COMSOL CONFERENCE ROTTERDAM2013

Numerical Modeling and Experimental Validation of the Standard Energy Consumption Test in Domestic Ovens

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October 23-25, 2013

Rotterdam – The Netherlands

INDEX

1. Introduction

2. Normative Oven Energy Class Test, EN 50304

3. Numerical Model (COMSOL Multiphysics®)

4. Results

5. Conclusions & Future Work

1. INTRODUCTION

Marie Curie label since 1996

Under FP7, implemented through the People Programme (2007-2013)

ITN (Initial Training Networks)
IEF (Intra-European Fellowships)
IOF (International Outgoing Fellowships)
IIF (International Incoming Fellowships)
CIG (Career Integration Grants)

IAPP (Industry-Academia Partnerships and Pathways)

IRSES (International Research Staff Exchange Scheme)
COFUND (Co-funding of regional, national, international programmes)

Pierre and Marie Curie honeymoon, 1895

IAPP (Industry-Academia Partnerships and Pathways)

GREENKITCHEN

University of Applied Sciences and Arts of Southern Switzerland

SUPSI

Whirlpool

Wrocław University

WP1 – Project management
Led by SUPSI

WP2 – Advanced heat recovery technologies
Led by SUPSI
T2.1: Heat capture and transfer
T2.2: Heat storage
T2.3: Heat recovery and conversion

WP3 – Advanced refrigeration technologies
Led by WUT
T3.1: Magnetic refrigeration
T3.2: Investigation of material exhibiting the GME

WP4 – Eco-design: resources sharing a[…] waste recovery (heat & water)
Led by WHIRLPOOL
T4.1: Appliance coupling and technologies for integ[…]
T4.2: Application of sol-gel sensors/markers for identification of chemicals and bacteria in grey water[…]

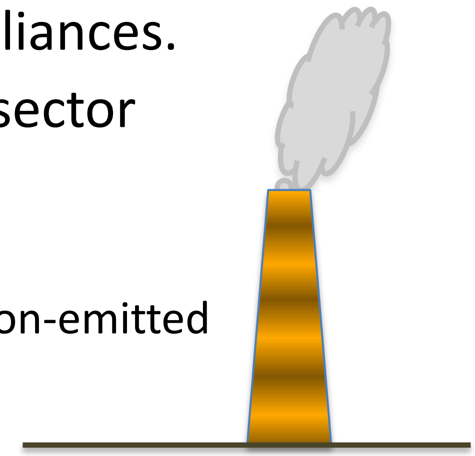
WP5 – Application controls for cooking and refrigeration of food
Led by POLIMI
T5.1: Innovative technologies for improving, monitoring and controlling the cooking process
T5.2: Innovative heat transfer models for cooking in ovens
T5.3: Innovative technologies (sensors and actuators) for monitoring and controlling the refrigeration process

WP6 – Envisioning the domotic house
Led by POLIMI
T6.1: Energy management scenarios
T6.2: Development of a central domotic control unit

Scopes

- Reduction of the Energy Consumption of home appliances.
- Final Annual Electricity Consumption in residential sector of European Union (EU-27) ≈850 TWh.

10% Reduction → 85 TWh → ≈**$50 \cdot 10^6$ Tn of CO_2** non-emitted



- Project High Efficient Ovens , HEO (Life+ program)

Highly Efficient Ovens MANCHESTER 1824 The University of Manchester Whirlpool EMEA Life

Whirlpool

GREENKITCHEN

2. NORMATIVE OVEN ENERGY CLASS TEST EN 50304

Brick Test (CEI EN 50304)

WHIRLPOOL MODEL: MINERVA OVEN

Oven model	Energy Consumption (kWh)	Energy consumption label	Heating function	Usable Volume (l)
MINERVA	**0.90**	**A**	**Static**	**73**

Brick Test (CEI EN 50304)

<u>BRICK</u>

-Position: on the geometric center of the cavity

-$T_{initial}$: 5 ± 2 °C

-T_{final}: $T_{initial}$ + ΔT (55 °C)

<u>OVEN</u>

-$T_{initial}$: 23 ± 2 °C

- ΔT: 180 ± 10 °C

Brick Test (CEI EN 50304)

