchange should be introduced. Active cooling can both positively and negatively influence relative humidity.

Ventilation can both positively and negatively influence R.H. dependent on the environmental conditions. O_2/ CO_2 concentration and smell are positively influenced by ventilation. Usually strong smell is removed from the ULD by ventilation. However, ventilation might introduce unwanted smells into the ULD that will be absorbed by the strawberries. In case ventilation increases R.H. in the ULD, condensation should be avoided to minimize microbiological decay. Ventilation increases temperature inside the ULD.

Circulation works positively on air temperature and the equal distribution of it. Circulation is as well positive for the R.H., O_2/ CO_2 concentrations and microbiological susceptibility.

Heating. If the outside temperature is too low heating is needed to establish the right temperature. Heating can be both positive and negative for R.H. and is positive for microbiological susceptibility.

Absorbers/ scrubbers. Various absorbers/ scrubbers are used take up water vapor, gasses like O_2 and CO_2 and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water.

Conditioning control is advantageous for temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations.

Adequate primary packaging as well as careful handling must be ensured to prevent strawberries from bruising, as strawberries are extremely susceptible for mechanical injury.

2.6 Conclusion

Table 7 summarizes the optimal storage and transport conditions of the four selected perishables.

Table 7: summarized overview of transport characteristics of selected perishables

	Roses		**Tomatoes**		**Raw salmon**		**Strawberries**	
Temperature								
Product temperature T	0-10 °C		8-15 °C		0-3 °C		0-5 °C	
Storage temperature	**0 < T < 10 °C**	**T > 10 °C**	**8 < T < 15 °C**	**T > 15 °C**	**0 < T < 3°C**	**T > 3°C**	**0 < T < 5°C**	**T > 5°C**
Heat production [W/t]	Low resp.	High resp.	Low resp. 40	High resp. 90 (20 °C)	No resp.	No resp.	Med./ High 45	290 (20 °C).
R.H.	90-100%	80-90%	90-100 %	80-90%	100	90-95	90-100	90-95
Optimal O_2/ CO_2 concentration [%]	Air	Air	5/ 5	5/ 5	0/ 60/ 100	>0/ 60-100	5/ 15	5/ 15
Ethylene production [μl/kg*hr]	Negligible	Low 0,3	Varies per type: 0,2-10	0,2-10	Not relevant	Not relevant	Negligible	Low
Ethylene sensitivity	Not sensitive	Moderate sensitive	Not sensitive	Sensitive	Not relevant	Not relevant	Not sensitive	Not sensitive
Microbiological susceptibility	Sensitivity	Very sensitive	Moderate sensitive	Sensitive	Sensitive	Very sensitive (toxin)	Highly sensitive	Extremely sensitive
Bruising	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive	Highly sensitive	Extremely sensitive
Smell uptake	Sensitive	Sensitive	Not sensitive	Not sensitive	Sensitive	Very sensitive	Sensitive	Sensitive

As you can see in Table 7 characteristics of perishables vary much per type. A distinction can be made between agricultural perishables (roses, strawberries and tomatoes) and fish and meat (salmon) Agricultural perishables still respire after harvesting while in fish and meat respiration is absent. Respiring perishables generate heat and use up stored reserves. Fish and meat on the other hand do not respire but are very susceptible for microorganisms. Therefore storage conditions of perishables differ very much per type.

For all perishables in the range studied however, during storage and transport the main focus has to be on temperature maintenance. The temperature very much influences the processes in perishables that lead to decay. Keeping the storage temperature within the optimum range is the easiest way and should be the steering point to preserve optimal product quality. In addition quality and storage life can be increased by regulating the other aspects printed in the lower half of Table 1.

Under no circumstances the products temperature may be lower than the indicated minimum temperatures. Too low temperatures lead to severe damaging of the product which is called chilling injury.

At too high product temperatures characteristics like respiration, microbiological activity and ethylene production and sensitivity increase. In this situation first of all product temperature has to be lowered. When this is impossible (for instance for logistic reasons) it is preferable to lower R.H. in order to remove condensation water and to use ventilation systems to keep C_2H_4 levels low. Active conditioning of the atmosphere when temperature is out of safety limits may be useful to minimize the risks of severe damage. However, instead of focussing on the management of a non-optimal situation and on available techniques it is always better to prevent temperature abuse.

To adequately transport the selected perishables the ULD has to be conditioned. Conditioning aspects are active cooling, ventilation, circulation, heating, absorbers/ scrubbers, conditioning control and adequate packaging.

Active cooling is necessary to reduce air temperature. In the actual supply chain wet ice makes only sense in combination with raw salmon. Melted ice halfway the supply chain in contact with the other perishables will stimulate growth of microorganisms. None of the selected products should be in the same room as the coolant dry ice (solid CO_2). Application of dry ice systems might cause gas injury if ventilation is not available. For respiring perishables a coolant that is separated from the perishables by a heat exchanger is preferable to avoid free water and high CO_2 levels. The best cooling method is a powered cooler with a direct expansion system. In case outside temperature is lower than appropriate, for example in wintertime or when tropical fruits are transported, heating may be needed. Heating is possible with a (reversed) gas compression system, which is the same gas compressor as used in a powered cooling with a direct expansion system.

Ventilation may be used to regulate both R.H. and gas concentrations inside the ULD. Ventilation may as well exchange moulds and spores, ethylene and smells between the inside and the outside of the ULD. In this case ventilation may be both positive and negative for product quality. Therefore, although necessary, the advantages of ventilation are partially annulled for roses, tomatoes and strawberries. For non-respiring products like salmon there is no need for ventilation, as long as condense is avoided.

Circulation increases the equal distribution of the temperature. Circulation is especially necessary for perishables that generate heat. Circulation is therefore not needed for conditioning of raw salmon.

In any case condensation should be prevented. Means of condensation prevention might be circulation, ventilation and active R.H. controls. Might condensation occur, it should be removed as soon as possible. Condensation can be removed in several ways for example absorbers, scrubbers and increasing temperature.

Temperature maintenance within limits is achieved by means of conditioning control. This can be done manually, with a fixed regulation system or with an active control system. Conditioning control may influence gas concentrations. Conditioning control is advantageous for all perishables selected.

Adequate primary packages can be used to prevent perishables from bruising.

Combining conditioning concepts like ventilation and circulation may increase their positive effect on perishable quality. For instance the combination of cooling and circulation is very effective to ensure efficient perishable cooling and coolant usage. Simultaneous application of heating and cooling can improve control of both temperature and R.H.

A from a perishable quality point of view ideal conditioning ULD for perishables consists of a cooler which lowers temperature, a ventilator to circulate this cold air, an active control system (thermostat) to stabilize temperature, possibilities to ventilate and a heater which can also be used as a drying system. However, in defining the optimum ULD aspects like costs, goods flows, modalities and return transport have to be taken into account as well. The optimal conditioning ULD will therefore be the result of a weighing of all those aspects.

One of the non-perishable related aspects that play a role in the design of an ULD has been studied by KLM BU Logistics. The results of this study will be described in chapter 3. To get an idea of the possibilities of realizing an ULD, in chapter 4, five different conditioning concepts will be presented that have been generated from the complete evaluation matrix. The concepts have been developed in cooperation with KLM Cargo.

Summarizing the results from this chapter, the following rules can, when applied with careful respect to the environmental and supply chain conditions, be used as guidelines for primary steps to conditioning perishables:

- Three temperature zones can be chosen to provide optimal temperatures for a large range of perishables:
  1. 0 – 5 °C (e.g. roses, strawberries, salmon)
  2. 5 – 10 °C (tropical fruits)
  3. 10 – 15 °C (e.g. tomatoes)

  A perishable must not at any time be subjected to either lower or higher temperatures than those within its adequate range. These temperature zones apply with the temperature zones in ATO report B 364 [9].
- Active cooling should be used in combination with a heat exchanger
- A constant temperature must be maintained, to avoid condense.
- An adequate transport packaging must prevent the perishable from bruising
- Sufficient air circulation and ventilation must be applied to avoid locally high temperatures and relative humidity, and to remove increased CO_2 or supply decreased O_2 concentrations for respiring perishables (flowers, fruits and vegetables)

3 Dimensioning ULD

Due to the fact that all different kinds of perishables like fruits and vegetables, flowers and fish will be transported in the conditioning ULD, dimensioning of the ULD is very important and has to be optimized to all these products. Amongst other things an optimum has to be found between the dimensions of the different cargo holds of the airplane and the dimensions of regular road trucks. KLM BU Logistics performed a study after the size determination [5]. As a result five sizes of ULDs have been proposed that are printed in Table 8.

Table 8: internal and external dimensions of five ULDs.

Perishable	ULD	Internal dimensions [m]			External dimensions [m]		
		Length	Width	Height	Length	Width	Height
Non flowers	Small	120	100	70	122	112	80
	Medium	224	150	70	224	159	80
Flowers	Half size	200/156	120	70	210/164	120	80
	Small	120	100	100/200	122	106	120/240 [1]
	Medium	240	100	100/200	244	106	120/240

When actually deciding which dimensions are needed, how many different sizes will be developed and designing the conditioning ULD, several aspects like logistics, costs and volumes transported of the various perishable products have to be analyzed more thoroughly. Aspects like the amount of isolation needed, the space taken by coolant, coolers, fans, energy supply etc. have to be taken into account. Furthermore a thorough optimization to three dimensions and multiple stacking patterns is desired. This information is likely to become available during a possible continuation of this study in which the most promising conditioning ULD will be worked out.

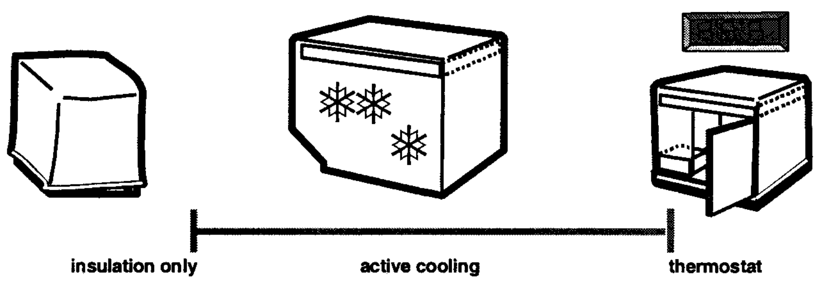
[1] For the flower-conditioning ULD a height of 2,40 m generates the same results as a height of 1,20 m.

