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Numerical and Experimental Analysis of Natural and Mixed Convection Heat Transfer for Vertically Arranged DIMM

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Outlines

- ✓ Introduction to DIMM
- ✓ Experimental set-up
- ✓ COMSOL Modelling
- ✓ Results
- ✓ Conclusions

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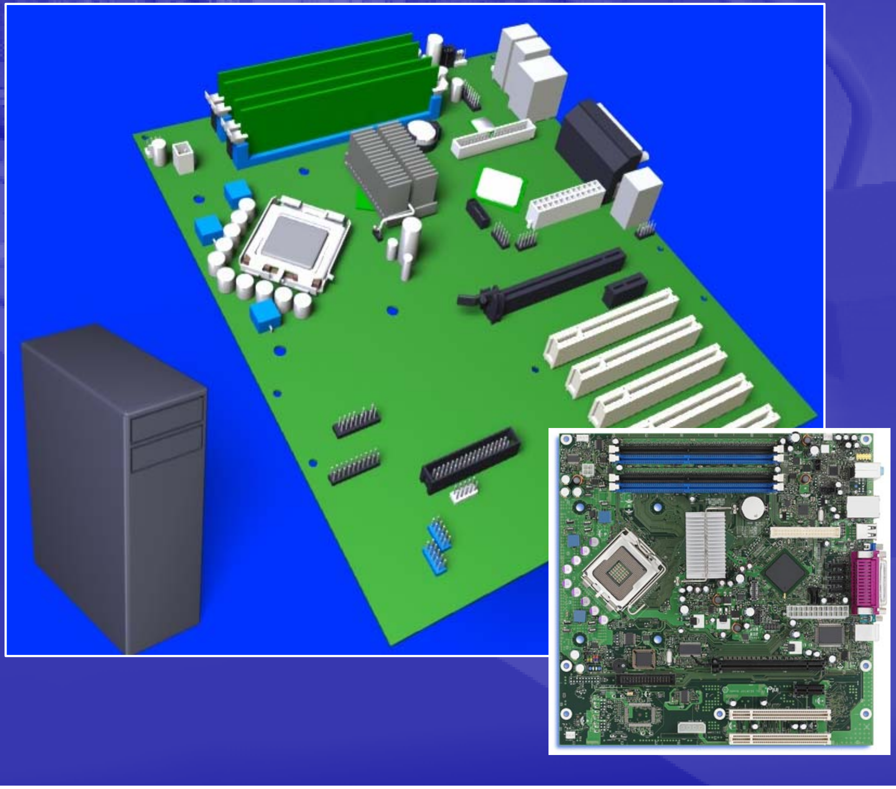
Introduction

Electronic devices produce a very important rate of specific heat as a by-product of their normal operation.

Among the high power components, Random Access Memory modules are one of the more sensitive thermal subsystem of an assembled computer.

Cooling of those devices is always performed by mechanical ventilation systems.

However, the forced air flow is often disturbed by many factors. Cables, drive bays and brackets can determinate bypass over the memory components, forcing the subsystem to operate in mixed or natural convection conditions.



Introduction

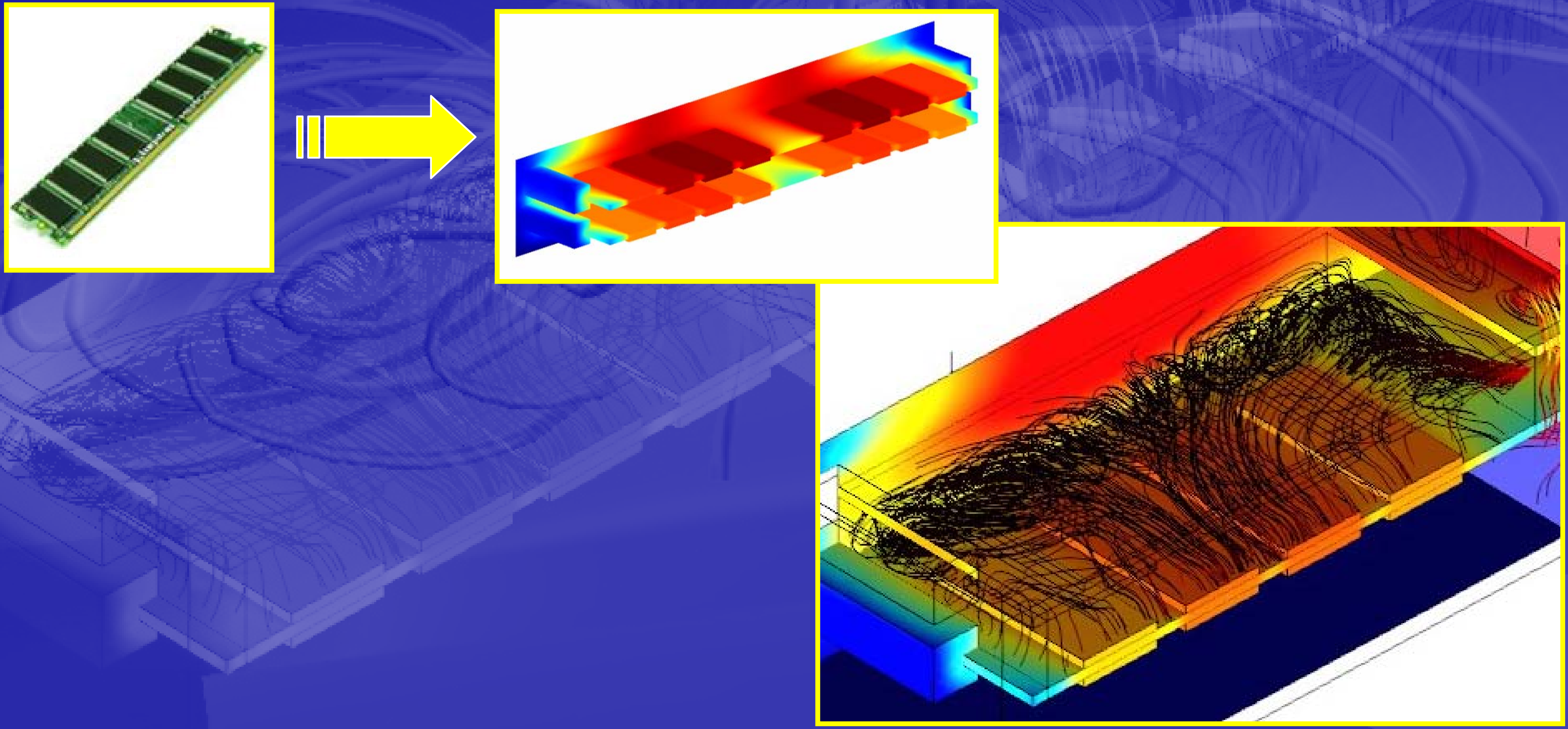
The actually most used memory in desktop Personal Computers is DIMM (Dual In-line Memory Module):

- 4-16 chip of synchrony dynamical memory with random access (SDRAM) type DDR [Vdd=2,5 V] (Double-Data Rate) o DDR2 [Vdd=1,8 V]
- Very small (135x30x1,3 mm) Printed Circuit Board (PCB)
- 184 different PIN on both faces of the PCB
- It is connected to the mainboard by a specific socket
- It is object of JEDEC (Joint Electron Device Engineering Council) standards

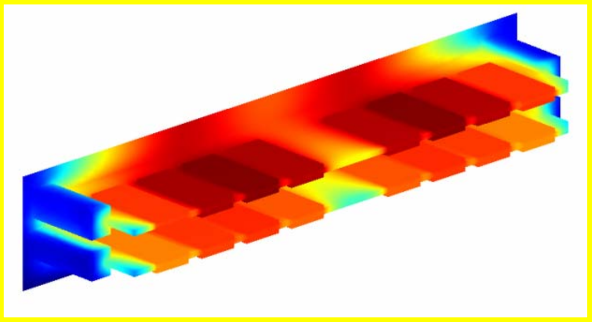
In order to guarantee the reliability of these systems, it is strictly necessary that the memory chip does not over, during its functioning, the maximum temperature recommended in the technical documentations of constructors (Micron Technology, 80-110°C).

Introduction

For predictive estimation of operative temperature of DIMM modules, leading constructors (Micron, Infineon, ...) recommend CFD modelling



Introduction



The numerical model (and so the results carried-out by simulations) is reliable ?

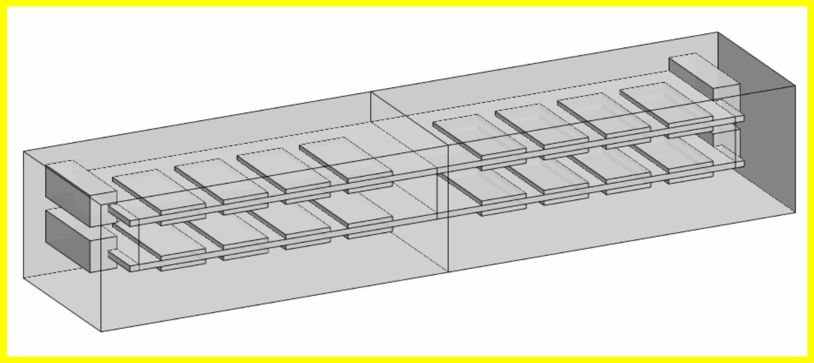
It is always advisable firstly testing its reliability.

One suitable way to proceed consists in:

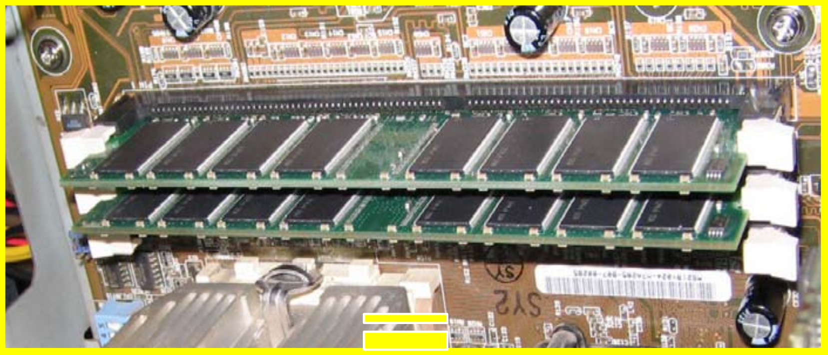
- ➢ setting-up an experimental apparatus reproducing a test section
- ➢ conducing test experiments on this set-up
- ➢ some data become available to be compared with those obtained by using the numerical model

