COLD CHAIN MANAGEMENT TOOLS FOR THE OPTIMIZATION OF READY-TO-EAT FOOD PRODUCTS COLD CHAIN

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Food cold chain in ... numbers

The main shelf-life determining post-processing parameter in chilled/frozen food products is temperature

- ⮔ **60%** the food we consume is **chilled**
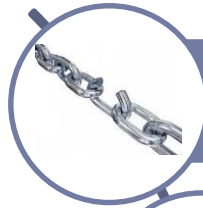- ⮔ **10%** the food we consume is **frozen**

Post-harvest/processing food waste:
about 25% of the food production worldwide

Cold chain management tools & Temperature control throughout the cold chain

☑ Reducing food food waste in post harvest/post processing of foods

☑ To minimize perishable foods that are lost before consumption

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Cold Chain Challenges

Food product temperature abuse

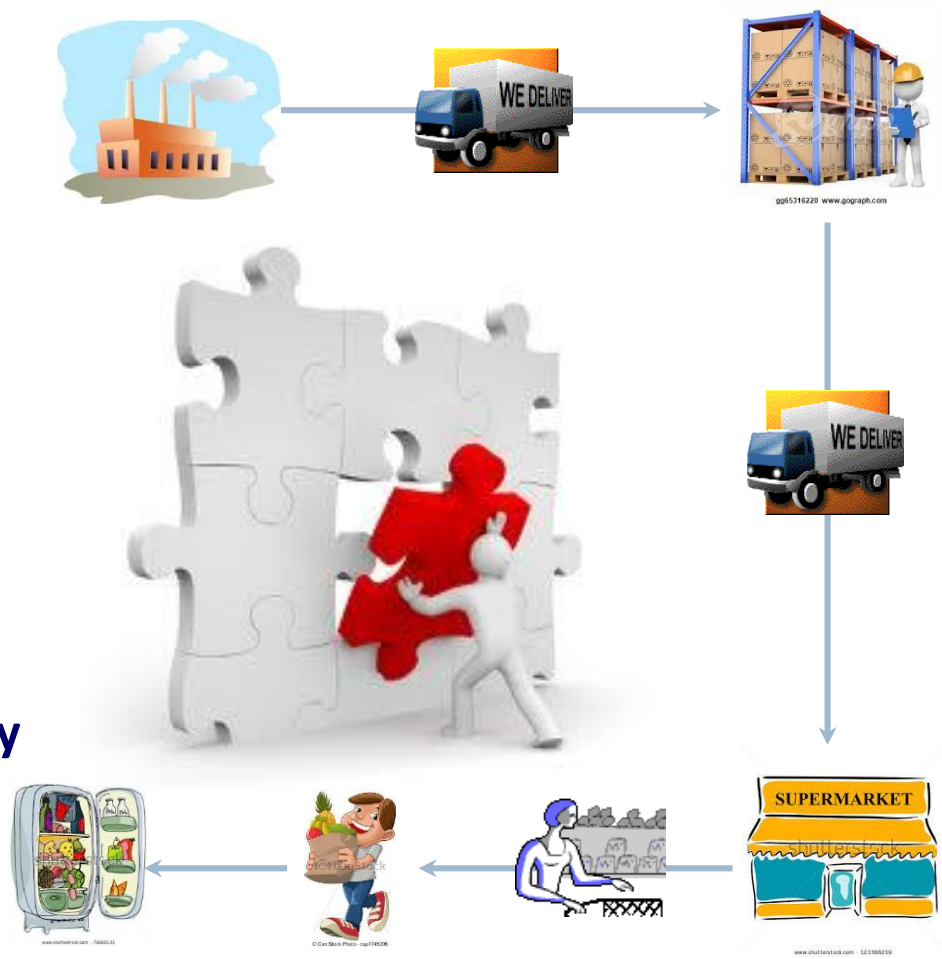Shelf-life labelling

Food waste

Energy consuming technologies

Environmental impact

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Taking cold chain's temperature

- ☑ **Assumptions**
- ☑ **"What if" scenarios**
- ☑ **Regulations**

- ❓ **How weak is the cold chain**

- ❓ **Which stage is the weakest link**

- ❓ **What is the impact on food quality and shelf life**

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Cold Chain Database development

☑ **Develop a comprehensive database of the cold chain in Europe**

☑ **Monitoring the food cold chain through focused field tests in Europe**

☑ **Assess food quality at different stages of the supply chain**

☑ **Develop cold chain management tools**

FRISBEE: European Union funded 4-year Project (2010-2014)
*F*ood *R*efrigeration *I*nnovations for *S*afety, consumers' *B*enefit,
*E*nvironmental impact and *E*nergy optimization along the cold chain in Europe

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Cold Chain Database development

Cold Chain Data Collection

Data from all stages of the cold chain (from production to consumption) were collected along the supply chain for products in different European regions.

- ✓ Consortium own data
- ✓ Published data
- ✓ Industry and cold chain parties (distributors, retailers)
- ✓ Associations
- ✓ Research projects

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Where can I find the Cold Chain Database?

www.frisbee-project.eu

www.frisbee-project.eu/coldchaindb

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Cold Chain Database

cold chain database
frisbee

Search Data   Build Cold Chain   Search Data (demo)   User : **National Technical University of Athens** - Logout

Stage/step of cold chain
- [ ] Production stage - food chilling operation
- [ ] Production stage - food freezing operation
- [ ] Production warehouse
- [ ] Transportation
- [ ] Distribution warehouse
- [ ] Retail warehouse

Food storage temperature range
- [ ] Chilled
- [ ] Superchilled
- [ ] Frozen

Selected Results

Please make your selections on the left pane or load a previously saved set of records.

Cold Chain Database Records

Total Records : 15237

Mean temperature value : -5.64 °C
Minimum temperature value : -41.5 °C
Maximum temperature value : 39.3 °C

Characterization of food
- [ ] Fresh unprocessed
- [ ] Fresh minimally processed
- [ ] Minimally processed ready to cook
- [ ] Processed ready to eat
- [ ] Other

Type of food
- [ ] Meat and meat product
- [ ] Fish and fish product
- [ ] Fruit and fruit product
- [ ] Vegetables
- [ ] Milk and milk product
- [ ] Mixed
- [ ] Fresh cut salads

Saved Recordsets

#	Filename	Date	Action
1	Vegetables Complete cold chain	26/08/2014	Load Set
2	wholeChainFrozen	01/07/2013	Load Set
3	consumer_freezer	01/07/2013	Load Set

Food product
- [ ]
- [ ] 4 slices of cooked ham
- [ ] Aubergine salad
- [ ] Banana
- [ ] Beef
- [ ] Beef carpaccio
- [ ] Beef joint

Packaging
- [ ] Air packaged
- [ ] Modified atmosphere packaged
- [ ] Vacuum packaged
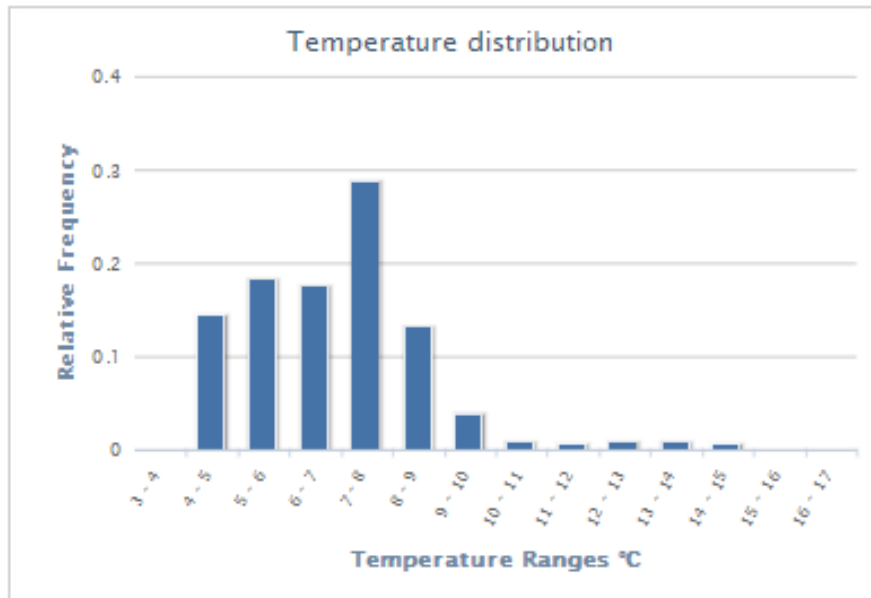- [ ] Non-packaged
- [ ] Bulk
- [ ] Other

View My Own Submitted Data

3529 total measurements
Click and drag in the plot area to zoom in
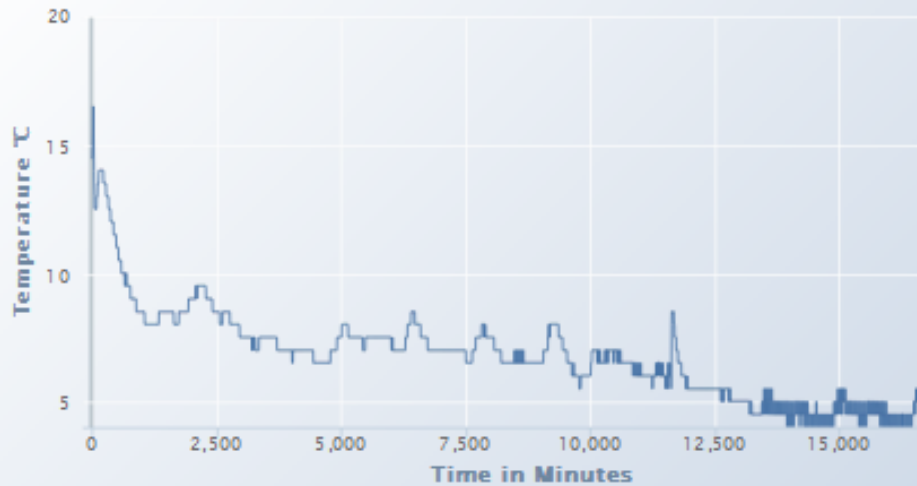
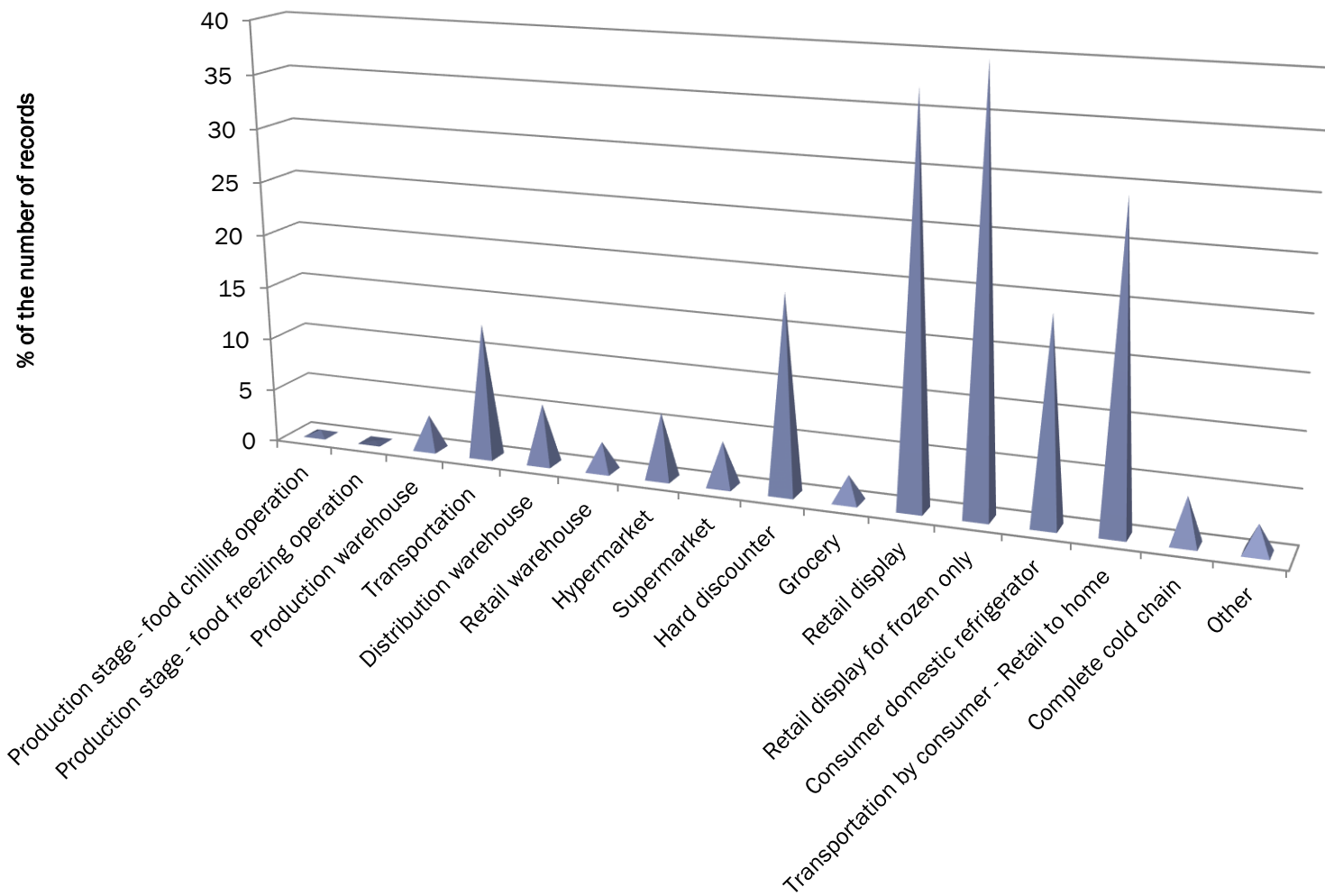

New total storage time : 17640 mins. ⇄ Reload Chart

Temperature distribution

Stage/step of cold chain	Consumer domestic refrigerator
Country of origin	France
Destination country	France
Time data logger started collecting data (hrs:min)	12:00
Food storage temperature range	Chilled
Characterization of food	Processed ready to eat
Type of food	Meat and meat product
Food product	Flaky product
Packaging	Air packaged
Packaging material	
Weight/size of food	220 g
Recommended food storage conditions (°C)	2 to 4 C
Temperature of facility -setting (°C)	
Type of storage and distribution equipment	
Characteristics of storage and distribution equipment (heat transfer mode, air velocity...)	
Data collecting equipment	Data logger
Type of data collecting	

Cold Chain Database….in numbers!

Not defined (20%)

Mixed (3%)

Milk and milk products (26%)

Meat and meat products (43%)

Vegetables (3%)

Fruit and fruit products (2%)

Fish and fish products (3%)

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Cold Chain Database....in numbers!

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Field test evaluation of the Cold Chain in Europe

☑ **Field test evaluation of the cold chain**

France, Greece, Hungary, The Netherlands, UK

☑ **Focusing on perishable Ready-To-Eat (RTE) chilled products**

Vacuum packed smoked turkey slices, MAP or cooked ham slices, other RTE

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Field Test Design-France

FOOD PRODUCT

✓ Product: Sliced cooked ham

✓ Shelf life: 30 days

✓ Two packages of 4 slices of ham/per package (sold together)

DATALOGGER

✓ Mini Nomad RFID temperature logger

✓ Omega Engineering Inc.

