A QUALITY, ENERGY AND ENVIRONMENTAL ASSESSMENT TOOL FOR THE EUROPEAN COLD CHAIN

S.G. GWANPUA[(a)], P. VERBOVEN[(a)], B. E. VERLINDEN[(b)], S. VAN DER SLUIS[(c)], E. WESSINK[(d)], J. EVANS[(e)], T.BROWN[(e)], D. LEDUCQ[(f)], G. ALVAREZ[(f)], P. TAOUKIS[(g)], V. STAHL[(h)], D. THUAULT[(i)], I.CLAUSSEN[(j)], E. INDERGÅRD[(j)], B. M. NICOLAI[(a)], A. GEERAERD[(a)]

[(a)] BIOSYST-MeBioS, K.U.Leuven, Leuven, Belgium (annemie.geeraerd@biw.kuleuven.be)
[(b)] Flanders Centre of Postharvest Technology, Leuven, Belgium (bert.verlinden@biw.kuleuven.be)
[(c)] SAINT TROFEE, Renesse, The Netherlands (s.m.vandersluis@gmail.com)
[(d)] TNO, City, The Netherlands (edo.wissink@tno.nl)
[(e)] LSBU, Langford, UK (j.a.evans@lsbu.ac.uk)
[(f)] CEMAGREF, Antony, France (graciela.alvarez@cemagref.fr)
[(g)] Chemical Engineering Department, NTUA, Athens, Greece (taoukis@chemeng.ntua.gr)
[(h)] Aérial, City, France (v.stahl@aerial-crt.com)
[(i)] ADRIA,Quimper, France (dominique.thuault@adria.tm.fr)
[(j)] SINTEF Energy Research, City, Norway (Ingrid.C.Claussen@sintef.no)

ABSTRACT

According to 5th Informatory Note on Refrigeration and Food published by the International Institute of Refrigeration, 20% of the global losses in perishable products was due to lack of refrigeration. It is expected that increased use of refrigeration to reduce these losses will help meet the increasing food demands of the growing world population. However, the use of refrigeration already accounts for about 15% of world's electricity usage. In addition, the use of refrigeration significantly contributes to global warming via emission of CO_2. In this paper, a software tool was developed to assess food quality and safety evolution, energy usage and CO_2 emission of different refrigeration technologies along the European cold chain. A reference product was chosen for the main different food categories in the European cold chain. Software code to predict the products temperature using the room temperature as input, based on validated heat and mass transfer models, were written in Matlab (The Mathworks Inc., Natick, USA). Also, based on validated kinetic models for the different quality indicators of the reference products, a software code was written to calculate the quality and safety evolutions of the food product, using the predicted product temperature as input. Finally, software code to calculate the energy usage and Total Equivalent Warming Impact (TEWI) value of different refrigeration technologies was also written in Matlab. All three software codes were integrated, and a graphical user interface was developed. Using the graphical user interface, a user can tailor a cold chain scenario by adding different cold chain blocks. Each cold chain block has properties that can be modified. The tool can be used to compare different cold chains with respect to quality, safety, energy usage, and environmental impact.

1. INTRODUCTION

Along the cold chain, products are usually exposed to different temperature scenarios, and this affects the rate of quality changes. Many models have been developed to explain how temperature affects the evolution of product quality (Tijskens et al., 1998; Hertog et al., 2001; Johnston et al., 2001; De Smedt et al., 2002; Hertog et al., 2007; Gwanpua et al., 2012), and microbial growth (Ross et al., 2000; Giannakouroua et al., 2005) along the food chain but they have not yet been combined into a user-friendly software. Moreover, although refrigeration is very important in extending the shelf life of perishable products, it has a setback of being a major user of energy and contributes to global warming. Many software tools exist to access energy usage and environmental impact, and also separate tools exist to model microbial growth (Geeraerd et al., 2005). However, there is no software that can simultaneously assess the product quality evolution, energy usage and environmental impact of different refrigeration technologies.

The objective of this paper is to present a software tool, the Quality, Energy and Environmental Assessment tools, QEEAT, that can be used to assess different refrigeration technologies, with respect to product quality, energy use and environmental impact.

2. COMPONENTS OF THE QEEAT SOFTWARE

As the name suggests, the QEEAT software is made up of three major components: quality assessment tools, energy assessment tools, and environmental impact assessment tools.