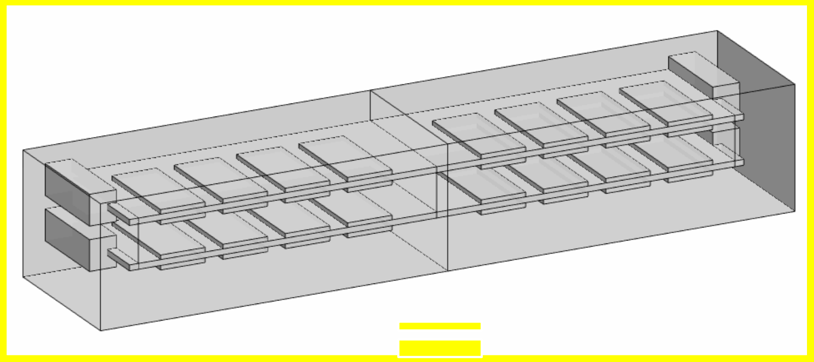
Introduction

The aim of this study has been comparing experimental and numerical results concerning thermal levels of operating DIMM



Introduction



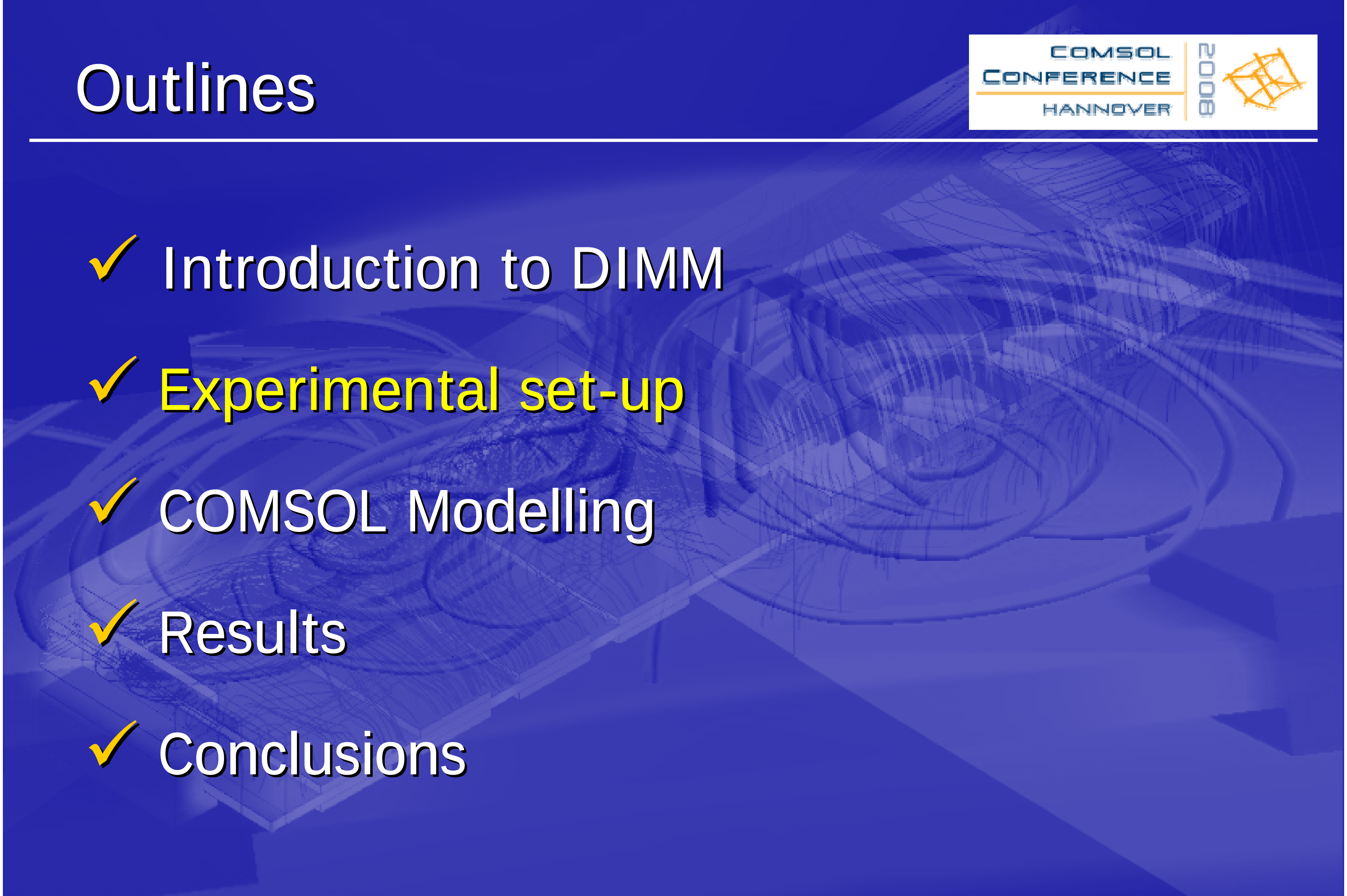


Tools

Infrared thermo-camera

COMSOL Multiphysics

Outlines



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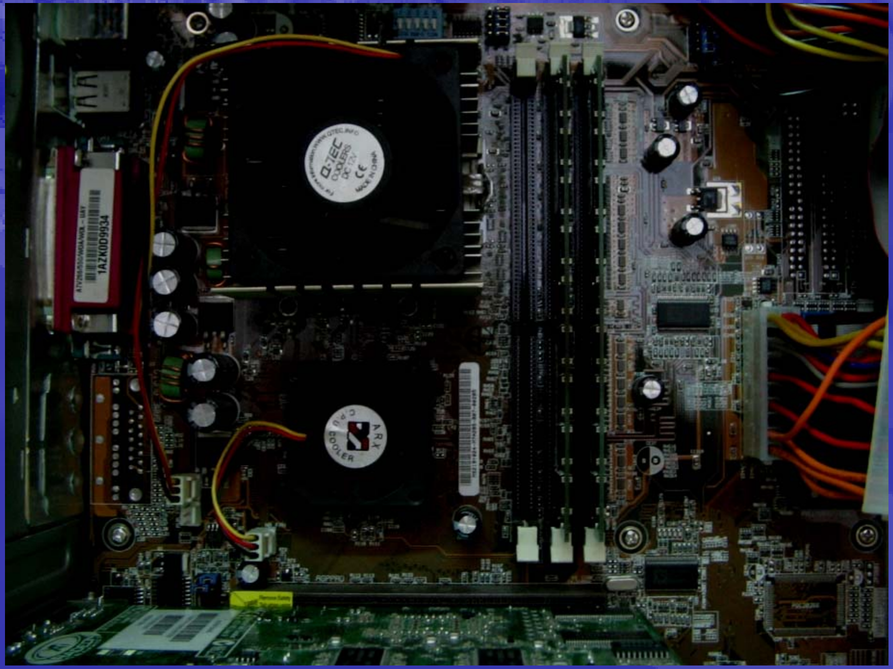
Experimental set-up

The experimental technique chosen to produce comparing data for numerical results lies on a thermo-graphic investigation on surfaces thermal distribution of Dual In-line Memory Modules during operative conditions.

The experimental apparatus mainly consists in:



- a test PC where two 16-chip memory modules (DDR - 512 MB - 266 MHz) were arranged on
- an infrared camera (ThermaCAM Flir SC 3000) for detection of surface thermal fields
- a laptop PC used for acquisition

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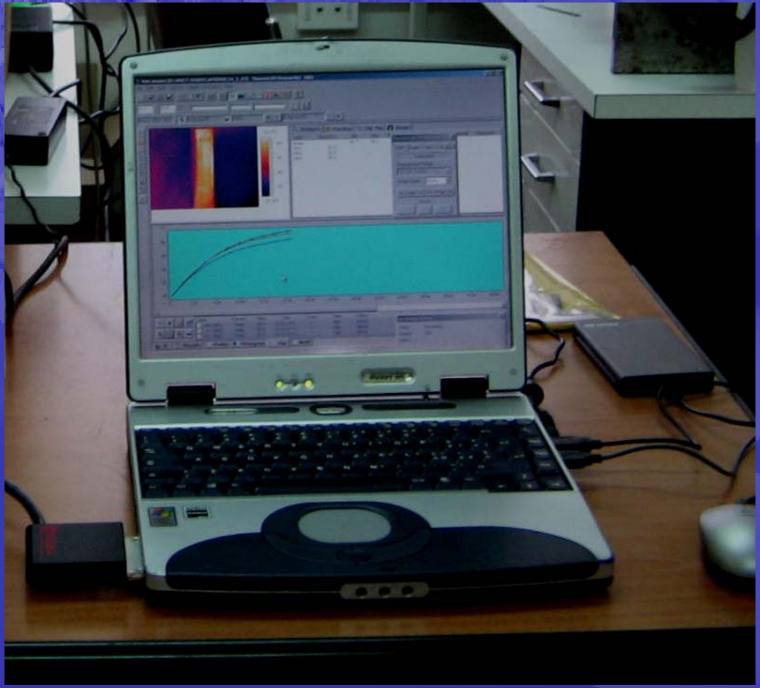
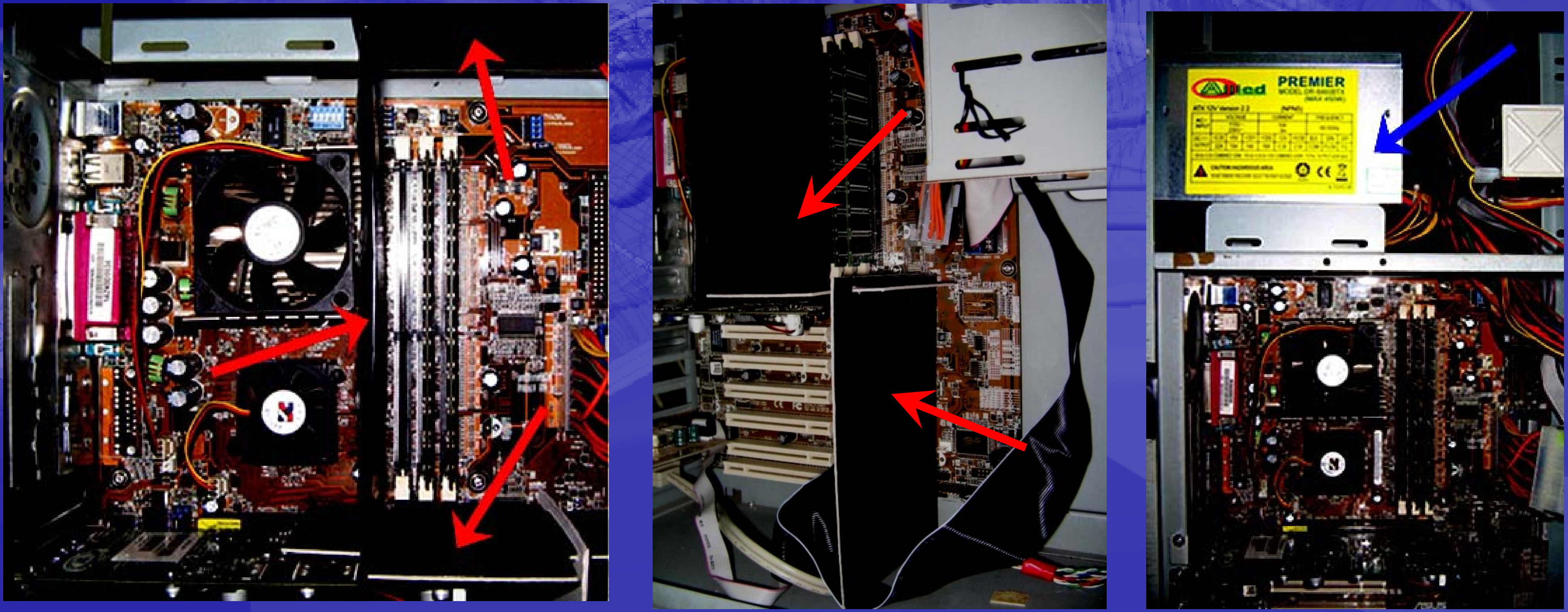