4 Conditioning concepts

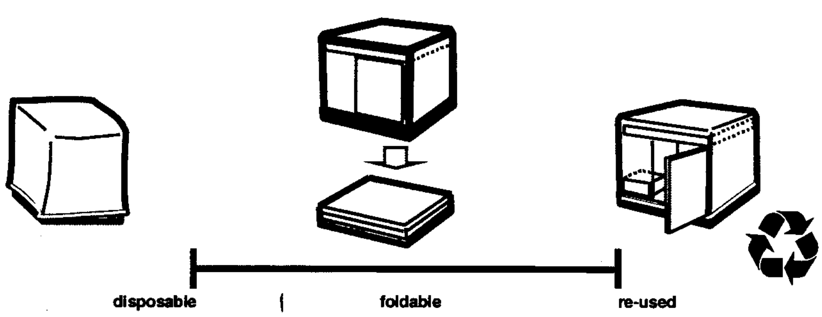
4.1 Introduction

As a result of the filling of the evaluation matrix some conditioning ULDs have been designed in cooperation with KLM Cargo. The ULD concepts have been generated in a systematic way for which five important ULD aspects have been defined. These aspects; degree of conditioning control, reverse logistics, flexibility of transport module, dimension of module to fit modality and how to control conditioning, have been varied between their extremes and are printed in Figure 4. In this way five completely different conditioning ULDs have been generated.

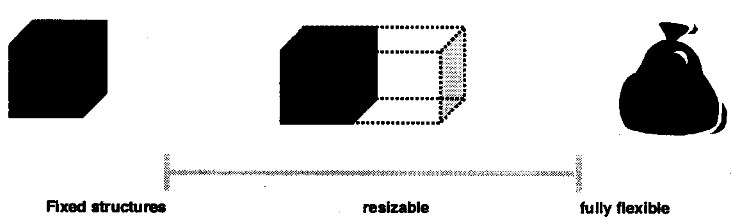
degree of condition control



reverse logistics



flexibility of transport module



dimension of module to fit modality

how to control condition

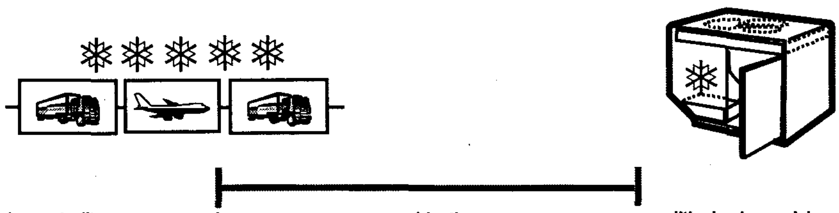
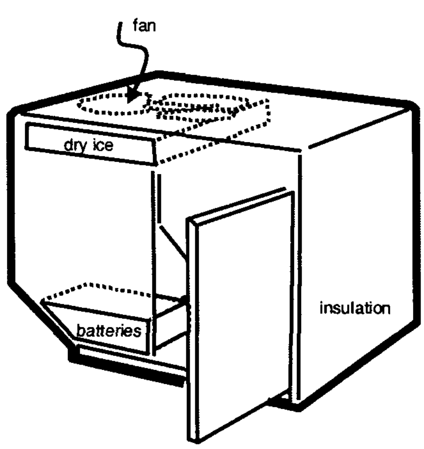


Figure 4: Five different aspects of concept ULDs and their extreme variations

4.2 Concept 1: thermostat aircraft container

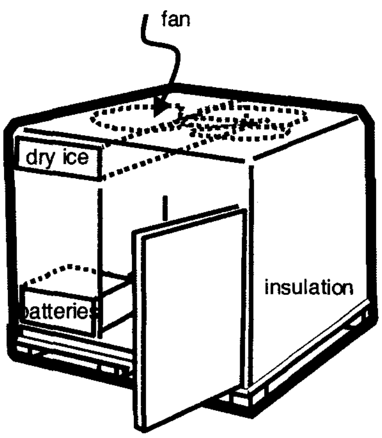


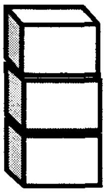
Characteristics	
Degree of control:	Thermostat
Reverse Logistics:	Re used
Flexibility of the transport module:	Fixed
Dimensions of the module to fit modality:	Aircraft
How to control condition:	Control by module

The cooling of the *thermostat aircraft container* is thermostat controlled. The device contains a cooling by means of dry ice. The concept is designed as a reusable device of which the dimensions are fixed. Folding to ease storage and empty return is not possible. The ULD is optimized for transport in aircraft. The module is not designed to be used in a modality different from an aircraft. Finally the conditioning of the perishables is performed by the ULD itself and not by facilities in the transport or handling process.

This device can be used for conditioned transport of perishables from one airport to another. Temperature is regulated by a thermostat and ventilation can be added to this concept. Further transport in road trucks requires repacking. It is advisable to have return cargo available because empty transport is costly due to a high lost volume. Because of its good cooling characteristics relatively much space is lost with insulation. This concept is suitable for all example perishable because it both cools and ventilates.

4.3 Concept 2: thermostat multi-modal module





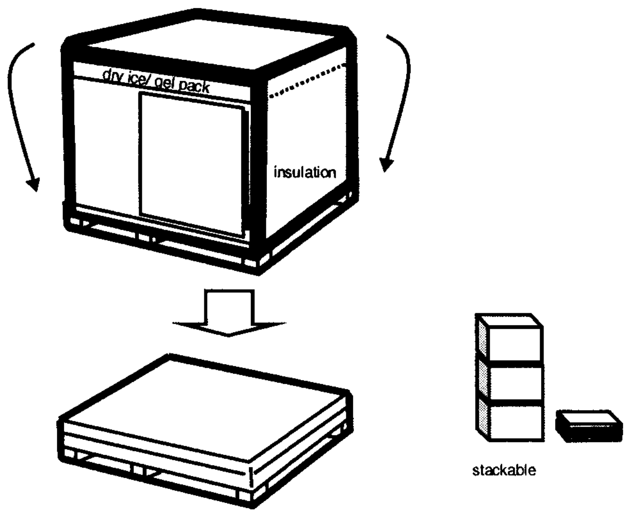
stackable

Characteristics	
Degree of control:	Thermostat
Reverse Logistics:	Re used
Flexibility of the transport module:	Fixed
Dimensions of the module to fit modality:	Aircraft and truck
How to control condition:	Control by module

Actually the *thermostat multi-modal module* looks very much like the first concept apart from the non inter-modality of the first concept. This concept is thermostat controlled. The concept is designed as a reusable device. However the dimensions are fixed and therefore the device can not be folded in case of empty return transport. A big advantage of this concept is the fact that dimensions of the ULD fit an aircraft as well as a road truck. In this way the device can be used throughout the entire supply chain. To increase the loading capacity of especially trucks this concept is stackable. Conditioning is controlled by the module itself.

This concept can be used to transport and condition perishables from grower to retailer. It fits in both an aircraft and a road truck and apart from thermostat controlled conditioning ventilation can be added. Just like the first concept for this reusable ULD it is advisable to have return cargo in order to minimize empty return flights. Concept 2 is suitable for all example perishables because it both cools and ventilates just like the first concept.

4.4 Concept 3: foldable cooling module

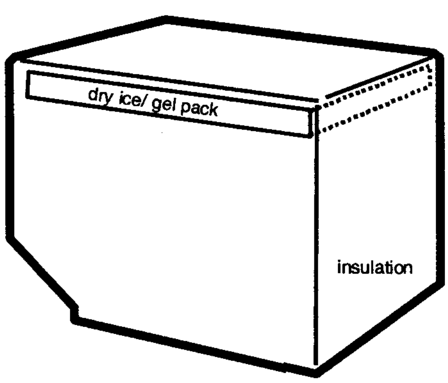


Characteristics	
Degree of control:	Insulation only
Reverse Logistics:	Foldable
Flexibility of the transport module:	Fixed
Dimensions of the module to fit modality:	Aircraft and truck
How to control condition:	Control by module

The conditions inside the *foldable cooling module* are regulated by active cooling. Just like the first two concepts this concept is re-used because of its technical features. Return transport and storage is simplified by a folding mechanism. The dimensions of the module are fully fixed. Resizing which might be interesting because of the fact that a device is not fully filled is not possible in this concept. The device is multi-modal (100 x 120 x 80) and stackable. In case of empty return transport and storage the concept can be folded. Conditioned transport of agricultural perishables in this concept is only possible when apart from cooling ventilation is available. In this case however we expect that cooling capacity will be too low. Therefore this concept is best suitable for raw salmon which can be transported in a completely closed ULD.

This concept is applicable from grower to retailer. It fits in aircraft holds as well as in normal road trucks. Contrary to the first two concepts return cargo is not necessary because it can be folded and therefore easily stored and transported back.

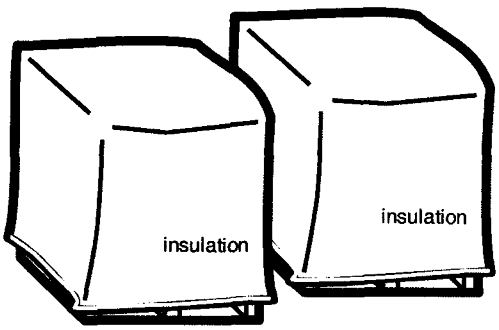
4.5 Concept 4: cooling bag



Characteristics	
Degree of control:	Active cooling
Reverse Logistics:	Disposable
Flexibility of the transport module:	Fully flexible
Dimensions of the module to fit modality:	Aircraft
How to control condition:	Partly by module, partly by transport and handling

The temperature in the *cooling bag concept* is regulated by active cooling. In the ULD wet ice, dry ice or a gel pack is added to lower the temperature. The insulating material that is applied, being in the form of a bag, is disposable. Because of this fact the transport module is fully flexible. Because the concept is based on devices used in air transport the concept only fits in the holds of aircrafts. The concept is not usable in road trucks. Conditioning control is a combined activity of the module itself and the transport and handling processes. While the conditioning aspects of this concept are identical to that of concept 3 in this concept it is best to transport raw salmon.

4.6 Concept 5: insulating bag



Characteristics	
Degree of control:	Insulation only
Reverse Logistics:	Disposable
Flexibility of the transport module:	Fully flexible
Dimensions of the module to fit modality:	Aircraft and truck
How to control condition:	Conditioning by transport and handling processes

The final concept *insulating bag* is a very simple one. The concept only offers insulation, a cooling medium is not included. This concept therefore implies pre-cooling at the storage facilities of KLM in order to deliver the perishables in the right conditions at the clients. The concept, being very simple and flexible, eliminates reverse logistics, which is especially interesting when reverse goods flows are significantly smaller than outward goods flows. The dimensions of the module are based on the standards used in road and rail transport and can be applied in aircraft holds as well. The concept is therefore made stackable. Considering the temperature track to which this ULD is exposed conditioning capabilities for the example products will probably not be sufficient.

4.7 Conclusion

Table 9: overview of ULD concepts

	Degree of condition control	Reverse logistics	Flexibility of transport module	Dimension of transport module to fit modality	How to control condition
Concept 1: Thermostat aircraft container	Thermostat	Reusable	Fixed	Aircraft	Module
Concept 2: Thermostat multi-modal module	Thermostat	Reusable	Fixed	Aircraft and truck	Module
Concept 3: Foldable cooling module	Active cooling	Reusable	Fully flexible	Aircraft and truck	Module
Concept 4: Cooling bag	Active cooling	Disposable	Fully flexible	Aircraft	Combination
Concept 5: Insulating bag	Insulation only	Disposable	Fully flexible	Aircraft and truck	Transport and handling processes

To get an overall view of the similarities and differences of the various conditioning concepts an overview has been printed in Table 9. As you can see concept 5 is the simplest design of a conditioning ULD. Concepts 2 and 3 are both very sophisticated with respectively the use of a thermostat and the fact that it is foldable.

