

Testing the MAP Model and Dealing With Reusability

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Preface

This document¹ is written within the framework of the SEO project 'MAP Model Maintenance & Validation'. I am grateful to anyone who contributed to or associated in this project, in particular (in alphabetical order): E. Boer, G. van den Boogaard, F. Kreft, J. Top, M. Vollebregt and A. Zegveld.

Summary

This project, project 'MAP Model Maintenance & Validation', embraces three main activities: validation of the Modified Atmosphere Packaging (MAP) model, making it more generic and reusable and repair of the current implementation of the model on the Intranet.

Testing the MAP Model

Validation of the MAP model concerns the moist modelling, consisting of the submodels product transpiration, condensation on the product, condensation on the inner side of the packaging and heat transfer through the product, the air and the packaging.

Additionally, the geometric aspect in the above-mentioned submodels as well as in other submodels of the MAP model is of interest. The respiration model, which is the only part of the model which is being used up to now, is already validated [Peppelenbos, 1996; Hertog *et al*, 1997].

Experience turned out that condensation is the most unknown and problematic issue. For this reason we have mainly focussed on this item in the current phase of the project. We have designed an experimental set-up for condensation measurements and we have performed experiments which we used in a first validation. By processing some parameter value changes in an iteration of simulation experiments it turned out that the air speed is falsely neglected in the condensation modelling. We have formulated some recommendations to overcome this neglect.

¹ Version December 31, 2001.

However, the experimental set-up is not optimal yet. It has to be developed further in order to perform more precise condensation experiments. Amongst other activities this is proposed to take place in **2002**.

Reusability and Standardization of the MAP Model

Concerning increasing the reusability of the MAP model, a bond graph implementation of a complete model alternative is made in IMMS (Integrated Model Management System). For now, this version sufficiently matches the currently used Matlab[®] implementation. Small differences in gas composition progress must be examined in **2002**. Also in that year the model parts compatibility must be dealt with, resulting in a library of complete and submodels. Additionally, documentation of the model is proposed to be developed in **2002**.

Repair of the Current MAP Model Application On the Intranet

We have found out why the current model implementation on Intranet does not work at the moment. Due to ATO virus protection, the model implementation on Intranet does not work at the moment and cannot be used in short terms.

1 Introduction

First, in Section 1.1, the MAP Model Maintenance & Validation project will be introduced. Second, in Section 1.2, the MAP model will be presented briefly. More detailed documentation of the model is planned to be written in 2002.

1.1 Outline of the Project

Modelling is a key activity of ATO, to be carried out in a professional way. That means that the modelling progresses effectively and efficiently and leads to high-quality models with exactly sufficient complexity. An important precondition is that models are transferable and reusable. However, often model code is little or not documented, the code is monolithical instead of modular, co-workers leave and take knowledge with them, more generations of modellers introduce modifications incrementally, etc.

The problem definition is:

The current design and implementation of the MAP model is not adequately maintainable, documented and validated. The validation concerns mainly the moisture part of the model, in particular the condensation processes.

The underlying idea is that ATO is able to perform quick simulations in favour of product storage with respect to moisture development in addition to labour-intensive experiments in this field, as well as that ATO can respond fast and adequately to specific questions and demands from the market concerning this subject.

1.1.1 Objectives

The project objectives are given below. The objectives adopted in 2001 only are printed **bold**. At this moment it is unclear whether the project will continue in its original form. The objectives are grouped in a modular way.

Project objectives 2001-2002:

- *Model Validation*
 1. Validation of the current model
 - a) **Acquisition of available data**
 - b) **Designing and testing a set-up for condensation experiments**
 - c) **Acquisition of new (OPP) data by means of the experimental design of 1b**
 - d) **Simulation of some experiments of 1a and c**
 - e) **Comparison between measured and simulated values**
 2. Recommendations for model improvements (2002?)
 3. Validation of the model after implementation of some suggested improvements
 - a) Resimulation of some experiments (2002?)
 - b) Recomparison between measured and simulated values (2002?)
- *Model Reusability & Genericity*
 4. Documentation
 - a) Documentation of the model (2002?)
 - b) More detailed documentation on submodel compatibility, focusing on material potentials (2002?)
 5. Module-oriented model design
 - a) **Design and implementation of a MAP model mode in IMMS**
 - b) Design and implementation of more MAP model alternatives and submodels in IMMS (2002?)
 - c) Design and development of support on material domains compatibility in IMMS (2002?)
- *Model Implementation Repair*
 6. **Repair of the current Intranet/Matlab[®] implementation**

The results of objectives 1a-e are given in Chapter 2, objective 5a in Chapter 3 and objective 6 in Chapter 4.

1.2 Model Description (In Dutch)

S. Douma

In het MAP-model zijn een aantal onderdelen te onderscheiden, nl.:

- de omgeving,
- de verpakking,
- de condenslaag op de verpakking,
- de lucht in de verpakking,
- het product en
- de condenslaag op het product.

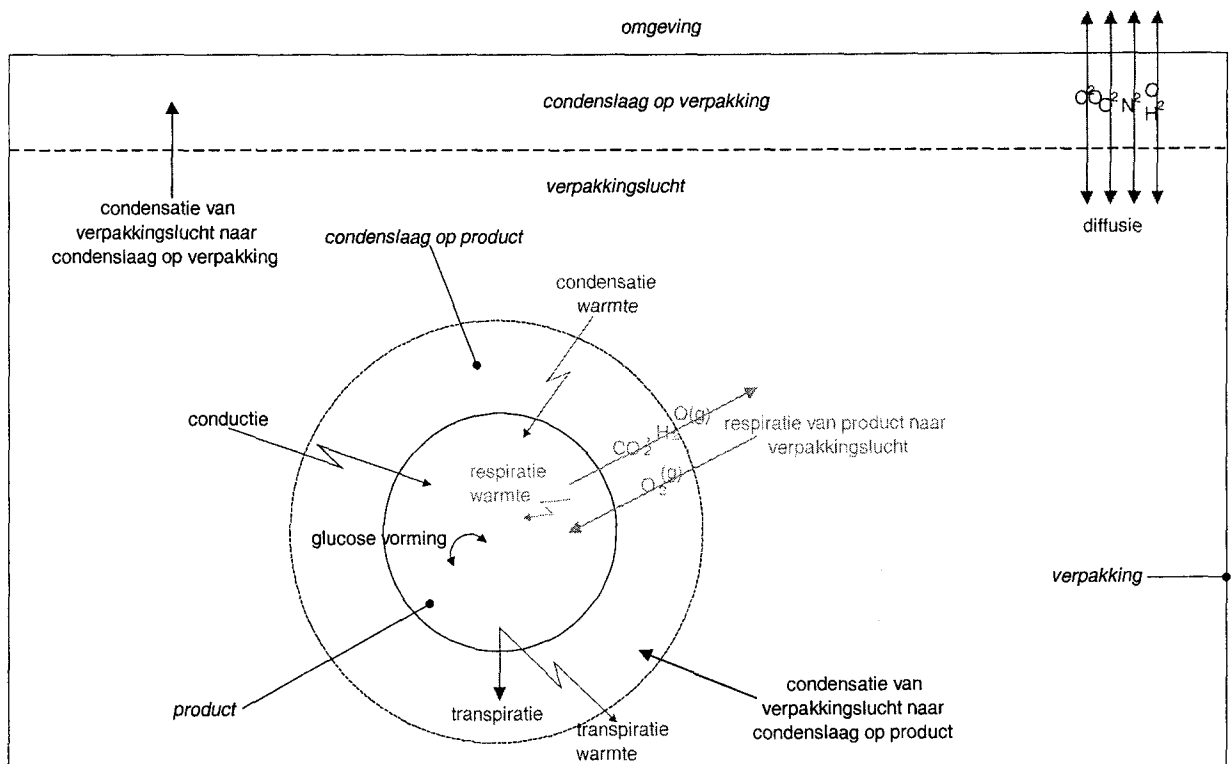
Deze onderdelen zijn weergegeven in figuur 1. Elk van deze onderdelen wordt gekenmerkt door een aantal toestandsvariabelen. De omgeving wordt beschreven door de concentraties CO₂, O₂, N₂, H₂O (g) en door de omgevingstemperatuur, de condenslaag op de verpakking door het aantal molen H₂O (l), de lucht in de verpakking door het aantal molen CO₂, O₂, N₂, H₂O (g) en door een verpakkingsluchttemperatuur die gelijk is aan de omgevingstemperatuur. Het product wordt beschreven door zijn massa en warmte (waaruit de producttemperatuur wordt berekend) en de condenslaag op het product door het aantal molen H₂O (l).

Tussen deze onderdelen vinden overdrachtsprocessen plaats. In de figuur zijn zij aangegeven met een kleur. Het betreft:

- diffusie,
- condensatie (2x),
- conductie,
- transpiratie en
- respiratie.

Tussen de omgeving en de lucht in de verpakking vindt diffusie plaats. De omgeving en de lucht in de verpakking wisselen CO₂, O₂, N₂ en H₂O (g) uit totdat de betreffende concentraties in de lucht van de verpakking gelijk zijn aan de corresponderende concentraties in de omgeving. De lucht in de

verpakking, om precies te zijn de waterdamp in de lucht van de verpakking, condenseert tegen de wand van de verpakking (condenslaag op de verpakking). Dit is het eerste condensatieproces dat plaats vindt. Het tweede is de condensatie van waterdamp uit de verpakingslucht op het (verpakte) product. De warmte die hierbij vrij komt wordt opgenomen door het product. Verder vindt er vanuit de lucht in de verpakking geleiding, oftewel conductie, van warmte plaats naar het product. Vanuit het product naar de lucht in de verpakking vinden er twee processen plaats: transpiratie en respiratie. Bij transpiratie wordt vocht vanuit het product naar buiten gedreven naar de condenslaag op het product. De warmte die dit kost wordt onttrokken aan het product. Bij respiratie (verbranding van glucose) neemt het product O_2 op uit de lucht in de verpakking en geeft zij af aan de lucht in de verpakking CO_2 en $H_2O(g)$. De warmte die dit oplevert wordt opgenomen door het product.



Figuur 1. Schematische weergave van het MAP-model.

2 Testing the MAP Model

In this project we focus on validation of the moisture processes in the MAP model, in particular condensation. The thermodynamic processes will be focussed on as well, since they play an important role in the moisture processes. The respiration process of the map model is already validated to a satisfying level [Peppelenbos, 1996; Hertog *et al*, 1997].

We obtain datasets, search for old and experiment new sets. We simulate these datasets and compare the results with the measurements. The results are discussed, conclusions drawn and recommendations formulated.

2.1 Searching Available Data

Available data at ATO which can be used for validation of the moisture modelling in the MAP model are listed in Table 1.

Table 1. Available data at ATO, grouped per project, of measurements which can be used for validation of the moisture modelling in the MAP model.

Project	Experiment		
	Product	Packaging	Description
HenK	Golden Delicious apples, nrs. 11 & 12	-	Four samples of produce at constant conditions. Two samples are weighed during time and two are temperature measured.
	Golden Delicious apples, nrs. 15 & 16 (1°)	-	
	Golden Delicious apples, nrs. 15 & 16 (2°)	-	
	Bell peppers, nrs. 5 & 6	-	
	Bell peppers, nrs. 5 & 6 (bis)	-	
	Asparaguses, nrs. 5 & 6	-	
	Asparaguses, nrs. 5 & 6 (bis)	-	
'Humidity In MA Boxes'	Tomato on the vine	Box of corrugated board, no coating	2.7 kg produce in a corrugated box, with different PE coatings: 1. (no coating) 2. on the outside 3. on both sides 4. 'sandwich coating' on both sides
	Tomato on the vine	Idem, PE coating on the outside	
	Tomato on the vine	Idem, PE coating on both sides	
	Tomato on the vine	Idem, 'sandwich coating' on both sides	
	Chicory	Idem, no coating	
	Chicory	Idem, PE coating on the outside	
	Chicory	Idem, PE coating on both sides	
	Chicory	Idem, 'sandwich coating' on both sides	

2.1.1 The HenK Project

Four samples of produce at constant conditions. The samples are contained in a box, its lid set ajar, in a cooling cell. Two samples are weighed during time and two are measured on temperature during time. The latter two act as monitors of the former two.

2.1.2 The 'Humidity In MA Boxes' Project

Tomato on the vine and chicory in corrugated boxes, with different PE coatings. The filled boxes are subjected to temperature regimes.

The relative humidity of the packaging air is measured during time and the mass of the produce and the mass of the packaging (both including condensate, if any) are measured at the beginning and at the end of each experiment.

2.2 Carrying Out New Experiments

New experiments are carried out within this project in order to:

- investigate if it is possible at ATO to experiment with and measure condensation,
- obtain new experimental data which can be used for validation of the MAP model, in particular validation of condensation processes (on the product and on the inner side of the packaging) and product transpiration.

The experimental set-up is shown in Figure 2.