✓ The data logger is placed between the two batches of
   4 slices of ham and all is filmed (the recorder is hidden)

FIELD TEST CONSUMER REWARD

Rewarding the consumers with a 5 € supermarket voucher

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Field Test Photos-France

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Field Test Design-France

Conducted in November 2012

223 recorders were used for the field test
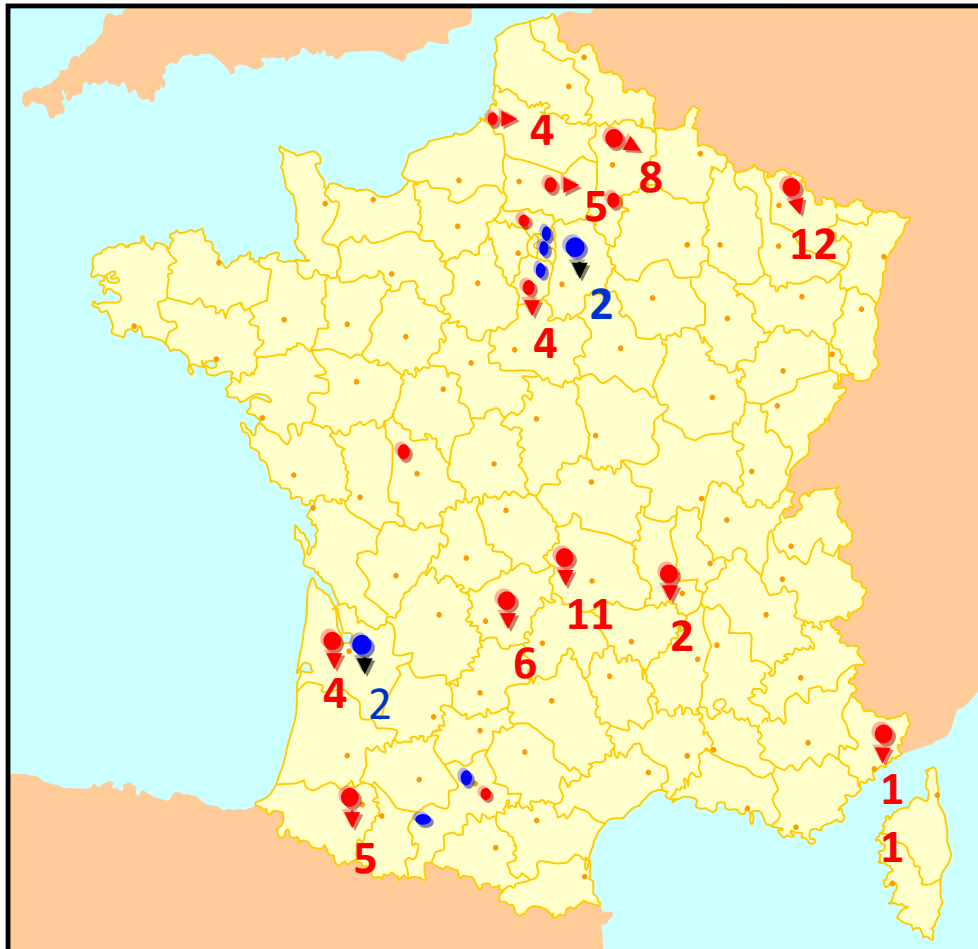
Production/Production Warehouse

Distribution platform for hypermarket → Distribution platform for supermarket

● Hypermarket

● Supermarket

Transport by consumer

Transport by consumer

Domestic refrigerator

Domestic refrigerator

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Field Test Design-Greece

DATALOGGER
✓Mini Nomad RFID temperature logger
✓Omega Engineering Inc.

FOOD PRODUCT

✓ **Product:** Smoked turkey slices

✓ **Shelf life:** 2 months

✓ **Packaging:** An outside plastic transparent container within which the slices are placed

✓ in vacuum packed (skin packed) in a second film

FIELD TEST GIFT COUPON
Rewarding the consumers with a free product like the one they purchased and contained the logger.

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Field Test Photos-Greece

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Field Test Design-Greece

240 products, 24 supermarket stores, 12 cities in Greece

Field Test Cold Chain Stages

Production/Production Warehouse
~12 hours

↓

Distribution Warehouse
2 distribution centers

↓

Supermarket Warehouse and Display
24 supermarkets stores in 12 cities

↓

Consumer transport

↓

Consumer domestic refrigerator

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Field test results-Retrieved time-temperature profile

Return rate: ~40%

Number of retrieved dataloggers in total (all countries): 350

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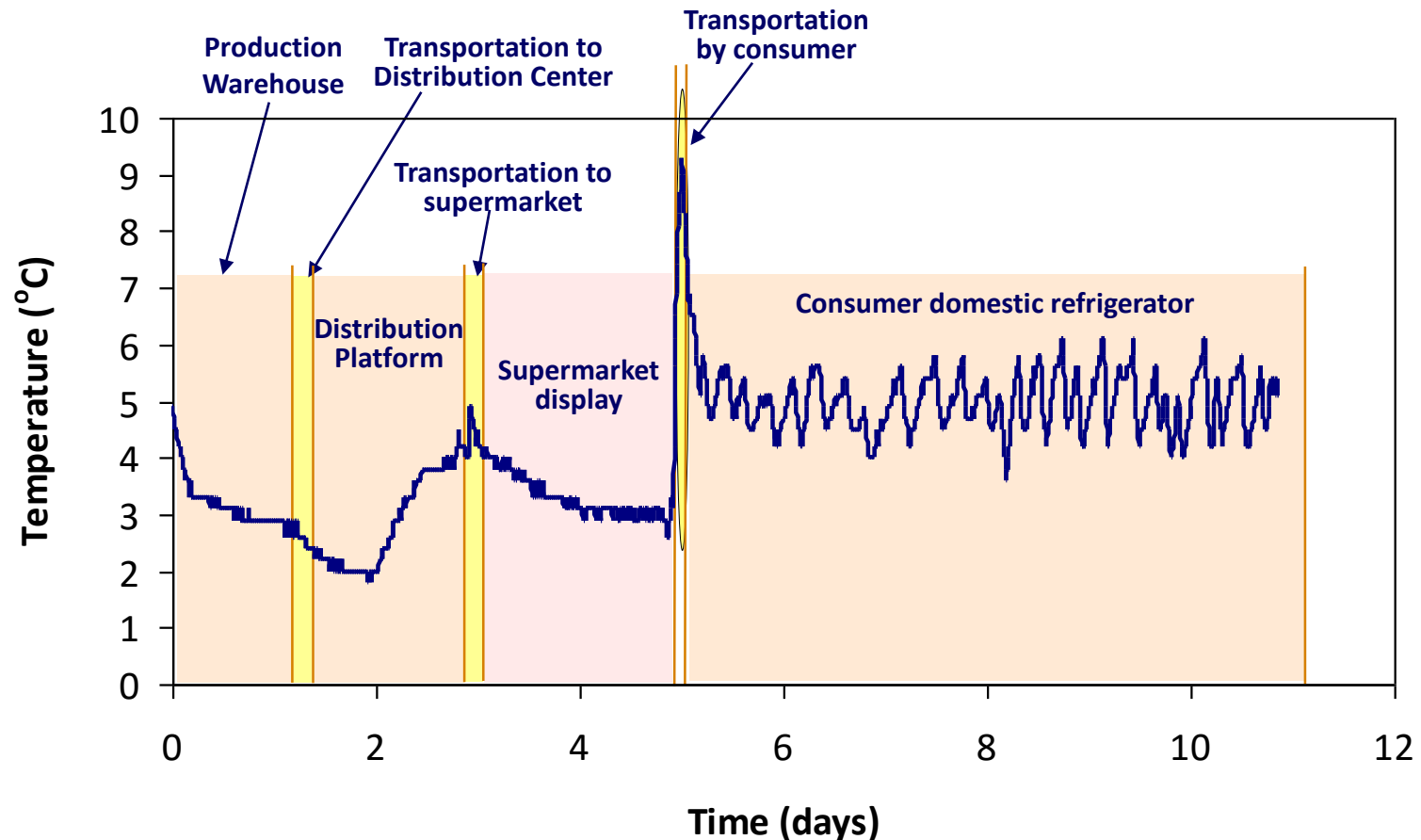
Field test time temperature retrieved profiles
Temperature distributions

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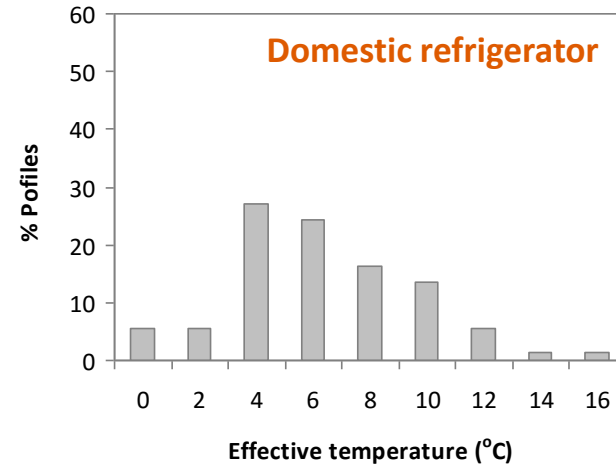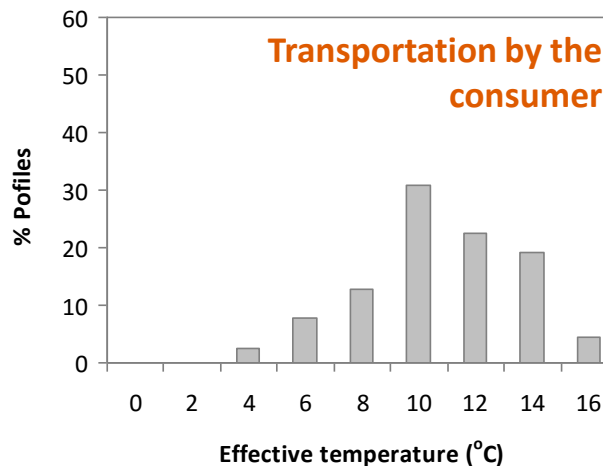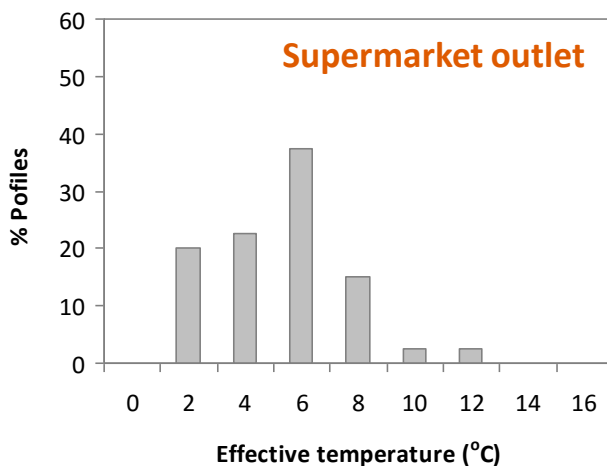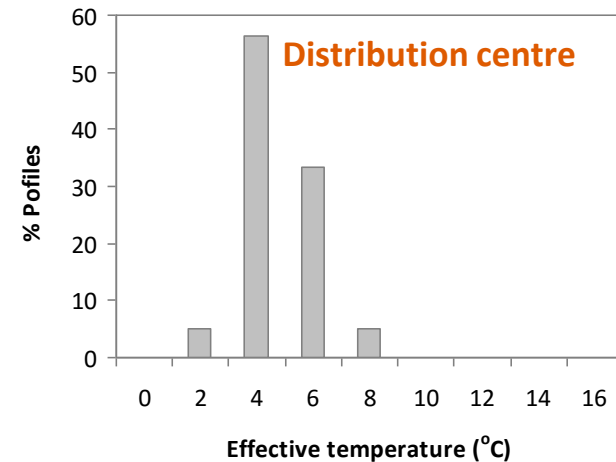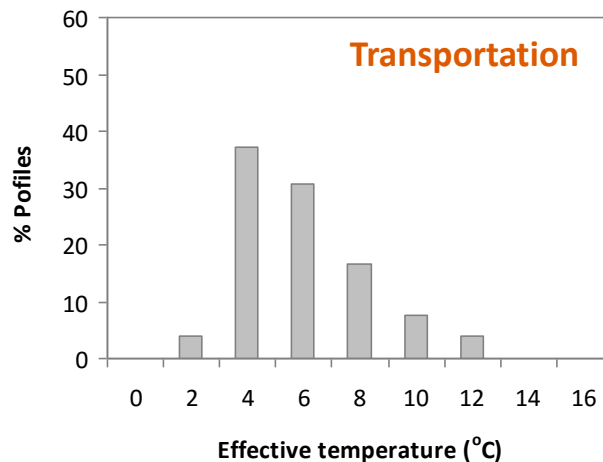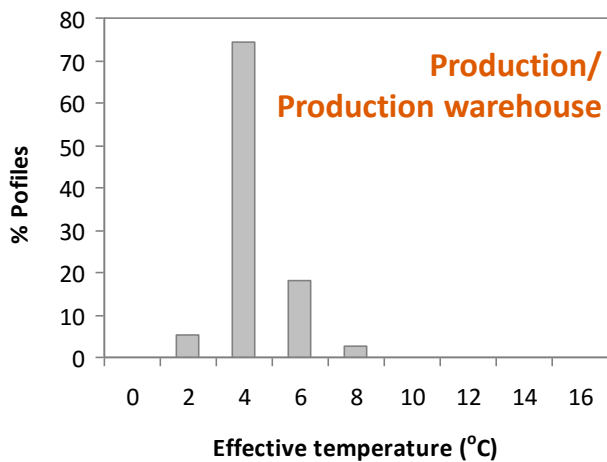
Field tests results uploaded to the Cold Chain Database

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www.frisbee-project.eu/coldchaindb

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Cold Chain Database tools:

Visualize & manage your own data
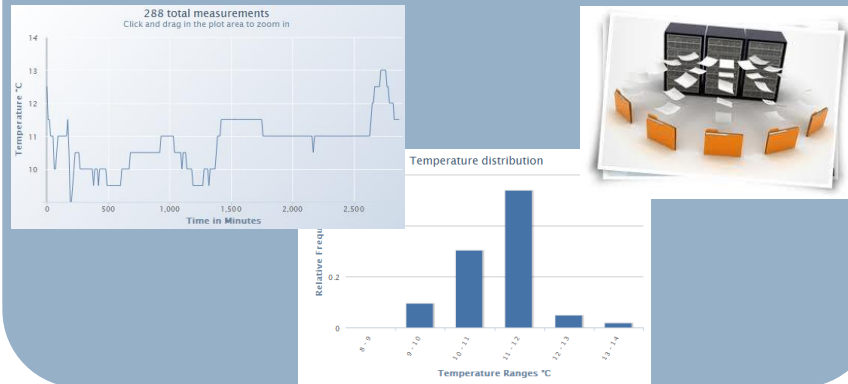
Search within more than 16.000 profiles of the Cold Chain Database

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Cold Chain Database tools:
Build Cold Chain Scenario Profiles

Visualize & manage your own data
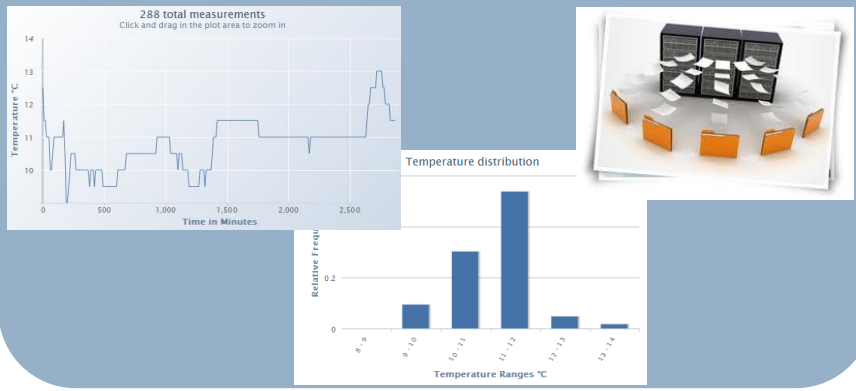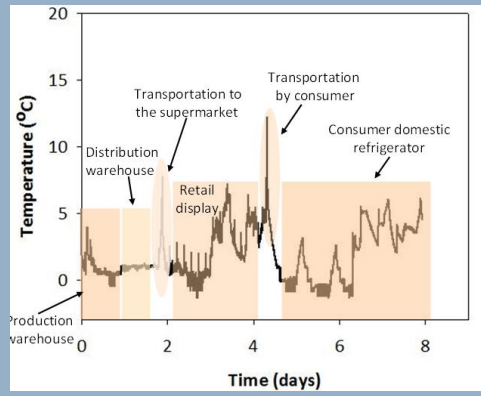
Search within more than 16.000 profiles of the Cold Chain Database

Build Cold Chain Scenario Profiles

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Cold Chain Database tools:
Determine food product quality

Visualize & manage your own data

Search within more than 16.000 profiles of the Cold Chain Database
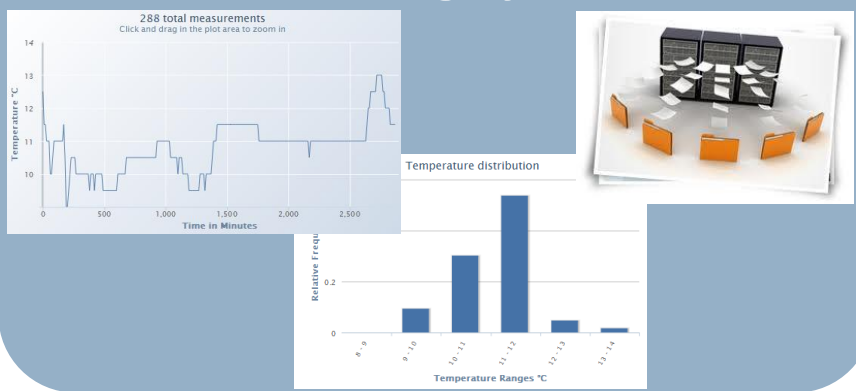
Determine food product quality along the cold chain

Cold Chain Predictor Software

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Cold Chain Predictor software

Cold Chain Predictor (CCP):

Designed to simulate a cold chain by "building" a time-temperature history based on real cold chain data contributed to the Cold Chain Database

Real data on temperature conditions throughout the cold chain from production to consumption for selected food product(s)