To get an overall impression of the possibilities and impossibilities of the various concepts concerning conditioning they will be evaluated in combination with the selected perishables. The evaluation is printed in Table 10. In this Table we have put the perishables (both pre-cooled and uncooled) on the vertical axis and the conditioning concepts on the horizontal axis. Concepts 1 and 2 and 3 and 4 are identical. We assume that concepts 3 and 4 contain enough ice to cool the perishables and that the walls offer sufficient insulation. The various conditioning concepts have been and given a number between 1 and 10 indicating their suitability for the specific perishables.

Concept 5 is not suitable for all of the selected perishables because it lacks a coolant. Keeping the temperature track (Table 13) in mind, the use of an insulating bag only might prove to be insufficient for heat producing perishables that require a low temperature. Concept 3 and 4 are suitable for (pre-cooled) tomatoes and raw salmon. In this concept heat can not be removed easily and it therefore less suits roses and strawberries. Concepts 1 and 2 are thermostat controlled and are able to ventilate and suit therefore all selected perishables. From economic point of view these concepts are sometimes overdone but do cool product well.

As you can see the coolants wet ice and dry ice are positive for raw salmon. Using a powered cooler extra care should be taken for raw salmon to avoid dehydration. No wet ice should be used with strawberries because of free water and pressure on the fruits. Uncooled salmon should better not be transported at all because of danger of toxin production by *Botrytis* in absence of oxygen. This Table is a first impression of the suitability of the concepts for specific perishables and therefore open for discussion.

When considering logistic and aircraft capacity load criteria and other criteria possibly concept 3 (foldable cooling module) might be preferred above concepts 1 and 2 while this concept is designed as a multi-modal module which can be folded as well for return transport. In this case conditioning characteristics should be studied more thoroughly to make it fit for all selected perishables.

Table 10: Overview of suitability of concepts for specific perishables

Suitability of concept for specific perishables	*Concept 1/ 2:* Thermostat module	*Concept 3/ 4:* Cooling module	*Concept 5:* Insulating bag
Pre-cooled Roses	10	6	5
Uncooled Roses	8	2	2
Pre-cooled Tomatoes	10	8	6
Uncooled tomatoes	6	5	5
Pre-cooled Raw salmon	10	10	2
Uncooled Raw salmon	8	6	2
Pre-cooled Strawberries	10	2	2
Uncooled strawberries	6	2	2

5 Brainstorm

5.1 Introduction

In this chapter the overall and global opinions of KLM Cargo clients on different conditioning ULDs will be presented. To obtain these opinions two sets of brainstorm sessions have been organized at ATO. In the first set clients from South America were invited and in the second set clients from the Netherlands were invited. Groups of about 20 people were put together to whom among others a system of slides, the five conditioning concepts and additional attributes were presented. During a brainstorm the opinions on the five concepts and on the separate attributes of which the concepts have been composed have been gathered.

It is difficult to present concrete numbers of the outcome of the brainstorm because a lot of variables differed in the different groups; for example the groups had different backgrounds (ranging from rose growers to exporters of bell peppers), resulting in example products that not all participants could identify with, different atmospheres in different groups: not all votings were performed in all groups and secondly votings were performed in different ways. Furthermore it appeared difficult for several participants to generate ideas while they were afraid of negative reactions and of competitors that were in their group as well. Some of the problems mentioned above will always occur in brainstorms but others could be taken into consideration a next time.

In Appendix B the results of the brainstorm have been printed in numbers as well.

5.2 Results

The group consisting of South American clients could not disconnect costs from the conditioning concepts. Therefore clients generally preferred the insulating bag because of the probably lower costs. They stated that KLM Cargo should in addition pre-cool their product and pay more attention to control of the chain. In this way KLM should be able to establish a sufficiently effective transport system for perishables. Most of the clients considered this as a responsibility of KLM. Further reasons for choosing the bag is its disposability, which is especially interesting because of the significantly bigger goods flows from South America to Europe than vice versa. Finally these clients were interested in how KLM would deal with availability and allocation in case reusable conditioning ULDs were introduced.

To successfully introduce a more 'intelligent' concept to these clients KLM Cargo should give additional information on the possibilities of the module. The advantages of for example exploring new markets, flying other trajectories because direct flights are overloaded, higher product quality and extended storage life need more explanation. The South American clients considerably focussed on direct costs and did not immediately see how they can save money by spending more on a conditioning ULD. Clients apparently do not easily draw these conclusions themselves.

If a more 'intelligent' concept is to be introduced, South American clients prefer it flexible, thermostat controlled and applicable on both airplanes and trucks. In any case the existing envirotainer is not interesting because of its inflexibility, its high costs, complexity, high loss of transport volume and the presence of CO_2. If a concept is to be chosen it would be number 3, the foldable cooling module while with this concept return flows are a minor problem and therefore costs will be low. Clients that prefer this concept consider cooling as a personal responsibility that should therefore be done by the ULD itself. Cooling of the air transport chain by KLM is not needed.

The group of Dutch exporters consisted of two groups that had often very opposite ideas on conditioning ULDs. One group preferred the insulating bag and stated that KLM should both pre-cool the products and cool the air transport chain. This group preferred a cheap transport device. The other group preferred a thermostat controlled, foldable ULD that is applicable in both airplane and truck (Concept 3, with a thermostat control included)

5.3 Conclusions

Clients tend to vote for an ideal conditioning ULD that is foldable and fits in both an airplane and a truck. However, it is not clear for the clients what the responsibilities of KLM are. Is KLM only a transporter or does KLM deliver additional services as well. Depending on the responsibilities of KLM, complete different conditioning ULD can be defined as the optimum. Therefore some clients tend to prefer an insulating bag in combination with pre-cooling at the airport.

Apart from the defined concepts a new idea has been stated. In this concept transport packages are not used and instead flowers are put directly into the conditioning ULD. In this way a far higher load capacity is achieved combined with better cooling, because boxes are absent. A disadvantage of this idea is the need of both large producers and large clients that can buy these amounts of products.

Finally, the fact that KLM asked their clients for their opinion on transporting and conditioning of fruits, vegetables and flowers has been greatly appreciated. The brainstorms have been experienced as a positive initiative.

6 Thermodynamics of existing ULDs

6.1 Introduction

From previous chapters thermodynamical aspects of conditioning ULDs appear to play an important role in conditioning. Therefore these aspects have been studied in more detail in this chapter. A simple thermodynamical model has been developed to perform a simulation study. In this way the thermodynamical aspects of existing ULDs can be analyzed and a description of an 'ideal' ULD with respect to thermodynamics may be made.

The main target in the transport of perishables is to keep product quality above a certain level during transport. Because product quality aspects as color, microbiological activity and texture depend on temperature this target is often translated into the target of keeping product temperature on a constant value. It has been concluded in chapter 3 that temperature should be maintained constant. Therefore, in the simulations described in this chapter perishable quality will be estimated as a function of the product temperature, as shown in formula (1) in appendix C.

There are several types of perishables that are transported in an ULD. Basically, for this thermodynamical study these products can be categorised in two different product types that are shown in Table 11. Products with a high specific heat in an ULD require a large amount of heat to be removed to decrease temperature. In addition, these products increase relatively slow in temperature. Products with a low specific heat increase and decrease more easily in temperature. Products that exhibit a large heat generation will heat up, unless the heat is removed.

Table 11: Categories of perishables

Product type		Examples of products
1.	High specific heat/ m^3 and large heat generation/ m^3 high ratio (product-air)	cucumbers, strawberries, cherries
2.	Low specific heat/ m^3 low ratio (product-air)	peppers, flowers

Both strawberries and flowers will be used to analyze the performance of several ULDs. The thermodynamical properties that will be used in this study are given in Table 12. For the thermodynamical aspects a reference transport-temperature trajectory is used, that is given in the Appendix C. We assume that the product is on target temperature as transport starts by the use of pre-cooling.

Table 12: Thermodynamical properties of example products, partly from [6]

Thermodynamical property	Strawberries	Flowers
Amount of water [%]	90 %	90 %
Density [kg/m^3]	1000	1000
Specific heat [J/kg K]	3770	3770
Ratio [%]	60 %	10 %
Heat generation [J/m^3 ULD hr]	480	144
Heat transfer [W/m^2 K]	2	2
Target temperature [°C]	4-12	12

6.2 ULD and model types

The existing ULDs have been categorized with respect to their thermodynamic behavior. The following types have been defined:

I. not insulated
II. insulated
III. insulated and cooling with ice
IV. insulated, cooling with ice and forced ventilation

From type I to IV temperature control improves, this involves higher costs of transport. In the transport of perishables an optimization problem must be solved to determine the most appropriate ULD type. Of course, this depends on the type of product and the desired product quality. Our analysis will give an indication on which ULD type to use in a certain situation. Besides analyzing existing ULDs we indicate possible directions to develop a more 'ideal' ULD. In this analysis a simple simulation model is built to illustrate the performance of the different ULD types.

A simple simulation model is built that will be explained in this section. First the thermodynamical aspects are modeled. Second, because product quality is the main target, two simple quality models for strawberries and flowers will be used to illustrate the dependence of the product and product quality on temperature. The performance of the different type of ULDs is analyzed with respect to thermodynamical aspect, but the main target should be product quality.

The thermodynamical model of the ULD is restricted to a so-called two-point model. This is motivated by the fact that the maximum temperature difference in a ULD is found between a point in the center and at the surface of the ULD. We are only interested in the temperature range in the ULD and not (in this stadium of the research) in the detailed spatial temperature distribution. Besides this two-point model the average temperature in the ULD is modeled. The main mechanisms that determine the thermodynamical behavior of an ULD are:

- Heat exchange with the environment;
- Heat exchange in the ULD by convection;
- Heat generation;
- Heat exchange with cooling medium.

All mechanisms are modeled and presented in the appendix.

6.3 Results

The thermodynamical aspect of transporting perishables with ULDs will be discussed using the results from the simulation study with the simple model. Both products (strawberries and flowers) will be used in this study.