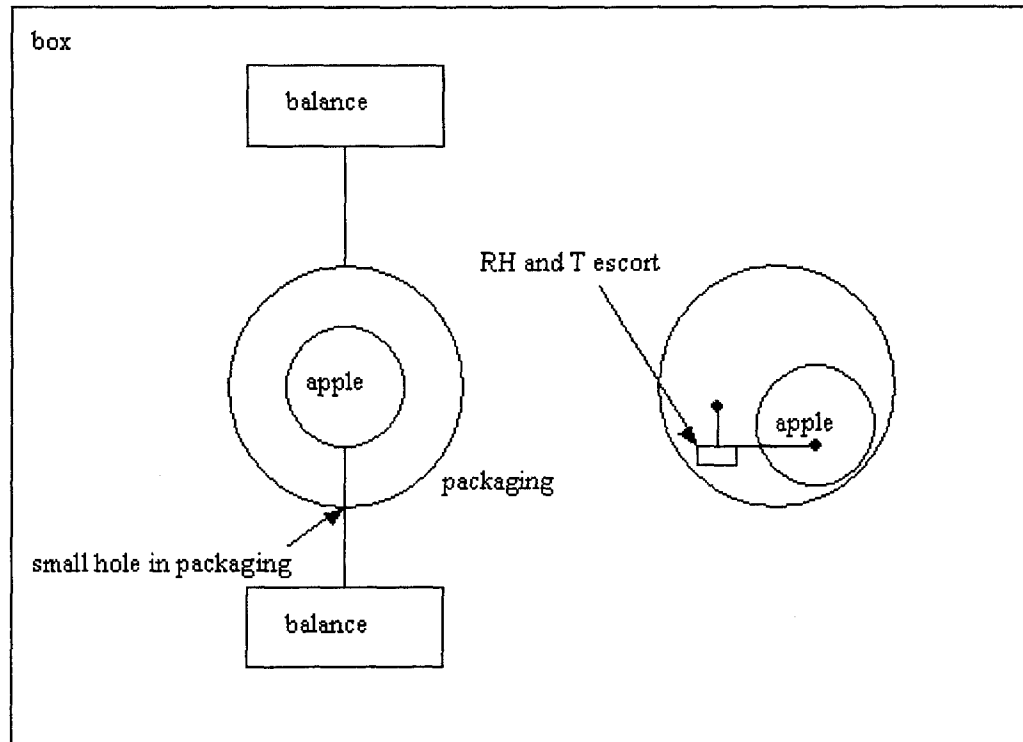


Figure 2. Set-up of the condensation experiments.

We have chosen to measure the weights of both the product and the packaging, that is including condensate, if any, during time. The temperature is measured by means of one or two monitor apples, lying next to the weighed apple and packaging in the same box. The Escorts are not situated with the packed apple, in order to prevent from condensation on the measuring instruments and cables instead of on the product or the packaging. A box surrounding the product was used to eliminate the effect of air movement in the measurements.

Relative humidity of the packaging air is not measured because of inaccuracy in high ranges, which are assumed to occur inside the MA packaging.

An overview of the experiments and the imposed temperature scenarios is given in Table 2.

Table 2. Overview of experiments, carried out within this project, in favour of validation of the MAP model moisture modelling.

Experiment		
Product	Packaging	Description
Cox apple	OPP film	Product and packaging with an initial temperature of 20 °C, placed in a 6 °C environment (2x)
Cox apple	OPP film	Idem, with an initial temperature of 6 °C, placed in a 20 °C environment
Cox apple	OPP film	Idem, with an initial temperature of 30 °C, placed in a 4 °C environment
Cox apple	OPP film	Idem, with an initial temperature of 4 °C, placed in a 30 °C environment

The first experiment is carried out twice, as indicated in the table. From the experiment from 6 to 20 °C on, the cover of the box is left open, in order to prevent a micro-climate from happening in the box. In the last two experiments the temperature monitor apple(s) are packed too, in order to measure temperature in a similar micro-climate as where the mass of the apple is measured.

2.3 Simulations

In the current phase of the project the simulations listed below are carried out.

Table 3. Experiments which are selected to simulate, grouped per project.

Project	Experiment		
	Product	Packaging	Description
HenK	Golden Delicious apples nrs. 15 & 16	-	Product with an initial temperature of 4 °C, placed in a 25 °C environment
'Humidity In MA Boxes'	Tomato on the vine	Box of corrugated board, PE coating on both sides	2.7 kg produce in a PE coated corrugated box
(This project)	Cox apple	OPP film	Product and packaging with an initial temperature of 20 °C, placed in a 6 °C environment (1°)
	Cox apple	OPP film	Product and packaging with an initial temperature of 6 °C, placed in a 20 °C environment
	Cox apple	OPP film	Product and packaging with an initial temperature of 30 °C, placed in a 4 °C environment

More experiments (see Tables 1 and 2) are planned to be simulated in the proposed next phase of the project in 2002.

The most important assumptions in the simulations are:

- The air speed in the cooling cell is assumed 0 m/s, or negligible. This assumption is made particularly because it is often made in our practice **and** because we think it is a questionable assumption (as we will see later).
- The products are considered sphere-shaped.

Sometimes parameter values must be estimated, like in the case of the gas specific diffusion coefficients of OPP. Some parameter values, like condensation and transpiration coefficients, can either be calculated or used for model calibration and therefor experimentally assessed. We have chosen to calculate them, which we think is in accordance with the practical use of the model, as a tool in the pre-design phase of a project or experiment.

The calculation of the condensation coefficient is based on the assumption that the air speed is zero. However, this assumption is debatable. Standing in the cooling cell, the amount of air movement, due to the cooling installation, is striking. The air speed is not measured in our practice.

The transpiration coefficient is known to depend on the vapour pressure deficit, such that the smaller the deficit, the greater the transpiration coefficient is [...]. However, there are indications that this relation is incomplete in low ranges, because it is hard to measure small vapour pressure deficits. In our simulations we have assumed a low, constant transpiration coefficient, going with a relatively high vapour pressure deficit, independent from the deficits actually occurring in practice.

For the Golden Delicious and Cox simulation experiments the respiration parameters are taken from Elstar.

Below, in Table 4, a selection of the model input parameter values of the first simulation experiment, the 'HenK Golden Delicious Apples Nrs. 15 & 16 of 4 °C, Placed In a 25 °C Environment', is given. For the complete list of input values, see Appendix A.

Table 4. Selection of input parameter values of ‘HenK Golden Delicious Apples Nrs. 15 & 16 of 4 °C, Placed In a 25 °C Environment’ simulation.

Object	Parameter
Environment	Air CO ₂ fraction: 0.03%
	Air O ₂ fraction: 21%
	Air N ₂ fraction: 79%
	Air temperature: 25 °C
	Relative humidity: 55%
	Air speed: 0 m/s
Product	Number of product samples: 4
	Sample mass: 0.18836 kg
	Total mass: 0.74786 kg
	Initial temperature: 4 °C
	Specific heat capacity: 3828 J/(kg K)
	Heat transfer coefficient: 0.438 W/(m K)
	Density: 820 kg/m ³
	Total volume: 0.00091883 m ³
	Sample radius: 0.037992 m
	Total area: 0.068 m ²
	Air speed round the product: 0 m/s
	DC_OUT: 0.0075985 m
	DC_IN: 0.030394 m
	Heat conduction
	Internal heat resistance: 1.0205 K/W
	External heat resistance: 9.8039 K/W
	Insulation heat resistance: 0 K/W
	Transpiration
	Transpiration coefficient (β_{ap}): $9.3 \cdot 10^{-5}$ m/s
	Condensation
	Condensation coefficient (β_{am}): 0.0006966 m/s
	Respiration
	VM_O2_REF: $194.44 \cdot 10^{-9}$ mol/(kg s)
	EA_VM_O2: 52721 J/mol
	KM_O2 = 4.61%
	KMC_CO2 = 7.36%
	KMU_CO2 = 42.7%
	VM_CO2_REF = $173.61 \cdot 10^{-9}$ mol/(kg s)
	EA_VM_CO2 = 87907 J/mol
	KMC_O2F = 2.013%
	KMC_CO2F = 19.25%
	Respiration quotient: 0.65
	Temperature reference: 8 °C
Packaging (Air)	Initial temperature: 25 °C
	Heat transfer coefficient: 0.56 W/m K
	Initial air CO ₂ fraction: 0.03%
	Initial air O ₂ fraction: 21%
	Initial air N ₂ fraction: 79%
	Initial relative humidity: 55%
	Length: 0.7 m
	Width: 0.7 m
	Height: 0.7 m
	Area: 2.94 m ²
	Volume: 0.343 m ³
	Condensation
	Condensation coefficient (β_{am}): 0.000439 m/s

See Appendix A for the parameter values of the other simulations:

- Tomato On the Vine In a Box of Corrugated Board PE Coated On Both Sides
- Cox Apple and OPP Packaging of 20 °C, Placed In a 6 °C environment (1°)
- Cox Apple and OPP Packaging of 6 °C, Placed In a 20 °C environment
- Cox Apple and OPP Packaging of 30 °C, Placed In a 4 °C Environment

2.4 Comparison of Experimental Data and Simulation Results

In the following the measured data and simulated data are compared. Each simulation experiment is discussed in a separate section.

2.4.1 Golden Delicious Apples Nrs. 15 &16 of 4 °C, Placed In a 30 °C Environment

Figure 3 shows the measured and simulated inner temperature of the product.

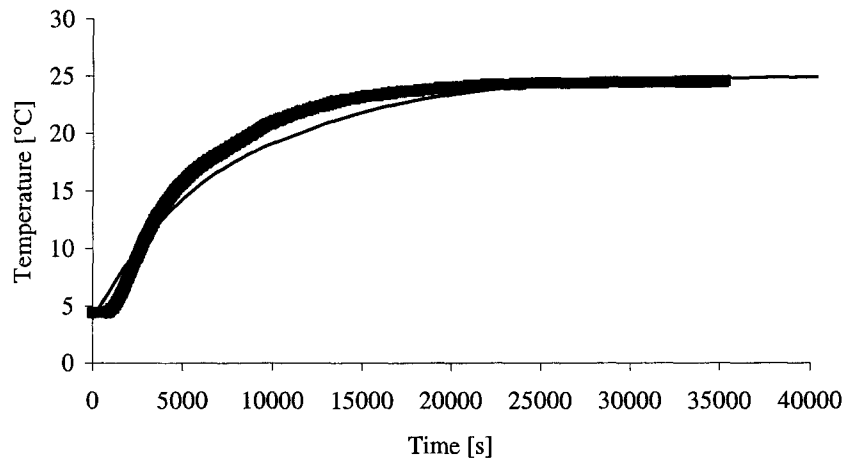


Figure 3. The inner product temperature, measured (■) and simulated (—).

As can be seen, the model predicts the inner temperature of the product quite well.

In Figure 4 the measured and simulated mass of the product including condensate, if any, are shown. The exact moment of the last measurement is approximated. It was taken at the moment the condensate was visually gone.

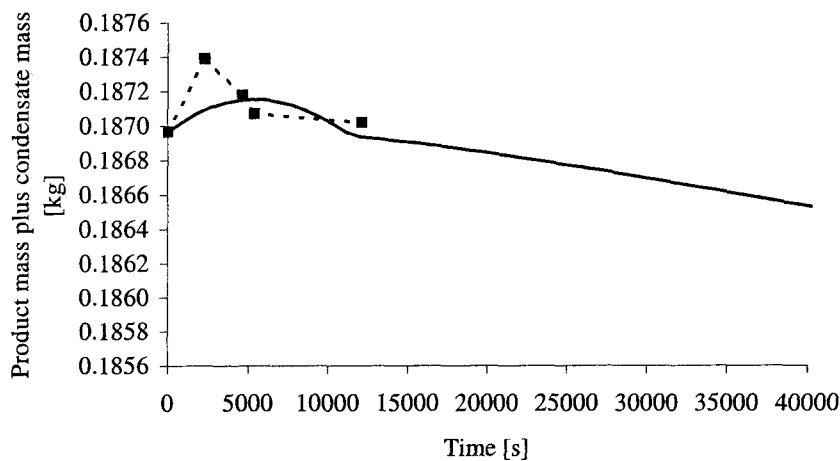


Figure 4. Product mass plus condensate mass, if any, measured (■) and simulated (—).

The measured and simulated values do not match sufficiently. The shapes of the ‘condensation tops’ are not exactly similar, in particular the amounts and occurrence times of the maximums. However, the moment the condensation was visually gone matches with the predicted moment. No statement about mass loss or transpiration after the initial ‘condensation top’ can be made, because of the limited duration the measurements were taken.

Concerning condensation, we conclude that the specified condensation coefficient is too low. The condensation coefficient β_{am} for spheric products can be calculated as follows:

$$\beta_{am} = \frac{Sh \cdot D_a}{6 \cdot \frac{V}{A}}$$

where Sh is the Sherwood number [-], D_a is the diffusivity of water vapour in air [m^2/s], V is the volume [m^3] of the product and A the area [m^2] of the product.

Since the diffusivity, volume and area are fixed, the condensation coefficient is increased by changing the Sherwood number. For cases in which the air velocity is zero, the Sherwood number is 2. Else, the Sherwood number depends on the velocity, via the Reynolds number in a relation of the form:

$$Sh = 2 + a \cdot Re^b \cdot Sc^c$$

where Re is the Reynolds number [-], being equal to $v \cdot D_a / \nu$, where v is speed [m/s] and ν is the viscosity of water vapour in air [m^2/s], Sc is the Schmidt number [-] and a , b and c are product dependent parameters. For tomato fruits Sc is equal to 0.63. a , b and c can be taken respectively 0.37, 0.6 and 0.33 [Leonardi].

When the condensation coefficient was taken 2.5 times greater, the corresponding air speed was 1 cm/s. The simulations lead to a product mass as shown in Figure 5. Air speeds were not measured during the experiments. Considering the used experimental set-up, an air speed unequal to zero is likely to occur.