2.1. Quality assessment tools

Five food categories (fruit, meat, fish, milk products, and vegetables) were identified as the main food categories in the European cold chain. In the framework of an EU-FP7-project FRISBEE, reference products for the different food categories and representative indicators were selected (Table 1).

Table 1. Safety and quality indicators for selected food products & start of the reference cold chains

Category	**Reference food product**	**Safety indicator**	**Quality indicator**
Chilled chain			
Fruit	Apple		Firmness Colour Weight loss Aroma
Meat	Pasteurized ham Pasteurized paté Raw smoked & salted ham (bacon)	*L. monocytogenes* Spoilage lactic acid bacteria	
Fish	Salmon fillets	Spoilage lactic acid bacteria	
Super chilled/super cooled			
Fish	Salmon fillets	Spoilage lactic acid bacteria	
Meat	Pork neck cutlet	Spoilage lactic acid bacteria	Drip loss
Frozen			
Milk products	Ice cream		Sensory perception Damping factor Firmness
Meat	Pork meat		Drip loss
Vegetables	Spinach		Chlorophyll content Sensory evaluation

Validated kinetic models were developed for the evolution of the different quality indicators, using real experimental data. These models, which consist of sets of coupled ordinary differential equations and/or algebraic equations, were programmed in Matlab (Matlab 2009b, The Mathworks Inc., Natick, USA).

2.2. Energy assessment tools

Energy use models were developed using simple heat balance models, taking into account the refrigerant used, the temperature sources, some data qualifying the efficiencies of the main components (heat exchangers, compressors…) and the global architecture of the refrigeration cycle. Software codes for these energy use models were also written in Matlab.

2.3. Environmental assessment tools

The environmental impact was estimated using CO_2 emission, based on the Total Equivalent Warming Impact (TEWI). These TEWI models were also programmed in Matlab.

2.4. The QEEAT user-interface

These three models were coupled and a user interface was built. A summary of the link between the QEEAT user-interface and the different models is shown in Figure 1.