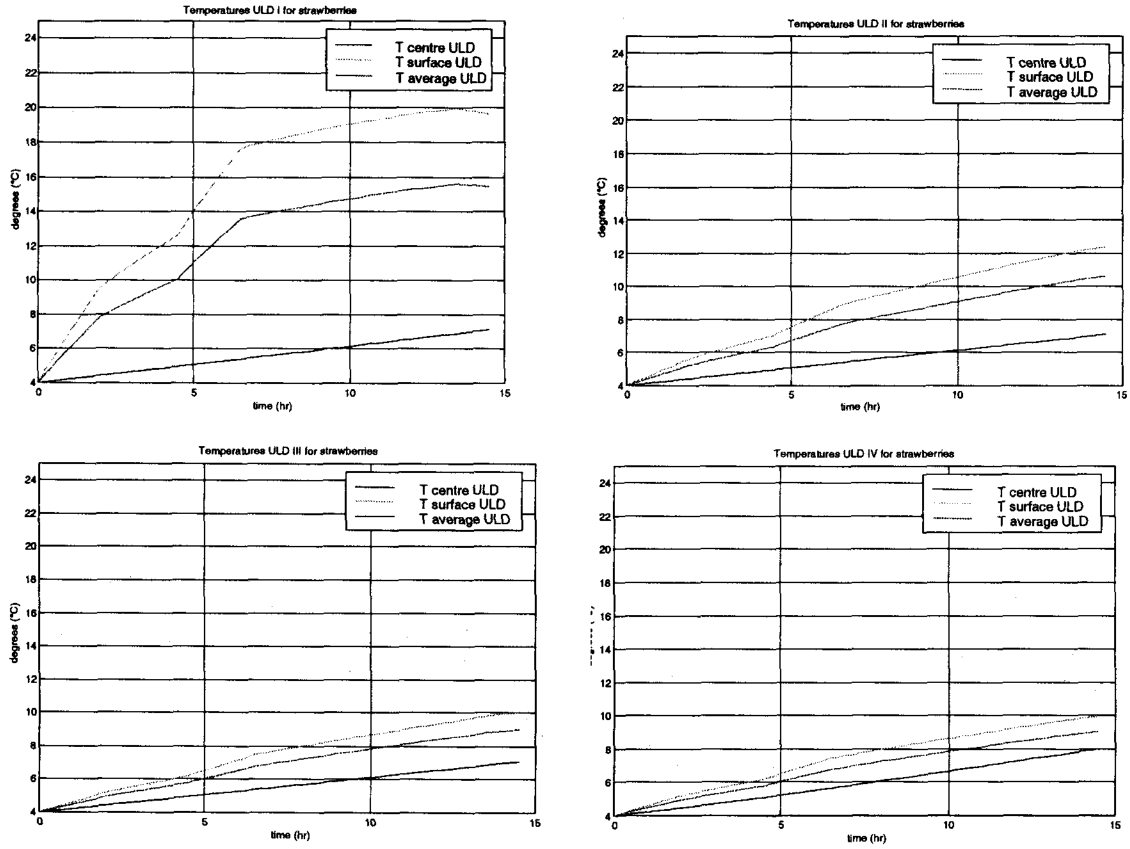
6.3.1 ULDs for strawberries

The transport of pre-cooled strawberries is characterized by a high specific heat per ULD with a large heat generation. For an ULD of type I this leads immediately to an enormous temperature increase during transport and a large temperature difference inside the ULD that continuously increases during transport as is shown in the upper left part of Figure 5.

Insulation of the ULD results in a much lower temperature which is caused by a lower heat exchange rate between ULD and environment which is illustrated in the upper right part of Figure 5. The heat exchange co-efficient for an insulated ULD with an insulated pallet wrap (foil, cover) is almost five times lower than for a not insulated ULD as is stated in [7]. The differences with regard to the heat exchange co-efficient between different pallet wraps are relatively small compared to the not insulated ULD.

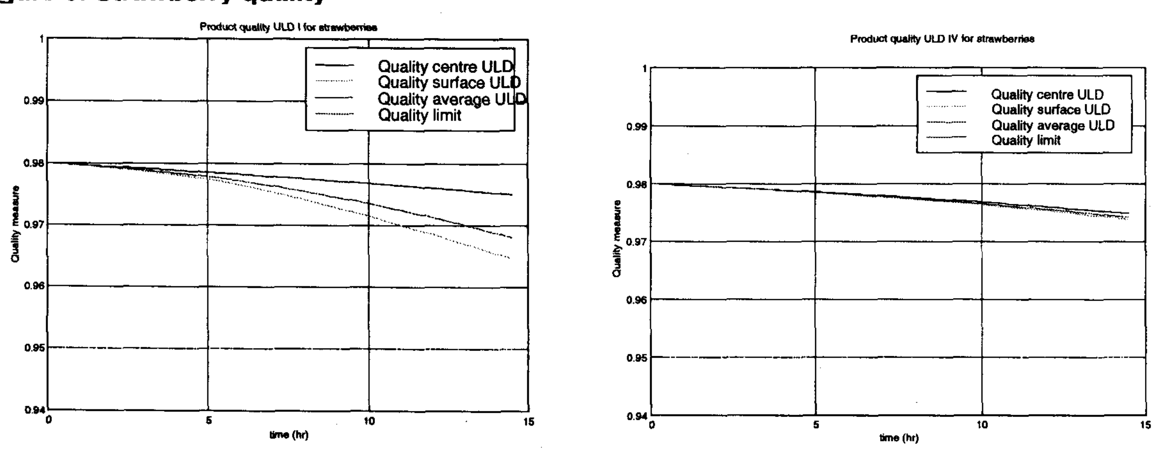
Ice, which is added to the ULD, removes heat by melting of the ice and as a result temperature increase is restricted as is shown in the lower left part of Figure 5. Although part of the ULD is filled with ice and not with product, this can be economically advantageous, because product quality will be higher after transport. Of course, this depends on product type and product price.

Figure 5: temperature for strawberries (target 4°)



To decrease temperature differences in the ULD air circulation can be introduced. This requires a small ventilation unit that uses a kind of battery. This unit blows air through the ULD causing a more homogeneous temperature distribution inside the ULD as is shown in the lower right part of Figure 5. As a result product quality is more homogenous, but we must keep in mind that such a ventilation unit adds energy to the ULD.

Figure 6: Strawberry quality

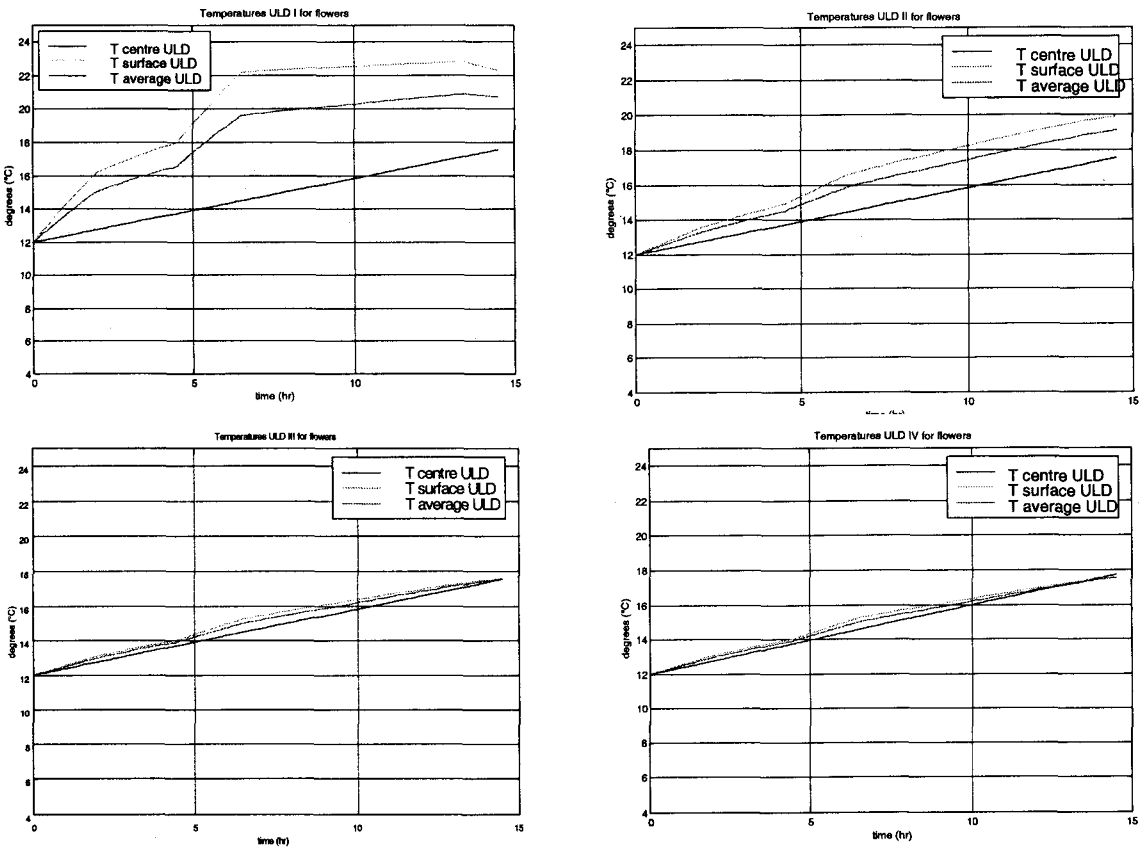


In Figure 6 strawberry quality is shown. In the left part of this Figure the quality evolution for a type I ULD is shown. Higher temperature and the large temperature difference inside the ULD result in a high quality decrease and a large quality difference inside the ULD. An ULD with better insulation exhibits a lower temperature rise and lower temperature difference resulting in a smaller quality decrease and quality distribution in the ULD as is shown in the right part of Figure 6. It should be emphasized that the application of the quality model is limited because only temperature is considered.

6.3.2 ULDs for flowers

Transport of flowers that are not densely packed is characterized by a low specific heat and heat generation inside an ULD. In general, a higher and faster temperature increase, and a less homogeneous temperature distribution can be expected compared to a product as strawberries. A simulation study was performed for pre-cooled flowers packed in all the different types of ULD. As expected temperature increases fast in case there is no insulation as is illustrated in the upper left part of Figure 7. Temperature differences are relatively large inside the ULD.

Figure 7: Temperature for flowers (target 12 °C)



In the upper right part of Figure 7 ULD type II with insulation is shown and as expected the temperature increase during the transport is decreased. As expected the temperature increases fast compared with the transport of strawberries, while temperature difference between environment and ULD is small for the transport of flowers with this target temperature. The temperature difference between surface and center of the ULD shows the same behavior for both products. After 5 hours the temperature difference is 2 degrees. It should be emphasized that pre-cooling is necessary in this situation.

The large temperature increase is restricted by the use of a cooling medium as is shown in the lower left part of Figure 7. The temperature differences are very small inside the ULD and this would result in a homogeneous product quality.

To assure a high product quality in the transport of flowers, circulation may be necessary. In the lower right part of Figure 7 results are presented. In this situation the effect of increased ventilation is almost negligible, because temperature differences already were small within ULD type III.

6.4 Conclusion

With this study only a small part of section I of the matrix has been elaborated and therefore information and conclusion in this may not be valid for other parts of this matrix. However some aspects with respect to the interaction of the perishable with the environment for different ULD types have become clear. These will be summarized for the different ULD types defined.