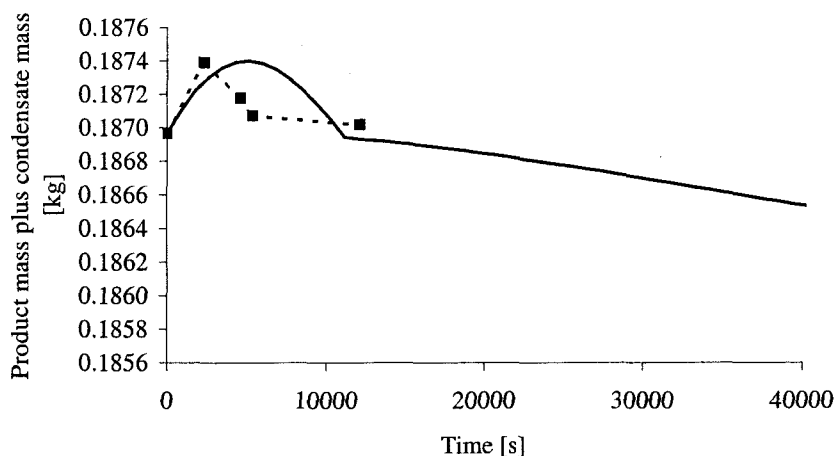


Figure 5. Product mass plus condensate mass, if any, measured (■) and simulated (—), with an increased condensation coefficient.

2.4.2 Tomato On the Vine In a Box of Corrugated Board PE Coated On Both Sides

The relative humidity development was approximately predicted with a deviation of a few percents. The product mass reduced too little, approximately ten times too few. Condensation did not take place in this experiment until only after vife days.

2.4.3 Cox Apple and OPP Packaging of 20 °C, Placed In a 6 °C environment (1°)

The measured inner product temperature decreased faster than the simulated product temperature, according to expectations, because the temperature monitor apples were not packed, where the simulated apple was.

Figure 6 shows the measured and simulated product mass including condensate mass, if any.

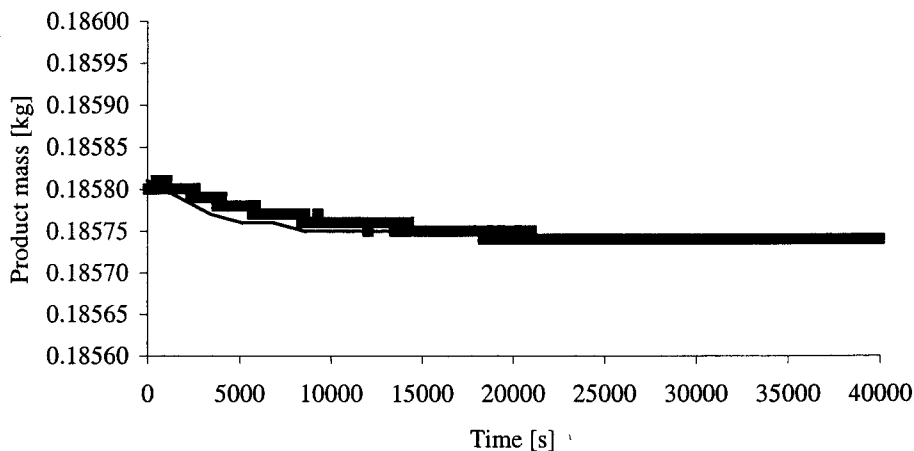


Figure 6. Product mass including condensate mass, if any, measured (■) and simulated (—).

The mass loss is predicted well by the model. Because in this experiment there is no condensation on the product, we may conclude that the transpiration of the product is predicted well by the model for this experiment.

In Figure 7 the measured and simulated amount of condensate on the inner side of the packaging is shown.

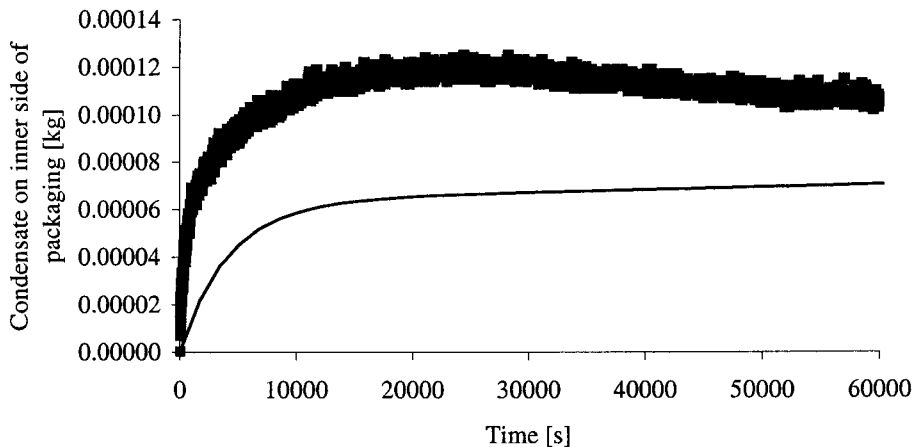


Figure 7. The amount of condensate on the inner side of the packaging, measured (■) and simulated (—).

The condensation is not well enough predicted by the model. The reason why is still to be found. Increasing the condensation coefficient iteratively did not have the desired effect. Moreover, the air speed should be very low inside the packaging.

2.4.4 Cox Apple and OPP Packaging of 6 °C, Placed In a 20 °C environment

Now the door of the box is being left open to avoid the development of a micro-climate.

The measured inner product temperature increased faster than the simulated product temperature, which was to be expected, because the temperature monitor apples were not packed, as was the simulated apple.

Figure 8 shows the measured and simulated product mass.

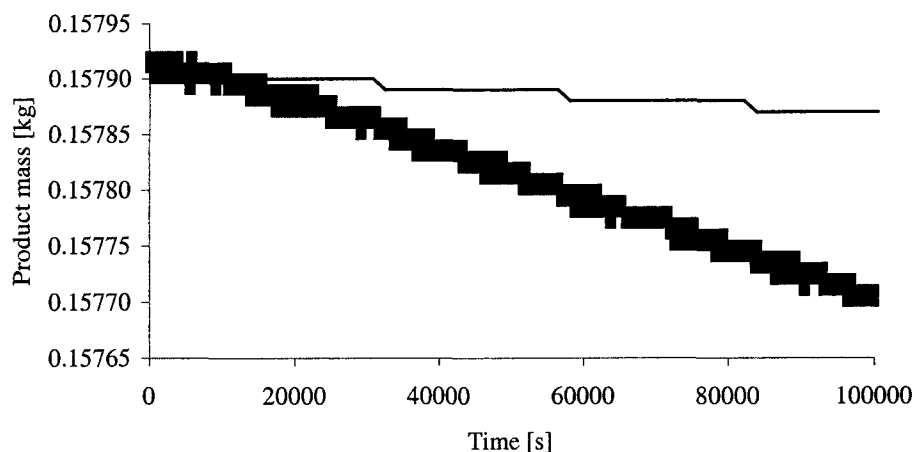


Figure 8. The product mass, including condensate mass, measured (■) and simulated (—).

Probably because the cover of the box is left open now, the measurements fluctuate. Moreover, the mass loss is predicted too small. A ten times greater transpiration coefficient caused a better match, as shown in Figure 9. Like the condensation coefficient, the transpiration coefficient depends on the air velocity, which, presumably, may not be assumed zero.

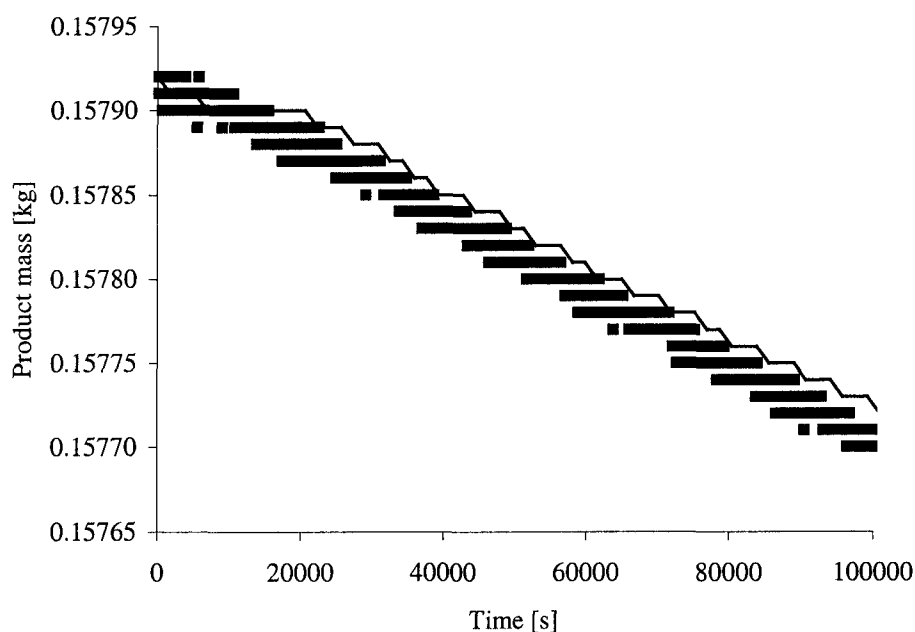


Figure 9. The product mass, including condensate mass, measured (■) and simulated (—), with an increased transpiration coefficient.

Figure 10 shows the condensation on the inner side of the packaging, measured and simulated.

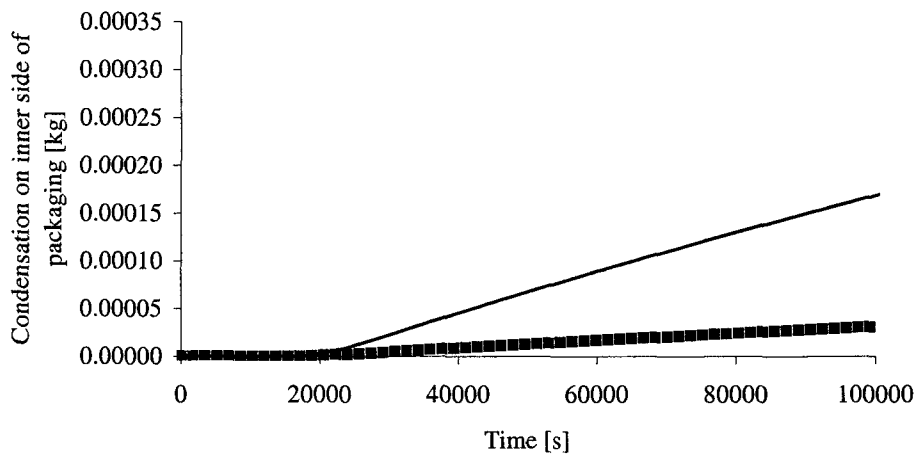


Figure 10. Condensation on the inner side of the packaging, measured (■) and simulated (—).

The duration of the stationary situation in the beginning of the curve is predicted well. However, the increase afterwards is predicted too large.

2.4.5 Cox Apple and OPP Packaging of 30 °C, Placed In a 4 °C Environment

In Figure 11 the inner product temperature is shown. Clearly, it is predicted well by the model.

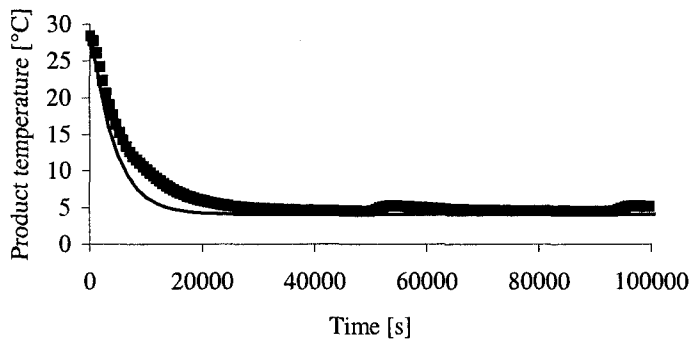


Figure 11. The inner product temperature, measured (■) and simulated (—).

Figure 12 shows the product mass including condensate mass. The simulation deviates from the trend that can be seen in the fluctuating measurements. Again the box is left open to prevent a micro-climate from developing in the box. The measurements oscillate because of defrost peaks occurring.

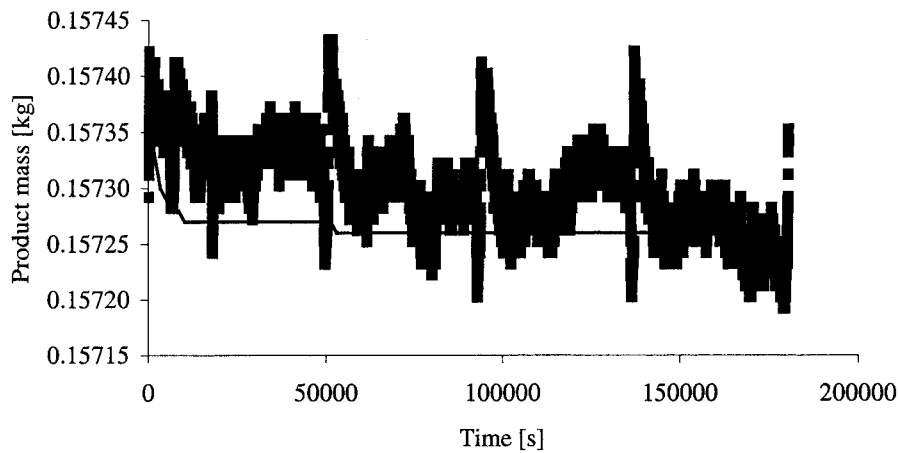


Figure 12. The product mass, including condensate mass, if any, measured (■) and simulated (—).

Figure 13 shows the condensation on the inner side of the packaging. The simulation deviates slightly from the trend that can be seen in the oscillating measurements, such that it is predicted a bit too large.