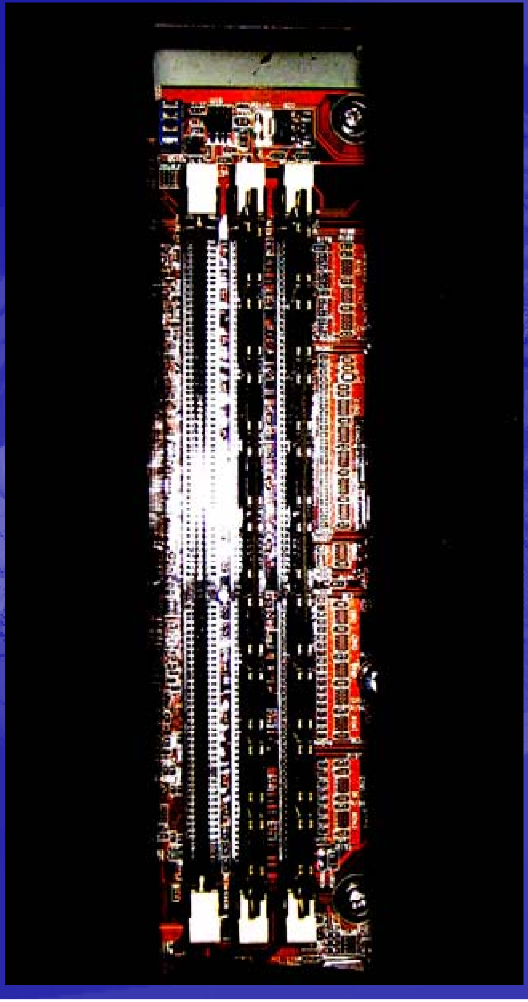
Experimental set-up

In order to reproduce the most critical heat transfer condition of functioning for the electronic devices, some black panels (red arrows) were employed in order to shield the memory modules by the forced air-flow produced by ventilators. The power-pack was put outside the case (blue arrow).



Experimental set-up

Frontal black box built around the DIMM also resulted helpful for thermographical acquisition.



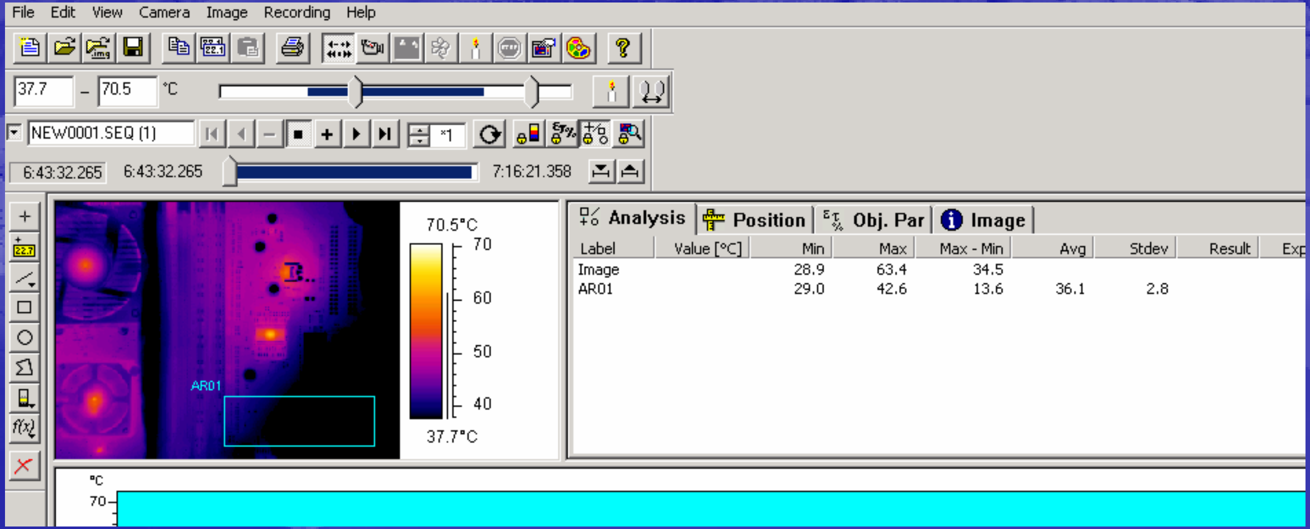
- Hot electronic components mounted on the mainboard were hindered by the black panels, allowing to set temperature range of the acquisition system with thermal values characteristic of the DIMM.

Experimental set-up

During experimental running specific applications were launched on the test PC in order to load memories by a known electrical power (0.3-0.4 [W]).

The experimental acquisitions were recorded each 5 seconds, during a transient time of 3-4 hours.

Exceeded this time a stationary thermal behaviour was reached by the dissipating components



Label	Value [°C]	Min	Max	Max - Min	Avg	Stdev	Result	Exp
Image		28.9	63.4	34.5				
AR01		29.0	42.6	13.6	36.1	2.8		

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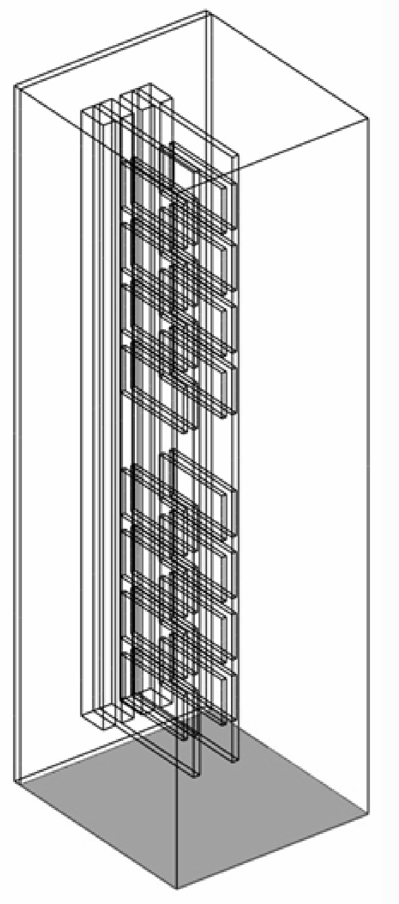
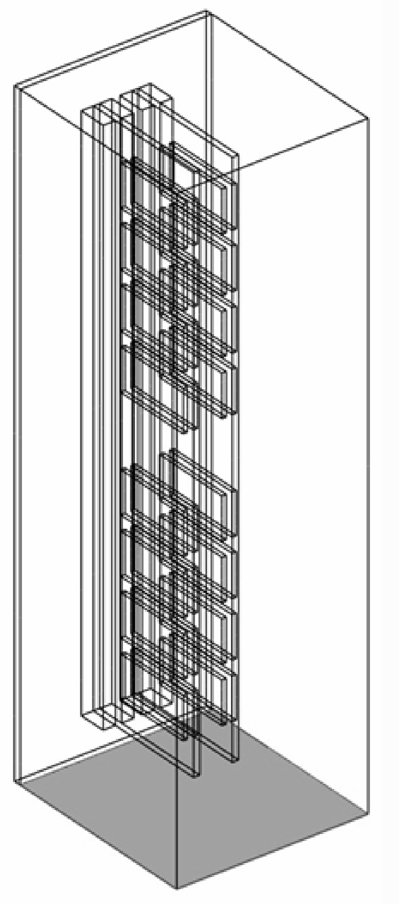
COMSOL Modelling

The considered physical system is outlined by parallel boards (Printed Circuit Board) surrounded by air and arranging on multiple heat sources (Chip)



COMSOL Modelling

Governing equations for solving thermal and dynamical fields read as:



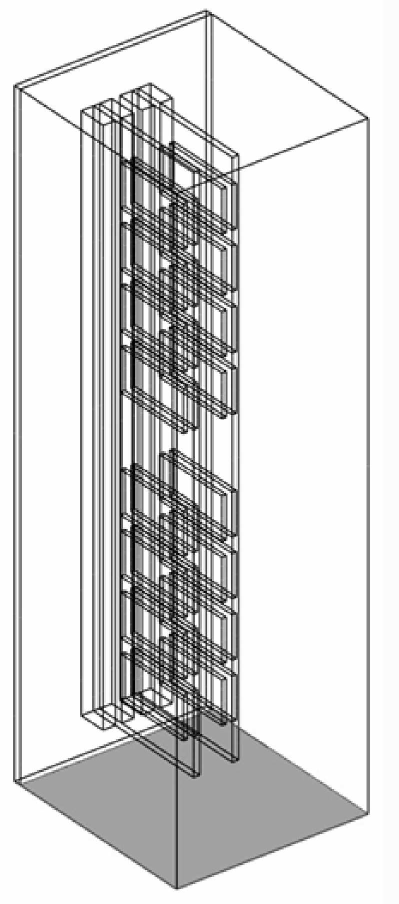
$$\rho\frac{D\vec{v}}{D\tau} = -\nabla p + \vec{F} + \mu\nabla^2\vec{v}$$

$$\frac{\partial\rho}{\partial\tau} + \nabla\cdot\left(\rho\vec{v}\right) = 0$$

$$\rho C_P\frac{DT}{D\tau} = \nabla\cdot\left(\lambda\nabla\cdot T\right) + q$$

COMSOL Modelling

The energy equation is solved in fluid as well as in solid sub-domains of system, by considering appropriate values for thermal conductivity



Schede: FR4

ρ = 1900 [kg / m³]

C_p = 1369 [J / (kg K)]

k = 0,3 [W / mK]

Fluido: Aria

P_0 = 101,3 [k Pa]

C_p = 1100 [J / (kg K)]

M_w = 0,0288 [kg / mol]

R = 8,314 [J / (mol K)]

Chip: Silicon

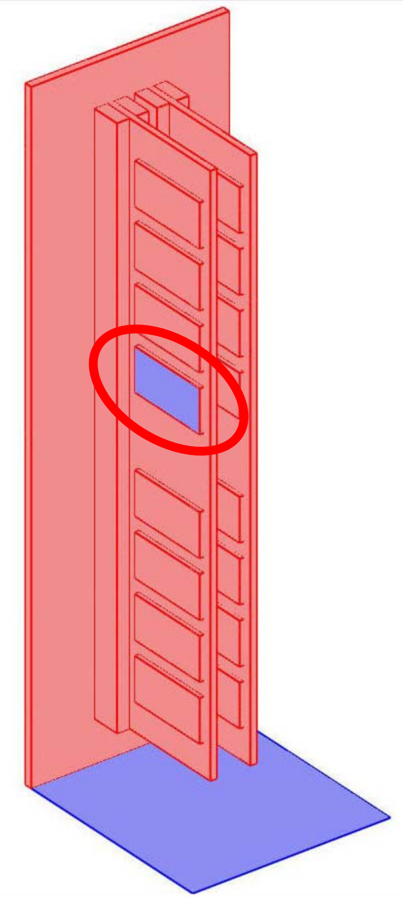
ρ = 2330 [kg / m³]