INPUT

Cold Chain Database
www.frisbee-project.eu/coldchaindb

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INPUT

Cold Chain Database
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FRISBEE Cold Chain Predictor v1.1

Cold Chain Predictor
Cold Chain Predicting and Shelf Life Calculating Tool

Build Representative Profile

Use your own t-T Profile

Use a specific Profile from Cold Chain Database

frisbee

© Copyright 2011 by NTUA, Greece   Disclaimer   Instructions

CCP software runs Monte Carlo simulation using retrieved real time-temperature data found in the Cold Chain Database

OUTPUT

☑ *Representative time-temperature profile of the cold chain for selected food products*
☑ *Estimation of food products remaining shelf life at different stages of the cold chain*

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Cold Chain Database
&
Cold Chain Predictor Software

Demonstration: RTE food products

Cooked ham case study
Determining the product quality status and shelf life at the different stages of the cold chain using

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Cooked ham kinetic model development

Storage tests experiments

Data generation

Primary modeling

Secondary modeling

Kinetic model development
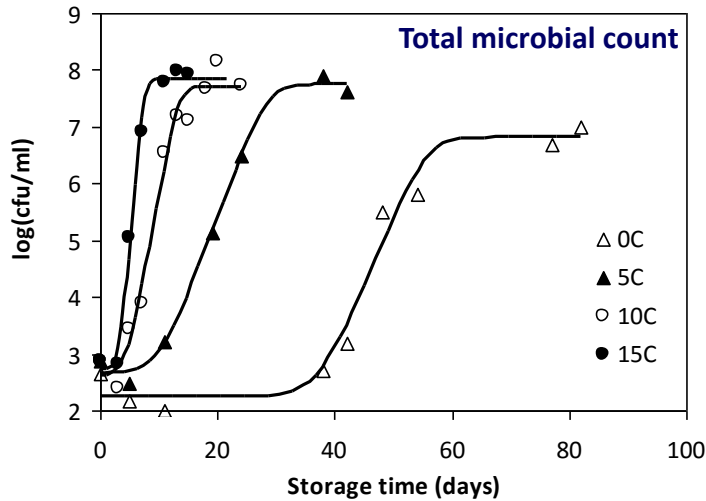
Baranyi model (*Baranyi & Roberts, 1994*)

$$y(t) = y_0 + \mu_{max}A(t) - \frac{1}{m}\ln\left(1 + \frac{e^{m\mu_{max}A(t)} - 1}{e^{m(y_{max}-y_0)}}\right)$$

Kinetic parameters determination
- Growth rate
- Lag phase
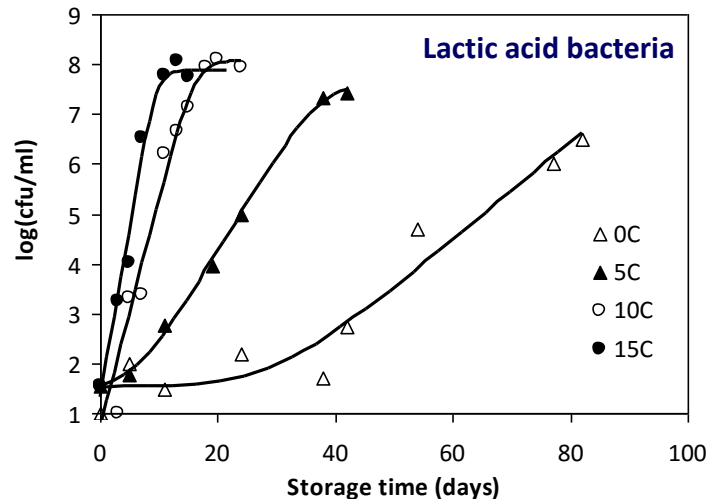
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Cooked ham kinetic model development

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Secondary modeling

Kinetic model development

Total microbial count

Growth rate (days^{-1}) vs $(1/T - 1/T_{ref}) \times 10^3$

Lactic acid bacteria

Growth rate (days^{-1}) vs $(1/T - 1/T_{ref}) \times 10^3$
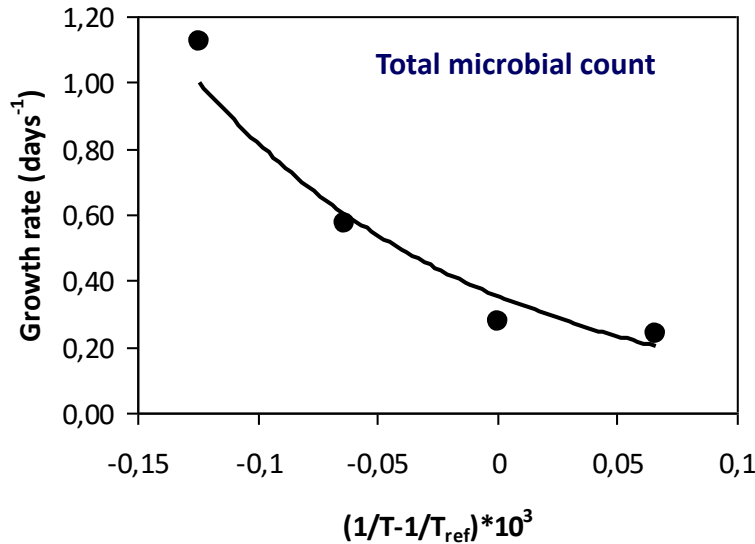
Determination of Arrhenius kinetic parameters:

☑ Growth rate at reference storage temperature

☑ Activation energy value (E_a)
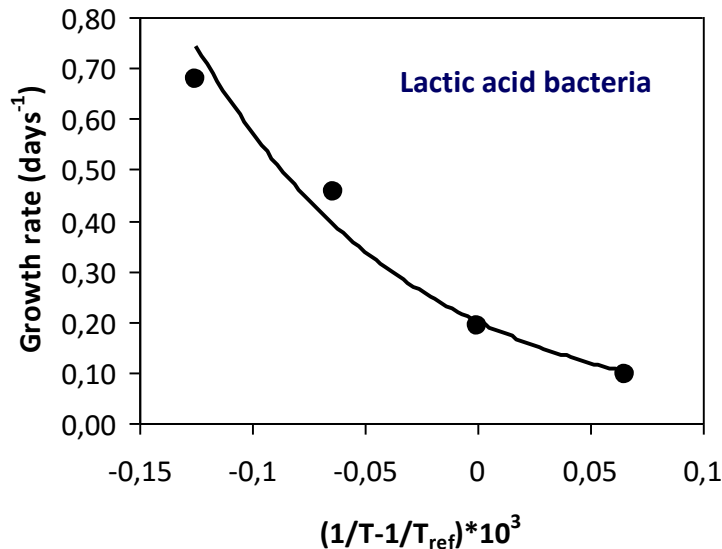
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Kinetic model development
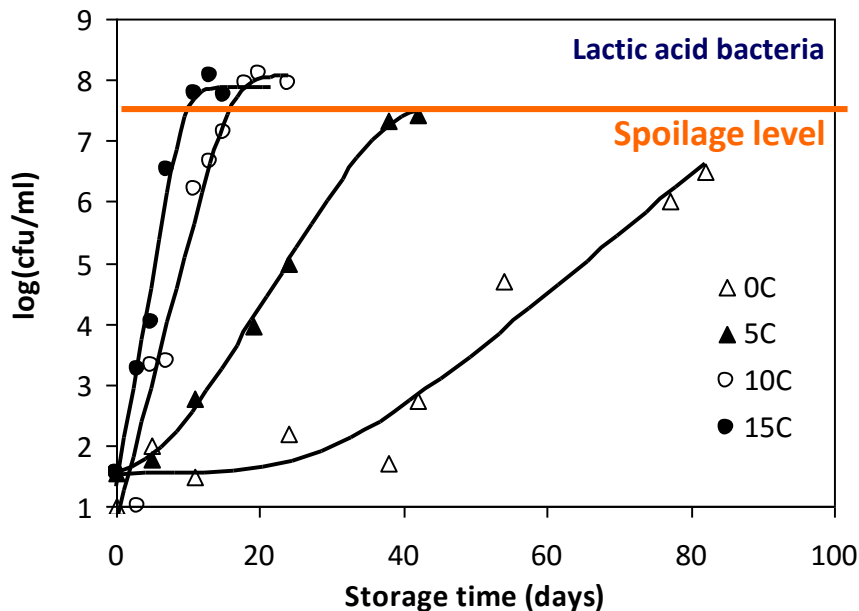
☑ **Lactic acid bacteria** was identified as the **specific spoilage organism** (SSO)

☑ Sensory results: **spoilage level** corresponding to the **end of shelf life** was **7.5 log(cfu/g)**

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Cooked ham kinetic model development

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Secondary modeling

Kinetic model development

☑ Kinetic model predicting the **microbial growth** of lactic acid bacteria in vacuum packed cooked ham as a function of storage temperature and time

$$\log N = \log N_o + k_{ref} \cdot \exp\left[-\frac{E_a}{R} \cdot \left(\frac{1}{(T_{storage} + 273,16)} - \frac{1}{(T_{ref} + 273,16)}\right)\right] \cdot t_{storage}$$

☑ Kinetic model predicting the **remaining shelf life** of vacuum packed cooked ham for a given storage temperature and time

$$SL_R = \frac{\log N_F - \log N_o - k_{ref} \cdot \exp\left[-\frac{E_a}{R} \cdot \left(\frac{1}{(T_{storage} + 273,16)} - \frac{1}{(T_{ref} + 273,16)}\right)\right] \cdot t_{storage}}{k_{ref}}$$

⮑ **Developed kinetic models incorporated in the FRISBEE Tool Software**

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Kinetic models validation prior to software implementation

☑ Time-temperature controlled storage cabinets simulating the representative time temperature profile generated by the Cold Chain Predictor Software

☑ Storage of cooked ham samples
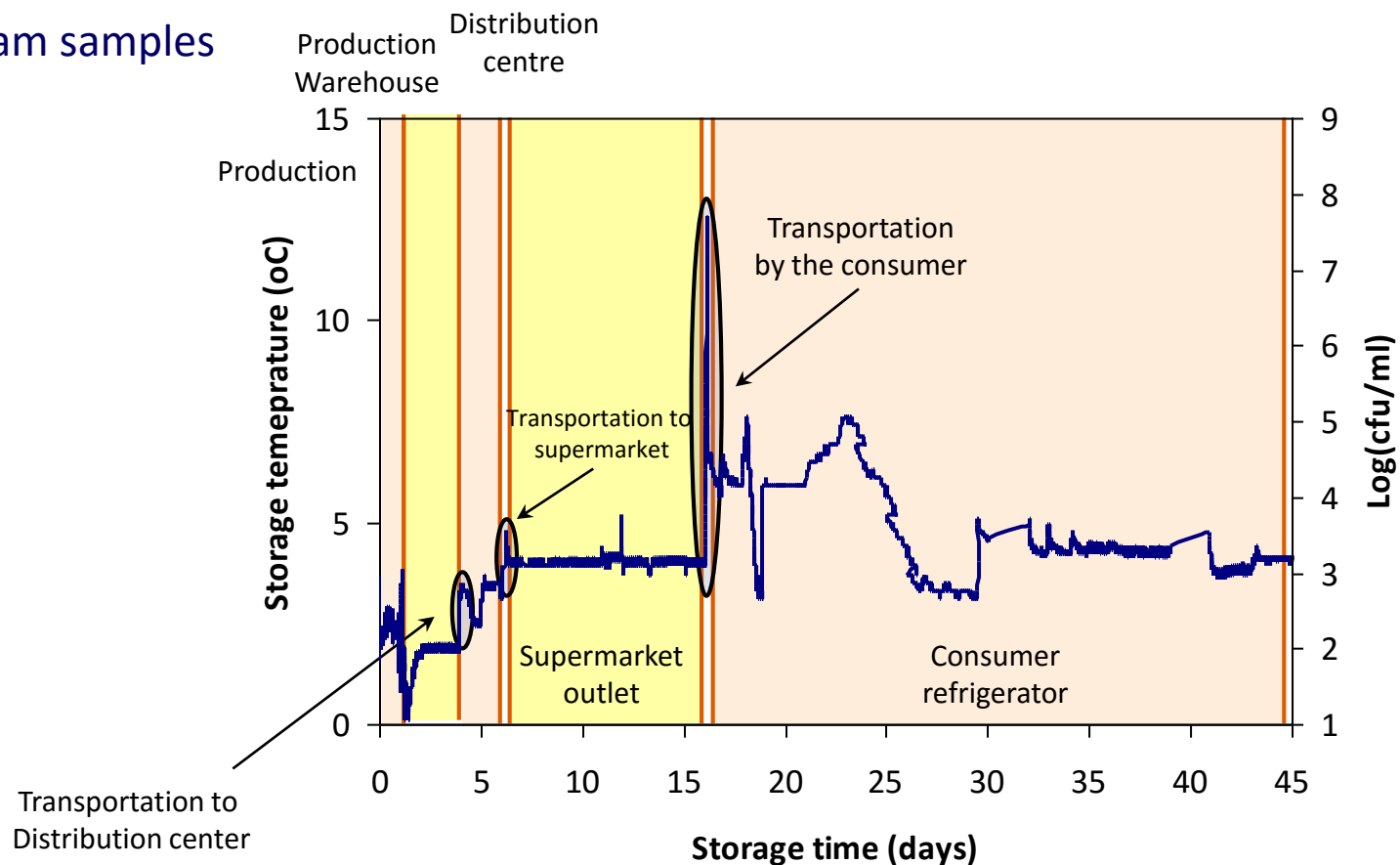
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Kinetic models validation prior to software implementation

☑ Time-temperature controlled storage cabinets

$$SL_R = \frac{\log N_F - \log N_o - k_{ref} \cdot \exp\left[-\frac{E_a}{R} \cdot \left(\frac{1}{(T_{storage} + 273,16)} - \frac{1}{(T_{ref} + 273,16)}\right)\right] \cdot t_{storage}}{k_{ref}}$$

☑ Storage of cooked ham samples

☑ Microbiological analysis performed at predetermined time intervals simulated to be the different cold chain stages

☑ Remaining shelf life estimation

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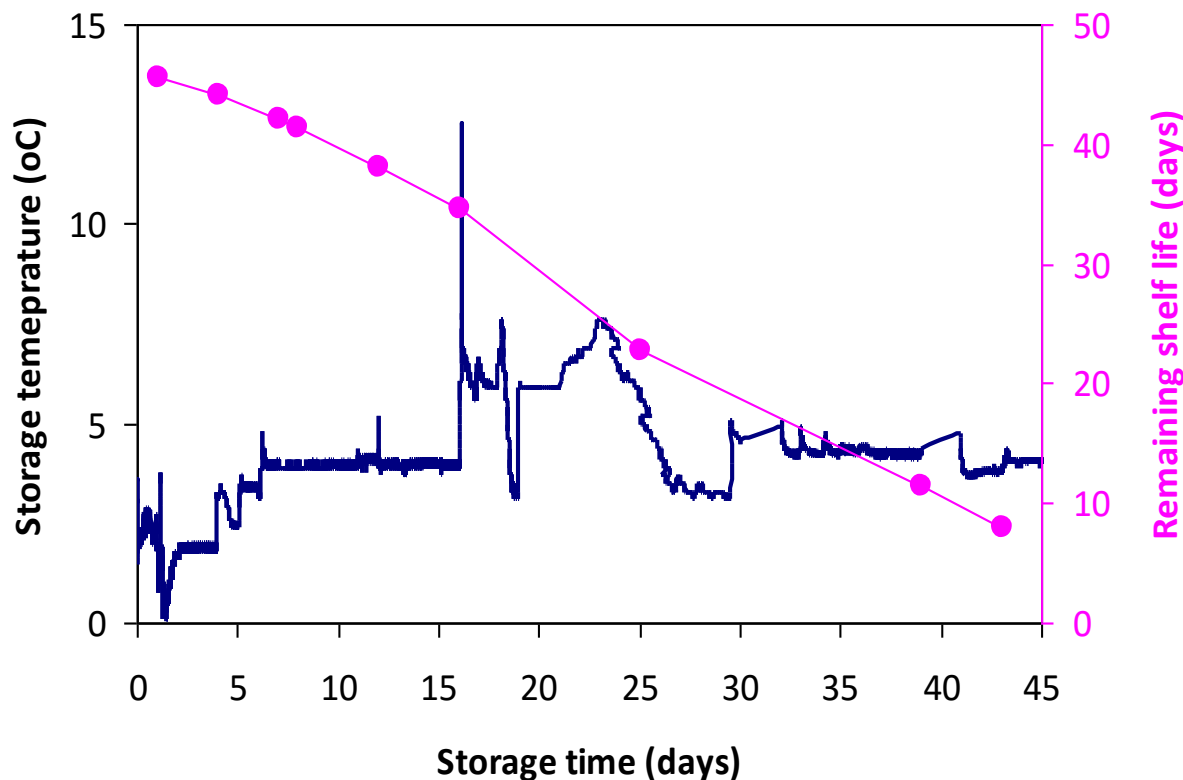
FRISBEE Cold Chain Management TOOLS

Cold Chain Database

Retrieve time-temperature profiles

Cold Chain Predictor Software

Build representative Time-temperature profile

Remaining shelf life prediction

frisbee **cold chain database**

Search Data   Build Cold Chain   Search Data (demo)   User : **National Technical University of Athens**

- Temperature Range

Chilled ▼

- Type of food

Meat and meat product ▼

- Build Cold Chain

Production warehouse ▼

Transportation ▼

Distribution warehouse ▼

Transportation ▼

Supermarket ▼

Transportation by consumer - Retail to home ▼

Consumer domestic refrigerator ▼

⊕ Add Stage   ✓ Submit Data

Selected Results

Please make your selections on the left pane or lo
previously saved set of records.