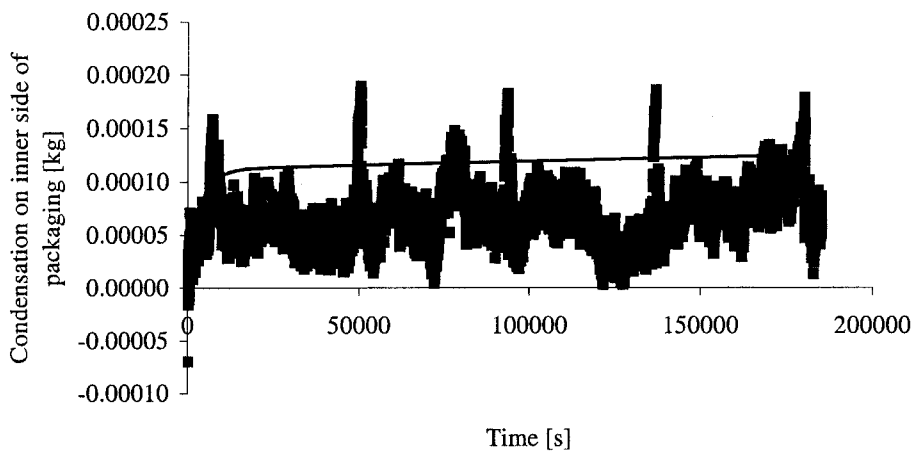


Figure 13. Condensation on the inner side of the packaging, measured (■) and simulated (—).

In Figure 14 the relative humidity of the packaging air is shown. It is unknown why the simulated relative humidity first drops.

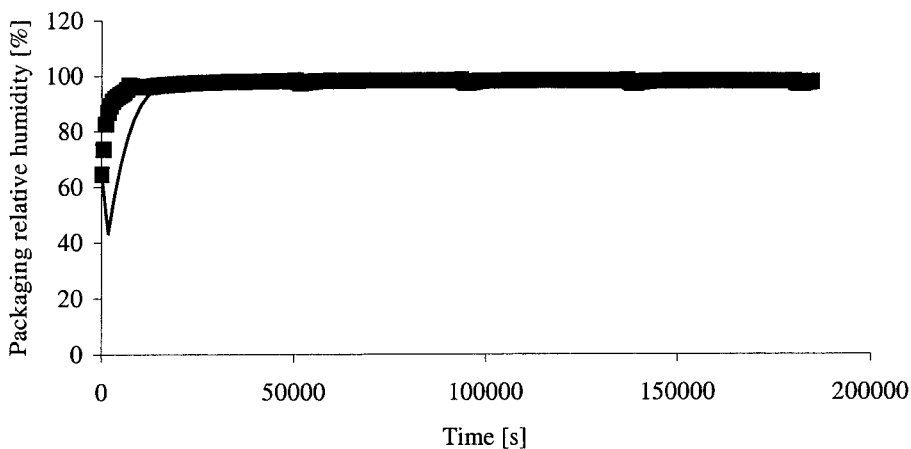


Figure 14. Relative humidity of the packaging air, measured (■) and simulated (—).

2.5 Conclusion

In this section subsequently the presented results are discussed, conclusions are drawn and recommendations are made.

2.5.1 Discussion

These are the most important things that have to be kept in mind, when reading the conclusions in the next subsection:

- The door of the box is left open in a situation where relative humidity stabilisers (salt solutions) are used. It is not known if so much moisture is added to the system this way, that condensation, indirectly, is influenced.
- The relative humidity of the environment was assumed constant, where in practice it was not.
- Too few experiments are carried out to draw trusty conclusion on. Therefor the conclusions are only indicative.

2.5.2 Conclusions

Some experimental datasets already existing within ATO have been found. New experiments have been carried out, to acquire new measurements which can be used for MAP moisture model validation, but also simply to show whether it is possible within the practice at ATO to carry out such experiments, especially concerning the measurement of amounts of condensation. We have shown that this is possible. The first measurements have already actually been used for validation yet.

Regarding the testing of the MAP model the following conclusions, formulated vaguely (see discussion) and only to be interpreted **indicatively** and as first estimates, may be drawn:

- The product temperature is predicted quite well.
- The product mass is predicted quite well, if the air speed is zero.
- The approximate order of magnitude of condensation is predicted well. The duration of the process is predicted well.

The product temperature is simulated well, mostly. The product and packaging air heat resistances are calculated well by the model.

Only a qualitative indication of the amount of condensation modelling can be given by the model. The condensation 'duration' is predicted fairly. The maximum amount of condensation is mostly not predicted quantitatively well.

2.5.3 Recommendations

The most important recommendations, apart from carrying out more experiments, concern the further investigation of:

- air speed,
- geometric shapes,
- diffusion versus convection

in the model. Revalidation, particularly concerning the moisture submodels, must take place afterwards.

Reduce the air speed in the cooling cells, in order to obtain an environment where moisture modelling can be tested more adequately. Furthermore, the air speed must be measured, so it can be taken into account in the future.

Experiment with different geometric shapes of the product and validate the model on that aspect, especially with relation to the calculation of condensation coefficients, a.o.

Diffusion and convection or the so-called pressure release represent different processes in the model. It is important for model users to know when and where to assume which one or both of the processes and how to assess the rate coefficients, particularly in relation to tight packagings. For example, some

try to assess diffusion coefficients for a film with perforations or a box with creases. Others claim this is no diffusion based on concentration or partial pressure differences, but convection based on total pressure differences.

Other topics that may be further investigated or tried out:

- The activity of water, although almost 100% in our case, may be important regarding the water processes.
- Test the model with using the calculated skin temperature instead of the inner product temperature, in favour of the processes where saturation pressures are involved.
- The pressure release process is only implemented in case of over-pressure of the packaging air in relation to the environment air. It should be implemented and validated for under-pressure as well. The author of the current implementation claims it is already in the model, however, we could not find it in the code.
- The transpiration coefficient for products is known to vary with air vapour pressure deficit, generally, the smaller the vapour pressure deficit, the greater the transpiration coefficient. However, it is stated that the transpiration coefficient is equal to zero at a vapour pressure deficit of zero and that it increases with the deficit till a certain maximum value is reached. This should be further investigated.
- The transpiration coefficient is known to depend on temperature. Check if it is worthwhile to implement this relation. At the moment it is constant and user-defined.
- Document how to calculate an area dependent transpiration coefficient from a mass dependent transpiration coefficient [RvdS]. The latter is often given in literature, e.g. in the orange Sprenger books. Another possibility is to implement the mass dependent transpiration process as well, so the user can choose between these two versions of the same process. For leaf products, such as endive, it may be valuable to use a mass dependent transpiration coefficient and accompanying model instead of an area dependent one, since it is much easier to assess a product's mass instead of its surface area.
- For some products, like apple, density is mass dependent. That is, a heavy apple usually has a greater density than a light one. Investigate the influence of this aspect.
- Investigate and process the activity of water in the product condensation and transpiration processes [Leonardi].
- Validate the (heat conduction) model at gliding temperature changes.

3 Reusability and Standardization of the MAP Model

3.1 Implementation In IMMS

The objective is to obtain a bond graph representing sufficient MAP model functionality, to make plausible that the entire MAP model can be implemented in bond graphs, in IMMS.

3.1.1 *Model mode focussed on*

A range of submodels can be turned on and off in the current implementation of the MAP model, resulting in a number of *modes*. We have chosen one of these modes to start the bond graph implementation of the model in IMMS.

The following processes were switched on:

- product condensation
- product transpiration
- product heat transfer
- product respiration
- condensation on inner side of packaging
- packaging air heat transfer
- packaging diffusion

For the complete listing of all input parameter values, see appendix B.

3.1.2 *Bond graph result*

The bond graph we have constructed is presented in Figure 15. It is shown as implemented in the IMMS environment.

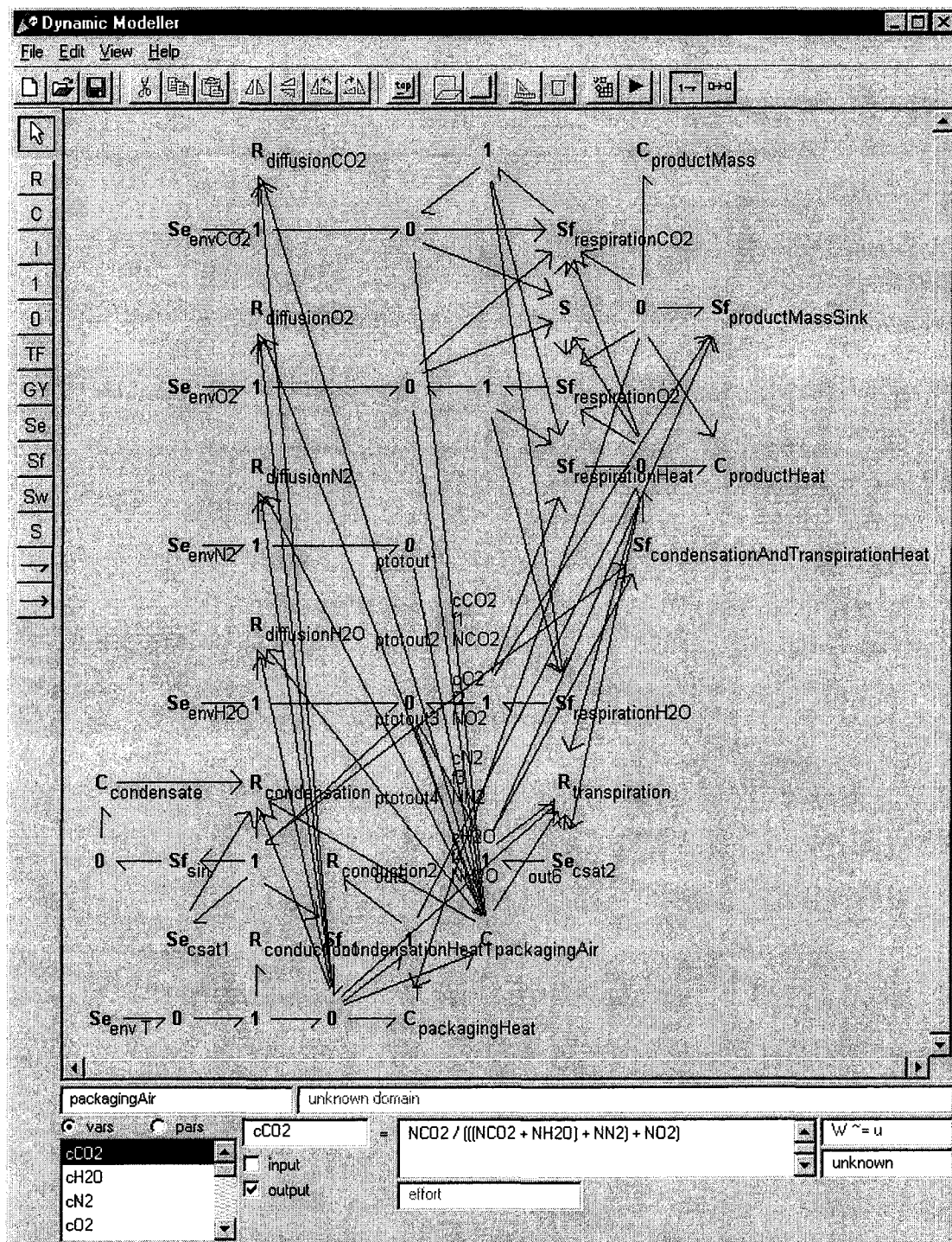


Figure 15. Sketch large bond graph of one entire MAP model mode in IMMS.

In favour of testing the bond graph model, we specified the same parameter values as in the chosen MAP model mode.

The simulated result of the output variables, like product temperature, product mass and the gas fractions of the packaging air are approximately the same. There are slight differences, probably due to:

1. the fixed time step in the original MAP model implementation and the non-fixed time step in the IMMS bond graph model.
2. different ODE solvers. The original implementation of the model uses a dedicated solver, myODE, with a fixed time step to avoid endless calculations and the IMMS model uses the standard ODE23 solver of Matlab®.

Summarizing, we can state that it is possible to implement the MAP model in bond graphs in the IMMS environment. The model will be better maintainable in that way, because bond graph modelling is supportive to modular and reusable modelling. The developed sketch bond graph can act as source for the derivation and design of more reusable and generic submodel components.

3.1.3 Future Activities

In 2002, we hope to have the opportunity to divide this whole bond graph in small, comprehensible parts, representing separate submodels, with standardized interfaces, stored in categories in the library and documented.

For further detailed comparison with the already existing model application the same ODE and time step in the IMMS model and the original implementation must be used and specified and the simulation results checked again.

3.2 Recommended Improvements To the Current Application

Some recommended improvements to the current model application on the Intranet concern the standardization of units, particularly those of potential variables and the extension of automated calculated parameter values.

3.2.1 Unit Standardization

The units of the diffusion coefficients for the air gas components are different from those commonly used. The diffusion coefficients, now, must be calculated *over* the entire diffusion area, instead of being specified per square meter. They have to be multiplied by 1 bar of pascals (approximately atmospheric pressure), instead of being given per pascal. The water vapour diffusion coefficient must be converted from per 0-85% water vapour deficit to per bar.

3.2.2 Automated Parameter Calculations

in the current MAP model application many parameters which depend on other, specified parameters are automatically calculated. however the causalities are not given explicitly, which can be problem regarding geometric properties. do i have to specify area and radius and will the volume of the product be calculated or must radius and volume be given so the area will be calculated? the same problem occurs with density, volume and mass.

At the moment the transpiration and condensation parameters have to be calculated and specified manually, which is, if one is not familiar with the matter, a difficult calculation. These calculations can be automated.

3.3 Recommended Improvements To the Current Database

Recommended improvements to the current database tables concern fields covering parameter value sources or references, ranges or minimum and maximum values, best estimates, standard deviations, and reliability indications.

With a growing database it is important to indicate whether parameter values are found in literature and where or if they are experimentally assessed and whom to contact for more information. At other times parameter values are simply copied from a more or less resembling product or packaging.