<u>BRICK</u>

-Dimensions: 230mm x 114mm x 64mm

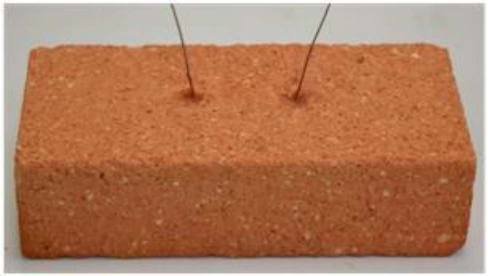
-Material: Hypor

C_p=0.80 J/g°C

ρ=550 ± 40 kg/m^3

Porosity=77%

→ Representing similar food matrix behavior inside the oven cavity



-Weight:

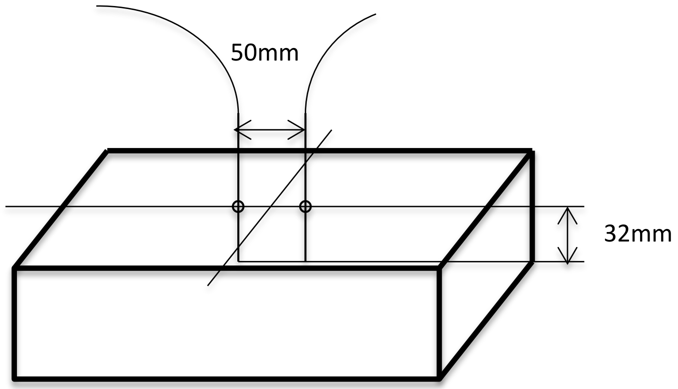
$W_{initial}$ ≈ 920g (brick) + 1050 g (water)

≈ 1050 g water absorved after 8h in chilled water)

Brick Test (CEI EN 50304)

Temperature monitoration:

-Thermocouples type J (iron/constatan)



-2 Holes of 2.1mm diameter
-32mm depth
-50mm separation between them

Data logger: Yokogawa MV100

Frequence: Every second

Range: −40 to +750 °C

Precision: 0.1 °C

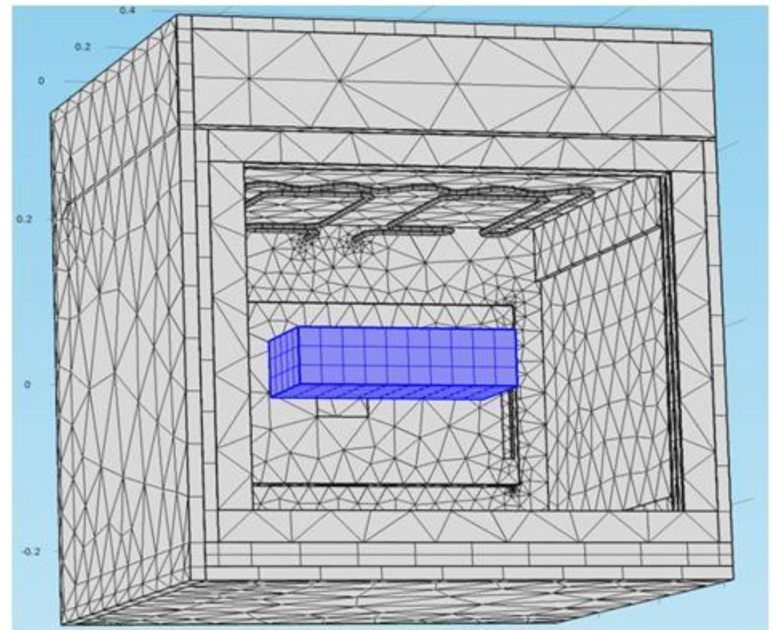
$T_{air\ out}$: 1 measurement
T_{cavity}: 2 measurements
T_{brick}: 2 measurements

3. NUMERICAL MODEL (COMSOL Multiphysics®)

Numerical Model Scope

- Important to model the transient behavior of the oven to be able to reduce the energy consumption
- For example, advanced design can be developed by performing some parametric analyses:
  - Emissivity of the glass
  - Dimensions of the cavity walls
  - Material properties of the cavity walls