6.4.1 Existing ULDs

As expected pre-cooled perishables in the ULD without insulation and cooling give the highest temperature raise and the highest temperature distribution. This results in a high product quality decrease as is illustrated for strawberries. Isolating measures result in a lower temperature rise during the transport, while additional cooling measures result in the lowest temperature raise and product quality decrease.

An ULD without insulation can only be used in short transports with products that exhibit a high specific heat in an ULD, low heat generation and low climate influence through a low respiration rate. Although this ULD is very cheap in transport product quality can not be guaranteed in this ULD type. It is necessary to pre-cool the perishables if they are transported in this type of ULD.

ULD type II exhibits a lower temperature increase during transport trough the insulation that restricts the heat exchange between ULD and environment. These ULDs can be useful when transporting product with low and medium product quality, for short or medium transport distances.

Type III ULDs restrict temperature increase in the ULD by adding cooling. Although this requires extra handling, products can be transported over longer distances than in a type II ULD. A problem is to determine the amount of cooling medium, the location of this medium in the ULD to enable guarantees that temperature and therewith product quality is kept within limits.

ULDs of type IV use increased ventilation and this allows higher product quality specifications in the transport of perishables, as illustrated for the transport of strawberries. Although more voluminous than the other types of ULD, restrictions on product quality on long transport distances may require the use of these ULDs. Product quality is in this situation a function of temperature.

6.4.2 Ideal ULD

In determining the 'ideal' ULD with respect to the thermodynamical aspects, at this stage there is much freedom to develop a design.

There are three basic ideas to create the 'ideal' ULD:
1. ventilation
2. spherical approximation
3. cooling medium

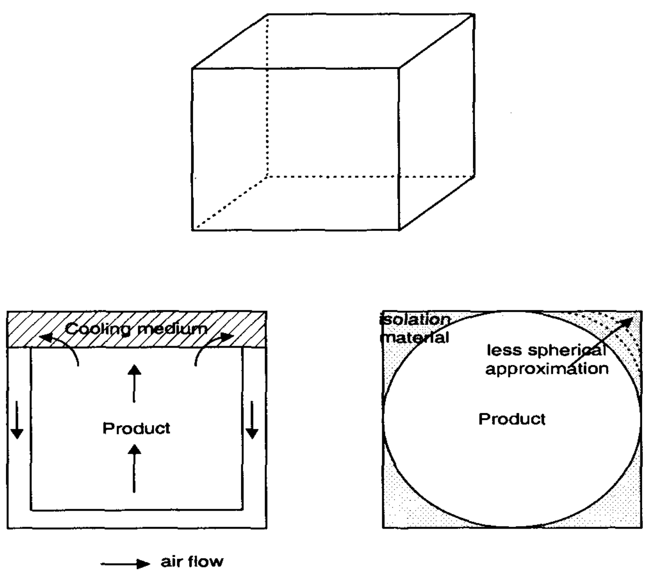
Ventilation
Because warm air rises cooling is most efficient at the top of the ULD (also most easy in the packaging of the ULD). In Figure 8a the ventilation scheme is illustrated. At the top of the ULD it is

possible to create some exchange of air between the ULD and its environment at a desired refresh-rate. Higher ventilation increases heat exchange between cooling medium and air inside the ULD. This prevents temperature to rise quickly.

Spherical approximation
The sphere is nature's most ideal form. Only, in transport this form reduces the amount of products that can be transported. However, the corners of the ULD are most sensitive for heat transfer (linear with surface) and need more isolating material than other parts of the ULD. Combining the natural spherical form with putting isolation material where it is most efficient, we have a spherical approximation of the ULD. This is illustrated in Figure 8b.

Cooling medium
The product in a ULD must be kept on the desired temperature during transport. Most energy absorption takes place in a phase change (e.g. from ice to water). Choosing the right cooling medium prevents chilling injury while absorbing the energy in the phase change. In Figure 8a the air flow is shown that would ideally be present inside a ULD.

Figure 8: The 'ideal' ULD



a: Ventilation scheme

b: Spherical approximation

In this chapter we analyzed the thermodynamical behavior of different types of ULD for transport of strawberries and flowers. Although a strongly simplified model is used in the simulation it will be clear that the existing ULDs do not satisfy all the criteria imposed on the transport of perishables. Only a more 'ideal' ULD can satisfy these criteria.

From this the following can be summarized:
- Isolating measures result in a lower temperature raise during the transport.
- Additional cooling measures result in the lowest temperature raise and product quality decrease.
- An ULD without insulation can only be used in short transports.
- It is necessary to pre-cool the perishables.
- Increased ventilation allows higher product quality specifications.
- When designing a module with cooling by means of a coolant (e.g. dry ice or wet ice) the focus must be on increasing the heat transfer between the air and the cooling medium

7 General conclusion

KLM has expressed the desire to monitor and control the process of transporting perishables by air. Therefore over the past two years the Coolmate system has been developed by the cooperation of KLM PMC perishables and ATO-DLO. From this project, in which perishable condition was recorded, it became clear that the conditioning capabilities in air transport are not sufficient. Therefore two new projects have been started: the project Cool Chain Control, that focuses on the general measurement and control of perishables throughout the supply chain, and the project described in this report: Unit Load Devices with conditioning capabilities – a feasibility study. This feasibility study is set up to aid in the development of a new and easy to use conditioning ULD, that maintains perishable quality during the flight trajectory, and if possible in a larger part of the supply chain.

From the overview of perishable conditions it is clear that temperature maintenance is by far the topic that should be focussed on first, for preserving optimal perishable quality. The temperature very much influences the processes in perishables that lead to decay. Temperature therefore should always be kept within the appropriate range. Within this range other factors generally only play a minor role. The other factors, which are quite different from those if temperature lies within the appropriate range, play a more significant role outside the optimal temperature range. In this situation extra care should be taken to avoid making bad things worse. Therefore the first situation may lead to different judgement of an ULD than considering the latter situation. For example an ULD with high insulating value may be useful for pre-cooled perishables, but also be damaging for perishables that are already too warm and also have a high respiration rate. Although the second situation should be avoided as much as possible, a good conditioning ULD should know how to cope with it as well.

Of four example perishables, roses, tomatoes, raw salmon and strawberries optimal transport conditions have been determined. These four products have been selected from four product groups and cover a considerable area of perishable characteristics. Additional selection criteria are a (potentially) high volume in air transportation. Fruit, vegetables and flowers need most attention since they produce heat and alter gas concentrations due to respiration. Fish does not respire but is very sensitive to microbiological susceptibility.

As environmental parameters in the supply chain the measurements that have been made during the trajectory that was assumed in the project Cool Chain Control have been chosen. This temperature trajectory is a fair representation of a flight from a country in e.g. South America, to e.g. the Netherlands. The most obvious observation in this trajectory is that the environmental temperature is generally far higher than the desired perishable temperatures, and environmental R.H. is generally far too low which indicates the need for a suitable ULD.

To preserve the selected perishables active cooling is needed. Ventilation and circulation increase efficiency of conditioning. Ventilation can both positively and negatively influence R.H dependent on the environment conditions. For agricultural perishables ventilation has a positive effect on O_2/ CO_2 and C_2H_4 concentration and smell. Usually strong smell is removed from the ULD by ventilation. Circulation improves a uniform distribution of temperature, R.H. and O_2 and CO_2 concentrations inside the ULD. To preserve salmon on the other hand, only cooling and maintenance of a high relative humidity is needed as raw salmon does not respire. Therefore ventilation and circulation is not necessary for salmon. A fully isolated ULD with a coolant included may therefore be a good solution for raw salmon. Heating, which can be applied independently, is only needed if outside temperature is below the optimum. Heating also lowers R.H. Therefore simultaneous application of heating and cooling may be advantageous for control of both temperature and relative humidity. Application of absorbers and scrubbers is used take up water, water vapor, gasses like O_2 and CO_2 and smell. Microbiological susceptibility is reduced due to the removal of vapor and free water. Conditioning control improves temperature maintenance within limits, R.H. and O_2/ CO_2 concentrations. Adequate packaging prevents bruising of especially strawberries.

Five different concepts have been designed with the conditioning criteria in mind. The concepts range from insulation only to a multi-modal, foldable conditioning ULD. In a seminar the opinion of KLM clients from South America and the Netherlands about the concepts was asked. The opinions fell out into two groups; one group preferred a very simple insulating bag combined with pre-cooling while another part preferred the sophisticated conditioning ULD. Opinions were very extreme while clients could not make clear which part of the supply chain KLM should be responsible for.

While the thermodynamic aspects of the ULD appear to be of major importance an analysis was made of these aspects concerning available ULDs. From this simple orientation study it can be concluded that the combination of insulation, a cooling medium and sufficient ventilation, possibly combined with circulation, effectively improve the conditioning aspects of ULDs.

After performing this feasibility study it can be concluded that a tool for evaluation of design concepts has been successfully developed. The matrix makes the development process transparent and eases decision-making as far as possible. The tool has helped to carry out this process of developing a conditioning ULD for perishables that meet the criteria and can with small changes be applied in other developing processes as well.

The development of well working and easy to use conditioning ULD by KLM is an important marketing instrument which can be used to approach (potential) clients. However, this study has also proved that further research is needed to successfully develop a conditioning ULD for perishables.

Summarizing the following items can be concluded:

- The conditioning of perishables is a complex mixture of criteria that are very much dependent on each other, and on the specific type of perishable.
- As perishable decay processes all very much depend on temperature, and these processes can be slowed down if temperature is maintained in its adequate range, temperature is the most important factor to control for minimizing quality decay.
- Like other factors, the optimal temperature is very much perishable dependant. However three temperature zones can be selected:
    1. 0 – 5 °C
    2. 5 – 10 °C
    3. 10 – 15 °C
- Respiring and non respiring perishables distinguished. Respiring perishables, flowers, fruits and vegetables generate heat, consume O_2 and produce CO_2. Non respiring products, fish and meat, do not generate heat, consume O_2 or produce CO_2 but are very susceptible to microbial contamination. Respiring products may therefore not be stored in a fully isolated module. Non respiring products on the other hand can efficiently be stored in a fully isolated module, with additional cooling and taking care of relative humidity.
- The concepts studied could be used for the following perishables:
    - Concepts 1 and 2 (thermostat controlled) could be used for respiring perishables.
    - Concepts 3 and 4 (active cooling with e.g. dry ice or wet ice) could be used for non-respiring perishables (pre-cooled). In order to get sufficient cooling for a flight trajectory of medium to long duration, no ventilation should be applied and/or the coolants should be in the same room as the perishables. In either case it is not applicable for respiring perishables.
    - Concept 5: An insulating blanket should only be used to keep pre-cooled perishables cool for a short period. For longer periods other alternatives should be used.
- Multi-modal transport is found very important. KLMs customers generally request a module that can be used in both airplane and truck. Secondly to prevent breakages in the cool chain, one single module throughout the supply chain is preferable.
- The interaction of the perishable, conditioning ULD and environment with the primary package should be taken into account. A primary package may prevent the perishable from bruising, but may also play a role in the circulation and ventilation processes.