Cold Chain Database Records

Total Records : 10243

Mean temperature value : -4.87 °C
Minimum temperature value : -40.5 °C
Maximum temperature value : 39.3 °C

Saved Recordsets

#	Filename	Date
1	wholeChainFrozen	01/07/20
2	consumer_freezer	01/07/20

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FRISBEE Cold Chain Management TOOLS
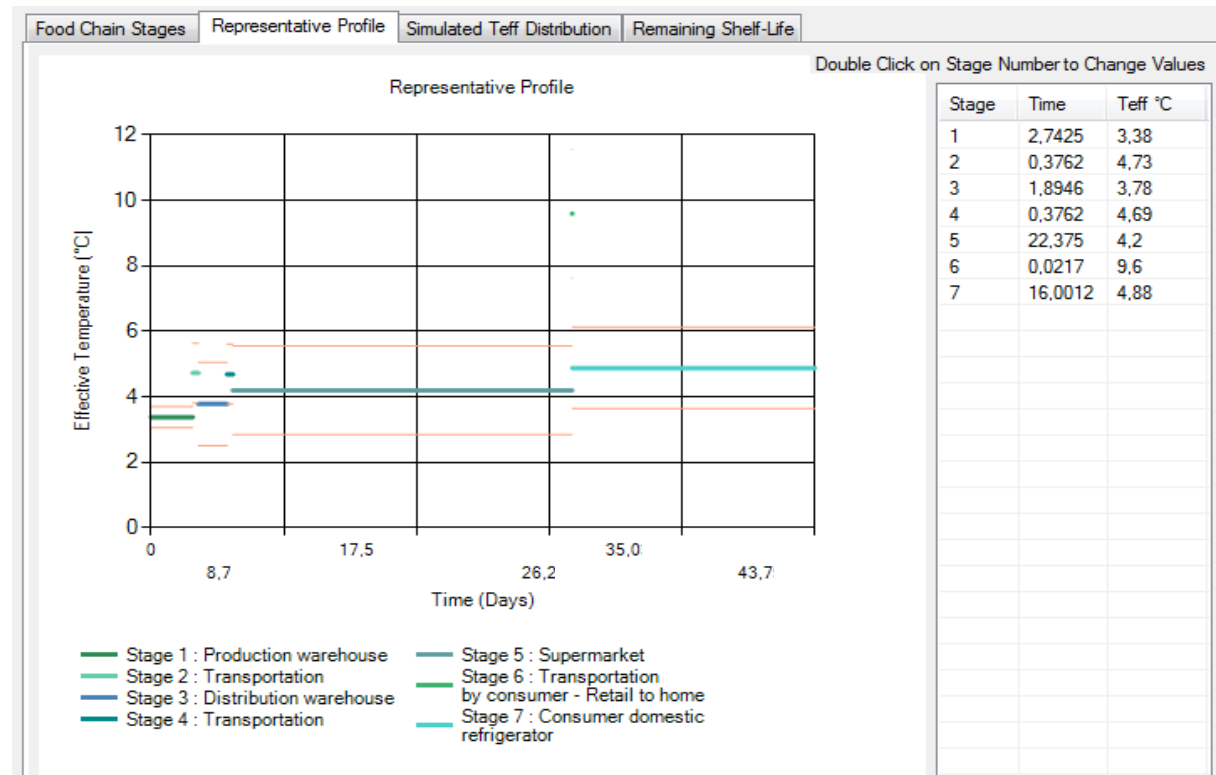
- **Cold Chain Database**
- **Retrieve time-temperature profiles**
- Cold Chain Predictor Software
- Build representative Time-temperature profile
- Remaining shelf life prediction

cold chain database
frisbee

Search Data   Build Cold Chain

- Temperature Range
  - Chilled
- Type of food
  - Meat and meat product
- Build Cold Chain
  - Production warehouse
  - Transportation
  - Distribution warehouse
  - Transportation
  - Supermarket
  - Transportation by consumer - Retail to home
  - Consumer domestic refrigerator

[+ Add Stage]   [Submit Data]

Microsoft Excel - Field test_Build cold chain csv file

D15   0,208355

	A	B	C	D	E	F	G
1	Report ID	Teff(70)	Average T(oC)	Standard Deviation	Time (min)		
2	[Stage : Production warehouse]						
3	[START]						
4	10563	3,39851	3,37988	0,557859	5210		
5	10564	3,27166	3,22854	0,878037	5210		
6	10565	3,85363	3,81111	0,868466	5210		
7	10566	3,00065	2,94157	1,0365	5210		
8	10567	3,30369	3,25805	0,91296	5210		
9	10568	3,92685	3,9113	0,524968	5210		
10	10569	0,803382	0,787165	0,51768	5210		
11	10570	2,61174	2,57107	0,845416	5210		
12	10571	9,35487	9,32739	0,683586	5210		
13	10572	3,26961	3,2249	0,887205	5210		
14	10573	2,30186	2,30053	0,102228	3770		
15	10574	3,37622	3,37513	0,208355	3770		
16	10575	3,6735	3,67196	0,204348	3770		
17	10576	4,77545	4,77302	0,284361	3770		
18	10577	4,61765	4,61243	0,209151	3770		
19	10578	4,04357	4,04138	0,277788	3760		
20	10579	3,70616	3,69151	0,631557	3760		
21	10580	2,99314	2,98778	0,287074	4490		
22	10581	3,7523	3,725	0,848946	670		
23	10717	4,1985	4,19653	0,255137	3740		
24	10718	4,02356	4,0144	0,522136	3740		
25	10719	3,45713	3,45119	0,393302	3760		
26	10720	3,54796	3,54613	0,167171	3740		
27	10721	3,66421	3,65909	0,208429	3730		
28	10722	4,09575	4,09413	0,146319	3740		
29	10723	3,19076	3,1851	0,289647	4420		
30	10724	2,98933	2,98886	0,240197	3760		
31	10725	2,22703	2,22438	0,222271	4420		
32	10726	3,1121	3,10271	0,436452	4420		

Field test_Build cold chain csv

Ready   NUM

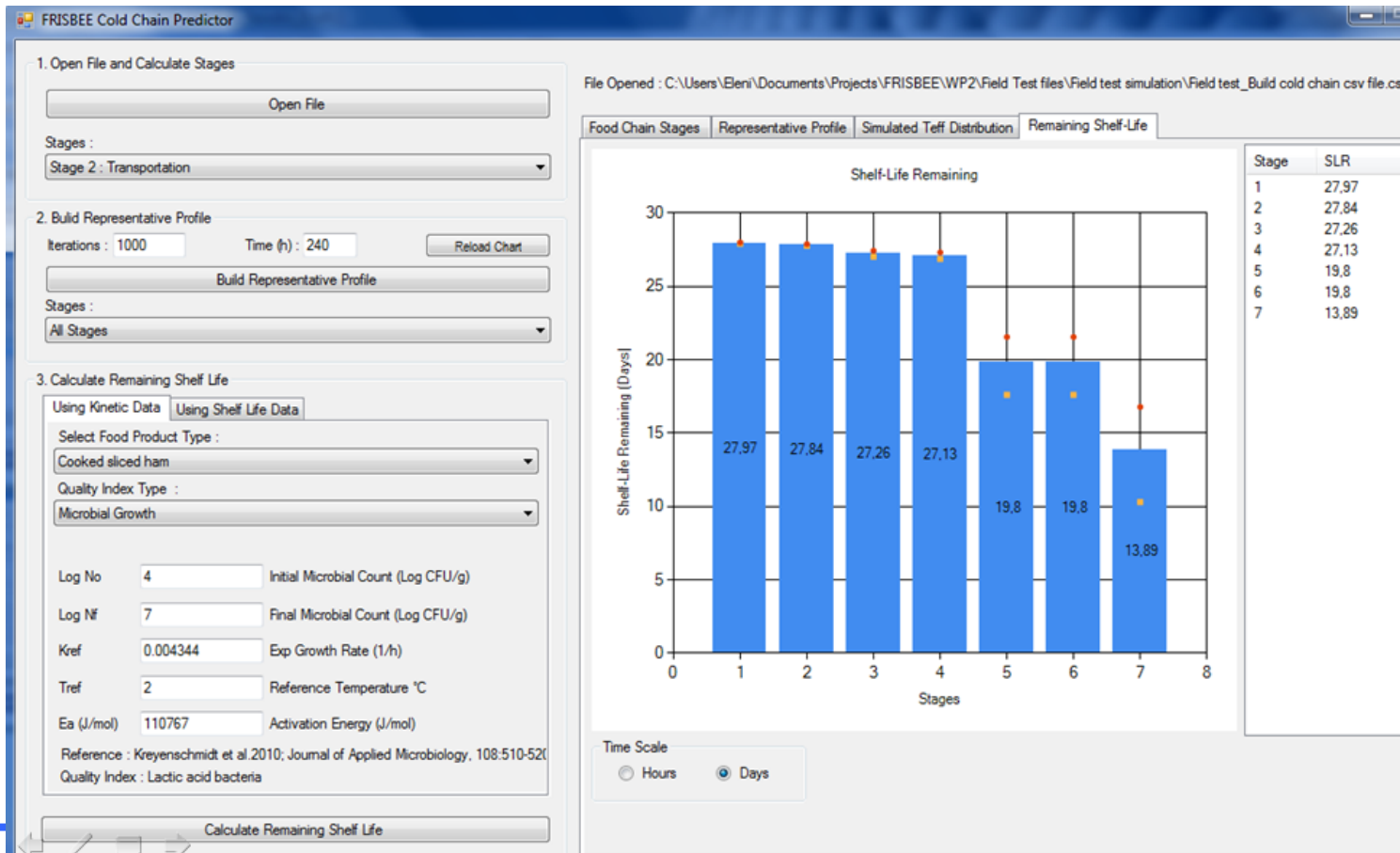# FRISBEE Cold Chain Management TOOLS

Cold Chain Database

Retrieve time-temperature profiles

Cold Chain Predictor Software

Build representative Time-temperature profile
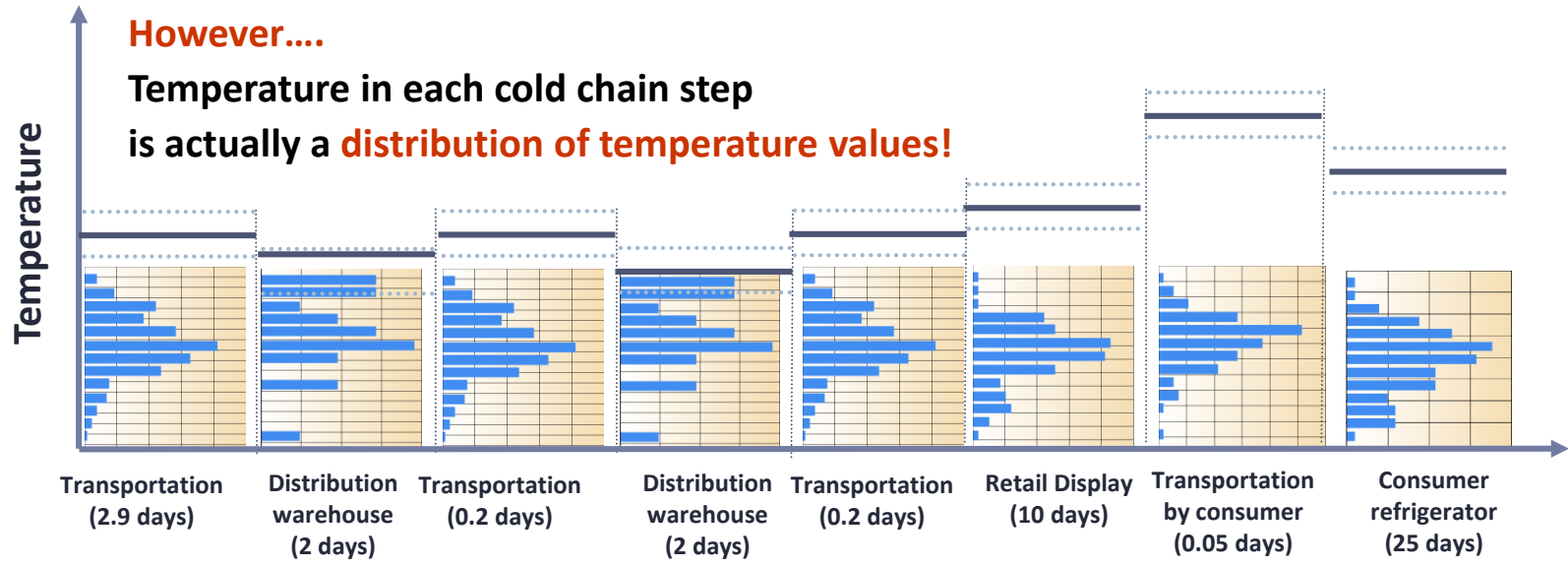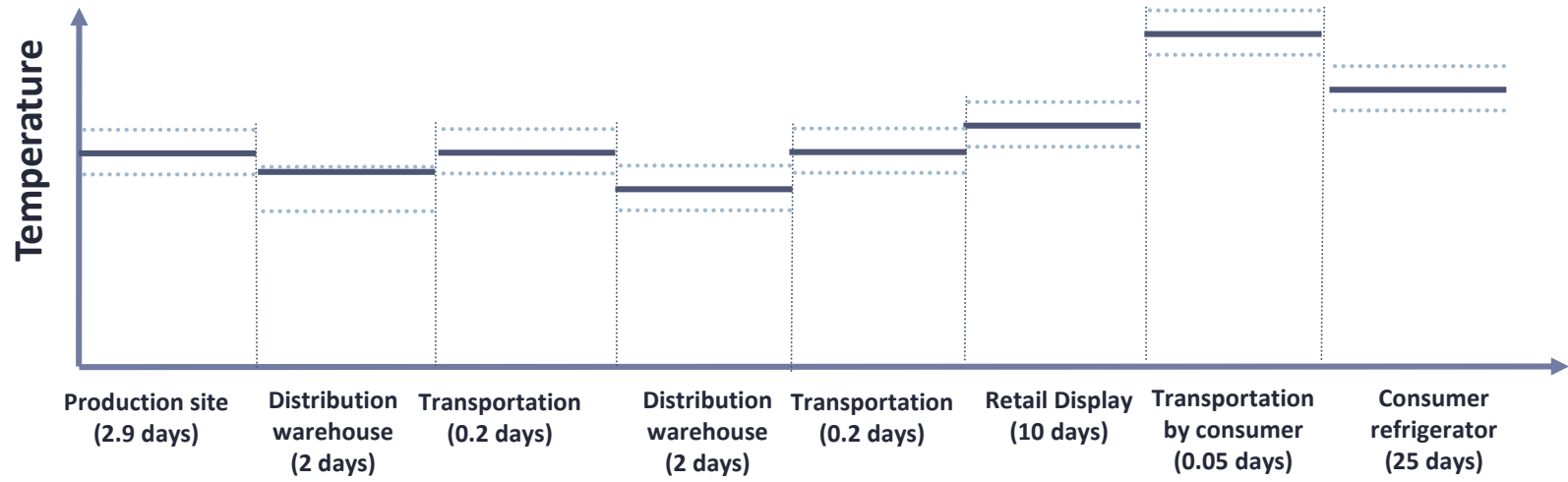
Remaining shelf life prediction

FRISBEE Cold Chain Predictor

1. Open File and Calculate Stages

Open File

File Opened : C:\Users\Eleni\Documents\Eleni\Projects\FRISBEE\WP2\Field Test files\Field test simulation\Field test_Build c

Stages :
Stage 7 : Consumer domestic refrigerator

2. Build Representative Profile

Iterations : 10000   Time (h) : 1051   Reload Chart

Build Representative Profile

Stages :
All Stages

3. Calculate Remaining Shelf Life

Using Kinetic Data | Using Shelf Life Data

Select Food Product Type :

Quality Index Type :

Log No   Initial Microbial Count (Log CFU/g)

Log Nf   Final Microbial Count (Log CFU/g)

Kref   Exp Growth Rate (1/h)

Tref   Reference Temperature °C

Ea (J/mol)   Activation Energy (J/mol)