Modeling a domestic oven with a 3-glasses door



"Heat and Mass Transfer" Module

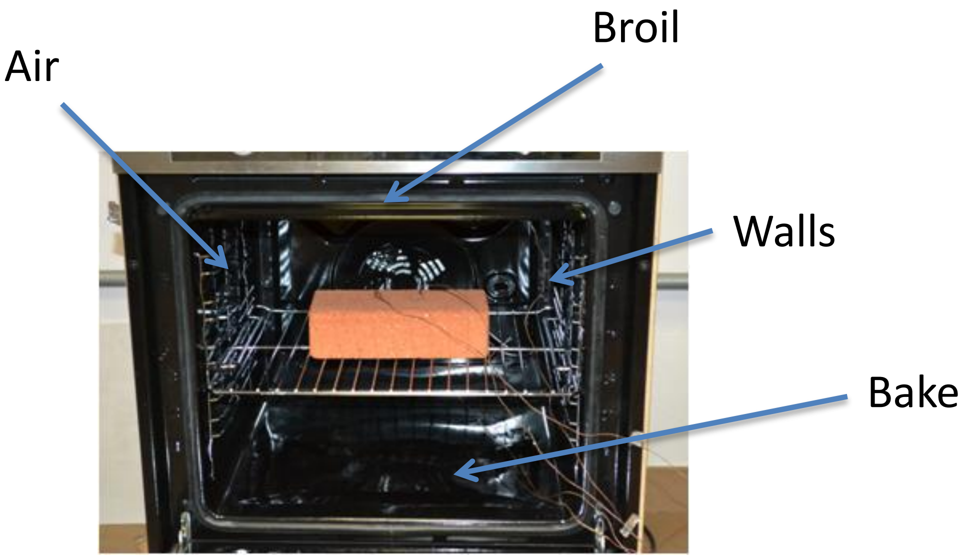
$$\rho C_P \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = Q$$

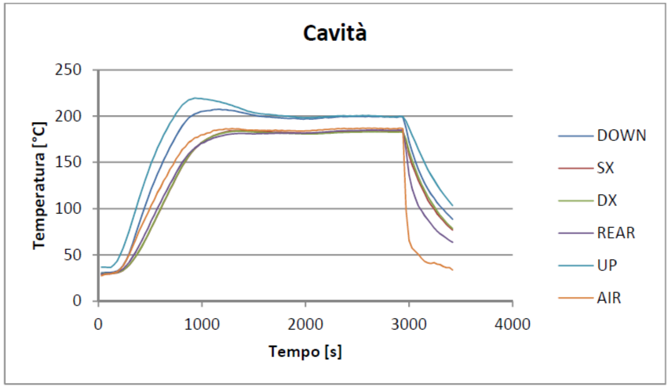
"Transport of Dilute Species" Module

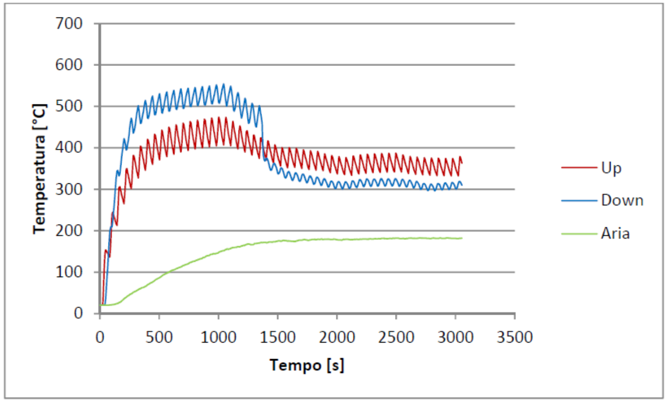
$$\frac{\partial c}{\partial t} + \nabla \cdot (-D \nabla c) = R$$

Boundary conditions:

Experimental transient temperature of different elements of the oven





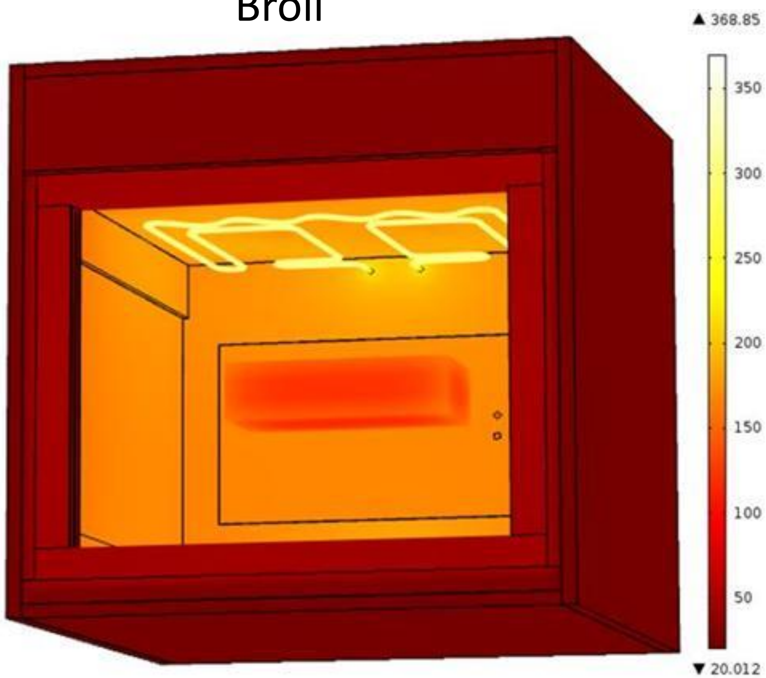


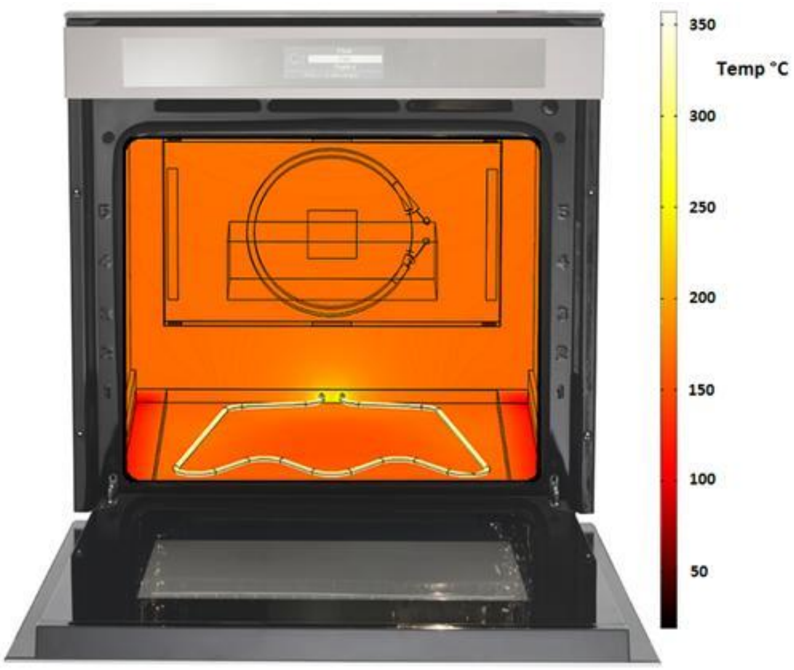
4. RESULTS

Results: Evolution of the Temperature

- Evolution of the Oven Temperature (t=50min)