4 Repair of the Current MAP Model Application On the Intranet

J. Vogels, H. Rijgersberg

This part of the project concerns the repair of the current application on the Intranet calling the Matlab® MAP model. Lately, this application has become off-line. We have investigated why and tried to fix the problem.

The technique offered by Active Server Pages (ASP) to start up executables and DLLs on a web server (Windows Scripting Host) is based on the same principle used by today's viruses. Many institutes and companies do not use this technique anymore for this reason. As is the case with ATO.

Dit probleem is binnen de huidige scope en aanpak niet oplosbaar. Gezocht moet worden naar nieuwe oplossingen.

This problem can not be solved within the scope and approach of this project. New solutions have to be found. A possible solution is to work with Common Gateway Interface (CGI)-scripts. However, this technique must be explored.

Literature

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Appendix A. Simulation Input Parameter Values

A.1 Golden Delicious Apples Nrs. 15 &16 of 4 °C, Placed In a 30 °C Environment

Below the input file for this particular experiment is given.

```

INF: Calcpack version 0.84
WAR: [param] VERSION = 0                default
WAR: [param] TIMEBEGIN = 0 days          default
INF: [param] TIMEEND = 1 days            map-file      (default 1)
INF: [param] NUMBEROFSTEPS = 1000        map-file      (default 100)
WAR: [param] NSAVE = 100                  default
WAR: [param] DXSAVE = 0.01 days           calculated    with {(param.tend-
param.t0)/param.nsave}
WAR: [param] MINIMUM_OUTPUT = 1           default
INF: [param] FIXED_TIME_STEP = 1          map-file      (default 1)
WAR: [param] html_create = 1              calculated    with {0:no / 1:end of computation /
2:each time step}
WAR: [param] html_temp = [1 2 3 4 5 6 7 8] calculated    with {colons of output file}
WAR: [param] html_conc = [9 10 11]        calculated    with {colons of output file}
WAR: [param] html_rh = [12 13]            calculated    with {colons of output file}
WAR: [param] html_mass = [15 16]          calculated    with {colons of output file}
INF: [param] CONDENSATION_TRESHOLD = 0     map-file      (default 0.01)
INF: [flag] TEMPERATURE = 1               map-file      (default 0)
INF: [flag] PRODUCT = 1                   map-file      (default 0)
INF: [flag] PRODUCT_CONDENSATION = 1       map-file      (default 0)
INF: [flag] PRODUCT_ABSORPTION_CO2 = 0     map-file      (default 0)
INF: [flag] PRODUCT_TRANSPIRATION = 1      map-file      (default 0)
INF: [flag] PRODUCT_TEMPERATURE = 1        map-file      (default 0)
INF: [flag] PRODUCT_RESPIRATION = 1        map-file      (default 0)
INF: [flag] PRODUCT_KEEPINGQUALITY = 0     map-file      (default 0)
INF: [flag] packaging = 1                  map-file      (default 0)
INF: [flag] packaging_CONDENSATION = 1     map-file      (default 0)
INF: [flag] packaging_TEMPERATURE = 0      map-file      (default 0)
WAR: [flag] packaging_ABSORPTION_H2O = 0   default
INF: [flag] packaging_FILM = 0              map-file      (default 0)
INF: [flag] packaging_PRESSURE_RELEASE = 0 map-file      (default 0)
INF: [flag] packaging_DIFFUSION = 1        map-file      (default 0)
INF: [flag] packaging_FLEXIBLE = 0         map-file      (default 0)
INF: [flag] packaging_OPEN = 1             map-file      (default 0)
INF: [flag] PALLET = 0                     map-file      (default 0)
INF: [flag] storage = 0                     map-file      (default 0)
INF: [flag] DRYICE = 0                     map-file      (default 0)
INF: [flag] SCRUBBER = 0                   map-file      (default 0)
INF: [flag] ABSORBER = 0                   map-file      (default 0)
INF: [environment] CO2 = 0.03 %             map-file      (default 0.03)
INF: [environment] O2 = 21 %               map-file      (default 21)
INF: [environment] N2 = 79 %               map-file      (default 79)
INF: [environment] TEMP = 25 C              map-file      (default 18)
INF: [environment] RH = 55 %               map-file      (default 80)
INF: [environment] P = 1 bar                map-file      (default 1)
INF: [environment] airspeed = 0 m/s         map-file      (default 0)
INF: [product] TOTAL_MASS = 0.74786 kg      map-file      (default 0)
INF: [product] TEMP = 4 C                   map-file      (default 25 with {environment.T(1,1)})
INF: [product] SPECHEAT = 3828 J/kg.K       map-file      (default 3900)
INF: [product] LAMBDA = 0.438 W/m.K         map-file      (default 0.46)

```

INF: [product] MASS_PER_PRODUCT = 0.18836 kg map-file (default 1)
 INF: [product] N = 4 map-file (default 3.9704 with {product.totalmass/product.massperproduct})
 INF: [product] DENSITY = 820 kg/m3 map-file (default 1000)
 INF: [product] LENGTH = 0.0735 m map-file (default 0)
 WAR: [product] VOLUME = 0.00022971 m3 calculated with {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.00091883 m3 calculated with {product.volume * product.N}
 WAR: [product] RADIUS = 0.037992 m calculated with {(3 * product.volume/(4 * pi))^(1/3)}
 INF: [product] AREA = 0.017 m2 map-file (default 0.017545 with {2 * pi * product.radius * product.length})
 WAR: [product] TOTAL_AREA = 0.068 m2 calculated with {product.N * product.area}
 INF: [product] AIRSPEED = 0 m/s map-file (default 0)
 WAR: [product] DC_OUT = 0.0075985 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.030394 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 1.0205 Ks/J calculated with {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 9.8039 Ks/J calculated with {1/(product.area * (6 + 4 * product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 721.04 J/kg calculated with {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 9.3e-005 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.0006966 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 194.44 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 52721 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 4.61 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 7.36 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 42.7 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 173.61 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 87907 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.013 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 19.25 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.65 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 8 C map-file (default 18)
 WAR: [packaging] MASS_PER_PACKAGING = 0.74786 kg calculated with {product.totalmass}
 INF: [packaging] TEMP = 25 C map-file (default 4 with {product.T})
 WAR: [packaging] SPECHEAT = 3828 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 0.74786 kg calculated with {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 0.74786 kg calculated with {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 55 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.7 m map-file (default 0)
 INF: [packaging] WIDTH = 0.7 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.7 m map-file (default 0)
 INF: [packaging] AREA = 2.94 m2 map-file (default 2.94 with {2 * packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 2.94 m2 calculated with {packaging.area * packaging.N}

INF: [packaging] VOLUME_0 = 0.343 m3 map-file (default 0.343 with {packaging.length * packaging.width * packaging.height})
INF: [packaging] VOLUME_MAX = 0.343 m3 map-file (default 0.343 with {packaging.volume})
WAR: [packaging] TOTAL_volume = 0.343 m2 calculated with {packaging.volume * packaging.N}
WAR: [packaging] TOTAL_volume_max = 0.343 m2 calculated with {packaging.volumemax * packaging.N}
WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
INF: [packaging] BETA_AM = 0.000439 m/s map-file (default 1e-005)
INF: [packaging] D_O2 = 0 ml/day map-file (default 0)
INF: [packaging] D_CO2 = 0 ml/day map-file (default 0)
INF: [packaging] D_N2 = 0 ml/day map-file (default 0)
INF: [packaging] D_H2O = 0 ml/day map-file (default 0)
WAR: [packaging] EA_O2 = 0 J/mol default
WAR: [packaging] EA_CO2 = 0 J/mol default
WAR: [packaging] EA_N2 = 0 J/mol default
WAR: [packaging] EA_H2O = 0 J/mol default
WAR: [packaging] TEMP_REF_O2 = 0 C default
WAR: [packaging] TEMP_REF_CO2 = 0 C default
WAR: [packaging] TEMP_REF_N2 = 0 C default
WAR: [packaging] TEMP_REF_H2O = 0 C default
INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 0.74786 with {packaging.totalmass})
INF: [pallet] N = 1 map-file (default 1)
WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
INF: [pallet] TEMP = 18 C map-file (default 25 with {packaging.T})
WAR: [pallet] SPECHEAT = 3828 J/Kg.K calculated with {packaging.specheat}
WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
INF: [storage] TEMP = 18 C map-file (default 18 with {pallet.T})
INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
WAR: [absorber] MASS_per_Packaging = 0 kg default
WAR: [absorber] MASS = 0 kg calculated with {absorber.massperpackaging*packaging.N}
WAR: [scrubber] AREA_per_packaging = 0 m2 default
WAR: [scrubber] AREA = 0 m2 calculated with {scrubber.areaperpackaging*packaging.N}

A.2 Tomato On The Vine In a Box of Corrugated Board PE Coated On Both Sides

INF: Calcpack version 0.84
WAR: [param] VERSION = 0 default
WAR: [param] TIMEBEGIN = 0 days default
INF: [param] TIMEEND = 1.67 days map-file (default 1)
INF: [param] NUMBEROFSTEPS = 3000 map-file (default 100)
WAR: [param] NSAVE = 100 default
WAR: [param] DXSAVE = 0.0167 days calculated with {(param.tend-param.t0)/param.nsave}
WAR: [param] MINIMUM_OUTPUT = 1 default
INF: [param] FIXED_TIME_STEP = 1 map-file (default 1)
WAR: [param] html_create = 1 calculated with {0:no / 1:end of computation / 2:each time step}
WAR: [param] html_temp = [1 2 3 4 5 6 7 8] calculated with {colons of output file}
WAR: [param] html_conc = [9 10 11] calculated with {colons of output file}
WAR: [param] html_rh = [12 13] calculated with {colons of output file}
WAR: [param] html_mass = [15 16] calculated with {colons of output file}
INF: [param] CONDENSATION_TRESHOLD = 0 map-file (default 0.01)
INF: [flag] TEMPERATURE = 1 map-file (default 0)
INF: [flag] PRODUCT = 1 map-file (default 0)
INF: [flag] PRODUCT_CONDENSATION = 1 map-file (default 0)
INF: [flag] PRODUCT_ABSORPTION_CO2 = 0 map-file (default 0)
INF: [flag] PRODUCT_TRANSPIRATION = 1 map-file (default 0)
INF: [flag] PRODUCT_TEMPERATURE = 1 map-file (default 0)
INF: [flag] PRODUCT_RESPIRATION = 1 map-file (default 0)
INF: [flag] PRODUCT_KEEPINGQUALITY = 0 map-file (default 0)
INF: [flag] packaging = 1 map-file (default 0)
INF: [flag] packaging_CONDENSATION = 1 map-file (default 0)
INF: [flag] packaging_TEMPERATURE = 0 map-file (default 0)
WAR: [flag] packaging_ABSORPTION_H2O = 0 default
INF: [flag] packaging_FILM = 0 map-file (default 0)
INF: [flag] packaging_PRESSURE_RELEASE = 0 map-file (default 0)
INF: [flag] packaging_DIFFUSION = 1 map-file (default 0)
INF: [flag] packaging_FLEXIBLE = 0 map-file (default 0)
INF: [flag] packaging_OPEN = 0 map-file (default 0)
INF: [flag] PALLET = 0 map-file (default 0)
INF: [flag] storage = 0 map-file (default 0)
INF: [flag] DRYICE = 0 map-file (default 0)
INF: [flag] SCRUBBER = 0 map-file (default 0)
INF: [flag] ABSORBER = 0 map-file (default 0)
INF: [environment] CO2 = 0.03 % map-file (default 0.03)
INF: [environment] O2 = 21 % map-file (default 21)
INF: [environment] N2 = 79 % map-file (default 79)
INF: [environment] TEMP = 18 C map-file (default 18)
INF: [environment] RH = 75 % map-file (default 80)
INF: [environment] P = 1 bar map-file (default 1)
INF: [environment] airspeed = 0 m/s map-file (default 0)
INF: [product] TOTAL_MASS = 2.7 kg map-file (default 0)
INF: [product] TEMP = 18 C map-file (default 18 with {environment.T(1,1)})
INF: [product] SPECHEAT = 4000 J/kg.K map-file (default 3900)
INF: [product] LAMBDA = 0.59 W/m.K map-file (default 0.46)
INF: [product] MASS_PER_PRODUCT = 0.12285 kg map-file (default 1)
WAR: [product] N = 21.978 calculated with {product.totalmass/product.massperproduct}
INF: [product] DENSITY = 1005 kg/m3 map-file (default 1000)
WAR: [product] LENGTH = 0 m default

WAR: [product] VOLUME = 0.00012224 m3 calculated with
 {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.0026866 m3 calculated with {product.volume *
 product.N}
 WAR: [product] RADIUS = 0.030787 m calculated with {(3 * product.volume/(4 *
 pi))^(1/3)}
 WAR: [product] AREA = 0.011911 m2 calculated with {4 * pi * product.radius^2}
 WAR: [product] TOTAL_AREA = 0.26179 m2 calculated with {product.N *
 product.area}
 WAR: [product] AIRSPEED = 0 m/s default
 WAR: [product] DC_OUT = 0.0061575 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.02463 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 0.87618 Ks/J calculated with
 {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 13.992 Ks/J calculated with {1/(product.area * (6 + 4 *
 product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 491.4 J/kg calculated with
 {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 4.0347e-006 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.00083152 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 121.94 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 67338 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 23.16 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 21.33 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 7.85 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 40.833 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 65159 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.741 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 12.98 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.906 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 10 C map-file (default 18)
 INF: [packaging] MASS_PER_PACKAGING = 2.7 kg map-file (default 2.7 with
 {product.totalmass})
 INF: [packaging] TEMP = 18 C map-file (default 18 with {product.T})
 WAR: [packaging] SPECHEAT = 4000 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 2.7 kg calculated with
 {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 2.7 kg calculated with
 {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 75 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.29 m map-file (default 0)
 INF: [packaging] WIDTH = 0.39 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.14 m map-file (default 0)
 INF: [packaging] AREA = 0.4166 m2 map-file (default 0.4166 with {2 *
 packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 0.4166 m2 calculated with {packaging.area *
 packaging.N}
 INF: [packaging] VOLUME_0 = 0.015834 m3 map-file (default 0.015834 with
 {packaging.length * packaging.width * packaging.height})
 INF: [packaging] VOLUME_MAX = 0.15834 m3 map-file (default 0.015834 with
 {packaging.volume})
 WAR: [packaging] TOTAL_volume = 0.015834 m2 calculated with {packaging.volume *
 packaging.N}