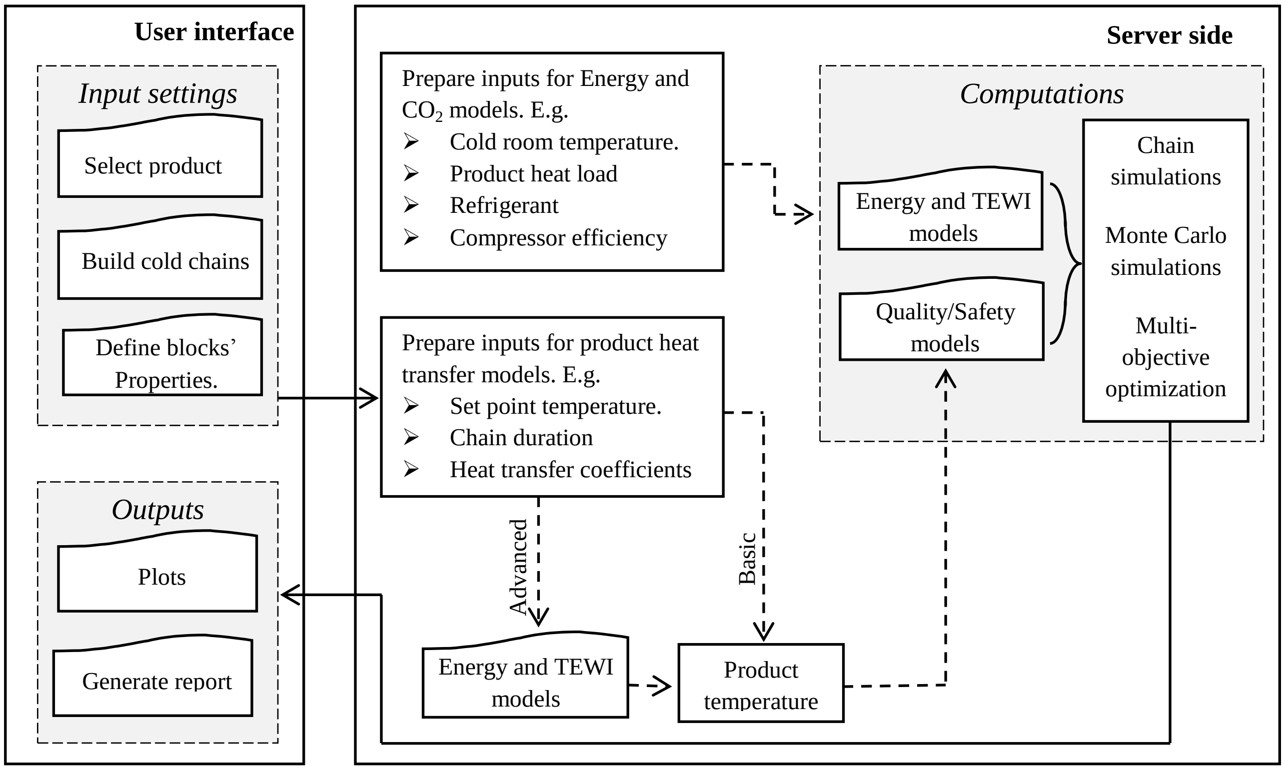

Figure 1. QEEAT structure.

There are two main simulation options, the Basic and the Advanced. In the Basic simulations, the product temperature is assumed to be the same as the set point temperature (room temperature), whereas in the Advanced simulations, heat and mass transfer models are used to predict the product temperature. These heat and mass transfer models were developed in Comsol Multiphysics (Comsol AB, Stockholm, Sweden), implying that this option can only be used if the user has his/her Matlab interfaced with Comsol.

The QEEAT software can be used to simulate the evolution of product quality, energy use, and environmental impact of the refrigeration technologies. In performing a simulation, the first step is to select a product. Next, different cold chains can be built either by adding cold chain blocks, either by relying on a reference cold chain, available for each product. Figure 2 shows an example of the QEEAT user-interface for a pasteurized ham chilled chain, with different cold chain blocks added. The properties for each block in the cold chain can be modified, as shown in Figure 3. The default values used in each block are based on a study that was carried out to define a reference cold chain for different food products in the European cold chain (Mieog and Verwoerd 2004).

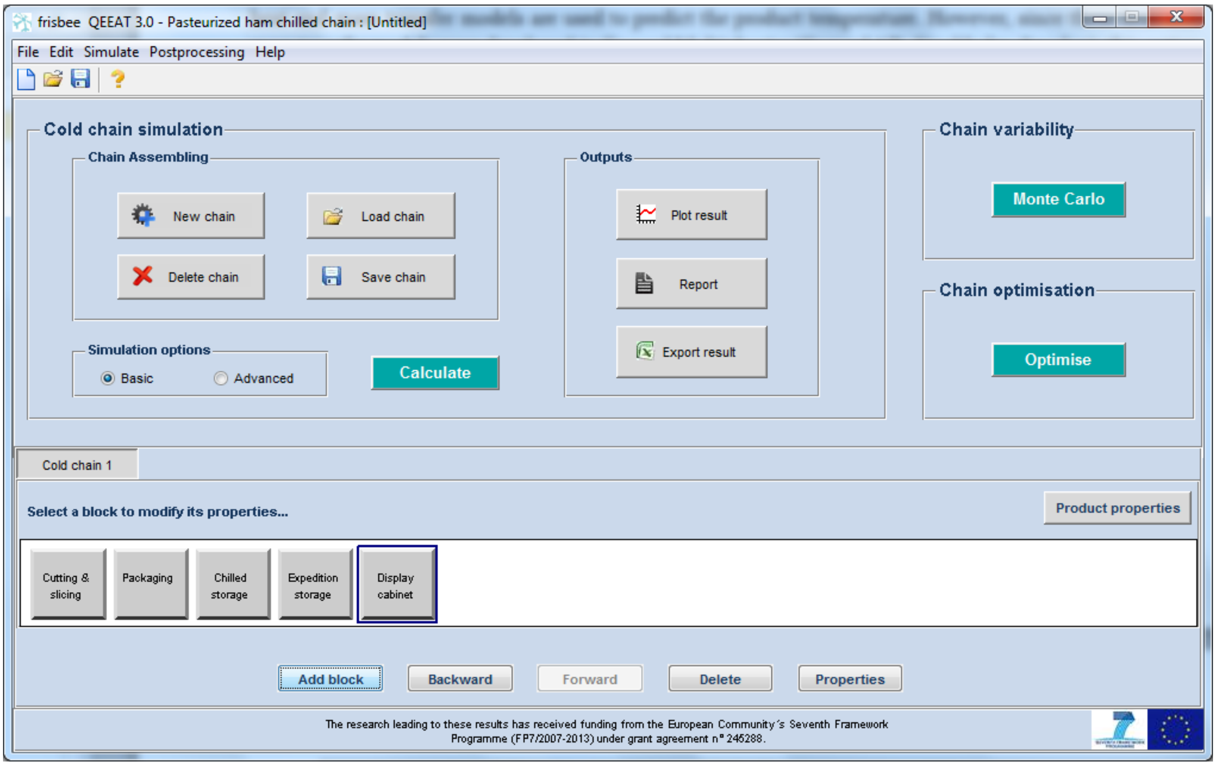

Figure 2. The QEEAT user-interface showing different cold chain blocks in a pasterurized chilled chain.