C_p = 703 [J / (kg K)]

k = 163 [W / (mk)]

COMSOL Modelling

Only in chip sub-domains the heat source term is different from zero

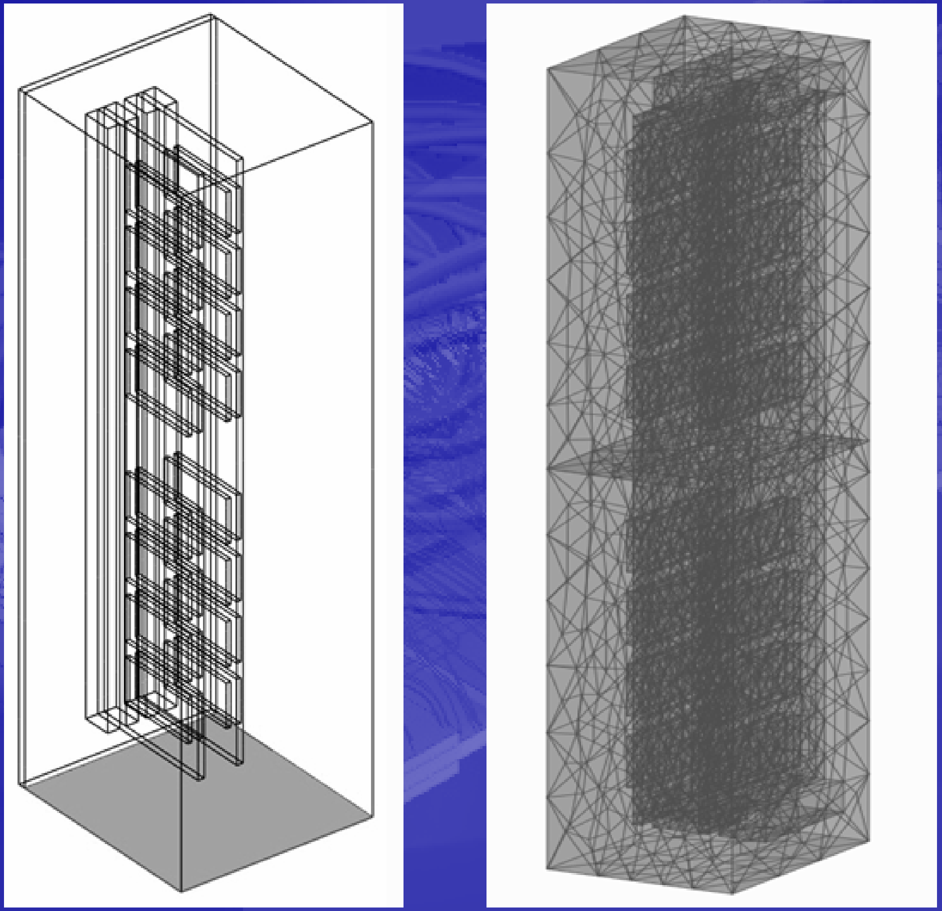


P(PRE_PDN)	4.8mW
P(PRE_STBY)	12.0mW
P(ACT_PDN)	9.7mW
P(ACT_STBY)	26.4mW
P(REF)	4.6mW
Total Background Power	**57.6mW**
P(ACT)	20.7mW
Total Activate Power	**20.7mW**
P(WR)	9.6mW
P(RD)	20.0mW
P(DQ)	6.2mW
Total Read/Write Power	**35.8mW**
Total DDR1 SDRAM Power	**114.1mW**

P(PRE_PDN)	2.0mW
P(PRE_STBY)	30.0mW
P(ACT_PDN)	0.0mW
P(ACT_STBY)	105.2mW
P(REF)	5.0mW
Total Background Power	**142.2mW**
P(ACT)	74.6mW
Total Activate Power	**74.6mW**
P(WR)	46.9mW
P(RD)	97.6mW
P(DQ)	18.6mW
Total Read/Write Power	**163.2mW**
Total DDR1 SDRAM Power	**380.0mW**

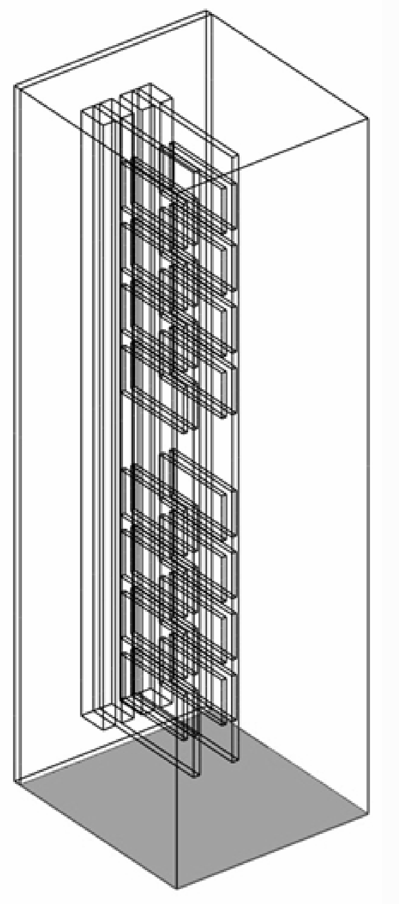
COMSOL Modelling

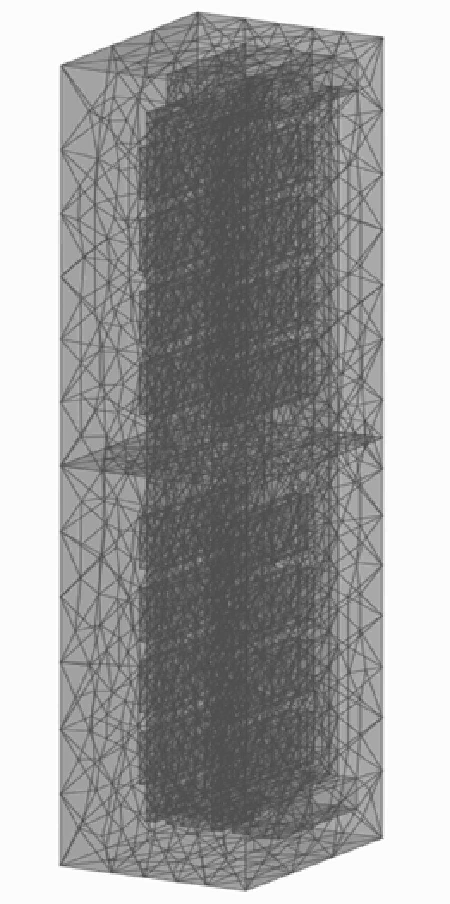
Spatial discretization of differential operators made on no-structured and no-uniform mesh

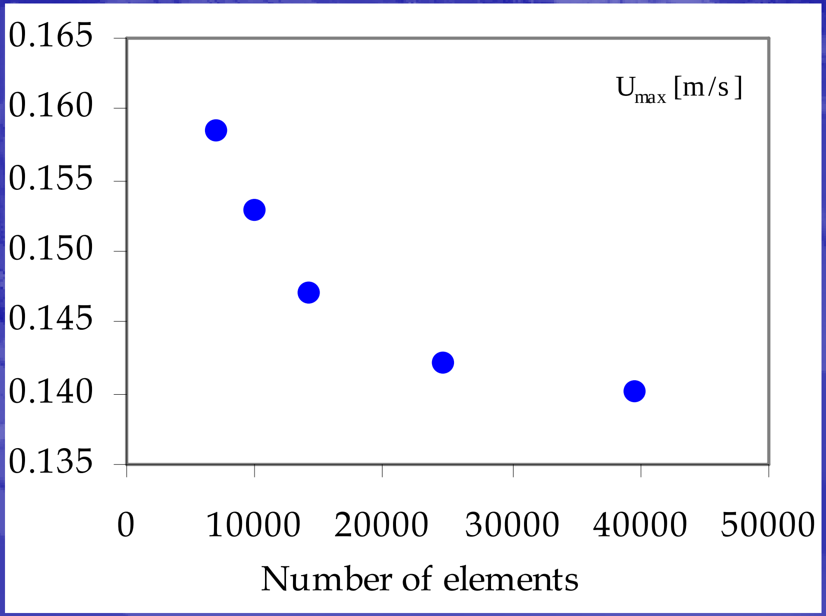


COMSOL Modelling

Influence of computational grid has been preliminary studied in order to assure mesh-independent results







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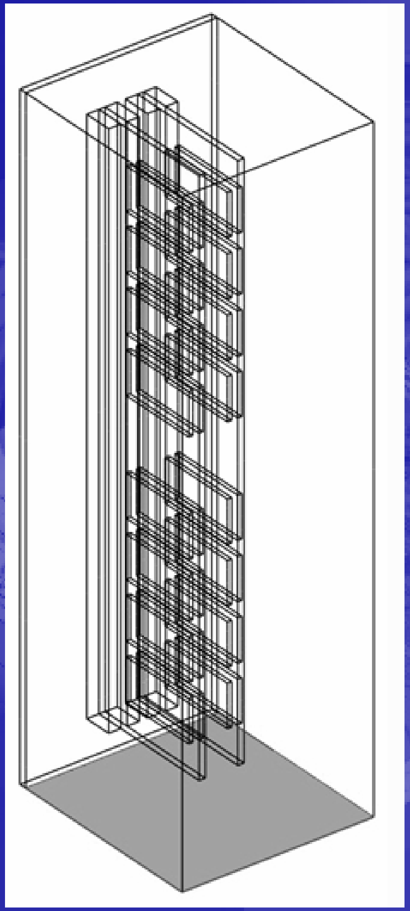