Calculate Remaining Shelf Life

File Opened : C:\Users\Eleni\Documents\Eleni\Projects\FRISBEE\WP2\Field Test files\Field test simulation\Field test_Build cold chain csv file.csv

Food Chain Stages | Representative Profile | Simulated Teff Distribution | Remaining Shelf-Life

Temperature Distribution Profile - Stage 7 : Consumer domestic refrigerator

FRISBEE Cold Chain Management TOOLS

- Cold Chain Database
- Retrieve time-temperature profiles
- Cold Chain Predictor Software
- Build representative Time-temperature profile
- Remaining shelf life prediction

☑ Monte Carlo simulation generates a representative time-temperature profile where each cold chain stage is represented by an isothermal step

☑ The temperature of each cold chain stage represents the most probable effective temperature of the t-T profiles for each stage of cold chain

Food Chain Stages | Representative Profile | Simulated Teff Distribution | Remaining Shelf-Life

Double Click on Stage Number to Change Values

Stage	Time	Teff °C
1	2,7425	3,38
2	0,3762	4,73
3	1,8946	3,78
4	0,3762	4,69
5	22,375	4,2
6	0,0217	9,6
7	16,0012	4,88

Representative Profile

Stage 1 : Production warehouse
Stage 2 : Transportation
Stage 3 : Distribution warehouse
Stage 4 : Transportation
Stage 5 : Supermarket
Stage 6 : Transportation by consumer - Retail to home
Stage 7 : Consumer domestic refrigerator

FRISBEE Cold Chain Management TOOLS

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Build representative Time-temperature profile

Remaining shelf life prediction

☑ Use the Representative t-T profile and predictive kinetic models

FRISBEE Cold Chain Management TOOLS

Cold Chain Database

Retrieve time-temperature profiles

Cold Chain Predictor Software

Build representative Time-temperature profile

Remaining shelf life prediction

☑ Use the Representative t-T profile and predictive kinetic models
☑ Remaining shelf life prediction

FRISBEE Cold Chain Management TOOLS

Cold Chain Database

Retrieve time-temperature profiles

Cold Chain Predictor Software

Build representative Time-temperature profile

Remaining shelf life prediction

☑ Use the Representative t-T profile and predictive kinetic models
☑ Remaining shelf life prediction
☑ Using what if scenarios: on temperature and/or time per chain stage
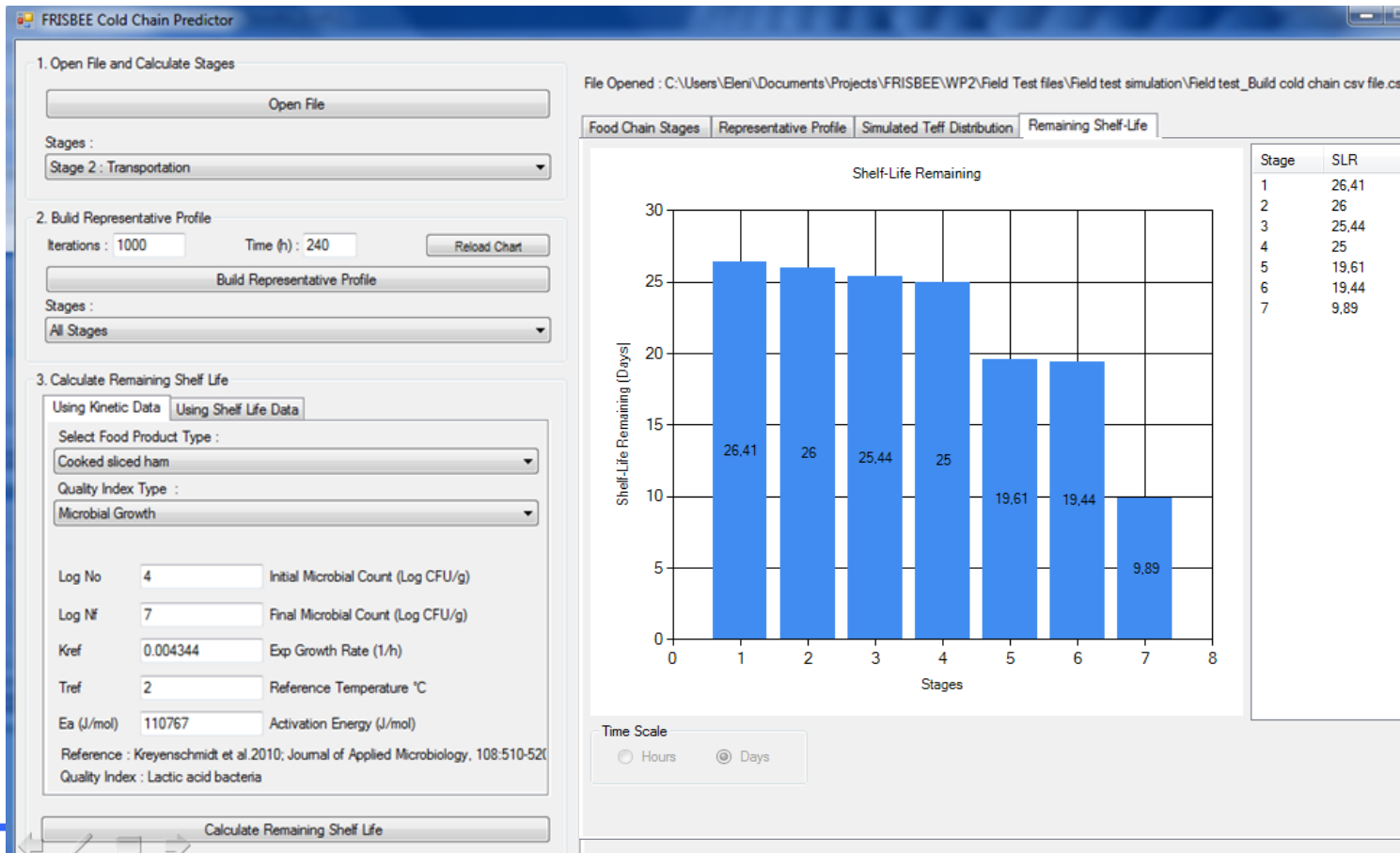
Determining the product quality status and shelf life at the different stages of the cold chain-MAP cooked ham case study

Taking into account the equivalent isothermal steps of representative t-T profile...

Shelf Life Remaining at the end of the cold chain: 8.9 days

Temperature

Production site (2.9 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Retail Display (10 days) | Transportation by consumer (0.05 days) | Consumer refrigerator (25 days)

However....

Temperature in each cold chain step is actually a distribution of temperature values!

Temperature

Transportation (2.9 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Retail Display (10 days) | Transportation by consumer (0.05 days) | Consumer refrigerator (25 days)

Determining the product quality status and shelf life at the different stages of the cold chain-MAP cooked ham case study

Taking into account the actual *distribution* of effective average temperature per stage throughout the cold chain…

The *distribution of remaining shelf life* values can NOT be overlooked!

Transportation (2.9 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Distribution warehouse (2 days) | Transportation (0.2 days) | Retail Display (10 days) | Transportation by consumer (0.05 days) | Consumer refrigerator (25 days)
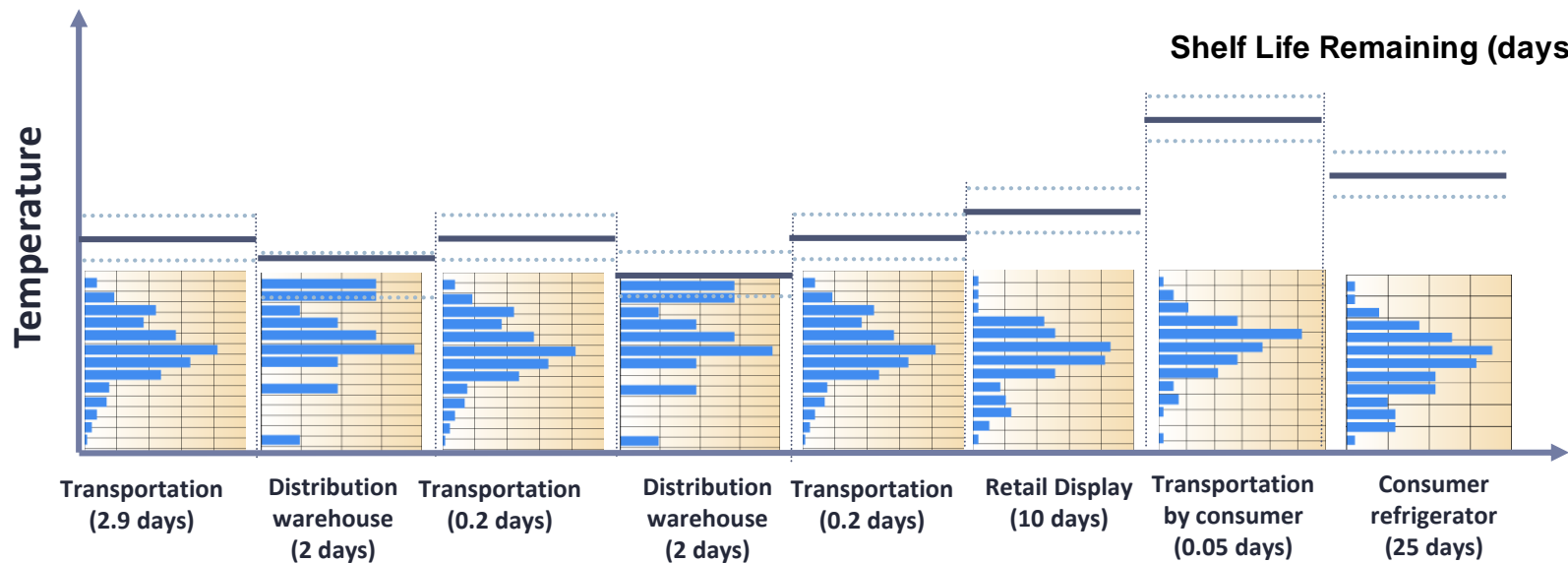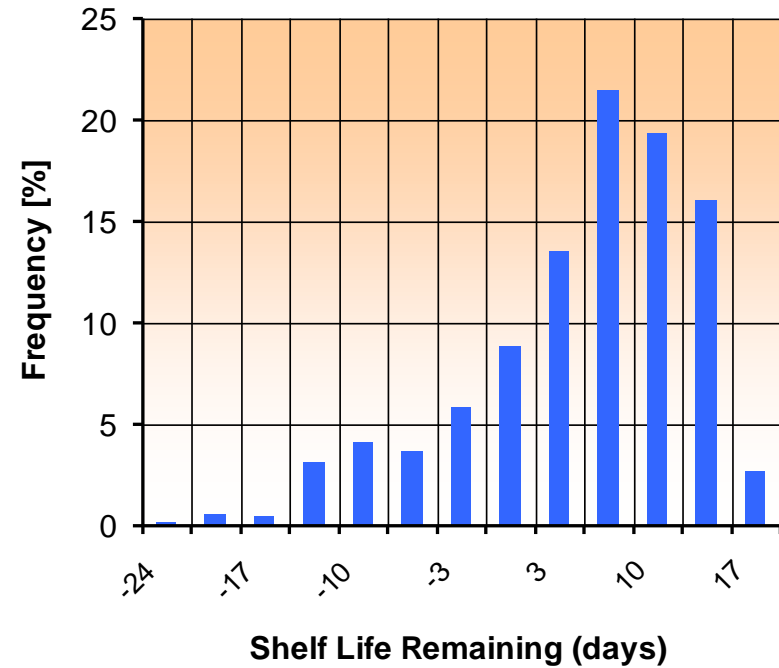
Cold Chain optimization: Reducing food waste
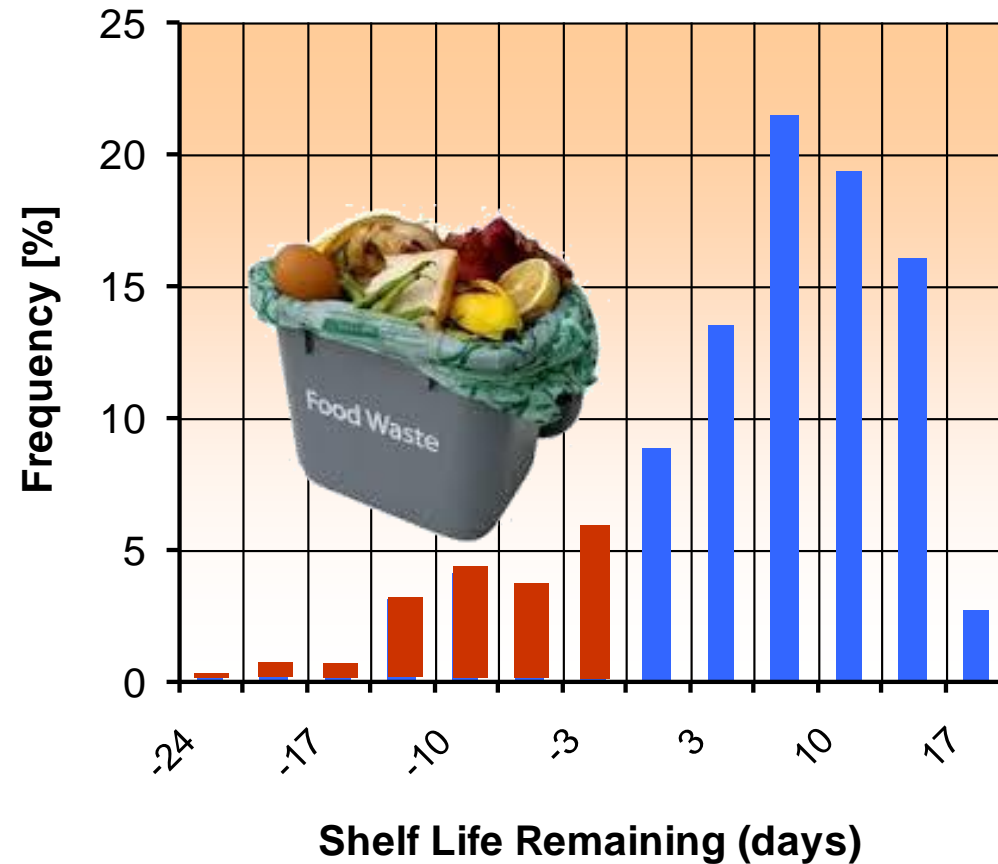
- ☑ **Narrowing the distribution**
- ☑ **Shifting the distribution to the right**

Chart axes: Frequency [%] (vertical), Shelf Life Remaining (days) (horizontal)

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Cold Chain Database
&
Cold Chain Predictor Software

Demonstration: RTE food products

Fresh cut salads case study
Determining the product quality status and shelf life at the different stages of the cold chain using

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Fresh cut salad-case study: Iceberg lettuce
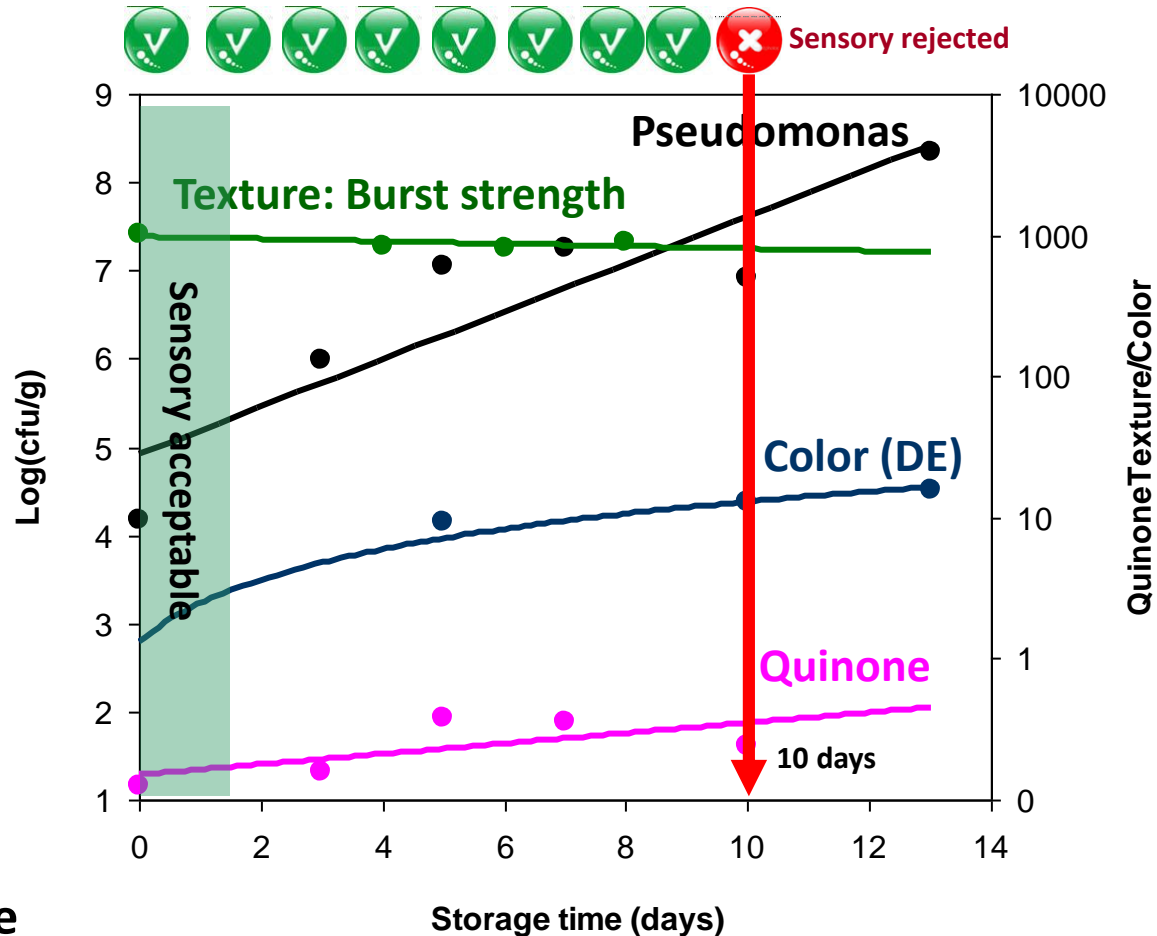
Iceberg lettuce
Packaging: Modified atmosphere, 15% O_2, 5% CO_2
Storage temperature: 10°C