WAR: [packaging] TOTAL_volume_max = 0.15834 m2 calculated with
 {packaging.volumemax * packaging.N}
 WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
 INF: [packaging] BETA_AM = 0.0013471 m/s map-file (default 1e-005)
 INF: [packaging] D_O2 = 12498 ml/day map-file (default 0)
 INF: [packaging] D_CO2 = 12498 ml/day map-file (default 0)
 INF: [packaging] D_N2 = 12498 ml/day map-file (default 0)
 INF: [packaging] D_H2O = 30000 ml/day map-file (default 0)
 WAR: [packaging] EA_O2 = 0 J/mol default
 WAR: [packaging] EA_CO2 = 0 J/mol default
 WAR: [packaging] EA_N2 = 0 J/mol default
 WAR: [packaging] EA_H2O = 0 J/mol default
 WAR: [packaging] TEMP_REF_O2 = 0 C default
 WAR: [packaging] TEMP_REF_CO2 = 0 C default
 WAR: [packaging] TEMP_REF_N2 = 0 C default
 WAR: [packaging] TEMP_REF_H2O = 0 C default
 INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 2.7 with
 {packaging.totalmass})
 INF: [pallet] N = 1 map-file (default 1)
 WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
 INF: [pallet] TEMP = 18 C map-file (default 18 with {packaging.T})
 WAR: [pallet] SPECHEAT = 4000 J/Kg.K calculated with {packaging.specheat}
 WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
 INF: [storage] TEMP = 18 C map-file (default 18 with {pallet.T})
 INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
 WAR: [absorber] MASS_per_Packaging = 0 kg default
 WAR: [absorber] MASS = 0 kg calculated with
 {absorber.massperpackaging*packaging.N}
 WAR: [scrubber] AREA_per_packaging = 0 m2 default
 WAR: [scrubber] AREA = 0 m2 calculated with
 {scrubber.areaperpackaging*packaging.N}

A.3 Cox Apple and OPP Packaging of 20 °C, Placed In a 6 °C environment (1°)

INF: Calcpack version 0.84

WAR: [param] VERSION = 0 default

WAR: [param] TIMEBEGIN = 0 days default

INF: [param] TIMEEND = 2 days map-file (default 1)

INF: [param] NUMBEROFSTEPS = 2e+005 map-file (default 100)

WAR: [param] NSAVE = 100 default

WAR: [param] DXSAVE = 0.02 days calculated with {(param.tend-param.t0)/param.nsave}

WAR: [param] MINIMUM_OUTPUT = 1 default

INF: [param] FIXED_TIME_STEP = 1 map-file (default 1)

WAR: [param] html_create = 1 calculated with {0:no / 1:end of computation / 2:each time step}

WAR: [param] html_temp = [1 2 3 4 5 6 7 8] calculated with {colons of output file}

WAR: [param] html_conc = [9 10 11] calculated with {colons of output file}

WAR: [param] html_rh = [12 13] calculated with {colons of output file}

WAR: [param] html_mass = [15 16] calculated with {colons of output file}

INF: [param] CONDENSATION_TRESHOLD = 0 map-file (default 0.01)

INF: [flag] TEMPERATURE = 1 map-file (default 0)

INF: [flag] PRODUCT = 1 map-file (default 0)

INF: [flag] PRODUCT_CONDENSATION = 1 map-file (default 0)

INF: [flag] PRODUCT_ABSORPTION_CO2 = 0 map-file (default 0)

INF: [flag] PRODUCT_TRANSPIRATION = 1 map-file (default 0)

INF: [flag] PRODUCT_TEMPERATURE = 1 map-file (default 0)

INF: [flag] PRODUCT_RESPIRATION = 1 map-file (default 0)

INF: [flag] PRODUCT_KEEPINGQUALITY = 0 map-file (default 0)

INF: [flag] packaging = 1 map-file (default 0)

INF: [flag] packaging_CONDENSATION = 1 map-file (default 0)

INF: [flag] packaging_TEMPERATURE = 1 map-file (default 0)

WAR: [flag] packaging_ABSORPTION_H2O = 0 default

INF: [flag] packaging_FILM = 0 map-file (default 0)

INF: [flag] packaging_PRESSURE_RELEASE = 1 map-file (default 0)

INF: [flag] packaging_DIFFUSION = 1 map-file (default 0)

INF: [flag] packaging_FLEXIBLE = 1 map-file (default 0)

INF: [flag] packaging_OPEN = 0 map-file (default 0)

INF: [flag] PALLET = 0 map-file (default 0)

INF: [flag] storage = 0 map-file (default 0)

INF: [flag] DRYICE = 0 map-file (default 0)

INF: [flag] SCRUBBER = 0 map-file (default 0)

INF: [flag] ABSORBER = 0 map-file (default 0)

INF: [environment] CO2 = 0.03 % map-file (default 0.03)

INF: [environment] O2 = 21 % map-file (default 21)

INF: [environment] N2 = 79 % map-file (default 79)

INF: [environment] TEMP = 6 C map-file (default 18)

INF: [environment] RH = 65 % map-file (default 80)

INF: [environment] P = 1 bar map-file (default 1)

INF: [environment] airspeed = 0 m/s map-file (default 0)

INF: [product] TOTAL_MASS = 0.18581 kg map-file (default 0)

INF: [product] TEMP = 19.25 C map-file (default 6 with {environment.T(1,1)})

INF: [product] SPECHEAT = 3828 J/kg.K map-file (default 3900)

INF: [product] LAMBDA = 0.438 W/m.K map-file (default 0.46)

INF: [product] MASS_PER_PRODUCT = 0.18581 kg map-file (default 1)

INF: [product] N = 1 map-file (default 1 with {product.totalmass/product.massperproduct})

INF: [product] DENSITY = 820 kg/m3 map-file (default 1000)

INF: [product] LENGTH = 0.0715 m map-file (default 0)

WAR: [product] VOLUME = 0.0002266 m3 calculated with {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.0002266 m3 calculated with {product.volume * product.N}
 WAR: [product] RADIUS = 0.03782 m calculated with {(3 * product.volume/(4 * pi))^(1/3)}
 WAR: [product] AREA = 0.016991 m2 calculated with {2 * pi * product.radius * product.length}
 WAR: [product] TOTAL_AREA = 0.016991 m2 calculated with {product.N * product.area}
 INF: [product] AIRSPEED = 0 m/s map-file (default 0)
 WAR: [product] DC_OUT = 0.007564 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.030256 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 1.0164 Ks/J calculated with {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 9.8094 Ks/J calculated with {1/(product.area * (6 + 4 * product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 711.28 J/kg calculated with {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 9.3e-005 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.00071608 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 194.44 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 52721 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 4.61 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 7.36 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 42.7 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 173.61 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 87907 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.013 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 19.25 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.65 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 8 C map-file (default 18)
 WAR: [packaging] MASS_PER_PACKAGING = 0.18581 kg calculated with {product.totalmass}
 INF: [packaging] TEMP = 19.25 C map-file (default 19.25 with {product.T})
 WAR: [packaging] SPECHEAT = 3828 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 0.18581 kg calculated with {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 0.18581 kg calculated with {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 65 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.1205 m map-file (default 0)
 INF: [packaging] WIDTH = 0.1205 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.108 m map-file (default 0)
 INF: [packaging] AREA = 0.0711 m2 map-file (default 0.081096 with {2 * packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 0.0711 m2 calculated with {packaging.area * packaging.N}
 INF: [packaging] VOLUME_0 = 0.00157 m3 map-file (default 0.0015682 with {packaging.length * packaging.width * packaging.height})
 INF: [packaging] VOLUME_MAX = 0.00157 m3 map-file (default 0.00157 with {packaging.volume})

WAR: [packaging] TOTAL_volume = 0.00157 m2 calculated with {packaging.volume * packaging.N}
 WAR: [packaging] TOTAL_volume_max = 0.00157 m2 calculated with {packaging.volumemax * packaging.N}
 WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
 INF: [packaging] BETA_AM = 0.23187 m/s map-file (default 1e-005)
 INF: [packaging] D_O2 = 85.3 ml/day map-file (default 0)
 INF: [packaging] D_CO2 = 248.9 ml/day map-file (default 0)
 INF: [packaging] D_N2 = 28.4 ml/day map-file (default 0)
 INF: [packaging] D_H2O = 1.8 ml/day map-file (default 0)
 WAR: [packaging] EA_O2 = 0 J/mol default
 WAR: [packaging] EA_CO2 = 0 J/mol default
 WAR: [packaging] EA_N2 = 0 J/mol default
 WAR: [packaging] EA_H2O = 0 J/mol default
 WAR: [packaging] TEMP_REF_O2 = 0 C default
 WAR: [packaging] TEMP_REF_CO2 = 0 C default
 WAR: [packaging] TEMP_REF_N2 = 0 C default
 WAR: [packaging] TEMP_REF_H2O = 0 C default
 WAR: [packaging] DC_OUT = 0.022082 m calculated with {packaging.volume / packaging.area}
 WAR: [packaging] DC_IN = 0.044163 m calculated with {2 * packaging.volume / packaging.area}
 WAR: [packaging] K = 99999 W/m2.K silly default
 WAR: [packaging] KW = 99999 W/K silly default
 WAR: [packaging] AIRSPEED = 0 m/s default
 WAR: [packaging] R_int = 0.55459 Ks/J calculated with {packaging.dc_out / (packaging.lambda * packaging.area)}
 WAR: [packaging] R_ext = 2.3441 Ks/J calculated with {1/(packaging.area * (6 + 4 * packaging.airspeed))}
 WAR: [packaging] R_INSULATION = 0 Ks/J default
 INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 0.18581 with {packaging.totalmass})
 INF: [pallet] N = 1 map-file (default 1)
 WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
 WAR: [pallet] TEMP = 19.25 C calculated with {packaging.T}
 WAR: [pallet] SPECHEAT = 3828 J/Kg.K calculated with {packaging.specheat}
 WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
 WAR: [storage] TEMP = 19.25 C calculated with {pallet.T}
 INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
 WAR: [product] R_int_prod_pack_center = 1.4616 Ks/J calculated with {(packaging.dc_in-product.dc_in) / (packaging.lambda * product.area)}
 WAR: [product] R_int_prod_pack_corner = 2.3208 Ks/J calculated with {packaging.dc_out / (packaging.lambda * product.area)}
 WAR: [absorber] MASS_per_Packaging = 0 kg default
 WAR: [absorber] MASS = 0 kg calculated with {absorber.massperpackaging*packaging.N}
 WAR: [scrubber] AREA_per_packaging = 0 m2 default
 WAR: [scrubber] AREA = 0 m2 calculated with {scrubber.areaperpackaging*packaging.N}

A.4 Cox Apple and OPP Packaging of 6 °C, Placed In a 20 °C environment

INF: Calcpack version 0.84
 WAR: [param] VERSION = 0 default
 WAR: [param] TIMEBEGIN = 0 days default
 INF: [param] TIMEEND = 2 days map-file (default 1)
 INF: [param] NUMBEROFSTEPS = 20000 map-file (default 100)
 WAR: [param] NSAVE = 100 default
 WAR: [param] DXSAVE = 0.02 days calculated with {(param.tend-param.t0)/param.nsave}
 WAR: [param] MINIMUM_OUTPUT = 1 default
 INF: [param] FIXED_TIME_STEP = 1 map-file (default 1)
 WAR: [param] html_create = 1 calculated with {0:no / 1:end of computation / 2:each time step}
 WAR: [param] html_temp = [1 2 3 4 5 6 7 8] calculated with {colons of output file}
 WAR: [param] html_conc = [9 10 11] calculated with {colons of output file}
 WAR: [param] html_rh = [12 13] calculated with {colons of output file}
 WAR: [param] html_mass = [15 16] calculated with {colons of output file}
 INF: [param] CONDENSATION_TRESHOLD = 0 map-file (default 0.01)
 INF: [flag] TEMPERATURE = 1 map-file (default 0)
 INF: [flag] PRODUCT = 1 map-file (default 0)
 INF: [flag] PRODUCT_CONDENSATION = 1 map-file (default 0)
 INF: [flag] PRODUCT_ABSORPTION_CO2 = 0 map-file (default 0)
 INF: [flag] PRODUCT_TRANSPIRATION = 1 map-file (default 0)
 INF: [flag] PRODUCT_TEMPERATURE = 1 map-file (default 0)
 INF: [flag] PRODUCT_RESPIRATION = 1 map-file (default 0)
 INF: [flag] PRODUCT_KEEPINGQUALITY = 0 map-file (default 0)
 INF: [flag] packaging = 1 map-file (default 0)
 INF: [flag] packaging_CONDENSATION = 1 map-file (default 0)
 INF: [flag] packaging_TEMPERATURE = 1 map-file (default 0)
 WAR: [flag] packaging_ABSORPTION_H2O = 0 default
 INF: [flag] packaging_FILM = 0 map-file (default 0)
 INF: [flag] packaging_PRESSURE_RELEASE = 1 map-file (default 0)
 INF: [flag] packaging_DIFFUSION = 1 map-file (default 0)
 INF: [flag] packaging_FLEXIBLE = 1 map-file (default 0)
 INF: [flag] packaging_OPEN = 0 map-file (default 0)
 INF: [flag] PALLET = 0 map-file (default 0)
 INF: [flag] storage = 0 map-file (default 0)
 INF: [flag] DRYICE = 0 map-file (default 0)
 INF: [flag] SCRUBBER = 0 map-file (default 0)
 INF: [flag] ABSORBER = 0 map-file (default 0)
 INF: [environment] CO2 = 0.03 % map-file (default 0.03)
 INF: [environment] O2 = 21 % map-file (default 21)
 INF: [environment] N2 = 79 % map-file (default 79)
 INF: [environment] TEMP = 20 C map-file (default 18)
 INF: [environment] RH = 65 % map-file (default 80)
 INF: [environment] P = 1 bar map-file (default 1)
 INF: [environment] airspeed = 0 m/s map-file (default 0)
 INF: [product] TOTAL_MASS = 0.15792 kg map-file (default 0)
 INF: [product] TEMP = 9.7 C map-file (default 20 with {environment.T(1,1)})
 INF: [product] SPECHEAT = 3828 J/kg.K map-file (default 3900)
 INF: [product] LAMBDA = 0.438 W/m.K map-file (default 0.46)
 INF: [product] MASS_PER_PRODUCT = 0.15792 kg map-file (default 1)
 INF: [product] N = 1 map-file (default 1 with {product.totalmass/product.massperproduct})
 INF: [product] DENSITY = 820 kg/m3 map-file (default 1000)
 INF: [product] LENGTH = 0.0675 m map-file (default 0)