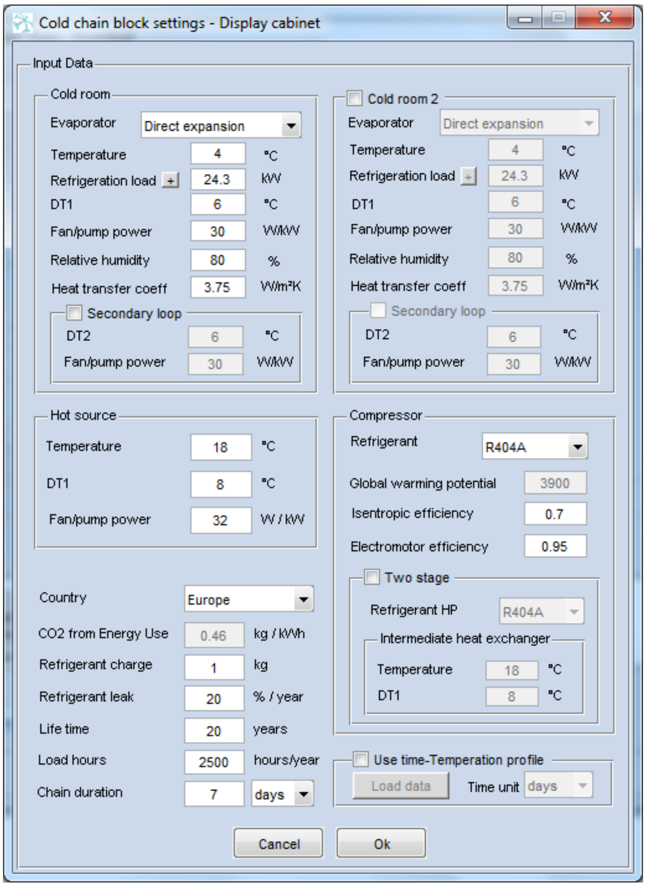

Figure 3. The properties sub-UI for a display cabinet in a pasteurized ham chilled chain.

3. ILLUSTRATIVE EXAMPLE

As a case study to illustrate the use of the QEEAT software, the apple chilled chain will be used to simulate the effect of different set point temperatures of the storage cool room, the use of controlled atmosphere (CA) storage, and different refrigerants on the performance of the cold chain. A simple reference apple chain was defined as follows: precooling for 7 days at 0°C, application of CA and storage at 1°C for 9 months, non-refrigerated transport to the super market, and storage at 12°C in display cabinets at retailers for 14 days. Three other scenarios were defined: in one, the temperature of the CA storage was changed to 3°C; in another, CA storage was replaced by normal storage in air; in the last, instead of using ammonia (R717) as a refrigerant in the refrigeration system for the long CA storage, the refrigerant R22 was used. The four different scenarios are summarized in Table 2.

Table 2. Different scenarios for the apple chilled chain.

Scenarios	Set point T(°C)	Controlled atmosphere	Refrigerant
1 (reference)	1	Yes	R717
2	1	No	R717
3	3	Yes	R717
4	1	Yes	R22

Using the QEEAT software, the 3 apple chains are compared to the reference. The results of the simulations are shown in Figure 4. One can observe that storing at 3°C, instead of the recommended storage at 1°C, will lead to more softening of the apples, but lesser energy use (about 6%) and CO_2 emission (Figure 4C and 4E). However, it is possible that although the fruit softens more when stored at 3°C, the firmness at the end of storage is still within an acceptable range. If this is the case, then the grower or auctioneer might consider increasing the storage temperature by about 1 or 2 °C, something that might significantly reduce the amount of energy used during storage. Before implementing such changes, it is very critical that the effect of increasing the temperature on other quality aspects of the fruit is considered, such as browning disorder or development of off flavors. The importance of CA storage can also be seen from Figure 4B, which shows that there is rapid softening when apple is stored in normal air.