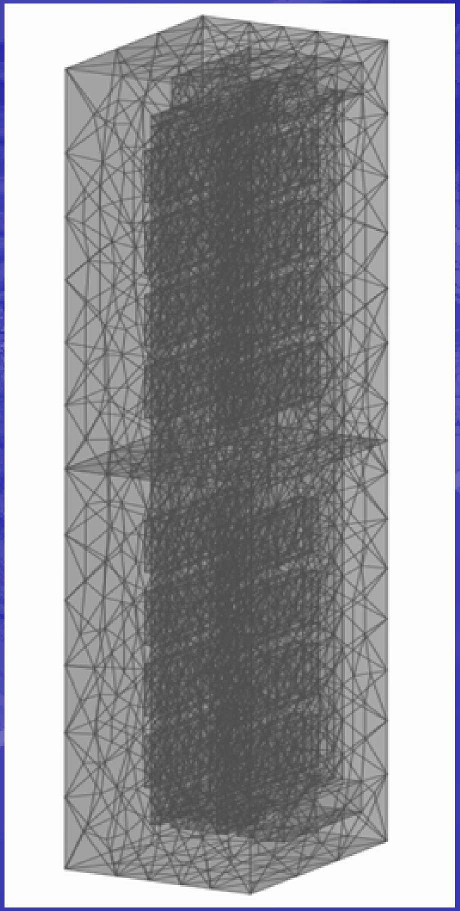

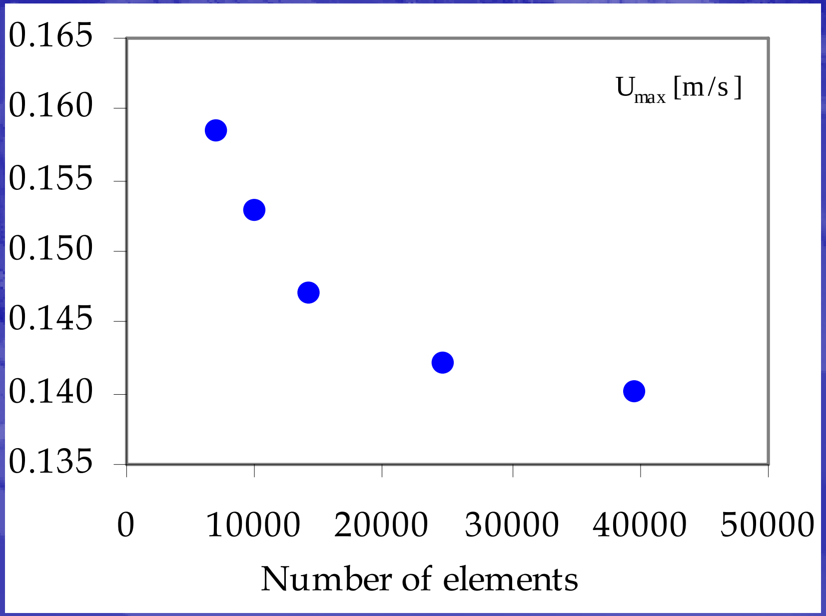

225600 Degrees of freedom

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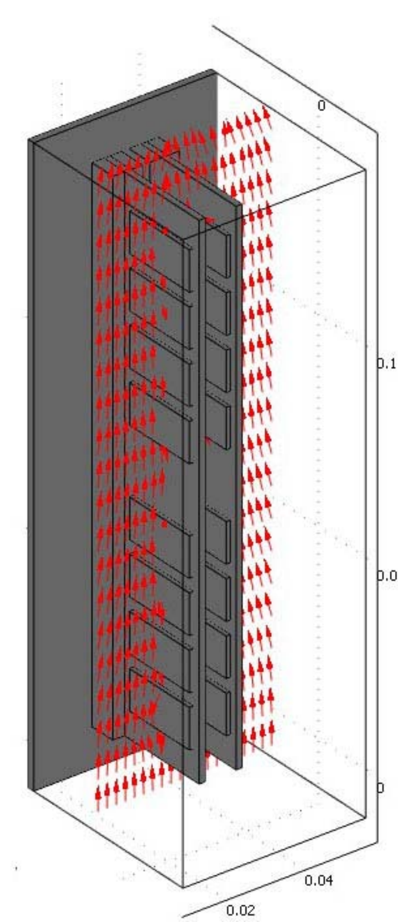
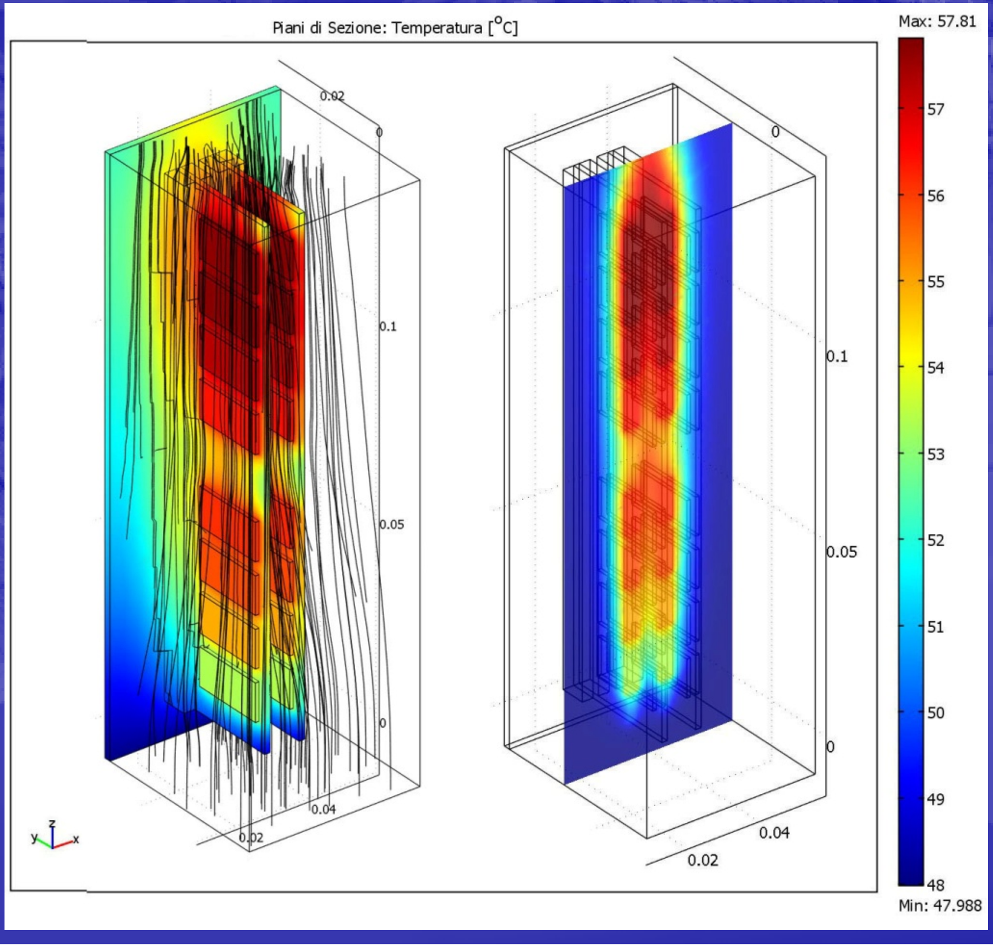
Results

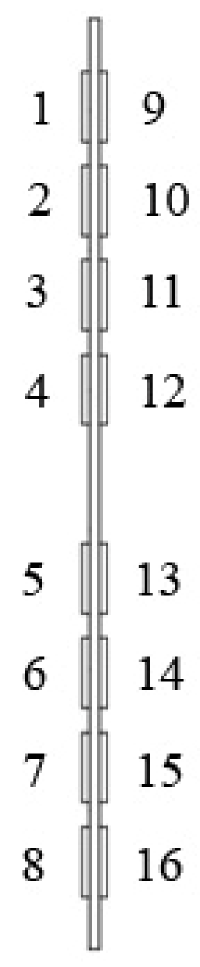
Fluid is propelled by buoyancy force to flow up. Heat is vertically transported. The integrated circuits arranged in the top portion of the modules manifest higher thermal levels

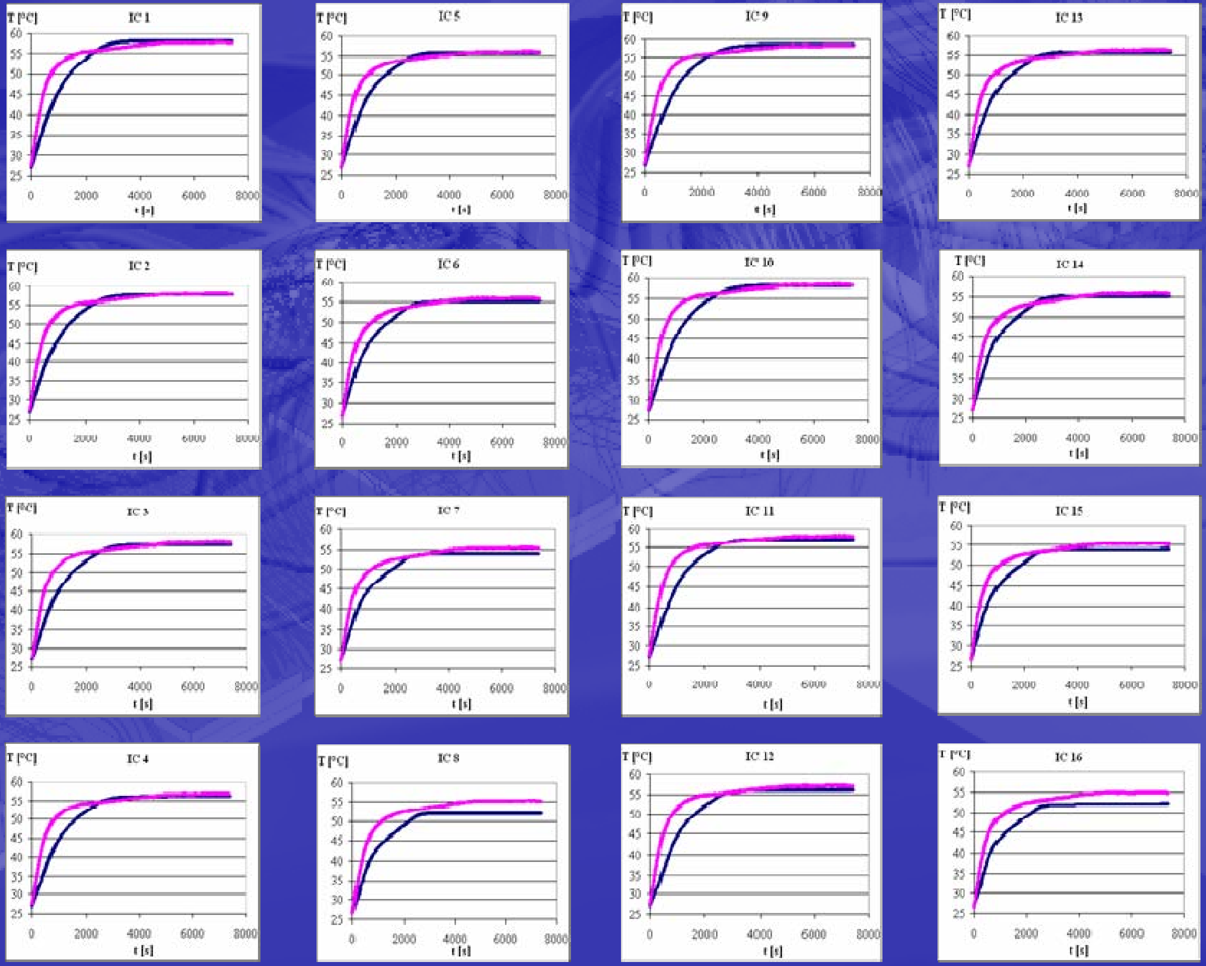




Results

Transient analysis: comparison of time evolution of experimental (magenta lines) and numerical (blue lines) chips mean temperature