WAR: [product] VOLUME = 0.00019259 m3 calculated with
 {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.00019259 m3 calculated with {product.volume *
 product.N}
 WAR: [product] RADIUS = 0.035824 m calculated with {(3 * product.volume/(4 *
 pi))^(1/3)}
 WAR: [product] AREA = 0.015194 m2 calculated with {2 * pi * product.radius *
 product.length}
 WAR: [product] TOTAL_AREA = 0.015194 m2 calculated with {product.N *
 product.area}
 INF: [product] AIRSPEED = 0 m/s map-file (default 0)
 WAR: [product] DC_OUT = 0.0071649 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.028659 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 1.0766 Ks/J calculated with
 {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 10.97 Ks/J calculated with {1/(product.area * (6 + 4 *
 product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 604.52 J/kg calculated with
 {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 0.00093 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.00075852 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 194.44 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 52721 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 4.61 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 7.36 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 42.7 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 173.61 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 87907 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.013 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 19.25 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.65 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 8 C map-file (default 18)
 WAR: [packaging] MASS_PER_PACKAGING = 0.15792 kg calculated with
 {product.totalmass}
 INF: [packaging] TEMP = 9.7 C map-file (default 9.7 with {product.T})
 WAR: [packaging] SPECHEAT = 3828 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 0.15792 kg calculated with
 {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 0.15792 kg calculated with
 {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 43 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.1205 m map-file (default 0)
 INF: [packaging] WIDTH = 0.1205 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.108 m map-file (default 0)
 INF: [packaging] AREA = 0.0711 m2 map-file (default 0.081096 with {2 *
 packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 0.0711 m2 calculated with {packaging.area *
 packaging.N}
 INF: [packaging] VOLUME_0 = 0.00157 m3 map-file (default 0.0015682 with
 {packaging.length * packaging.width * packaging.height})
 INF: [packaging] VOLUME_MAX = 0.00157 m3 map-file (default 0.00157 with
 {packaging.volume})

WAR: [packaging] TOTAL_volume = 0.00157 m2 calculated with {packaging.volume *
 packaging.N}
 WAR: [packaging] TOTAL_volume_max = 0.00157 m2 calculated with
 {packaging.volumemax * packaging.N}
 WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
 INF: [packaging] BETA_AM = 0.0023187 m/s map-file (default 1e-005)
 INF: [packaging] D_O2 = 85.3 ml/day map-file (default 0)
 INF: [packaging] D_CO2 = 248.9 ml/day map-file (default 0)
 INF: [packaging] D_N2 = 28.4 ml/day map-file (default 0)
 INF: [packaging] D_H2O = 1.8 ml/day map-file (default 0)
 WAR: [packaging] EA_O2 = 0 J/mol default
 WAR: [packaging] EA_CO2 = 0 J/mol default
 WAR: [packaging] EA_N2 = 0 J/mol default
 WAR: [packaging] EA_H2O = 0 J/mol default
 WAR: [packaging] TEMP_REF_O2 = 0 C default
 WAR: [packaging] TEMP_REF_CO2 = 0 C default
 WAR: [packaging] TEMP_REF_N2 = 0 C default
 WAR: [packaging] TEMP_REF_H2O = 0 C default
 WAR: [packaging] DC_OUT = 0.022082 m calculated with {packaging.volume /
 packaging.area}
 WAR: [packaging] DC_IN = 0.044163 m calculated with {2 * packaging.volume /
 packaging.area}
 WAR: [packaging] K = 99999 W/m2.K silly default
 WAR: [packaging] KW = 99999 W/K silly default
 WAR: [packaging] AIRSPEED = 0 m/s default
 WAR: [packaging] R_int = 0.55459 Ks/J calculated with {packaging.dc_out /
 (packaging.lambda * packaging.area)}
 WAR: [packaging] R_ext = 2.3441 Ks/J calculated with {1/(packaging.area * (6 + 4 *
 packaging.airspeed))}
 WAR: [packaging] R_INSULATION = 0 Ks/J default
 INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 0.15792 with
 {packaging.totalmass})
 INF: [pallet] N = 1 map-file (default 1)
 WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
 WAR: [pallet] TEMP = 9.7 C calculated with {packaging.T}
 WAR: [pallet] SPECHEAT = 3828 J/Kg.K calculated with {packaging.specheat}
 WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
 WAR: [storage] TEMP = 9.7 C calculated with {pallet.T}
 INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
 WAR: [product] R_int_prod_pack_center = 1.8222 Ks/J calculated with {(packaging.dc_in-
 product.dc_in) / (packaging.lambda * product.area)}
 WAR: [product] R_int_prod_pack_corner = 2.5953 Ks/J calculated with {packaging.dc_out /
 (packaging.lambda * product.area)}
 WAR: [absorber] MASS_per_Packaging = 0 kg default
 WAR: [absorber] MASS = 0 kg calculated with
 {absorber.massperpackaging*packaging.N}
 WAR: [scrubber] AREA_per_packaging = 0 m2 default
 WAR: [scrubber] AREA = 0 m2 calculated with
 {scrubber.areaperpackaging*packaging.N}

A.5 Cox Apple and OPP Packaging of 30 °C, Placed In a 4 °C Environment

INF: Calcpack version 0.84

WAR: [param] VERSION = 0 default

WAR: [param] TIMEBEGIN = 0 days default

INF: [param] TIMEEND = 2 days map-file (default 1)

INF: [param] NUMBEROFSTEPS = 20000 map-file (default 100)

WAR: [param] NSAVE = 100 default

WAR: [param] DXSAVE = 0.02 days calculated with {(param.tend-param.t0)/param.nsave}

WAR: [param] MINIMUM_OUTPUT = 1 default

INF: [param] FIXED_TIME_STEP = 1 map-file (default 1)

WAR: [param] html_create = 1 calculated with {0:no / 1:end of computation / 2:each time step}

WAR: [param] html_temp = [1 2 3 4 5 6 7 8] calculated with {colons of output file}

WAR: [param] html_conc = [9 10 11] calculated with {colons of output file}

WAR: [param] html_rh = [12 13] calculated with {colons of output file}

WAR: [param] html_mass = [15 16] calculated with {colons of output file}

INF: [param] CONDENSATION_TRESHOLD = 0 map-file (default 0.01)

INF: [flag] TEMPERATURE = 1 map-file (default 0)

INF: [flag] PRODUCT = 1 map-file (default 0)

INF: [flag] PRODUCT_CONDENSATION = 1 map-file (default 0)

INF: [flag] PRODUCT_ABSORPTION_CO2 = 0 map-file (default 0)

INF: [flag] PRODUCT_TRANSPIRATION = 1 map-file (default 0)

INF: [flag] PRODUCT_TEMPERATURE = 1 map-file (default 0)

INF: [flag] PRODUCT_RESPIRATION = 1 map-file (default 0)

INF: [flag] PRODUCT_KEEPINGQUALITY = 0 map-file (default 0)

INF: [flag] packaging = 1 map-file (default 0)

INF: [flag] packaging_CONDENSATION = 1 map-file (default 0)

INF: [flag] packaging_TEMPERATURE = 1 map-file (default 0)

WAR: [flag] packaging_ABSORPTION_H2O = 0 default

INF: [flag] packaging_FILM = 0 map-file (default 0)

INF: [flag] packaging_PRESSURE_RELEASE = 1 map-file (default 0)

INF: [flag] packaging_DIFFUSION = 1 map-file (default 0)

INF: [flag] packaging_FLEXIBLE = 1 map-file (default 0)

INF: [flag] packaging_OPEN = 0 map-file (default 0)

INF: [flag] PALLET = 0 map-file (default 0)

INF: [flag] storage = 0 map-file (default 0)

INF: [flag] DRYICE = 0 map-file (default 0)

INF: [flag] SCRUBBER = 0 map-file (default 0)

INF: [flag] ABSORBER = 0 map-file (default 0)

INF: [environment] CO2 = 0.03 % map-file (default 0.03)

INF: [environment] O2 = 21 % map-file (default 21)

INF: [environment] N2 = 79 % map-file (default 79)

INF: [environment] TEMP = 4 C map-file (default 18)

INF: [environment] RH = 65 % map-file (default 80)

INF: [environment] P = 1 bar map-file (default 1)

INF: [environment] airspeed = 0 m/s map-file (default 0)

INF: [product] TOTAL_MASS = 0.15737 kg map-file (default 0)

INF: [product] TEMP = 28.4 C map-file (default 4 with {environment.T(1,1)})

INF: [product] SPECHEAT = 3828 J/kg.K map-file (default 3900)

INF: [product] LAMBDA = 0.438 W/m.K map-file (default 0.46)

INF: [product] MASS_PER_PRODUCT = 0.15737 kg map-file (default 1)

INF: [product] N = 1 map-file (default 1 with {product.totalmass/product.massperproduct})

INF: [product] DENSITY = 820 kg/m3 map-file (default 1000)

INF: [product] LENGTH = 0.068 m map-file (default 0)

WAR: [product] VOLUME = 0.00019192 m3 calculated with
 {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.00019192 m3 calculated with {product.volume *
 product.N}
 WAR: [product] RADIUS = 0.035783 m calculated with {(3 * product.volume/(4 *
 pi))^(1/3)}
 WAR: [product] AREA = 0.015288 m2 calculated with {2 * pi * product.radius *
 product.length}
 WAR: [product] TOTAL_AREA = 0.015288 m2 calculated with {product.N *
 product.area}
 INF: [product] AIRSPEED = 0 m/s map-file (default 0)
 WAR: [product] DC_OUT = 0.0071566 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.028626 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 1.0687 Ks/J calculated with
 {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 10.901 Ks/J calculated with {1/(product.area * (6 + 4 *
 product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 602.42 J/kg calculated with
 {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 9.3e-005 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.00075294 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 194.44 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 52721 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 4.61 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 7.36 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 42.7 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 173.61 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 87907 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.013 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 19.25 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.65 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 8 C map-file (default 18)
 WAR: [packaging] MASS_PER_PACKAGING = 0.15737 kg calculated with
 {product.totalmass}
 INF: [packaging] TEMP = 28.4 C map-file (default 28.4 with {product.T})
 WAR: [packaging] SPECHEAT = 3828 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 0.15737 kg calculated with
 {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 0.15737 kg calculated with
 {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 65 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.1205 m map-file (default 0)
 INF: [packaging] WIDTH = 0.1205 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.108 m map-file (default 0)
 INF: [packaging] AREA = 0.0711 m2 map-file (default 0.081096 with {2 *
 packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 0.0711 m2 calculated with {packaging.area *
 packaging.N}
 INF: [packaging] VOLUME_0 = 0.00157 m3 map-file (default 0.0015682 with
 {packaging.length * packaging.width * packaging.height})
 INF: [packaging] VOLUME_MAX = 0.00157 m3 map-file (default 0.00157 with
 {packaging.volume})