Predictive models developed within SOPHY project
www.sophy-project.eu

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Fresh cut salad-case study: Romaine lettuce
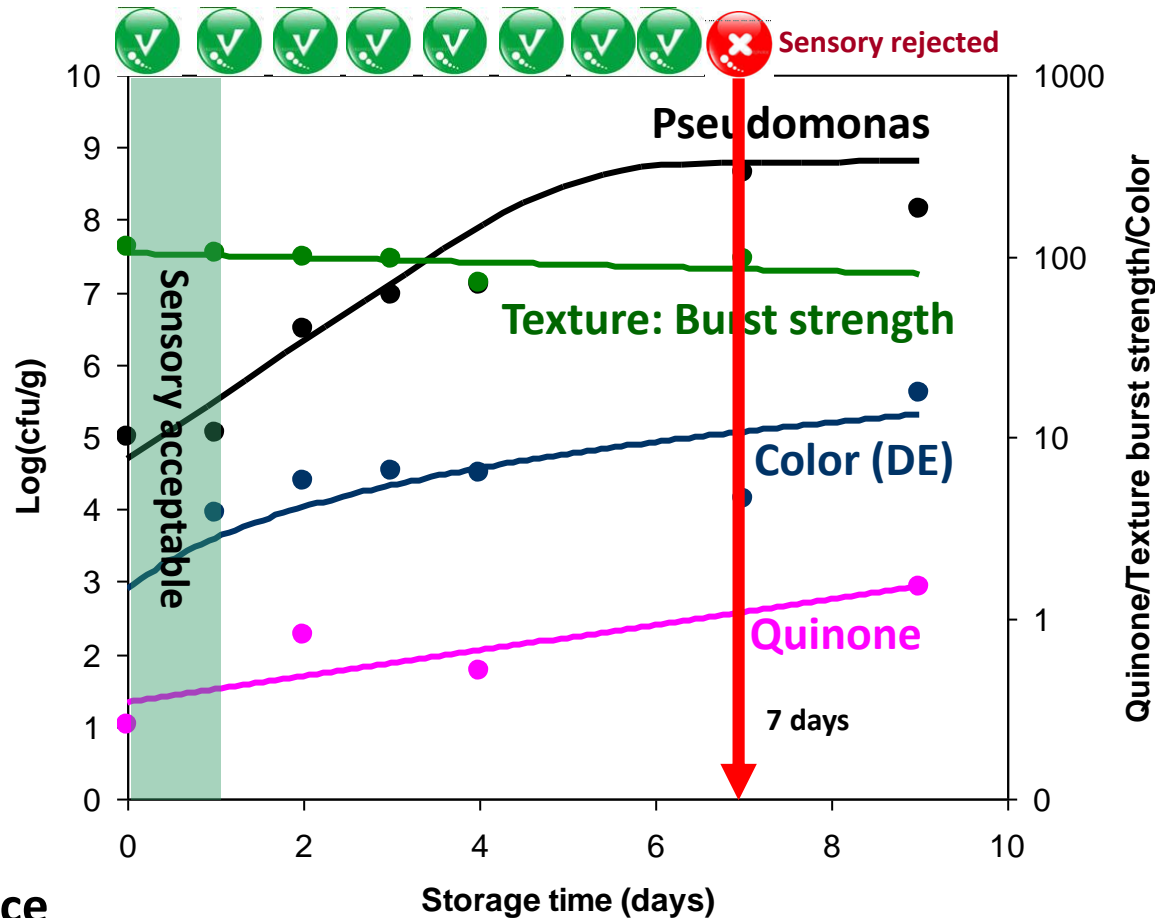
Romaine lettuce
Packaging: Modified atmosphere, 5% O_2, 15% CO_2
Storage temperature: 10°C

Predictive models developed within SOPHY project
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Fresh cut salad-case study: Rocket
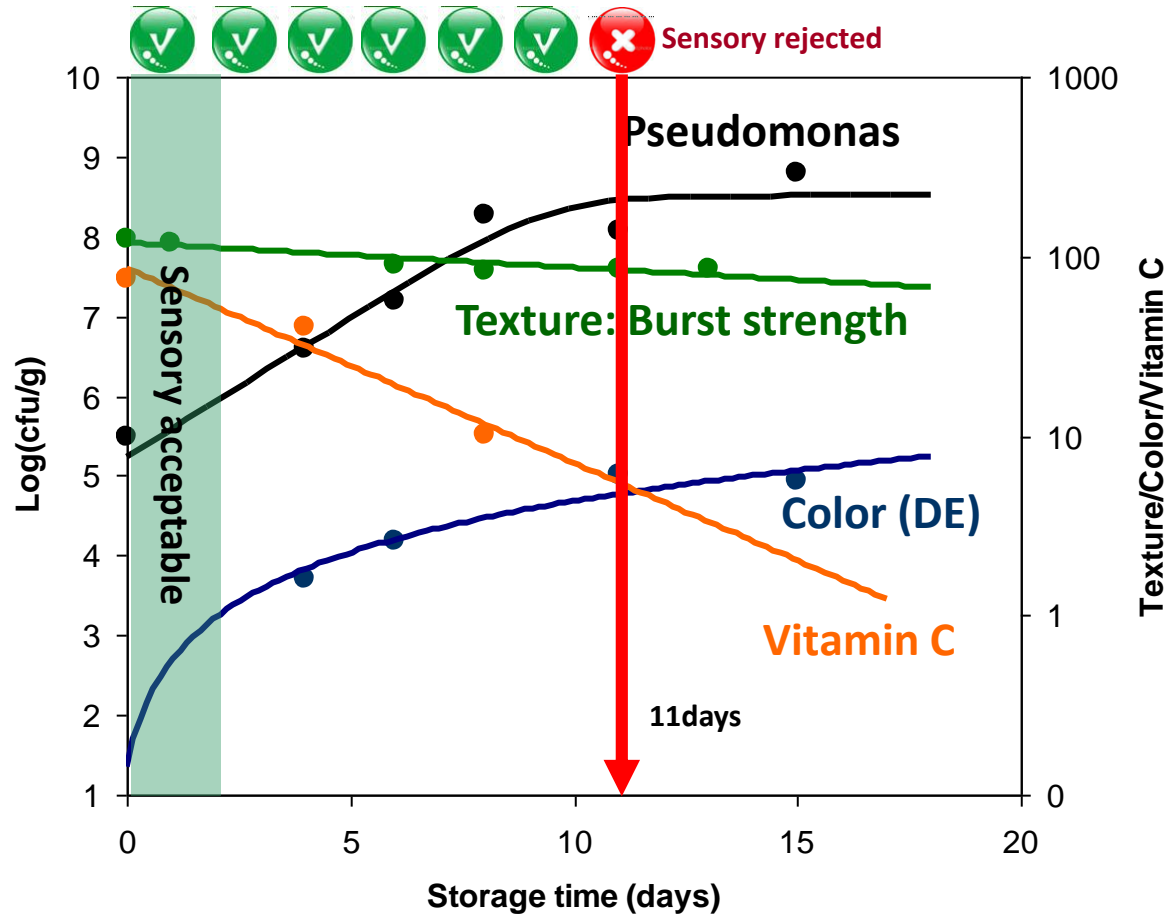
Rocket
Packaging: Aerobic conditions
Storage temperature: 10°C

Predictive models developed within SOPHY project
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Retrieving real cold chain data from the Cold Chain Database
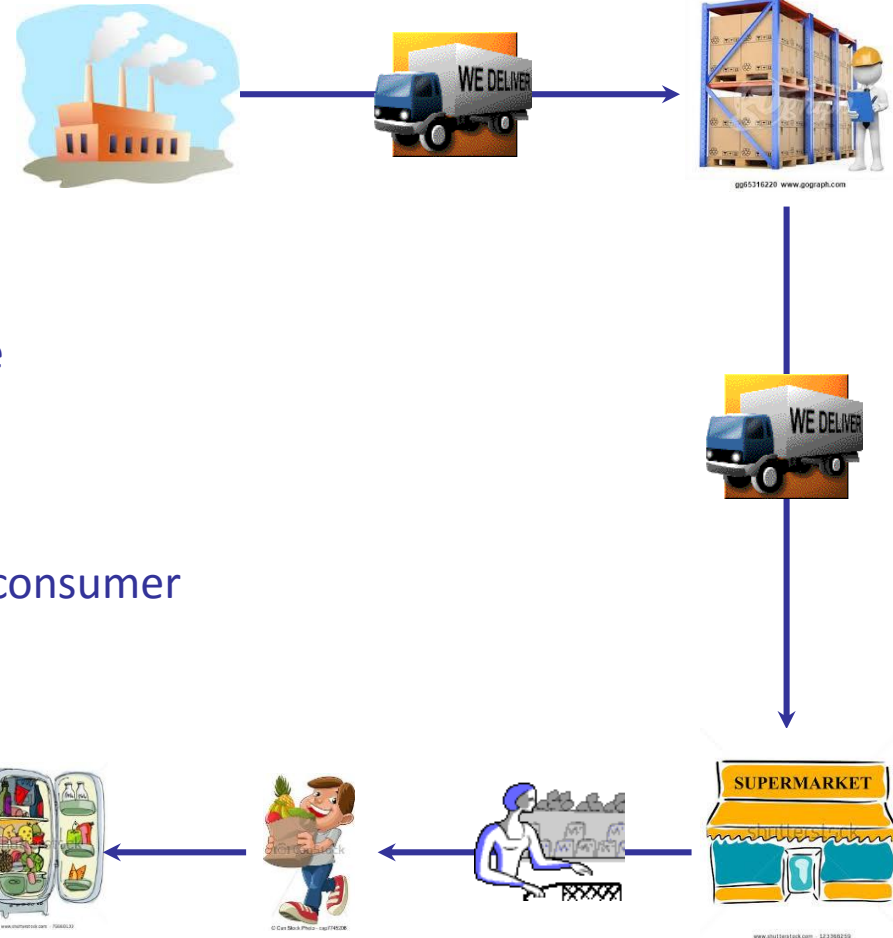
⊃ **Building cold chain successive stages:**

1. Production site
2. Transportation to Distribution warehouse
3. Distribution warehouse storage
4. Transportation to supermarket
5. Supermarket storage (retail display)
6. Transportation (non refrigerated) by the consumer
7. Consumer domestic refrigerator

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Cold Chain Database: Retrieving temperature profile