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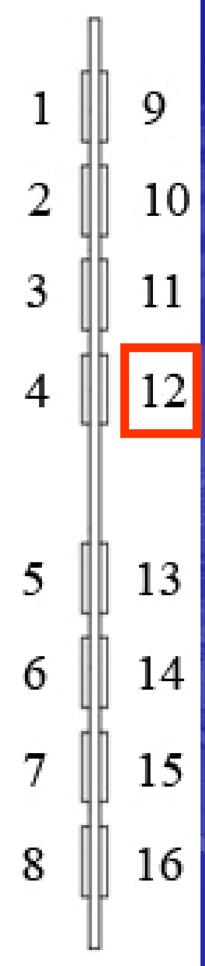
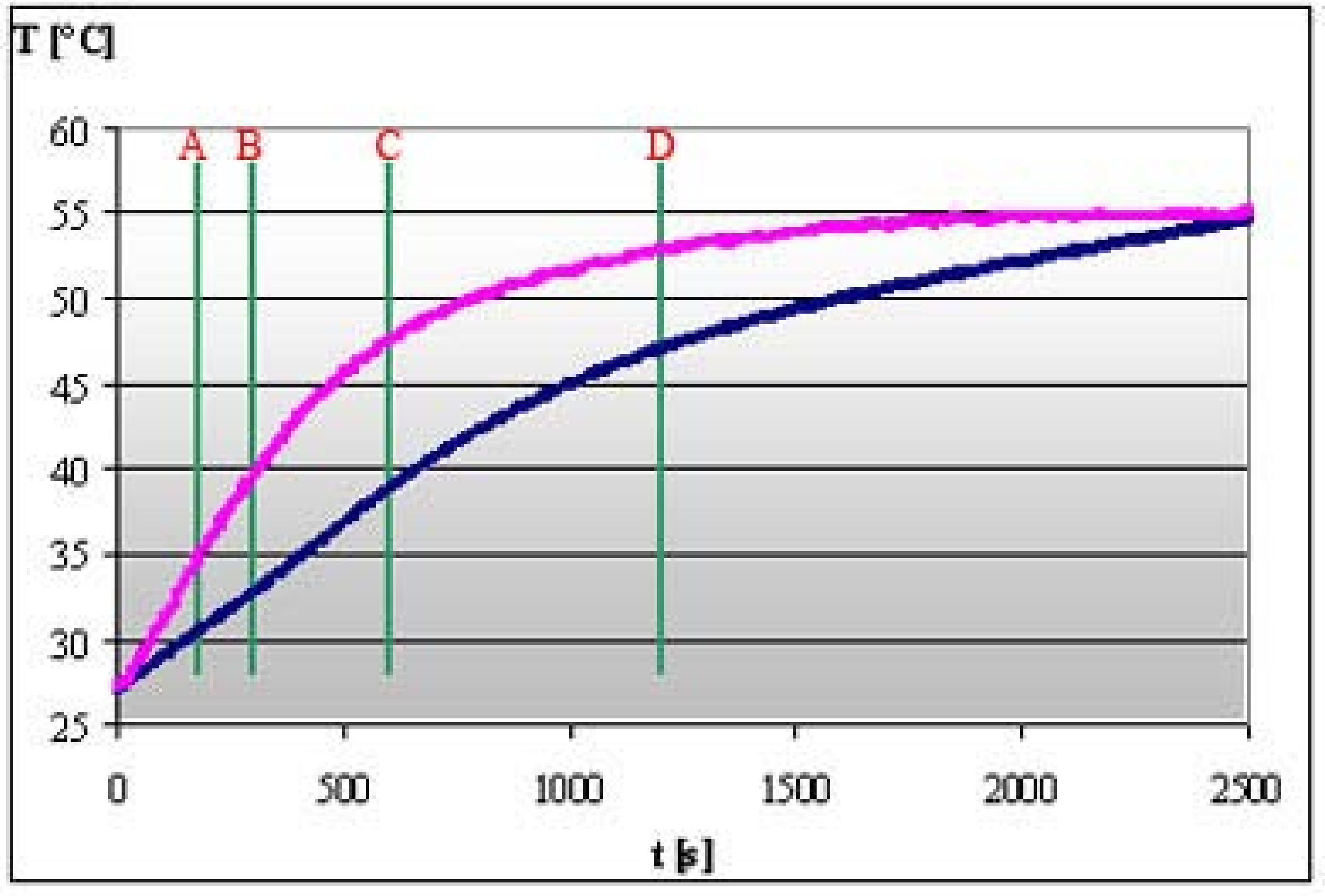
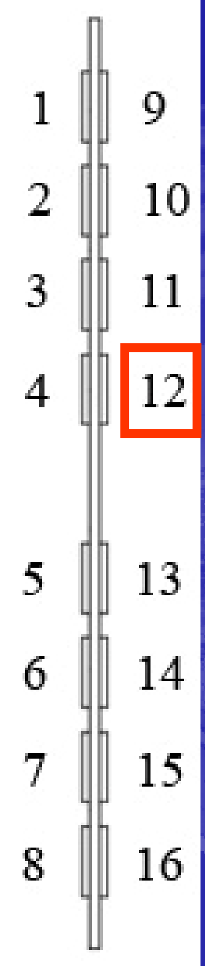
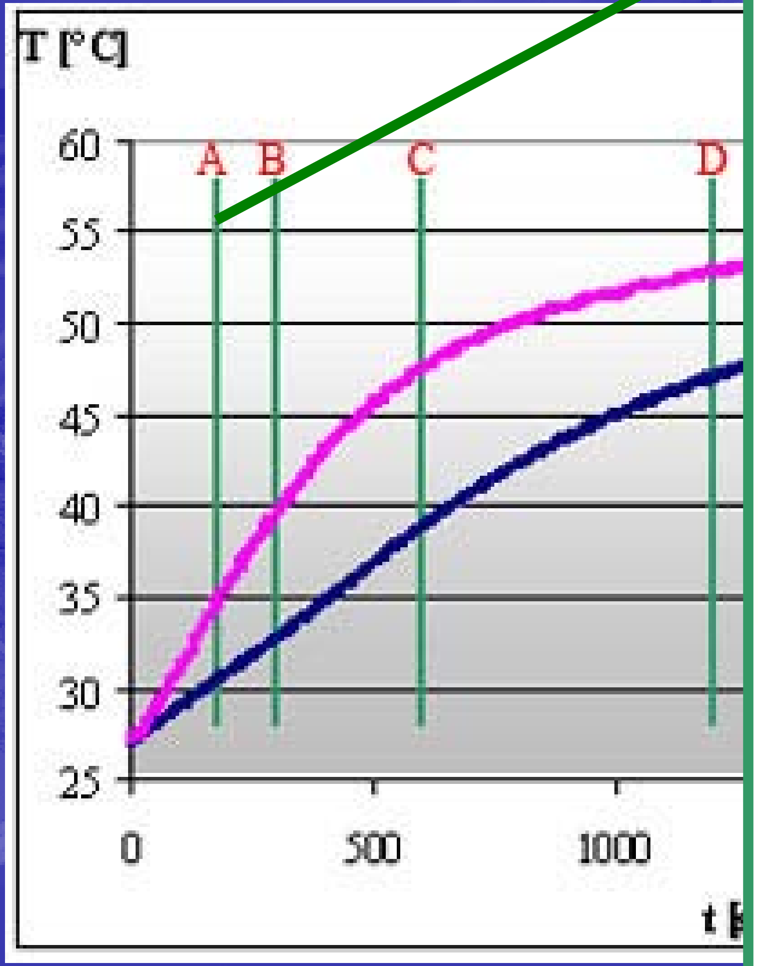


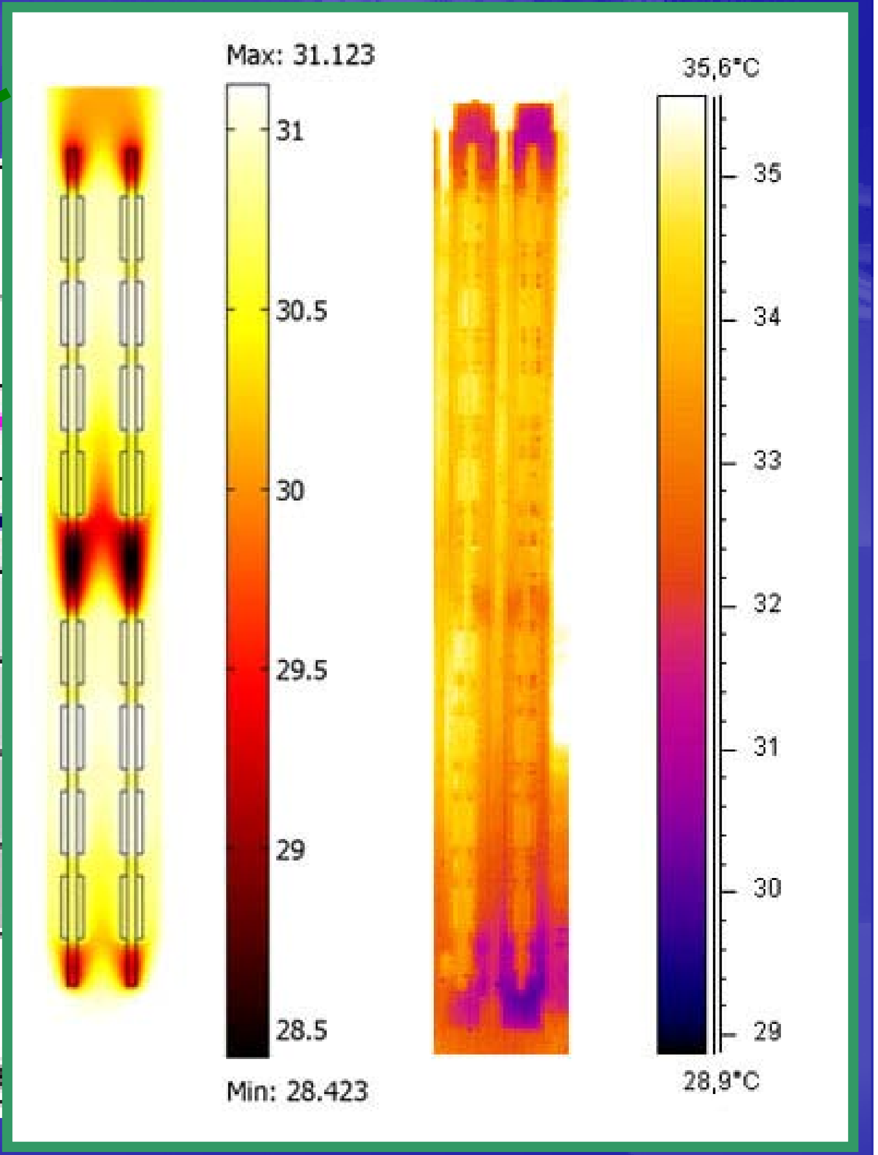


Results

Numerical Vs Experimental: frontal thermal field







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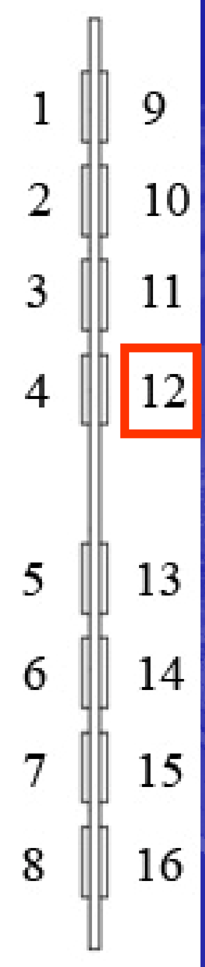