8 Recommendations and future research

The development of a conditioning ULD by KLM is an important marketing instrument, which can be used to approach (potential) clients with arguments like better product quality and longer storage life, exploration of new markets and other trajectories that become available. However, further research is needed to successfully develop a conditioning ULD for perishables. Some directions that seem important to analyze and future research that should be performed according to ATO-DLO are:

- More depth and an economic foundation of the value added concepts
- Specification of the module dimensions and other logistic constraints
- Strategic experiments with the most important products
- Specification of the interaction between product quality, primary packaging, conditioning and the supply chain
- Effectiveness of different conditioning concepts
- Specification of the preferred conditioning system

In order to develop a new generation of conditioning ULD's three different phases can be distinguished:
1. The preliminary phase. In this phase the developed ULD-evaluation matrix is completed including all logistical and economical aspects.
2. The development phase. In this phase a new concept is developed by a simultaneous experimental and modeling approach. This phase is concluded by a real-life test of the newly developed ULD in a simulated distribution chain.
3. Market introduction phase: This phase is started with an extended practical pilot test. Subsequently, the ULD will be commercially introduced in the real distribution chain. Our experience is that this introduction will only be successful if it is strongly supported by companies like KLM and ATO-DLO, especially at the beginning of the introduction.

8.1 Preliminary phase

The evaluation matrix as it is presented in the current report yields an elaborate list of criteria that need to be taken into account while designing concept Unit Load devices. An overview has been given in the processes that play a role in the conditioning of perishables and their influences on ULD design. To complete the overview as presented in the evaluation matrix, more insight in the aircraft loading, logistics, handling, cleaning, maintenance processes should be gained and these processes should be adequately described.

A more detailed economical basis of the value added ULD concepts is needed. Some of these aspects have been considered globally in this report but before the preferred concept will be developed in detail and a prototype will be manufactured more specific information on the economics of a conditioning ULD should be gathered. What are the advantages in guilders or dollars of certain improvements? How much money is saved when the amount of ice needed is reduced or even absent. What are the profits when other flying routes via North America become available for perishable transport apart from the overcrowded flights from South America directly to Europe? These economic aspects are needed to prove that the development of a conditioning ULD for perishables is not only interesting from a conditioning point of view but from an economic point of view as well. Obviously in these economical considerations, many logistical aspects should be included.

Dimensions and logistics should not only be considered theoretically, the practice of air transport should be considered as well. For example wall thickness, goods flows, and product weight play an important role in both air and road transport as they all highly influence the costs. Apart from a specification of dimensions the amount of different module formats that may be introduced should be considered as well. All the formats to be produced should be available for clients at all places and at all times. In case of five sizes the total amount of ULDs needed will be significantly larger than in case only one or two sizes are to be used. Hence, logistical demand and economical considerations should be integrated in one model to obtain a complete list of all the costs and benefits.

The preliminary phase is ended by determining a concrete list of economical and logistical boundary conditions for the new ULD. This list, together with the perishable conditioning aspects as described in this report, forms a good starting point for developing an actual ULD concept

After the economic and logistics constraints have been determined, for selected products the interaction of the product quality, the primary packaging, the conditioning ULD and the supply chain should be determined. This way, the best method for and the amount of quality improvement can be determined. Obviously this information is essential for a successful introduction of the newly developed ULD on the market. Therefore experiments and models simulating the perishable, conditioning ULD and circumstances in the supply chain should be designed simultaneously and in close contact with each other.

8.2 Development phase

The development phase is started by selecting two model products for which a new ULD should be developed. Experiments should be performed on the selected products stored under conditions that correspond to that in the air transport chain. In the form of pilot tests as well as tests in climate rooms at ATO-DLO perishables transport should be simulated and monitored. In these experiments the relation between coolant, temperature and perishable quality can be studied as well.

In order to support the experiments and the ULD development a thermodynamical model will need to be developed. Such a model makes a more flexible approach possible. By means of computer simulations insight can be gained in the complex interaction between product, package, ULD and distribution chain for many different situations. By simulating the thermodynamical behavior sufficient insight can be gained to predict, to a certain extend, the product quality during transport. Furthermore questions about the effectiveness of the coolant medium can be answered. E.g. how much coolant is used currently and is this amount used effectively? Cooling may be more effective if the heat transfer between the air and the cooling medium is increased. In this study ways can be determined in which we may be able to increase the heat transfer between coolant and air. In decreasing the amount of coolant used, both coolant weight and coolant volume transported will be decreased. All kinds of chains can be simulated by combining the experimental and modeling approach and the functionality of the new ULD can be tested in detail.

Finally by means of the completely filled-in ULD evaluation matrix and the economical and logistical constraints and benefits, the preferred material choice should be specified. At the end of the development phase, a complete list of all ULD design parameters must be established. For example on the use of dry ice, how much is used, efficient cooling, inside and outside dimensions considering the insulating walls and inter-modality, etc. etc. This should be done in cooperation with a transport module manufacturer. The development phase will be concluded with a practical supply chain test on the product-ULD combination in an ATO-DLO laboratory. Test perishables will be used and environmental conditions throughout the supply chain will be simulated in these laboratories. Redesign should take place in co-operation with the manufacturer according to the findings in these tests.

8.3 Market introduction phase

A final version of a module should be tested further within the supply chain, and links to a logistics and supply chain control system should be verified thoroughly. By performing strategic experiments before introduction possible complications can be noticed very fast and clients will not be confronted with them. Just introducing the conditioning ULD into practice and wait for problems and consequent negative publicity to come is not a way that leads to success

A solid plan should be set up for pilot and large-scale production, distribution, information and introduction of the resulting ULD with conditioning. In close cooperation with the manufacturer and selected clients the use of the Unit Load Device should be monitored and evaluated in a pilot test. Finally a complete introduction should take place, which should be very well supervised.

In Figure 9 a schematic drawing of the research plan as described is shown.

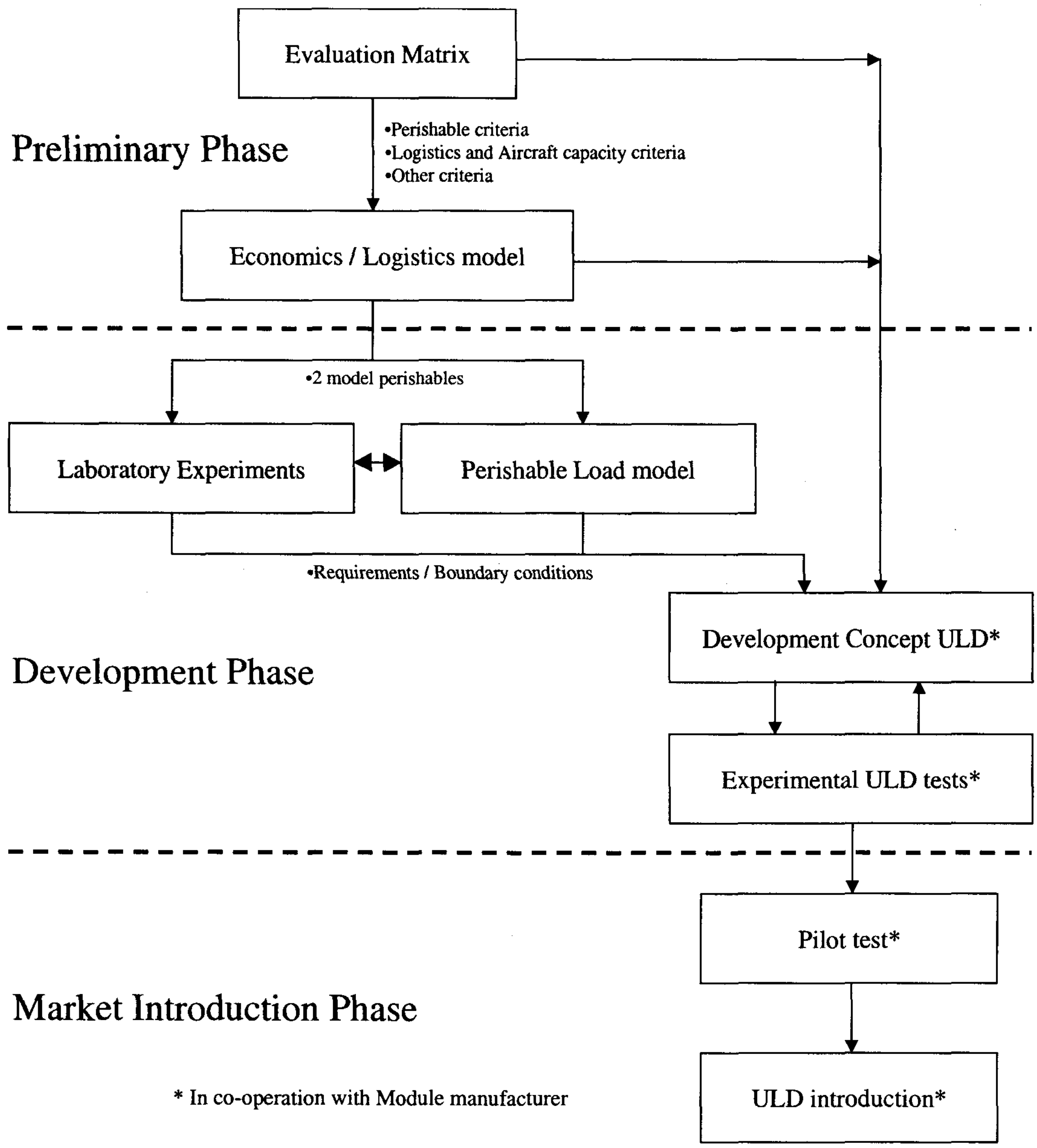


Figure 9 Proposed research plan for the development of a ULD with conditioning

Appendix A: Predefined temperature track and Evaluation matrix

In this appendix the filling in of a perishables part of the evaluation matrix and the assumptions that have been made are described.

Assumptions

A predefined temperature track as shown in Table 13 is assumed to which perishables are exposed during air transport. This track is representative for a large amount of perishables, because a lot of perishables are imported from South America. On other continents where products are imported from, like Asia and Africa, climatical conditions are similar. Most important aspect of this temperature trajectory is that the product is heated during its stay at the airport platform and in aircraft cargo hold while environmental temperatures are far above the optimum of the perishables.