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Laboratory of Food Chemistry & Technology
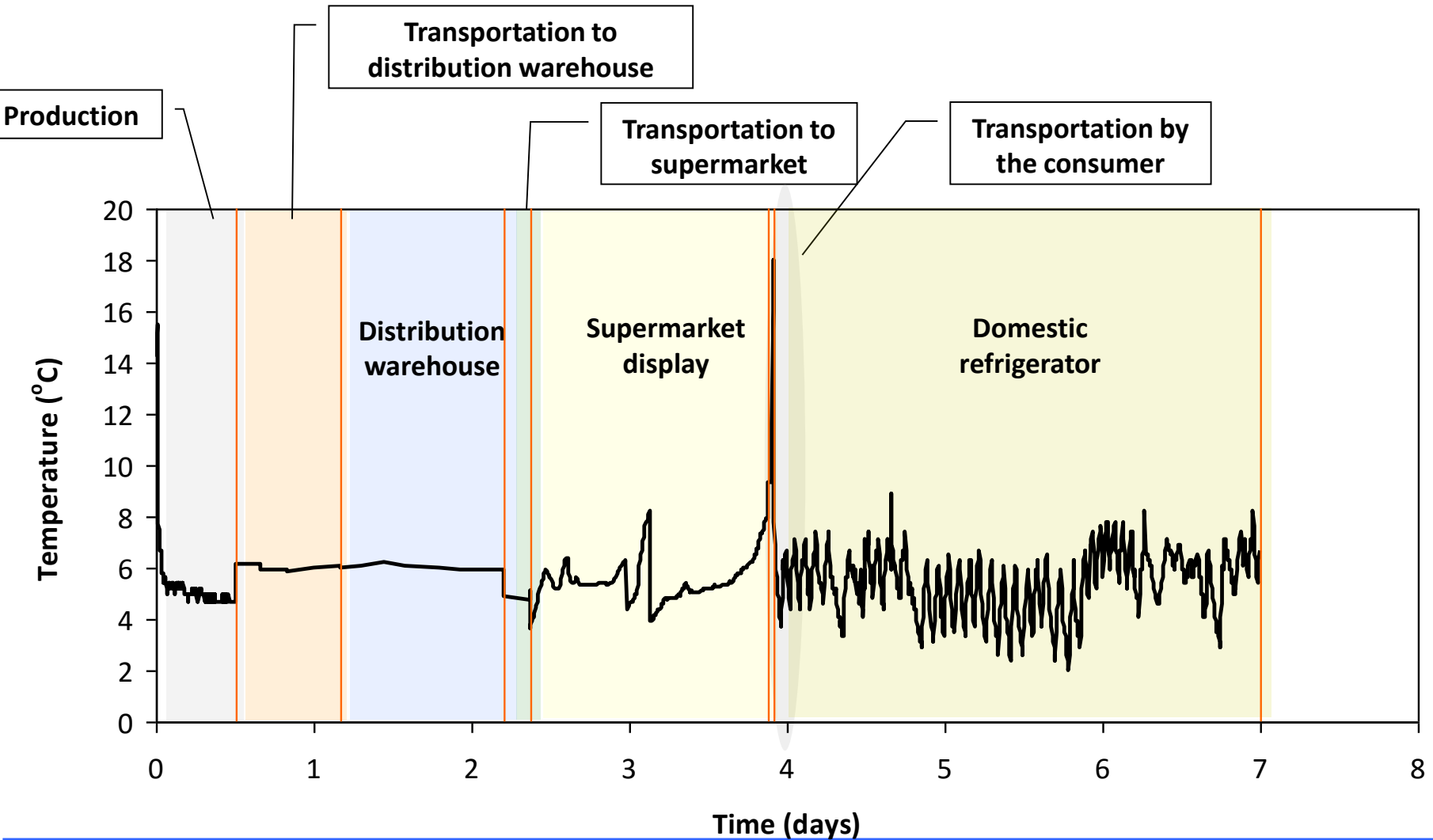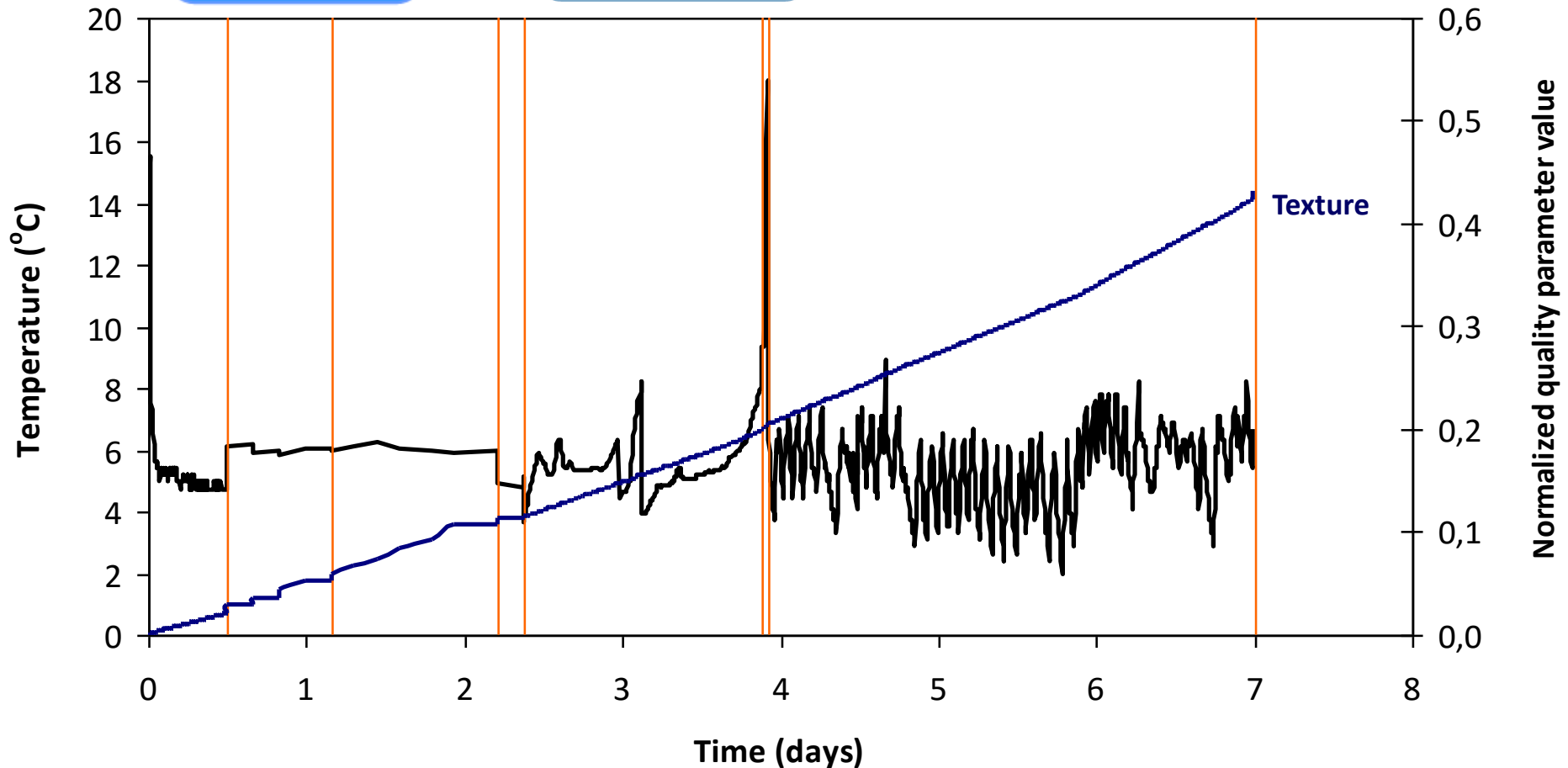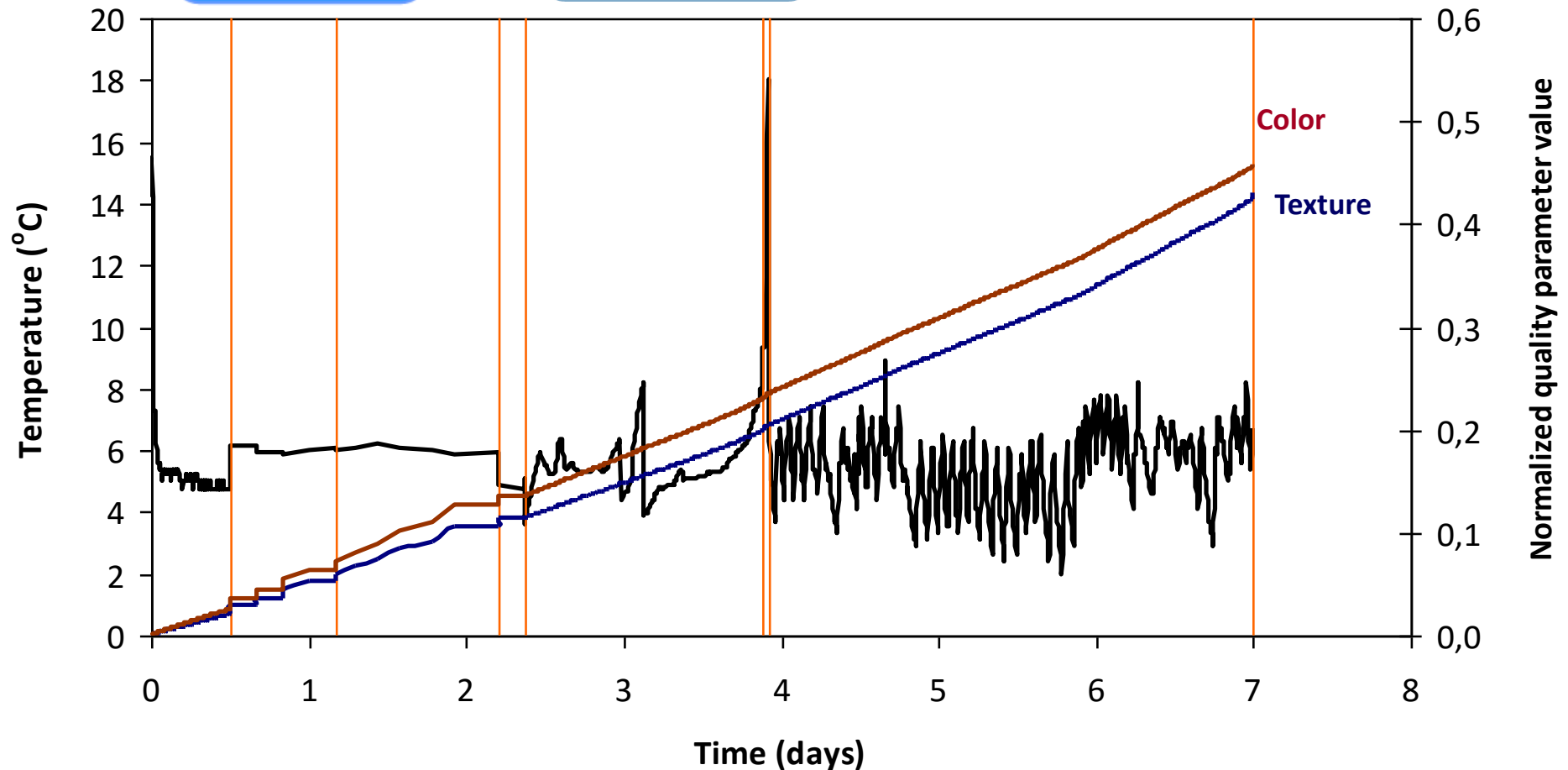*School of Chemical Engineering - National Technical University of Athens*

Fresh cut salad-case study: Rocket

FRISBEE INPUT
Cold Chain Database
Representative temperature profiles of the supply chain

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Fresh cut salad-case study: Rocket

FRISBEE INPUT
Cold Chain Database
Representative
temperature profiles
of the supply chain
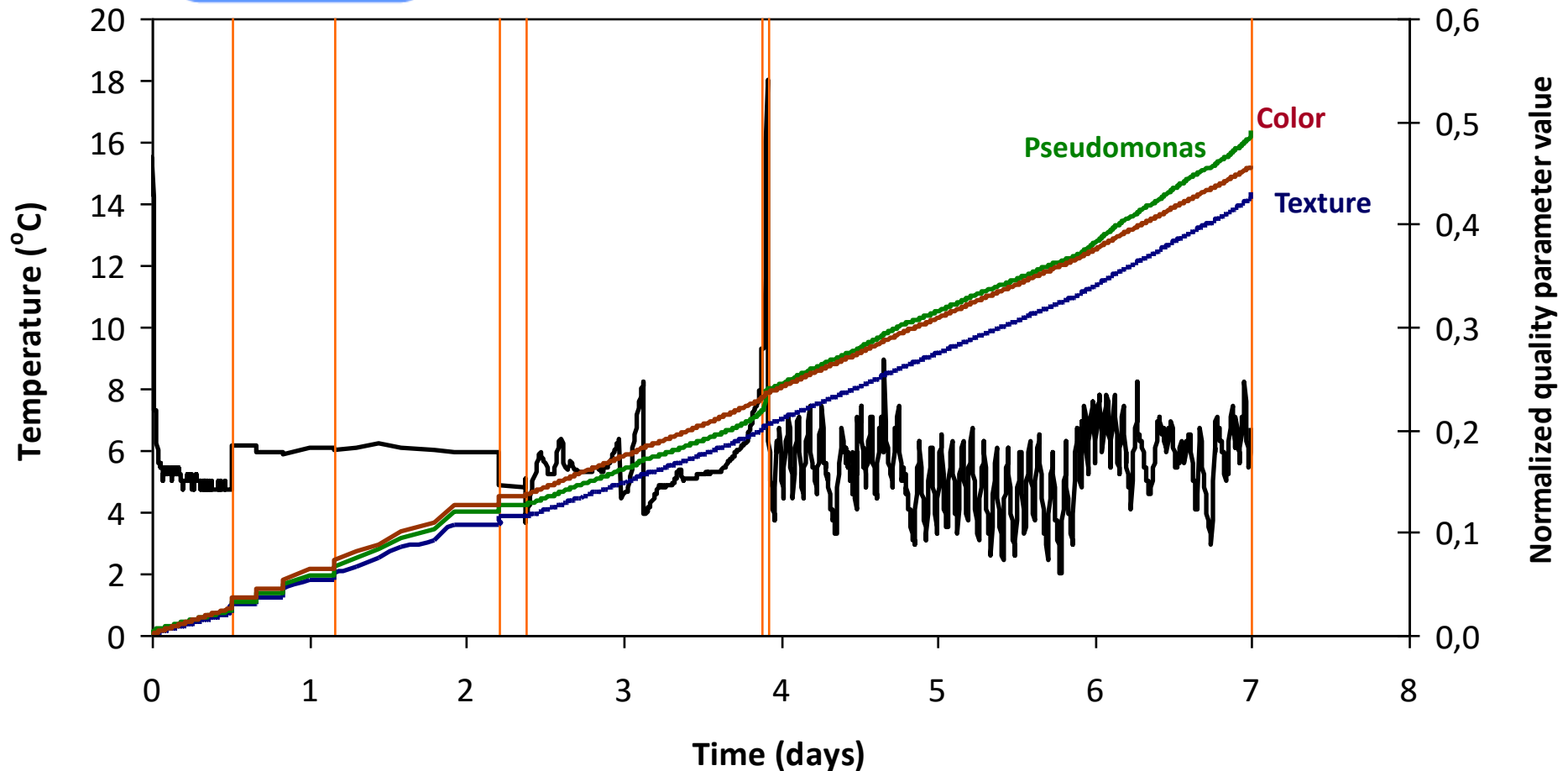
**Predictive models
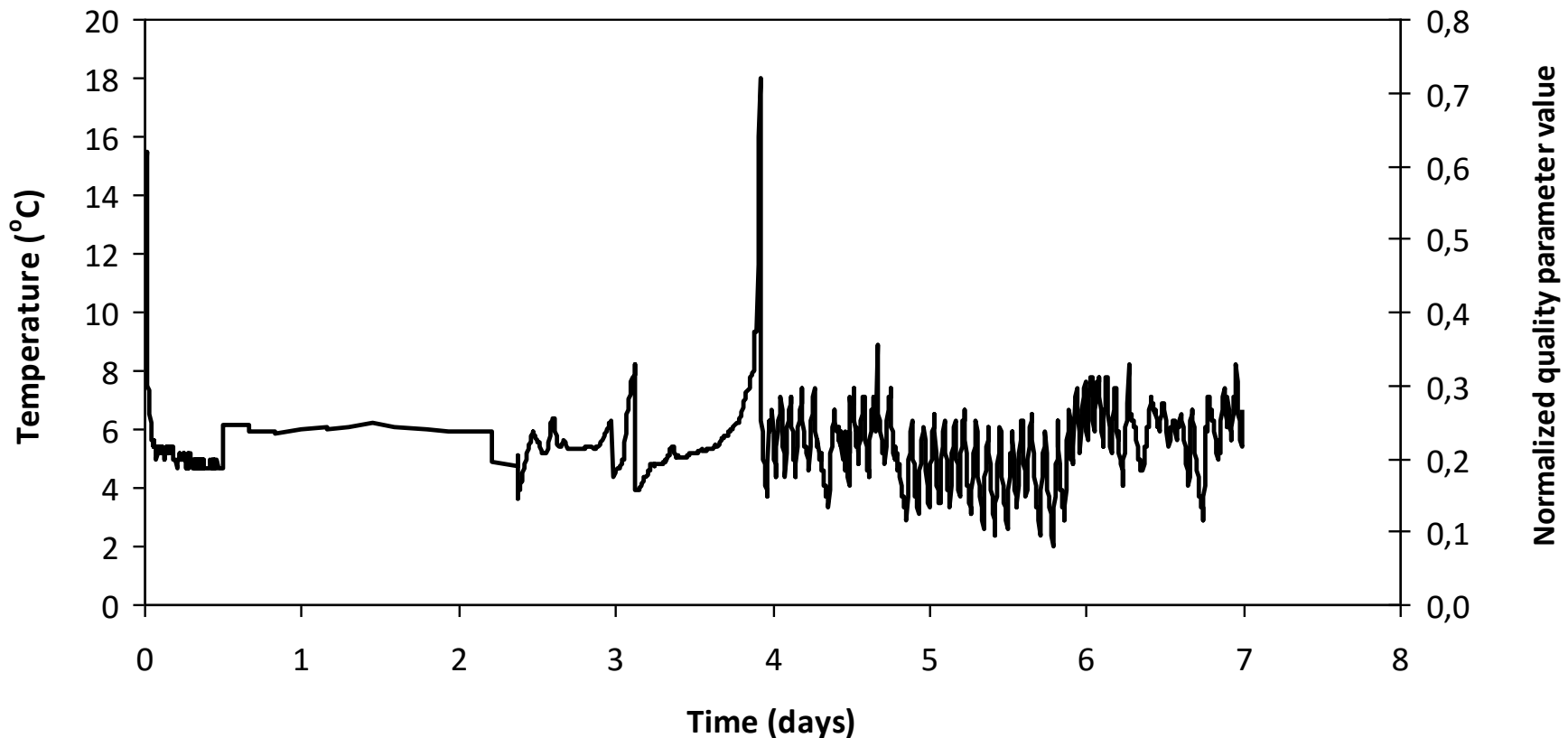Spoilage & Quality
indicators**

Texture

Temperature (°C)

Normalized quality parameter value

Time (days)

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Fresh cut salad-case study: Rocket

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Cold Chain Database
Representative
temperature profiles
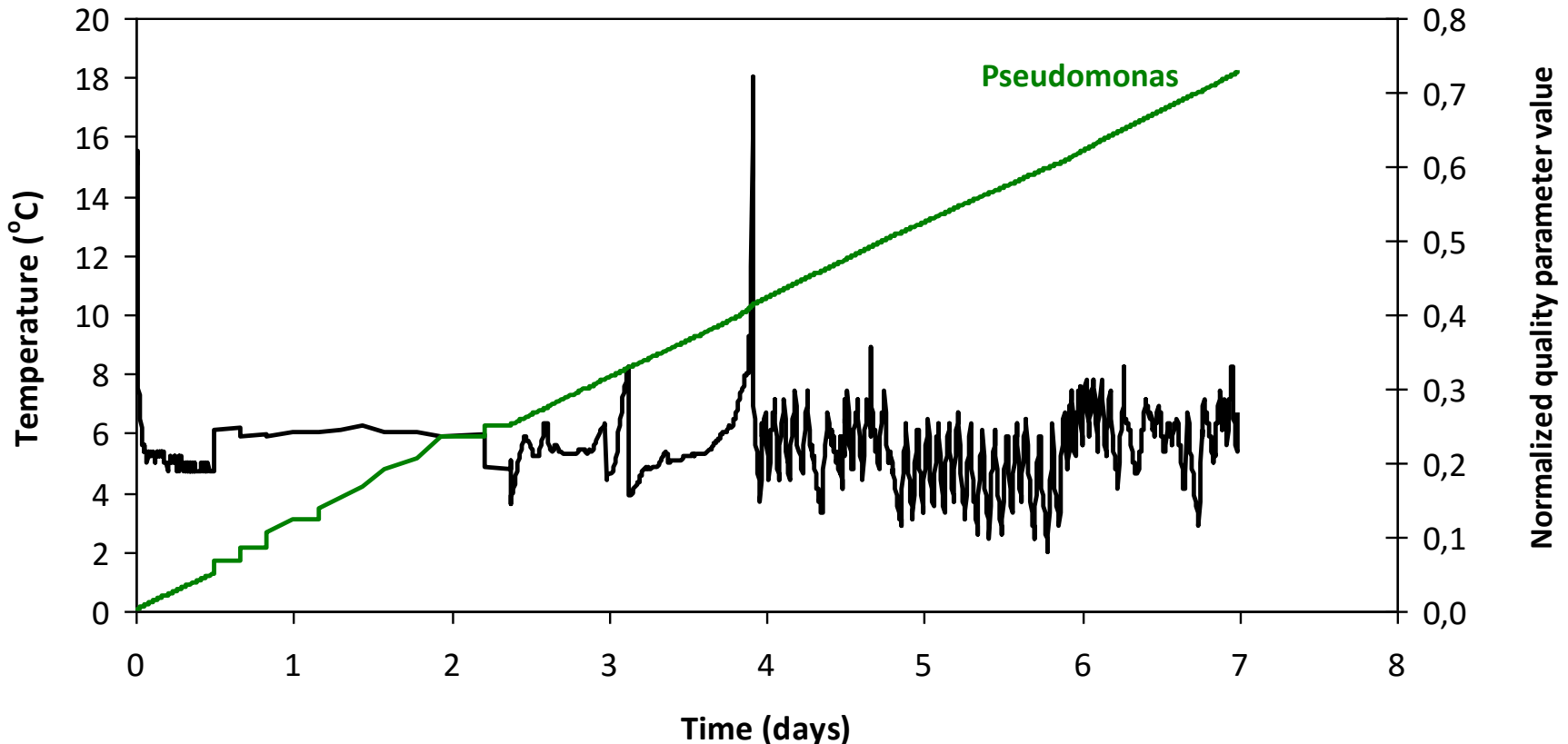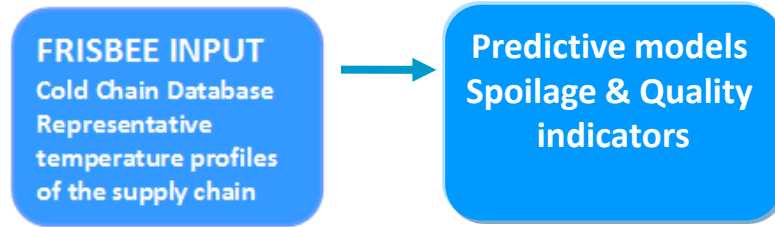of the supply chain