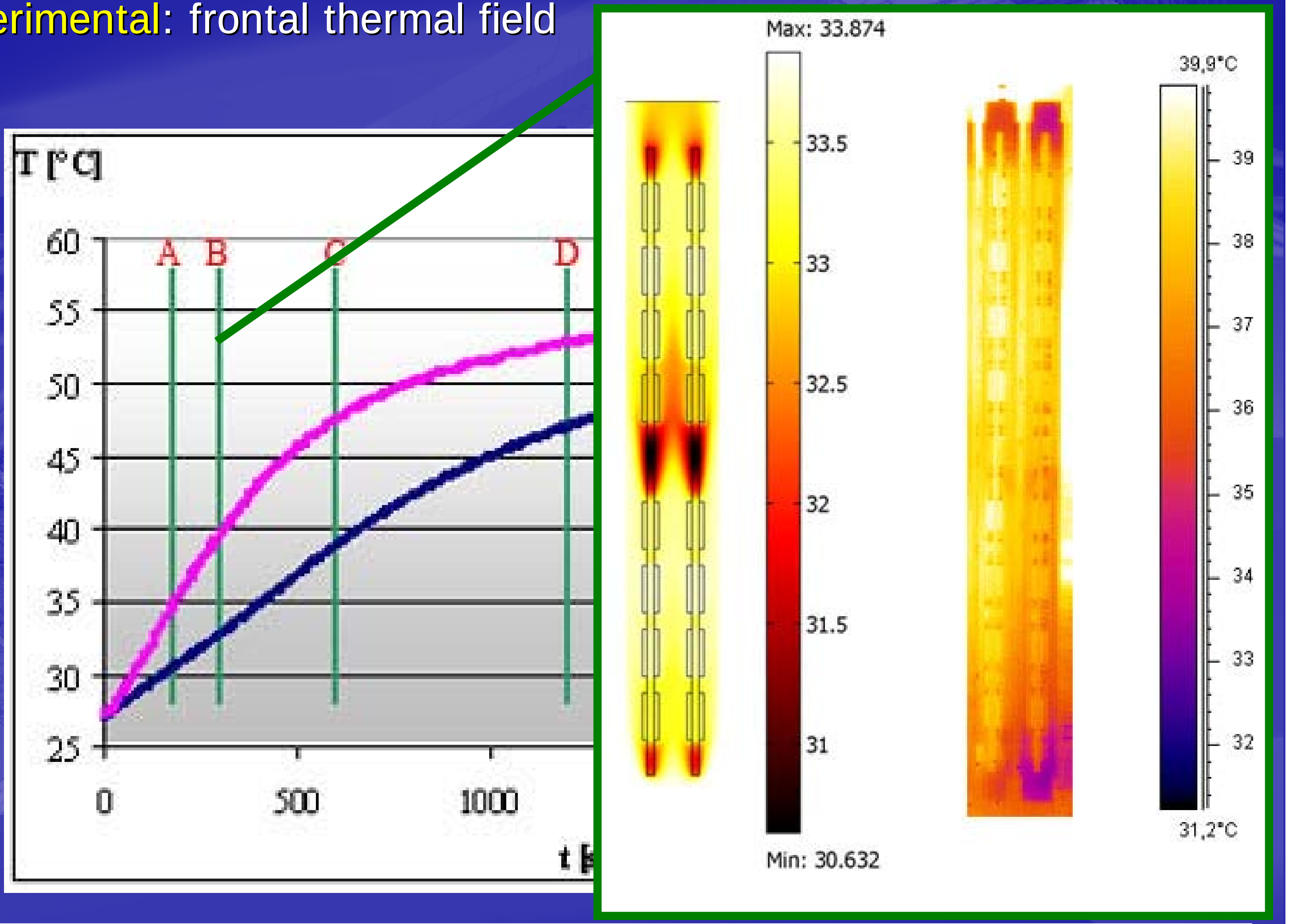

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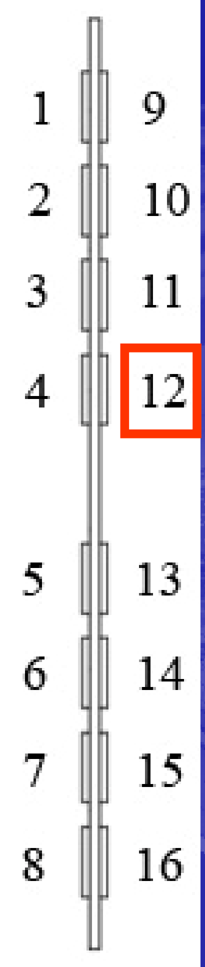