Table 13: Standard chain with conditions of environment [8]

id	description *(South America – Curacao/hub – Amsterdam)*	average duration [hour]	average temp [°C]	average humidity [%]	*remarks*
010	Farm	-	15	70	*hill side*
020	loading	1			
030	transport (farm to airport)	3...8			*truck no conditioning; time depending on stretch*
040	unloading	1	20	75	*manual*
050	temporary storage	4			
060	acceptance and unitization	2			
070	temporary storage	1			
080	customs	2			*no conditioning*
090	platform / ramp handling	2			
100	flight	4...6	18	60	*Freighter – no hold settings =>16..20 °C*
110	ramp handling	1	28	75	*subject to extreme conditions*
120	temporary storage	2			
130	ramp handling	1			
140	flight	8...10	18	30	*MD11 high temp-setting with ventilation*
150	platform / ramp handling	1	12	80	
160	customs	2			
170	temporary storage	3			
180	depalletization	1	18	80	*cargo storage*
190	temporary storage	-			*usually skipped*
200	loading	0.5			
210	transport (airport to retailer)	3...8	5	80	*time depending on stretch, conditioned truck*
220	unloading	1	12	75	
230	DC/ retailer	-	5	80	

Perishable characteristics A perishable is considered that respires and thus generates heat, consumes O_2 and produces CO_2.

Two temperature effects are assumed to interact within a module:

- The air temperature in the module can be modified by e.g. a cooler in the module or outside or by hot environment temperature (sun) that heats up the module.
- The product heats itself up due to biochemical reactions.

Both the air temperature and the product temperature may be acted upon to prevent the temperature from exceeding its optimal range (maintenance within limits), fluctuating (temperature stability) or being unevenly distributed throughout the box (equal temp. throughout box).

Circulation. The effect of circulation will be noticeable as a more even distribution of the temperature over the module. Gases and vapor are supposed to spread quickly throughout the whole module and therefore circulation will not improve the distribution of the gases and the R.H. Only ventilation is assumed to significantly control gas concentrations and the R.H

The effect of *ethylene* on mixed loads is not taken into account in this matrix. Possible interference of two modules containing perishables can be viewed by regarding ethylene production and ventilation. Only in very specific cases the ethylene exchange between two semi-closed modules might be noticeable. The effect of ethylene can be viewed in the description of perishable characteristics that is summarized in Table 7

Heating is supposed only to be active if the environmental temperature is below the minimum temperature of the perishables. This may be the case if the module is on the platform in cold weather.

Explanation of filling

Ventilation is air exchange between module and environment. Ventilation is defined as to act on the air temperature, not on the perishable temperature (think of densely stacked perishables). Perishables are assumed to be pre-cooled on the airport and therefore the environmental temperature as assumed in the temperature track of Table 13 will generally be higher than the temperature in the module. Thus ventilation will generally increase the air temperature in the module. Furthermore ventilation may exchange ethylene, moulds and smell with the environment. Depending on the conditions in the module and the environment conditions this can either be positive or negative.

Circulation is rotation of air within the module. Circulation has two effects; the product temperature will be lowered, by removal of the heat produced by the perishable and, if a cooler is available, the cooling will be more effective due to better heat exchange between coolant and air.
In the matrix the effect of circulation on air temperature is determined assuming a coolant in the module. If no coolant is available in the module, circulation will have no effect on air temperature, only on perishable temperature. An extra advantage of the combination of coolant and circulation is the speeding up of the cooling of the perishable. This effect will however be attributed to the coolant and not to the circulation. Even if no coolant is available circulation helps lowering the temperature by removing heat produced by the perishables from the ULD.

Conditioning control concerns measurement and/ or control methods designed to maintain or adjust the conditioning such that the parameters (temperature, R.H., etc.) stay at their set points. The control can consist of an active control system, that e.g. measures the temperature and adjusts fans etc. to keep the temperature on their desired values. These active control systems can be made very flexible and may be optimized to best respond to the actual heating and cooling processes that take place. Another option can be found in fixed regulation systems. These systems are less complicated and control some parameter (e.g. air flow) dependent on the value of this or some other parameter (e.g. temperature) according to a fixed relationship. An example could be a valve that closes when temperature increases due to an expansion of the material caused by the temperature increase. In this example the relationship between temperature and airflow is fixed.

Table 14: Influence of conditioning concepts on perishable criteria (Group1)

Legend

Influence of concept on criterion:
++ = very positive influence
+ = positive influence
empty = no influence
- = negative
-- = very negative influence

	Conditioning cluster																				
	Cooling/ Coolant				**Ventilation** (in - out)				**Circulation** (inside module)						**Heating**		**Condense Removal**		**Conditioning Control**		
Criteria perishable condition	wet-ice (H_2O)	dry-ice (CO_2)	ice cooling via heat exchange	powered cooler	no ventilation	cargo room airflow	thermodynamic	powered fan	no circulation	cargo room airflow	thermodynamic	powered fan	fixed air ducts/shelves	prescribed built-up method	chemical reaction	powered heater	condensation absorber	transport away from products	manually	fixed regulation system	active control system
Temperature																					
Product temperature																					
Maintenance within limits	++	++	+	++					--	+	+	++	++	+							
Temperature stability																			+	+	++
Equal temp. throughout box									--	+	+	++	++	+							
Air temperature																					
Maintenance within limits	++	++	+	++	+	-	-	-		+	+	++	++	+	++	++					
Temperature stability																			+	+	++
Equal temp. throughout box										+	+	++	++	+							
Relative Humidity	--				+	-	-	-													
Condensation removal	--				--	+	+	++									++	++			
CO_2 concentration		--			--	+	+	+													
O_2 concentration					--	+	+	+													
Ethylene production	++	++	+	++																	
Ethylene sensitivity					+/-	+/-	+/-	+/-													
Microbiological susceptibility	--				+/-	+/-	+/-	+/-													
Mechanical Strength																					
Smell uptake					+/-	+/-	+/-	+/-													

From Table 14 can be read that temperature maintenance is the most important aspect of a conditioning ULD for perishables. This is best achieved by a coolant like wet or dry ice or a powered cooler. Circulation within the ULD positively influences temperature maintenance as well as an equal temperature distribution throughout the ULD. Temperature stability is best regulated by controlled conditioning. Ventilation positively influences condensation removal as well as CO_2 and O_2 gas concentrations and may negatively influence R.H. For respiring products however the positive effect of condensation removal and gas concentration is bigger than the negative effect of ventilation on R.H. An optimum should be found for the amount of ventilation in order to provide enough CO_2 and O_2 while maintaining a high enough relative humidity.

Appendix B: Outcome of brainstorm at KLM seminar

In terms of Attributes results of five voting rounds have been recorded. The results are shown in the table below.

Attributes	**R1**	**R2**	**R3**	**R4**	**R5**	**Total**
Re-usability	1	3	4	1	8	17
Semi-reusable	0	0	0	5	4	9
Disposability	0	0	11	3	1	15
Flexible	6	3	17	3	9	38
Fixed	0	0	0	5	1	6
Thermostatically controlled	14	6	4	9	0	33
Cooled	0	0	0	0	4	4
Insulated	0	0	7	0	7	14
Suitable for road and air	0	5	13	0	12	30
Suitable for air only	0	0	0	6	0	6
Protection by packaging	13	0	3	9	3	28
Protection by process control	0	1	19	9	9	38
Additional attributes						
Container weight	0	0	0	0	0	0
Total cost of use	0	11	0	0	0	11
Service- & Maintenance	0	0	0	0	0	0
Handling	0	0	0	0	0	0
Different colors	0	4	0	0	0	4
Availability of containers	0	6	0	0	0	6
Validation of containers	0	5	0	0	0	5
Various sizes	0	13	0	0	0	13

In terms of ULD concepts results from voting rounds during the Perishables Seminars are as follows:

	Round 1	Round 2	Total
Concept 1: Protection by packaging, Fixed, Thermostatically controlled, Fitting with Aircraft dimensions, Re-usable	0	2	**2**
Concept 2: Protection by packaging, Fixed, Thermostatically controlled, Fitting with Aircraft/Truck dimensions, Re-usable	0	7	**7**
Concept 3: Protection by packaging, Fixed, Cooling, Fitting with Aircraft/Truck dimensions, Foldable	16	5	**21**
Concept 4: Protection by packaging, Fixed, Cooling, Fitting with Aircraft/Truck dimensions, Foldable	9	0	**9**
Concept 5: Protection by Conditioned Chain Control, Flexible, Insulation, Fitting with Aircraft/Truck dimensions, Disposable	12	0	**12**

Appendix C: Background of thermodynamics of existing ULDs

Table 15: Reference transport-temperature trajectory

Transport phase	Length (hr.)	Location	Temperature
0: pre-cooling			Target
1.	2	Platform	27
2.	2.5	Airplane	20
3.	2	Platform	35
4.	7	Airplane	20
5.	1	Platform	15

Notation

α	Amount of convection
φ	density
Δ	Difference
h	heat exchange coefficient
ratio	product-air ratio
A	heat exchanging surface
Cp	specific heat
M	mass
T	Temperature
V	Volume
Q	heat

Subscript

average	average of the ULD
centre	location in the center of the ULD
surface location	at the surface of the ULD
air	air phase
product	product phase
tot	total amount
cool	cooling medium

Quality of strawberries

The quality attribute for the transport of strawberries that we used in this study is the microbial activity. This modeled following [9] with

$$\dot{P}_Q = k_0 + k_1 P_Q + k_2 \frac{1}{P_{Q_{\min}}} (P_Q)^2 \qquad (1)$$

$$Quality = 1 - P_Q$$

where the coefficients depend on temperature. Parallel with the temperature modeling three qualities are modeled, center, surface and average of the ULD. A quality limit of acceptance is set at 95 %. Initial product quality for a good batch is 99.28% and for a bad batch 98 %. Both are simulated.

Quality of flowers

Product quality in the transport of flowers is defined as storage life, assuming that for retail a certain vase-life after the storage life is demanded, and this demand is not to be influenced. Flower quality and can be modeled using (1) where only the first coefficient k_0 is non-zero.

Thermodynamics of an ULD

Heat exchange with the environment

$$Q_{env} = U\ A\ (T_{env} - T_{product}) \tag{A1}$$

Heat exchange in the ULD by convection

$$Q_{inside} = \alpha\ Cp_{air}\ (T_{centre} - T_{surface}) \tag{A2}$$

Heat generation

$$Q_{bron} = c(T_{product}) \tag{A3}$$

Heat exchange with cooling medium

$$Q_{cool} = U\ A\ (T_{env} - T_{product}) \tag{A4}$$

The resulting differential equations for the temperatures in the simple model and the average temperature are

$$\dot{T}_{centre} = \frac{1}{M_{product\text{-}centre}\ Cp_{product} + V_{centre}\ \varphi_{air}\ (1 - ratio)\ Cp_{air}}[Q\,M_{product\text{-}centre} - \alpha\,Cp_{air}(T_{centre} - T_{surface})] \tag{A5}$$

$$\dot{T}_{surface} = \frac{1}{M_{product-surface}\ Cp_{product} + V_{surface}\ \varphi_{air}\ (1 - ratio)\ Cp_{air}}[h\ (A_{surface} - A_{cool})\Delta T + Q\ M_{product2} + \alpha\ Cp_{air}(T_{centre} - T_{surface}) - Q_{cool}] \tag{A6}$$

$$\dot{T}_{average} = \frac{1}{M_{tot}\ Cp_{product} + V_{tot}\ \varphi_{air}\ (1 - ratio)\ Cp_{air}}[h\ (A_{tot} - A_{cooltot})\Delta T + Q\ M_{producttot} - Q_{cool}] \tag{A7}$$

Amount of coolant

The amount of ice that is necessary to keep the product at target temperature can be calculated from the total heat that must be removed. For a total mass of M=0.6 *1000=600 kg is the total heat that must be absorbed by the cooling medium

(800*M+12*3600*dT)dt=(800 M dt +43200 dT dt)=16334,4 kJ/kg

for the reference transport-temperature trajectory. The melting heat of ice is 334 kJ/kg and this means that 48.9 kg ice is required to melt to absorb the energy from production and exchange. With a density of 0.917 kg/dm^3 53.3 dm^3 ice is required, which corresponds to 5.33 % of total ULD volume for cooling medium. However not all heat will be removed by the cooling medium with this ULD-type as can be seen in Figure 5, Figure 7, Figure 8 and Figure 11. In reality the amount of cooling medium that is used is much lower, because the melting of the medium is not fast enough to prevent a temperature increase in the ULD.