WAR: [packaging] TOTAL_volume = 0.00157 m2 calculated with {packaging.volume *
 packaging.N}
 WAR: [packaging] TOTAL_volume_max = 0.00157 m2 calculated with
 {packaging.volumemax * packaging.N}
 WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
 INF: [packaging] BETA_AM = 0.0023187 m/s map-file (default 1e-005)
 INF: [packaging] D_O2 = 85.3 ml/day map-file (default 0)
 INF: [packaging] D_CO2 = 248.9 ml/day map-file (default 0)
 INF: [packaging] D_N2 = 28.4 ml/day map-file (default 0)
 INF: [packaging] D_H2O = 1.8 ml/day map-file (default 0)
 WAR: [packaging] EA_O2 = 0 J/mol default
 WAR: [packaging] EA_CO2 = 0 J/mol default
 WAR: [packaging] EA_N2 = 0 J/mol default
 WAR: [packaging] EA_H2O = 0 J/mol default
 WAR: [packaging] TEMP_REF_O2 = 0 C default
 WAR: [packaging] TEMP_REF_CO2 = 0 C default
 WAR: [packaging] TEMP_REF_N2 = 0 C default
 WAR: [packaging] TEMP_REF_H2O = 0 C default
 WAR: [packaging] DC_OUT = 0.022082 m calculated with {packaging.volume /
 packaging.area}
 WAR: [packaging] DC_IN = 0.044163 m calculated with {2 * packaging.volume /
 packaging.area}
 WAR: [packaging] K = 99999 W/m2.K silly default
 WAR: [packaging] KW = 99999 W/K silly default
 WAR: [packaging] AIRSPEED = 0 m/s default
 WAR: [packaging] R_int = 0.55459 Ks/J calculated with {packaging.dc_out /
 (packaging.lambda * packaging.area)}
 WAR: [packaging] R_ext = 2.3441 Ks/J calculated with {1/(packaging.area * (6 + 4 *
 packaging.airspeed))}
 WAR: [packaging] R_INSULATION = 0 Ks/J default
 INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 0.15737 with
 {packaging.totalmass})
 INF: [pallet] N = 1 map-file (default 1)
 WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
 WAR: [pallet] TEMP = 28.4 C calculated with {packaging.T}
 WAR: [pallet] SPECHEAT = 3828 J/Kg.K calculated with {packaging.specheat}
 WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
 WAR: [storage] TEMP = 28.4 C calculated with {pallet.T}
 INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
 WAR: [product] R_int_prod_pack_center = 1.8147 Ks/J calculated with {(packaging.dc_in-
 product.dc_in) / (packaging.lambda * product.area)}
 WAR: [product] R_int_prod_pack_corner = 2.5792 Ks/J calculated with {packaging.dc_out /
 (packaging.lambda * product.area)}
 WAR: [absorber] MASS_per_Packaging = 0 kg default
 WAR: [absorber] MASS = 0 kg calculated with
 {absorber.massperpackaging*packaging.N}
 WAR: [scrubber] AREA_per_packaging = 0 m2 default
 WAR: [scrubber] AREA = 0 m2 calculated with
 {scrubber.areaperpackaging*packaging.N}

Appendix B. Simulation Input Parameter Values For IMMS Bond Graph Implementation

INF: Calcpack version 0.84		
WAR: [param] VERSION = 0	default	
WAR: [param] TIMEBEGIN = 0 days	default	
INF: [param] TIMEEND = 2 days	map-file	(default 1)
INF: [param] NUMBEROFSTEPS = 20000	map-file	(default 100)
WAR: [param] NSAVE = 100	default	
WAR: [param] DXSAVE = 0.02 days	calculated	with {(param.tend-param.t0)/param.nsave}
WAR: [param] MINIMUM_OUTPUT = 1	default	
INF: [param] FIXED_TIME_STEP = 1	map-file	(default 1)
WAR: [param] html_create = 1	calculated	with {0:no / 1:end of computation / 2:each time step}
WAR: [param] html_temp = [1 2 3 4 5 6 7 8]	calculated	with {colons of output file}
WAR: [param] html_conc = [9 10 11]	calculated	with {colons of output file}
WAR: [param] html_rh = [12 13]	calculated	with {colons of output file}
WAR: [param] html_mass = [15 16]	calculated	with {colons of output file}
INF: [param] CONDENSATION_TRESHOLD = 0	map-file	(default 0.01)
INF: [flag] TEMPERATURE = 1	map-file	(default 0)
INF: [flag] PRODUCT = 1	map-file	(default 0)
INF: [flag] PRODUCT_CONDENSATION = 1	map-file	(default 0)
INF: [flag] PRODUCT_ABSORPTION_CO2 = 0	map-file	(default 0)
INF: [flag] PRODUCT_TRANSPIRATION = 1	map-file	(default 0)
INF: [flag] PRODUCT_TEMPERATURE = 1	map-file	(default 0)
INF: [flag] PRODUCT_RESPIRATION = 1	map-file	(default 0)
INF: [flag] PRODUCT_KEEPINGQUALITY = 0	map-file	(default 0)
INF: [flag] packaging = 1	map-file	(default 0)
INF: [flag] packaging_CONDENSATION = 1	map-file	(default 0)
INF: [flag] packaging_TEMPERATURE = 1	map-file	(default 0)
WAR: [flag] packaging_ABSORPTION_H2O = 0	default	
INF: [flag] packaging_FILM = 0	map-file	(default 0)
INF: [flag] packaging_PRESSURE_RELEASE = 0	map-file	(default 0)
INF: [flag] packaging_DIFFUSION = 1	map-file	(default 0)
INF: [flag] packaging_FLEXIBLE = 0	map-file	(default 0)
INF: [flag] packaging_OPEN = 0	map-file	(default 0)
INF: [flag] PALLET = 0	map-file	(default 0)
INF: [flag] storage = 0	map-file	(default 0)
INF: [flag] DRYICE = 0	map-file	(default 0)
INF: [flag] SCRUBBER = 0	map-file	(default 0)
INF: [flag] ABSORBER = 0	map-file	(default 0)
INF: [environment] CO2 = 0.03 %	map-file	(default 0.03)
INF: [environment] O2 = 21 %	map-file	(default 21)
INF: [environment] N2 = 79 %	map-file	(default 79)
INF: [environment] TEMP = 6 C	map-file	(default 18)
INF: [environment] RH = 55 %	map-file	(default 80)
INF: [environment] P = 1 bar	map-file	(default 1)
INF: [environment] airspeed = 0 m/s	map-file	(default 0)
INF: [product] TOTAL_MASS = 0.18581 kg	map-file	(default 0)
INF: [product] TEMP = 20 C	map-file	(default 6 with {environment.T(1,1)})
INF: [product] SPECHEAT = 3828 J/kg.K	map-file	(default 3900)
INF: [product] LAMBDA = 0.438 W/m.K	map-file	(default 0.46)
INF: [product] MASS_PER_PRODUCT = 0.18581 kg	map-file	(default 1)
INF: [product] N = 1	map-file	(default 1 with {product.totalmass/product.massperproduct})
INF: [product] DENSITY = 820 kg/m3	map-file	(default 1000)
INF: [product] LENGTH = 0.0715 m	map-file	(default 0)

WAR: [product] VOLUME = 0.0002266 m3 calculated with
 {product.massperproduct/product.density}
 WAR: [product] TOTAL_VOLUME = 0.0002266 m3 calculated with {product.volume *
 product.N}
 WAR: [product] RADIUS = 0.03782 m calculated with {(3 * product.volume/(4 *
 pi))^(1/3)}
 WAR: [product] AREA = 0.016991 m2 calculated with {2 * pi * product.radius *
 product.length}
 WAR: [product] TOTAL_AREA = 0.016991 m2 calculated with {product.N *
 product.area}
 INF: [product] AIRSPEED = 0 m/s map-file (default 0)
 WAR: [product] DC_OUT = 0.007564 m calculated with {product.radius / 5}
 WAR: [product] DC_IN = 0.030256 m calculated with {4 * product.radius / 5}
 WAR: [product] R_int = 1.0164 Ks/J calculated with
 {product.dc_out/(product.area*product.lambda)}
 WAR: [product] R_ext = 9.8094 Ks/J calculated with {1/(product.area * (6 + 4 *
 product.airspeed))}
 WAR: [product] R_insulation = 0 Ks/J default
 WAR: [product] CAPACITY = 711.28 J/kg calculated with
 {product.specheat*product.massperproduct}
 INF: [product] TRANSPIRATION_BETA_AP = 9.3e-005 m/s map-file (default 1e-005)
 INF: [product] CONDENSATION_BETA_AM = 0.00071608 m/s map-file (default 1e-005)
 INF: [product] RESPIRATION_VM_O2_REF = 194.44 nmol/kg.s map-file (default 1.7)
 INF: [product] RESPIRATION_EA_VM_O2 = 52721 J/mol map-file (default 74836)
 INF: [product] RESPIRATION_KM_O2 = 4.61 % map-file (default 2.82)
 INF: [product] RESPIRATION_KMC_CO2 = 7.36 % map-file (default 3)
 INF: [product] RESPIRATION_KMU_CO2 = 42.7 % map-file (default 10000)
 INF: [product] RESPIRATION_VM_CO2_REF = 173.61 nmol/kg.s map-file (default 0.376)
 INF: [product] RESPIRATION_EA_VM_CO2 = 87907 J/mol map-file (default 57375)
 INF: [product] RESPIRATION_KMC_O2F = 2.013 % map-file (default 1)
 INF: [product] RESPIRATION_KMC_CO2F = 19.25 % map-file (default 10000)
 INF: [product] RESPIRATION_RQ = 0.65 - map-file (default 0.9)
 INF: [product] RESPIRATION_TEMP_REF = 8 C map-file (default 18)
 WAR: [packaging] MASS_PER_PACKAGING = 0.18581 kg calculated with
 {product.totalmass}
 INF: [packaging] TEMP = 20 C map-file (default 20 with {product.T})
 WAR: [packaging] SPECHEAT = 3828 J/kg.K calculated with {product.specheat}
 WAR: [packaging] LAMBDA = 0.56 W/m.K default
 INF: [packaging] N = 1 map-file (default 1)
 WAR: [packaging] TOTAL_MASS = 0.18581 kg calculated with
 {packaging.massperpackaging*packaging.N}
 WAR: [product] MASS_per_packaging = 0.18581 kg calculated with
 {product.totalmass/packaging.N}
 INF: [packaging] CO2 = 0.03 % map-file (default 0.03)
 INF: [packaging] O2 = 21 % map-file (default 21)
 INF: [packaging] N2 = 79 % map-file (default 79)
 INF: [packaging] RH = 43 % map-file (default 80)
 INF: [packaging] P = 1 bar map-file (default 1)
 INF: [packaging] LENGTH = 0.1205 m map-file (default 0)
 INF: [packaging] WIDTH = 0.1205 m map-file (default 0)
 INF: [packaging] HEIGHT = 0.108 m map-file (default 0)
 INF: [packaging] AREA = 0.0711 m2 map-file (default 0.081096 with {2 *
 packaging.length * packaging.width + 2 * packaging.height * (packaging.length + packaging.width)})
 WAR: [packaging] TOTAL_AREA = 0.0711 m2 calculated with {packaging.area *
 packaging.N}
 INF: [packaging] VOLUME_0 = 0.00157 m3 map-file (default 0.0015682 with
 {packaging.length * packaging.width * packaging.height})
 INF: [packaging] VOLUME_MAX = 0.00157 m3 map-file (default 0.00157 with
 {packaging.volume})

WAR: [packaging] TOTAL_volume = 0.00157 m2 calculated with {packaging.volume * packaging.N}
 WAR: [packaging] TOTAL_volume_max = 0.00157 m2 calculated with {packaging.volumemax * packaging.N}
 WAR: [packaging] PRESSURE_RELEASE_RATE = 1e-010 m3/Pa.s default
 INF: [packaging] BETA_AM = 0.0023187 m/s map-file (default 1e-005)
 INF: [packaging] D_O2 = 85.3 ml/day map-file (default 0)
 INF: [packaging] D_CO2 = 248.9 ml/day map-file (default 0)
 INF: [packaging] D_N2 = 28.4 ml/day map-file (default 0)
 INF: [packaging] D_H2O = 1.8 ml/day map-file (default 0)
 WAR: [packaging] EA_O2 = 0 J/mol default
 WAR: [packaging] EA_CO2 = 0 J/mol default
 WAR: [packaging] EA_N2 = 0 J/mol default
 WAR: [packaging] EA_H2O = 0 J/mol default
 WAR: [packaging] TEMP_REF_O2 = 0 C default
 WAR: [packaging] TEMP_REF_CO2 = 0 C default
 WAR: [packaging] TEMP_REF_N2 = 0 C default
 WAR: [packaging] TEMP_REF_H2O = 0 C default
 WAR: [packaging] DC_OUT = 0.022082 m calculated with {packaging.volume / packaging.area}
 WAR: [packaging] DC_IN = 0.044163 m calculated with {2 * packaging.volume / packaging.area}
 WAR: [packaging] K = 99999 W/m2.K silly default
 WAR: [packaging] KW = 99999 W/K silly default
 WAR: [packaging] AIRSPEED = 0 m/s default
 WAR: [packaging] R_int = 0.55459 Ks/J calculated with {packaging.dc_out / (packaging.lambda * packaging.area)}
 WAR: [packaging] R_ext = 2.3441 Ks/J calculated with {1/(packaging.area * (6 + 4 * packaging.airspeed))}
 WAR: [packaging] R_INSULATION = 0 Ks/J default
 INF: [pallet] MASS_PER_PALLET = 0 kg map-file (default 0.18581 with {packaging.totalmass})
 INF: [pallet] N = 1 map-file (default 1)
 WAR: [pallet] TOTAL_MASS = 0 kg calculated with {pallet.massperpallet*pallet.N}
 WAR: [pallet] TEMP = 20 C calculated with {packaging.T}
 WAR: [pallet] SPECHEAT = 3828 J/Kg.K calculated with {packaging.specheat}
 WAR: [pallet] LAMBDA = 0.56 W/m.K calculated with {packaging.lambda}
 WAR: [storage] TEMP = 20 C calculated with {pallet.T}
 INF: [storage] TOTAL_MASS = 0 kg map-file (default 0 with {pallet.totalmass})
 WAR: [product] R_int_prod_pack_center = 1.4616 Ks/J calculated with {(packaging.dc_in-product.dc_in) / (packaging.lambda * product.area)}
 WAR: [product] R_int_prod_pack_corner = 2.3208 Ks/J calculated with {packaging.dc_out / (packaging.lambda * product.area)}
 WAR: [absorber] MASS_per_Packaging = 0 kg default
 WAR: [absorber] MASS = 0 kg calculated with {absorber.massperpackaging*packaging.N}
 WAR: [scrubber] AREA_per_packaging = 0 m2 default
 WAR: [scrubber] AREA = 0 m2 calculated with {scrubber.areaperpackaging*packaging.N}