Predictive models
Spoilage & Quality
indicators

Color

Texture

Temperature (°C)

Normalized quality parameter value

Time (days)

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Fresh cut salad-case study: Rocket

FRISBEE INPUT
Cold Chain Database
Representative
temperature profiles
of the supply chain

→

**Predictive models
Spoilage & Quality
indicators**

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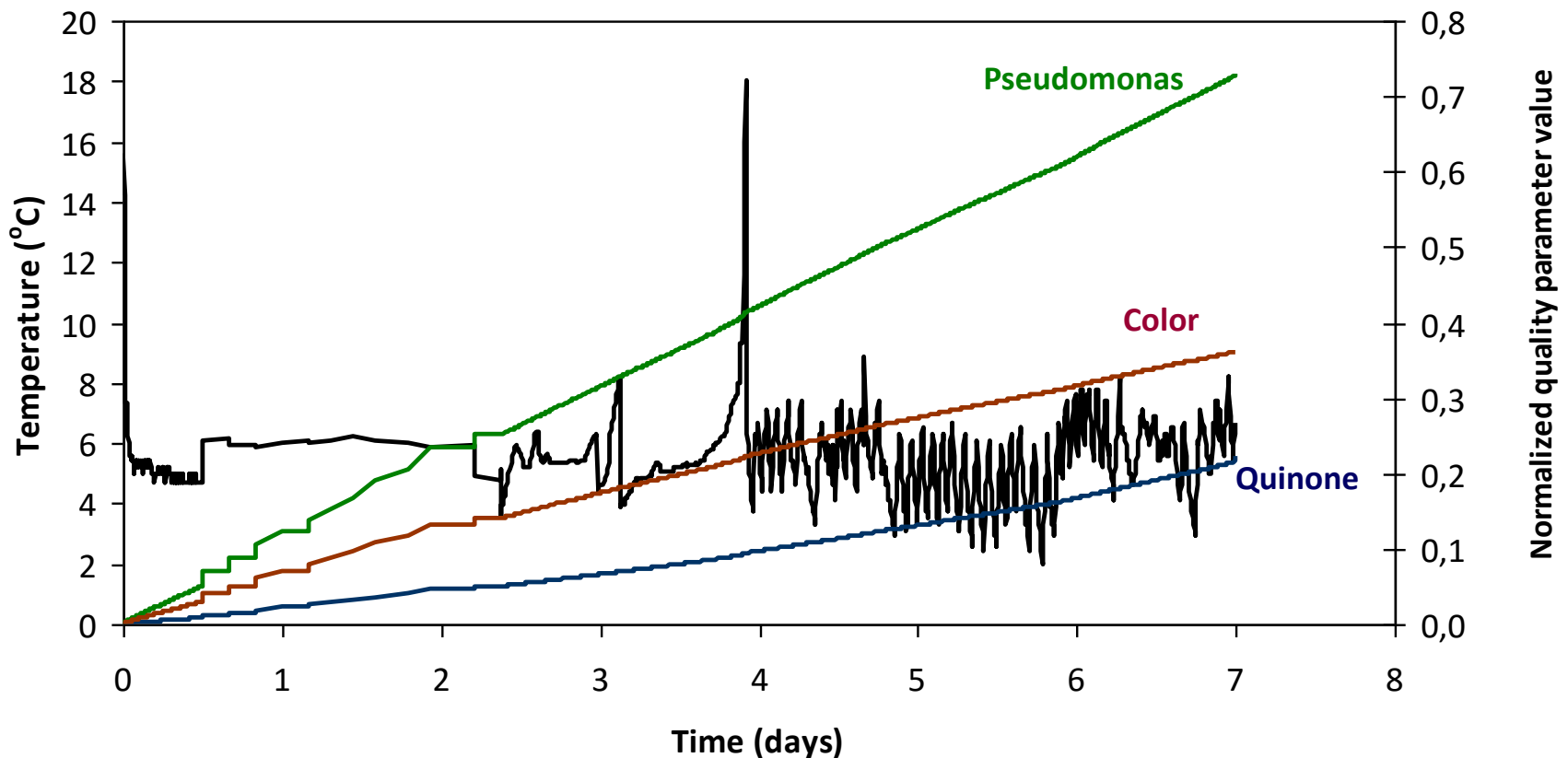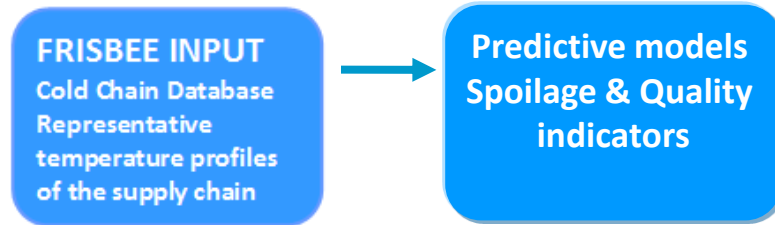*School of Chemical Engineering - National Technical University of Athens*

Fresh cut salad-case study: Romaine lettuce

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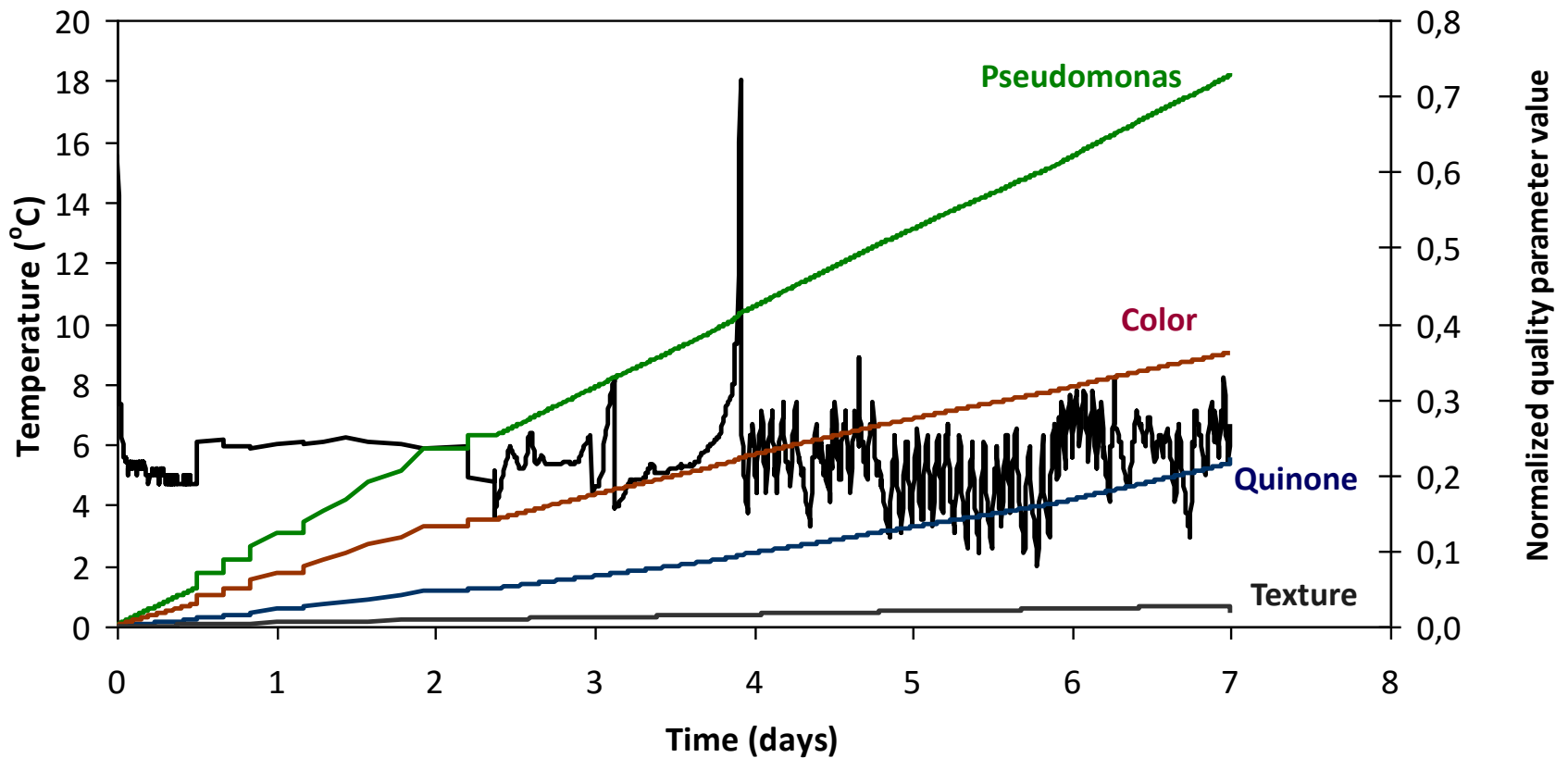*School of Chemical Engineering - National Technical University of Athens*

Fresh cut salad-case study: Romaine lettuce

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**Predictive models
Spoilage & Quality
indicators**

Pseudomonas

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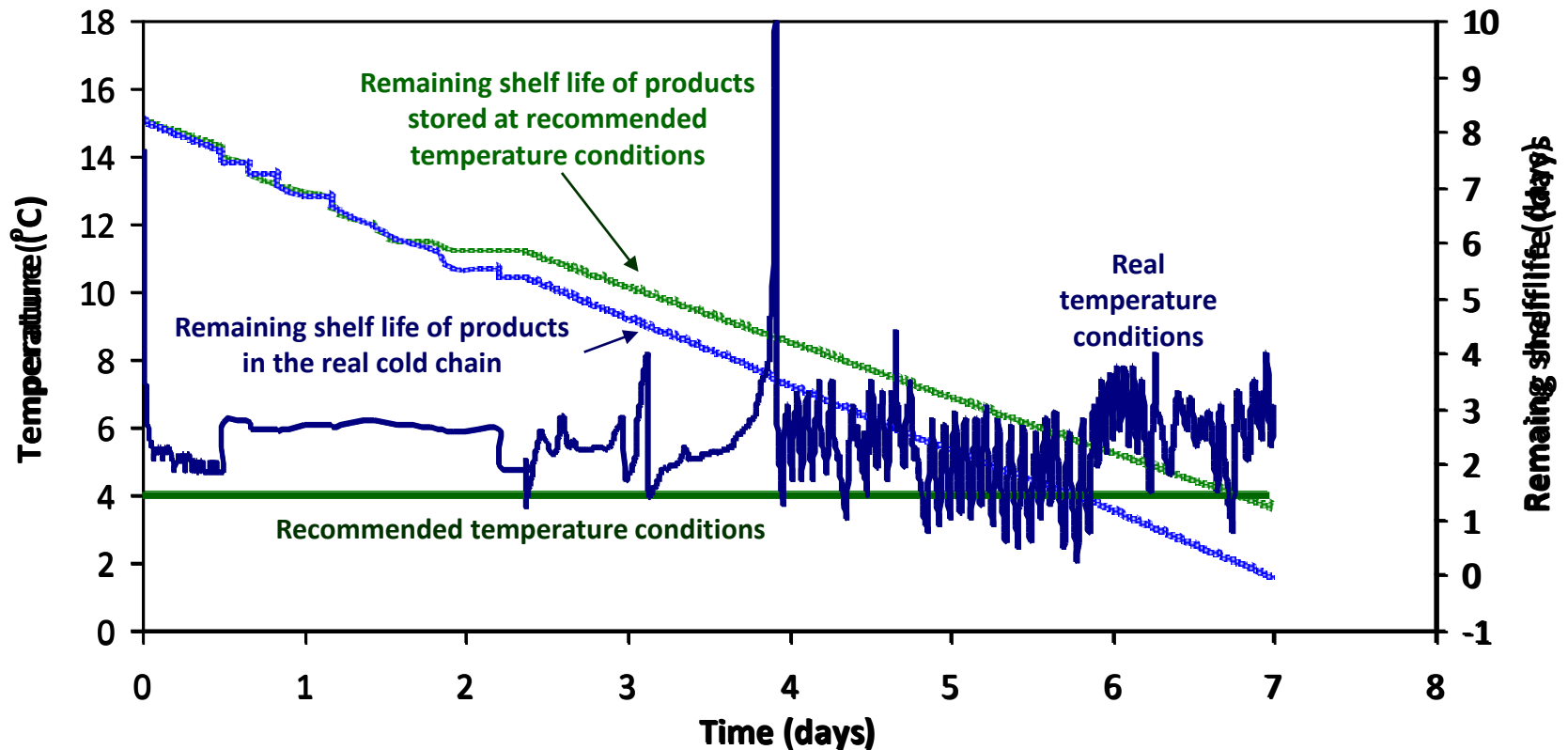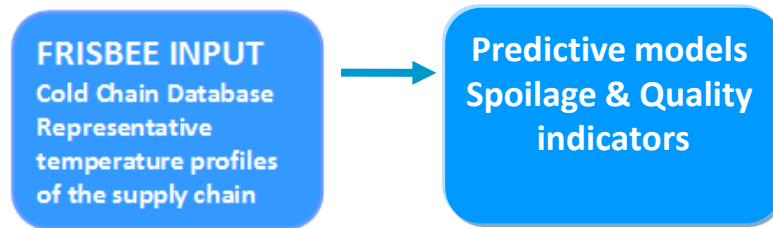*School of Chemical Engineering - National Technical University of Athens*

Fresh cut salad-case study: Romaine lettuce

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Representative
temperature profiles
of the supply chain

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**Predictive models
Spoilage & Quality
indicators**

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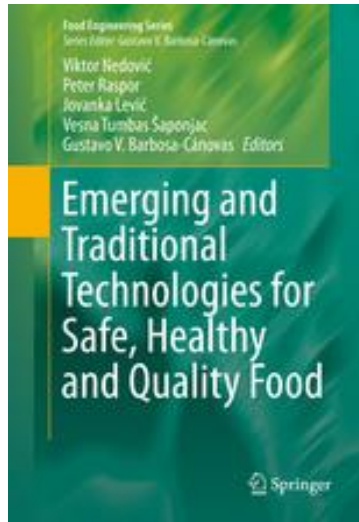*School of Chemical Engineering - National Technical University of Athens*

Fresh cut salad-case study: Romaine lettuce

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Cold Chain Database
Representative temperature profiles of the supply chain

→ Predictive models Spoilage & Quality indicators

Pseudomonas

Color

Quinone

Temperature (°C) vs Time (days)

Normalized quality parameter value

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Fresh cut salad-case study: Romaine lettuce

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Remaining shelf life estimation

FRISBEE INPUT
Cold Chain Database
Representative
temperature profiles
of the supply chain

→ Predictive models
Spoilage & Quality
indicators

Remaining shelf life of products
stored at recommended
temperature conditions

Remaining shelf life of products
in the real cold chain

Real
temperature
conditions

Recommended temperature conditions

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Related publications

Taoukis P.S., Gogou E., Tsironi T., Giannoglou M., Dermesonlouoglou E., Katsaros G. 2016. *Chapter 16: Food Cold Chain Management and Optimization*.

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COLD CHAIN MANAGEMENT TOOLS FOR THE OPTIMIZATION OF READY-TO-EAT FOOD PRODUCTS COLD CHAIN

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Athens, Greece

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