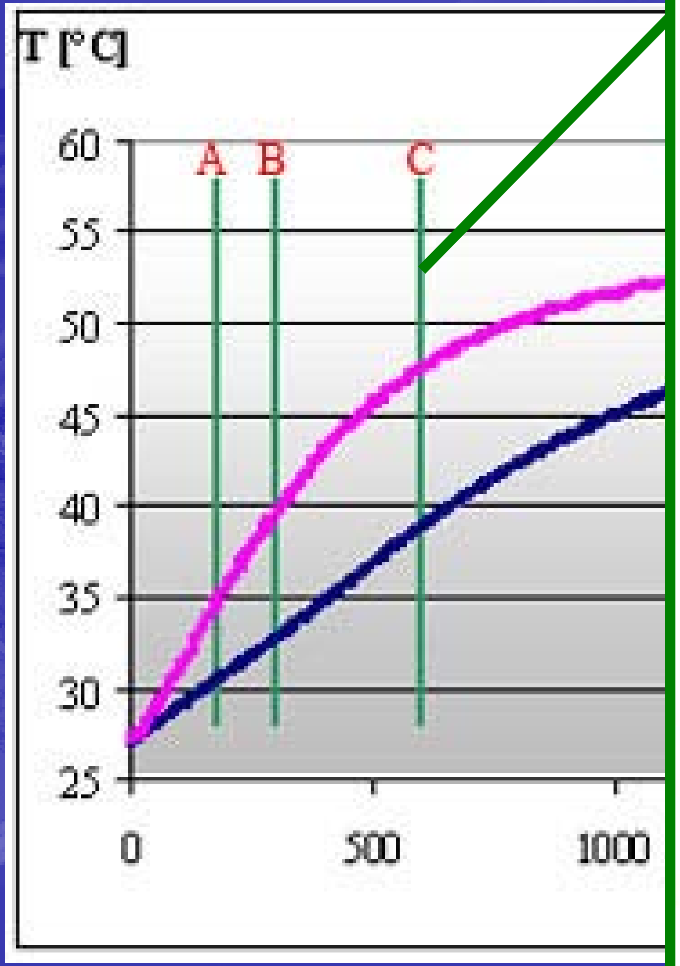

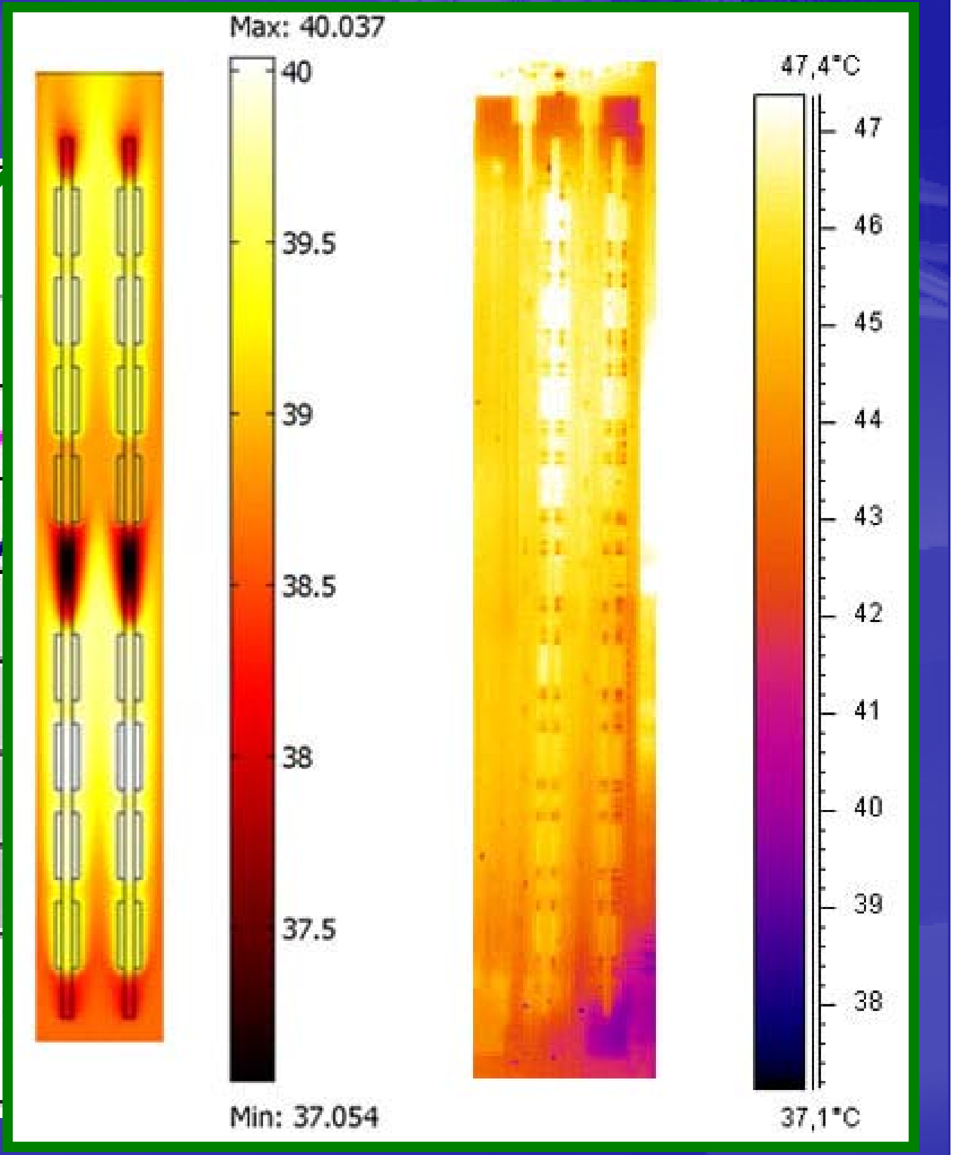

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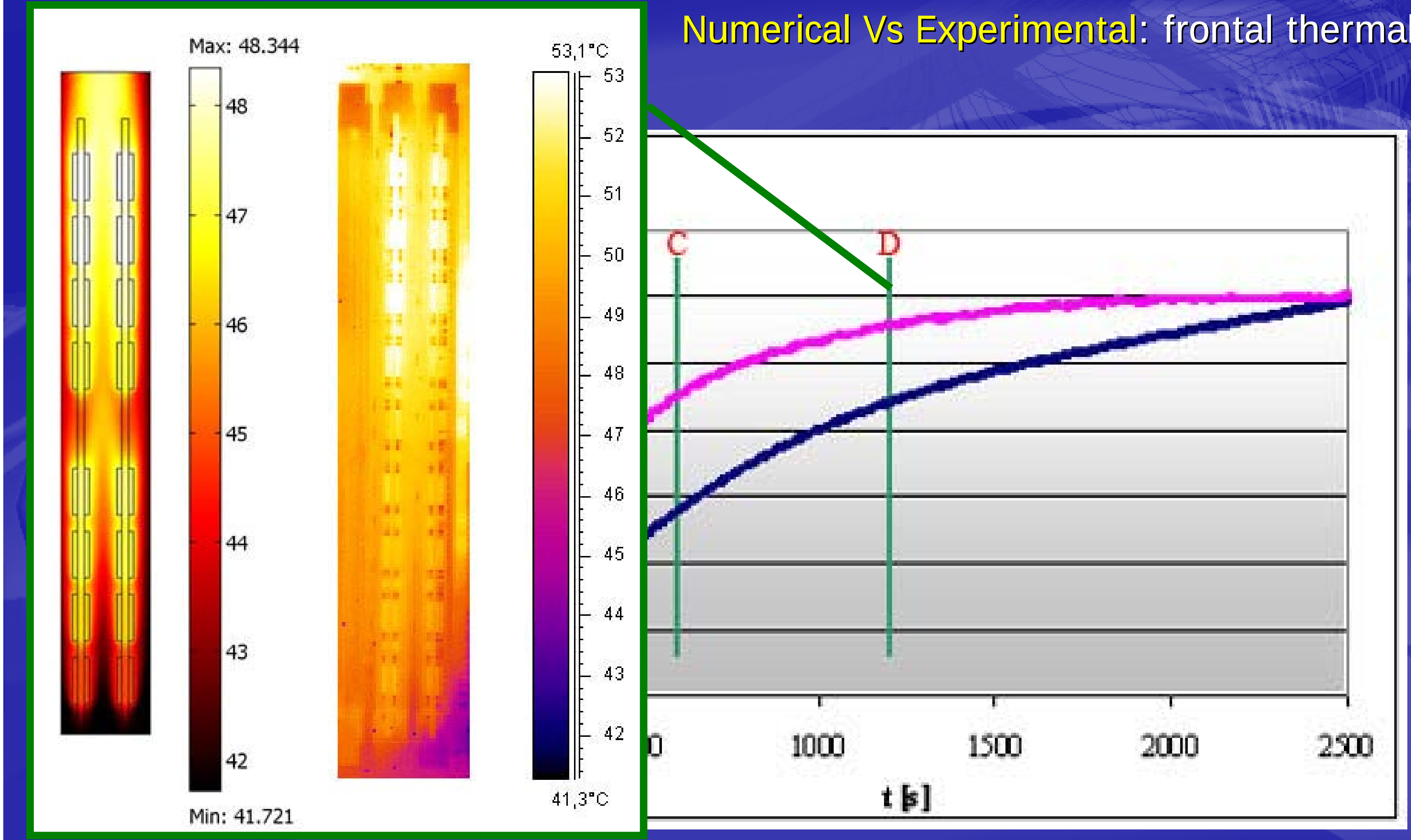
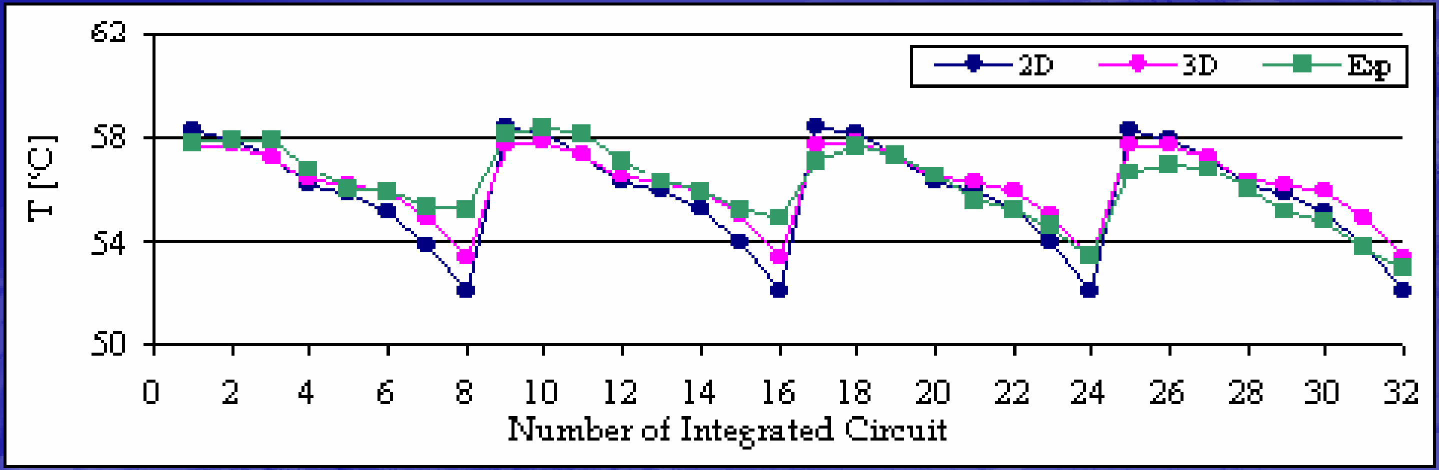


Results

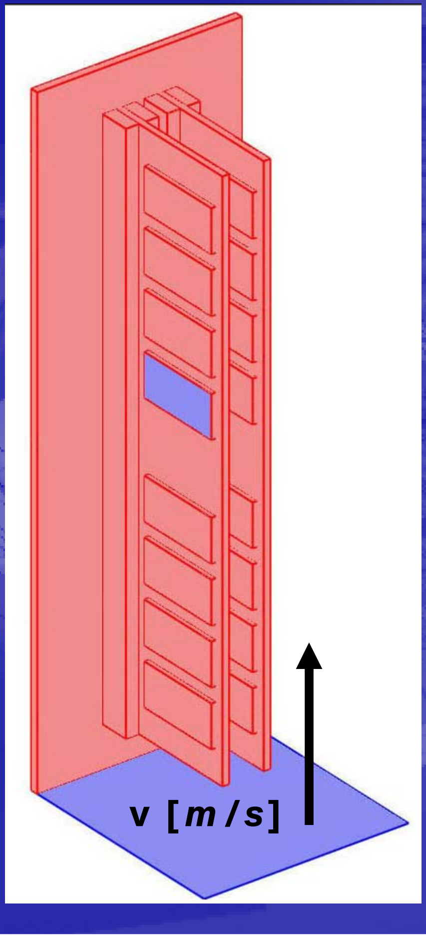
Steady solution: comparison of experimental and numerical chips mean temperature



IC	Num	Exp	(Num-Exp)/Exp %
1	57.66	57.80	0.24
2	57.72	57.95	0.40
3	57.25	57.88	1.09
4	56.38	56.74	0.63
5	56.14	55.96	0.32
6	55.84	55.86	0.04
7	54.92	55.33	0.74
8	53.34	55.26	3.47

Results

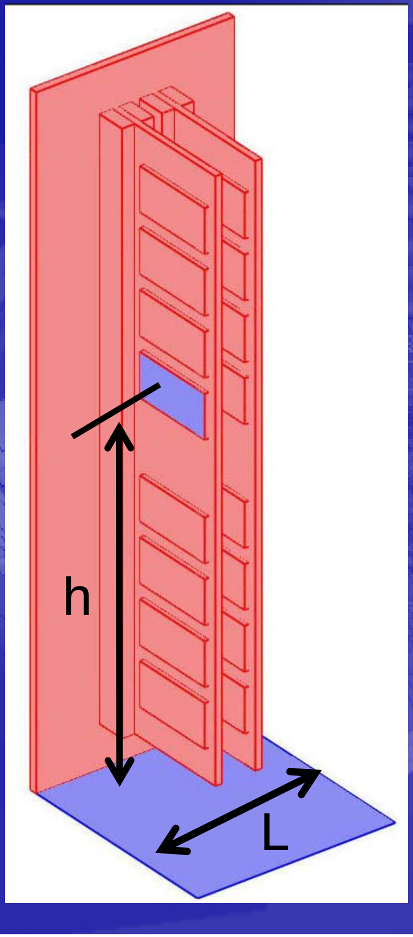
Models considering imposed air flow rate coming from the bottom surface of the outlined air volume have been built



Results

Convective heat transfer coefficient have been computed

Natural and mixed convective heat transfer coefficients have been compared



$$Nu = \frac{\frac{1}{h \cdot b}\int_{z_1}^{z_2}\int_{y_1}^{y_2}\frac{\partial T}{\partial x}dydz}{\frac{T_P - T_\infty}{L}}$$

IC	$\frac{T_{nat}-T_{v=0.1}}{T_{nat}}\%$	$\frac{T_{nat}-T_{v=0.2}}{T_{nat}}\%$	$\frac{Nu_{v=0.1}-Nu_{nat}}{Nu_{nat}}\%$	$\frac{Nu_{v=0.2}-Nu_{nat}}{Nu_{nat}}\%$
1	1.59	3.25	12.52	32.32
2	1.68	3.34	13.52	35.54
3	1.75	3.59	15.59	39.81
4	1.83	3.89	20.48	48.80
5	2.53	5.27	25.79	47.04
6	3.20	5.81	26.76	47.38
7	3.89	5.86	30.20	54.42
8	4.02	5.30	50.81	85.19
9	1.58	3.23	17.42	34.74
10	1.67	3.38	26.84	53.77
11	1.73	3.56	34.96	70.68
12	1.81	3.86	45.88	115.72
13	2.52	5.24	80.97	228.95
14	3.24	5.93	101.31	291.41
15	3.99	6.06	192.06	311.35
16	4.11	5.46	197.02	327.19

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Conclusions

- This study highlights the opportunity to exploit a numerical approach in order to simulate thermal and fluid-dynamical behaviour of electronic devices.
- The paper otherwise underlines the unquestionable importance of a validation step for the numerical model, strictly needed in order to assure effectiveness and reliability of the results carried-out
- Comparison has been made between DIMM thermal fields experimentally detected and numerically computed
- Results show good agreement each other
- The validated numerical model has been exploited in order to quantify heat transfer coefficients during several operating conditions

THANK YOU !!!

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