Figure 10: temperatures and cool-medium for strawberries

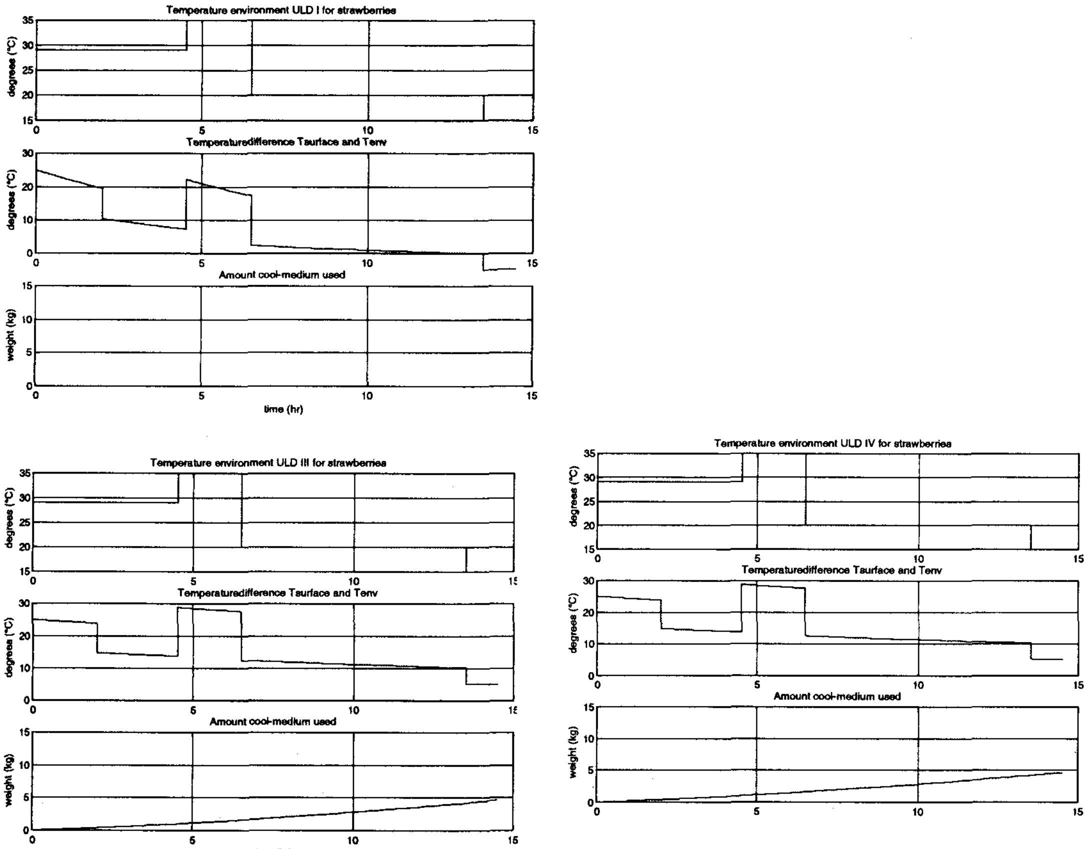
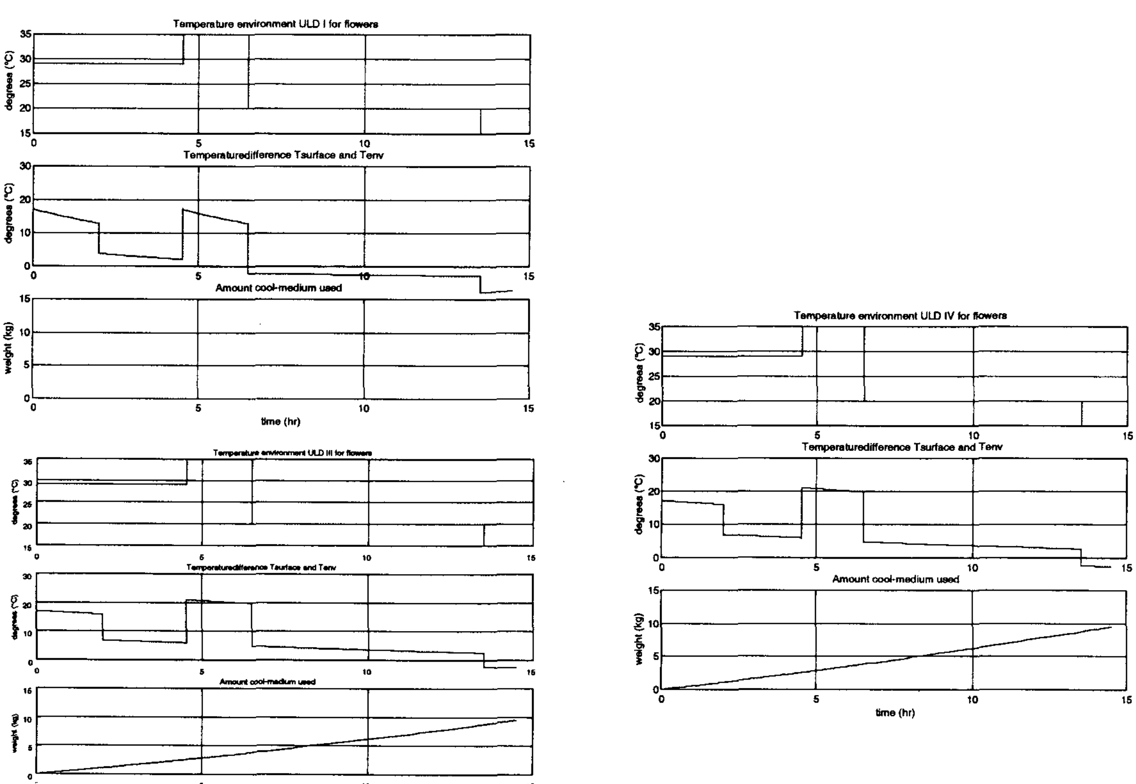


Figure 11: temperature and cool medium of flowers



In Table 16 the evaluation criteria for ULD's with respect to the thermodynamical aspects are given. The criteria illustrate the possibilities of each ULD type and support the choice of the optimal ULD given the length of the flight, target temperature, product type and product quality specifications, as is illustrated in Table 4.

Table 16: Evaluation criteria ULD types

	ULD Type	Criteria						
		$\Delta T_{average}$<2 °C			$\Delta T_{inside\ ULD}$ <2 °C		Energy Usage	Product Quality
		5 hr.	10 hr.	>10 hr.	10 hr.	>10 hr.		
Stand-Alone	Type I	--	--	--	--	--	++	--
	Type II	-	--	--	-	--	++	-
	Type III	+	+	-	+	-	++	-
	Type IV	++	++	+	++	+	-	+
	Type "ideal"	++	++	+	++	+	++	++
Not stand-Alone	Type V	++	++	++	++	++	--	++

-- bad performance, - insufficient performance, + sufficient performance, ++ good performance

Appendix D: Feasibility matrices

Table 17: feasibility conditioning-construction clusters

Technical Feasibility		**Construction cluster**															
		Size				**Coolant refill method**			**Power-Supply**		**Usage range**			**Reusability**			
		Maindeck pallet 6x2,5x2,5 m	Lowerdeck pallet 3,2x2,5x1,6 m	Air-Module 1,2x1x1,5 m	Other size	fill coolant only once	refill from outside module	refill from inside module	battery	electrically	Specialized	Multi-purpose	Modular combination	Reusable	Disposable + reusable	Disposable	Foldable
Conditioning cluster																	
Cooling/ Coolant	wet-ice (H_2O)																
	dry-ice (CO_2)																
	ice cooling via heat exchange																
	powered cooler																
Ventilation (in - out)	no ventilation																
	cargo room airflow																
	thermodynamic																
	powered fan																
Circulation (inside module)	no circulation																
	cargo room airflow																
	thermodynamic																
	powered fan																
	fixed air ducts/shelves																
	prescribed built-up method																
Heating	chemical reaction																
	powered heater																
Condense Removal	condensation absorber																
	transport away from products																
Conditioning Control	manually																
	fixed regulation system																
	active control system																

Table 18: feasibility material-conditioning clusters

Materialization		Material cluster								
		Materials					Coatings/per meability			
		aluminum	steel	polyurethane	fiber composite material	natural fiber material	plastic (non permeable)	bio-degradable	aluminum foil	semi-permeable
Conditioning cluster										
Cooling/ coolant	wet-ice (H_2O)									
	dry-ice (CO_2)									
	ice cooling via heat exchange									
	powered cooler									
Ventilation (in – out)	no ventilation									
	cargo room airflow									
	thermodynamic									
	powered fan									
Circulation (inside module)	no circulation									
	cargo room airflow									
	thermodynamic									
	powered fan									
	fixed air ducts/shelves									
	prescribed built-up method									
Heating	chemical reaction									
	powered heater									
Condense removal	condensation absorber									
	transport away from products									
Conditioning control	manually									
	fixed regulation system									
	active control system									
	active control system									

Table 19: feasibility material-construction cluster

Materialization		**Material cluster**								
		Materials					**Coatings/ permeability**			
		Aluminum	steel	polyurethane	fiber composite material	natural fiber material	plastic (non permeable)	bio-degradable	aluminum foil	semi-permeable coating
Construction cluster										
Size	Maindeck pallet 6x2,5x2,5 m									
	Lowerdeck pallet 3,2x2,5x1,6 m									
	Air-Module 1,2x1x1,5 m									
	Other size									
Coolant refill method	fill coolant only once									
	refill from outside module									
	refill from inside module									
Power-supply	battery									
	electrically									
Usage range	Specialized									
	Multi-purpose									
	Modular combination									
Reusability	Reusable									
	Disposable + reusable parts									
	Disposable									
	Foldable									

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