Broil

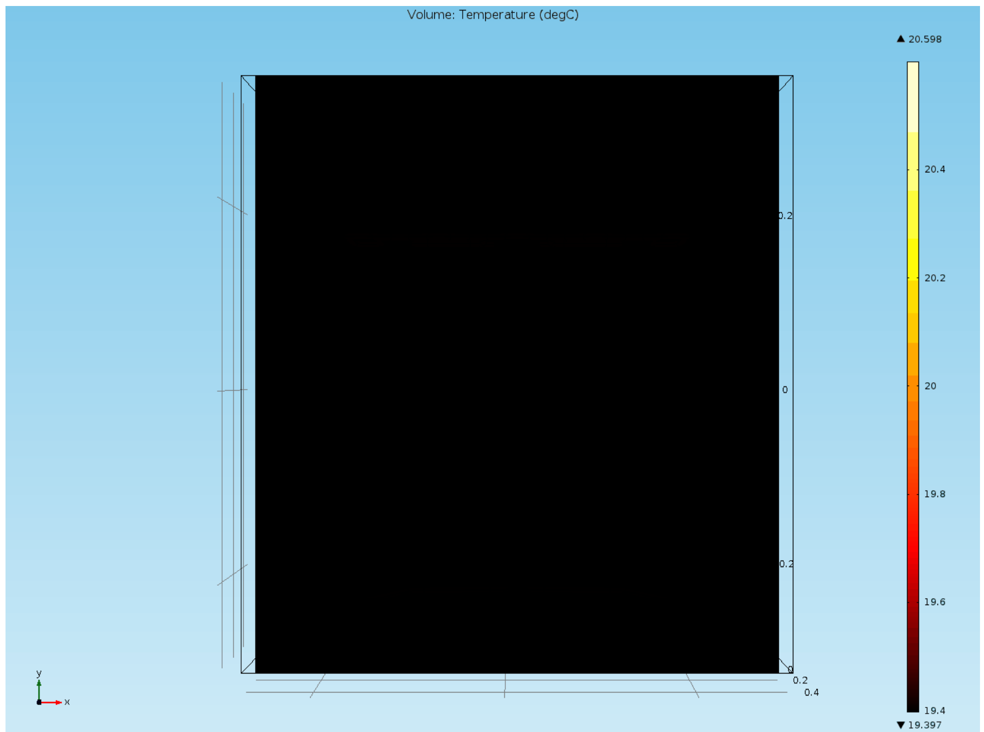




Bake

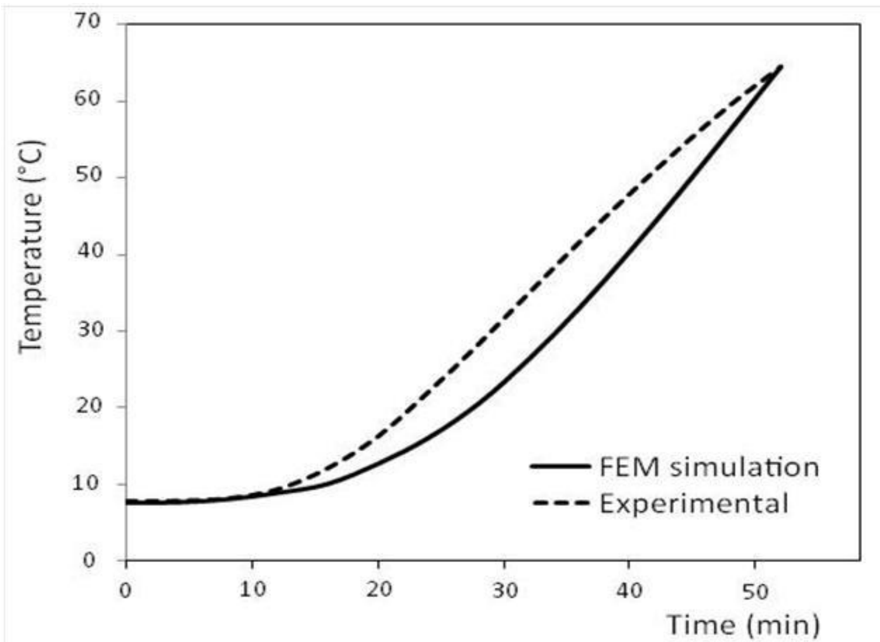
Results: Evolution of the Temperature

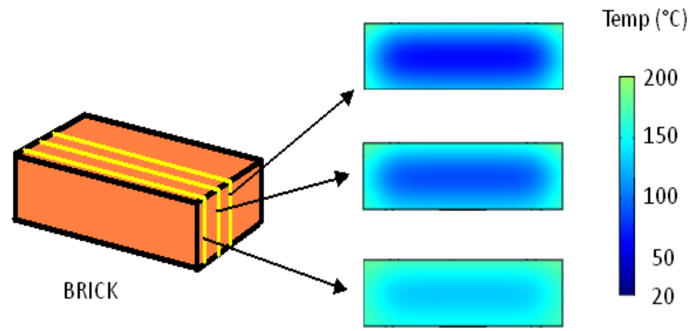
- Evolution of the Oven Temperature (transient)