Another observation from Figure 4F is that using R22 refrigerant, there is more emission of CO_2 to the environment, when compared to R717 (ammonia), due to its high global warming potential, a (Figure 4D).

4. DISCUSSIONS

The software presented in this publication offers a very useful tool that can be used to assess different refrigeration systems with respect to quality of the food products, energy use and environmental impact. It can be used to predict what-if scenarios, such as temperature abuse or alternative process values. The current software will be the basis for a future tool to test alternative and emerging refrigeration technologies. It can also aid the design of new refrigeration technologies. Other aspects of the software not illustrated in this paper are the on-going developments on multi-objective optimization of a cold chain and Monte Carlo simulations.

All the quality models that are implemented in this tool are based on data obtained from dedicated experiments. This software is developed as part of the FIRBEE project, and the different quality models were developed by different partners which are research groups with expertise in their respective products.

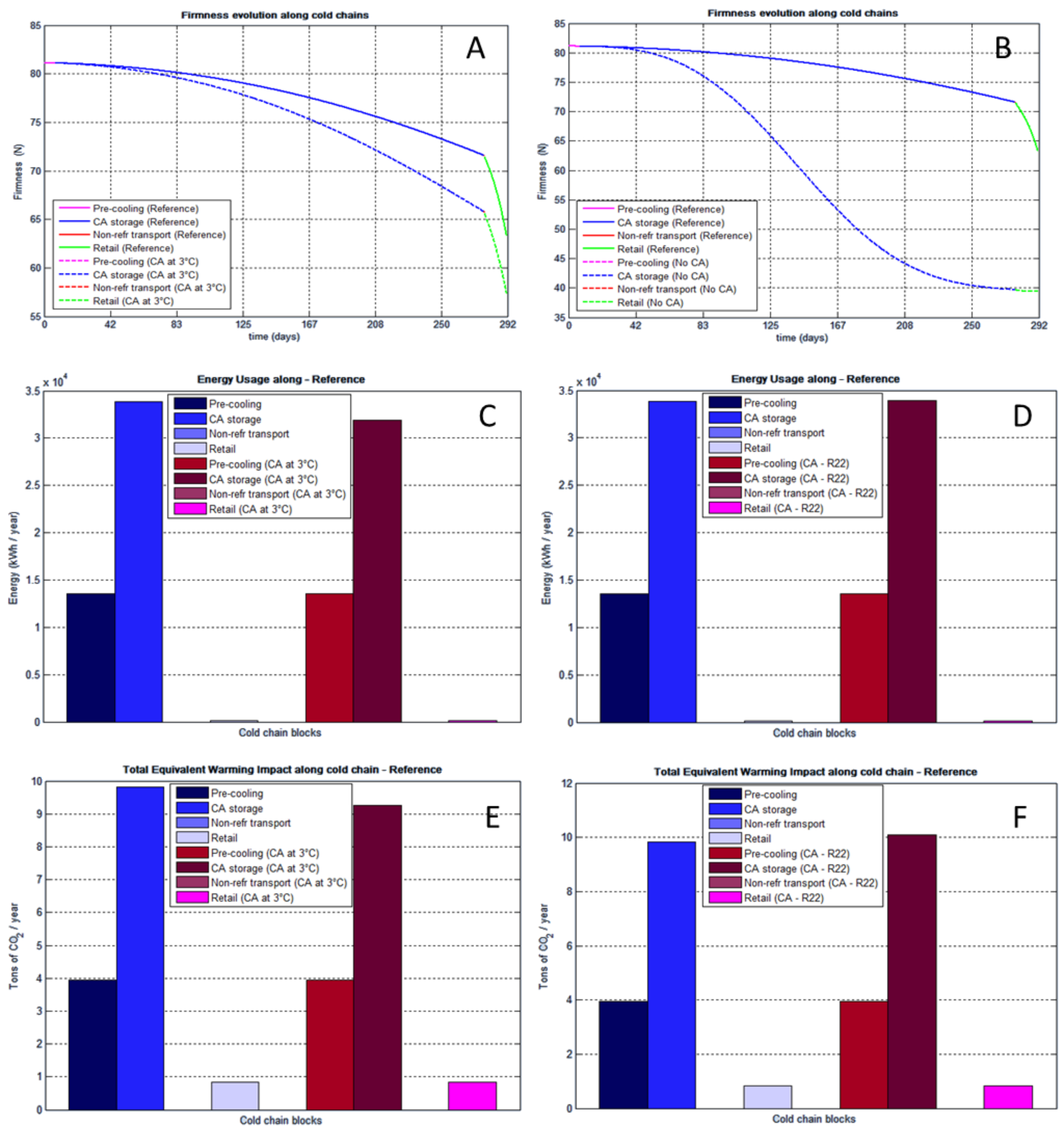

Figure 4. Graphical output from QEEAT chain simulations. In A and B, the reference chain is compared to using CA storage at 3°C and storage in normal air respectively; in C and D, the energy usage for the reference chain is compared to when CA storage was done at 3°C or using R22 refrigerant; in E and F the CO_2 emission for the reference chain is compared to when CA storage was done at 3°C or using R22 refrigerant.

5. CONCLUSIONS

We believe that the QEEAT 3.0, which is a third version of the QEEAT software, is very user-friendly. Although the QEEAT 3.0 is built on Matlab, a compiled version is also available for both Windows 32 and 64 bits. At the moment, it is the purpose to incorporate the tool through a website-interface, namely the Virtual European food refrigeration platform, which will contain besides the tool, also other results and cosumer information related with the FIRSBEE project. .

6. ACKNOWLEDGEMENT

This publication has been produced with the financial support of the European Union (grant agreement FP7/2007-2013 – Frisbee). The opinions expressed in this document do by no means reflect the official opinion of the European Union or its representatives.

REFERENCES

De Smedt, V., Barreiro, P., Verlinden, B.E., Veraverbeke, E.A., De Baerdemaeker, J., Nicolaï, B.M., 2002. A mathematical model for the development of mealiness in apples. Postharvest Biol. Technol. 25, 273 – 291.

Geeraerd, A.H., Valdramidis, V.P., Van Impe, J.F., 2005. GInaFiT, a freeware tool to assess non-log-linear microbial survivor curves. Int. J. Food Microbiol. 102, 95–105

Giannakouroua, M.C., Koutsoumanisb, K., Nychasc, G.J.E., Taoukisa, P.S., 2005. Field evaluation of the application of time temperature integrators for monitoring fish quality in the chill chain. Int. J. Food Microbiol. 102, 323–336.

Gwanpua, S.G., Verlinden, B.E., Hertog, M.L.A.T.M., Bulens, I., Van de Poel, B., Van Impe, J., Nicolaï, B.M., Geeraerd, A.H., 2012. Kinetic modeling of firmness breakdown in "Braeburn" apples stored under different controlled atmosphere conditions. Postharvest Biol. Technol. 67, 68–74.

Gwanpua, S.G, Verlinden, B., Van der Sluis, S., Wessink, E., Evans, J., Brown, T., Leducq, D., Graciela, A., Taoukis, P., Stahl, V., Thuault, D., Claussen, I., Verboven, P., Nicolai, B., Geeraerd, A., 2011. Towards a framework for evaluation of energy consumption, sustainability and associated food quality in the European cold chain. International Congress on Engineering and Food (ICEF 2011). Athens, Greece, 22 - 26 May 2011.

Hertog, M.L.A.T.M., Lammertyn, J., De Ketelaere, B., Scheerlinck, N., Nicolaï, B.M., 2007. Managing quality variance in the postharvest food chain. Trends Food Sci. Technol. 18, 320–332.

Hertog, M.L.A.T.M., Nicholson, S.E., Banks, N.H., 2001. The effect of modified atmospheres on the rate of firmness change in "Braeburn" apples. Postharvest Biol. Technol. 23, 175–184.

Johnston, J.W., Hewett, E.W., Hertog, M.L.A.T.M., Roger Harker, F., 2001. Temperature induces differential softening responses in apple cultivars. Postharvest Biol. Technol. 23, 185–196.

Mieog A.J. and Verwoerd M., 2004. Eindrapport aanvulling bouwwijzer. TNO report R 2400/530 (in Dutch), Apeldoorn, NL.

Ross, T., Dalgaard, P. and Tienungoon, S., 2000. Predictive modelling of the growth and survival of Listeria in fishery products. Int J Food Microbiol 62, 231–245.

Tijskens, L.M.M., Rodis, P.S., Hertog, M.L.A.T.M., Kalantzi, U., van Dijk, C., 1998. Kinetics of polygalacturonase activity and firmness of peaches during storage. J. Food Eng. 35, 111–126.