Results: Evolution of the Temperature

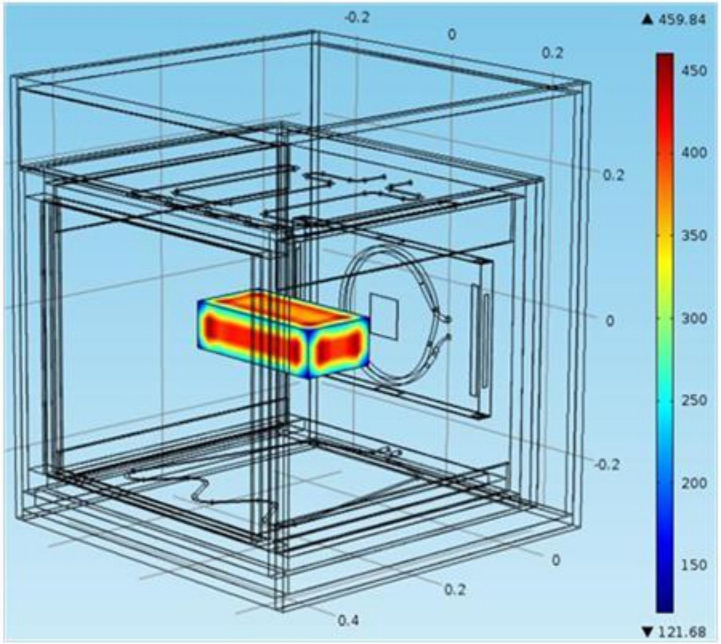
- Evolution of the Brick Temperature (transient)





Results: Evolution of the Temperature

- Evolution of the Brick Concentration (t=50min)



EVAPORATED WATER (BRICK)

166g (Predicted) vs 171 g (Experimental)

5. CONCLUSIONS & FUTURE WORK

Conclusions

- Experimental Study Information:
  - Standard test for energy consumption, EN 50304.
- Temperature Evolution obtained in the test:
  - Similar to the predictions of evolution of the temperature obtained in the theoretical model.
- Experimental Validation of the Model:
  - Make possible to further study innovative strategies to obtain an optimized oven performance
    - Parametric study
    - Design optimization

Future Work

- Next steps:
  - Use the developed model to optimize the use of energy resources when designing the oven.
    - Parametrical studies to enhance the heat transfer paths.
  - Increase the experimental temperature points:
    - Inside the brick at different depths and positions.
    - In the air boundary layer near the brick surface.
    - In the door glasses.

Thank You for Your Attention

Questions?

Annexes

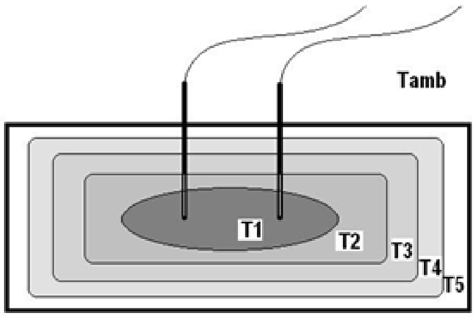
Thermal Efficiency

$$\text{Efficiency}(\%) = \frac{E_{load}}{E_{cable}} \cdot 100$$

$$E_{load} = \left(m_B \cdot Cp_B + m_{(H_2O)L} \cdot Cp_{(H_2O)L}\right) \cdot \Delta T + m_{(H_2O)V} \cdot Lv_{(H_2O)V}$$

E_{load}= energy to heat the load = Energy to heat the Brick + Energy to heat the liquid water + Energy to water vaporization

E_{cable}= energy suppied to oven



Data:

m_B= Brick mass= 920 g

$m_{(H2O)L}$ = Liquid water mass = 1050 g

$m_{(H2O)v}$ = Vaporized water mass = 120 g

Cp_B = Brick specific heat* = 0.8 J/g.K

$Cp_{(H2O)L}$ = Liquid water specific heat = 4.204 J/g.K

$Lv_{(H2O)v}$= Water latent heat (at 100°C) = 2260 J/g

1 J = 0.000278 Wh

E_{load}= 154.14 Wh

E_{cable}= 860 Wh (base case) → **Efficiency = 17.9 %**