Presented at the COMSOL Conference 2010 Paris

Thermal modelling for the implementation of an energetic efficiency control system in a room of meetings of singular geometry

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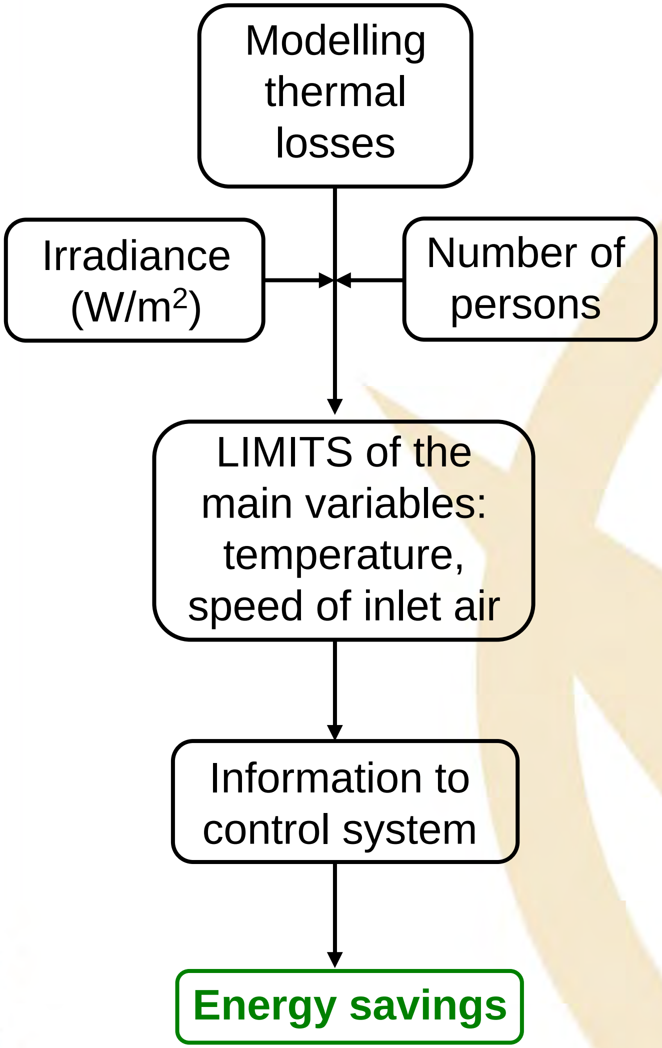
Introduction & objectives

- **Introduction & objectives.**
- Construction details.
- Irradiance data.
- Simulation scenarios.
- Irradiance curve fitting.
- Restrictions and b. c. approach.
- Finite Element mesh.
- Results.
- Conclusions



Modelling thermal losses

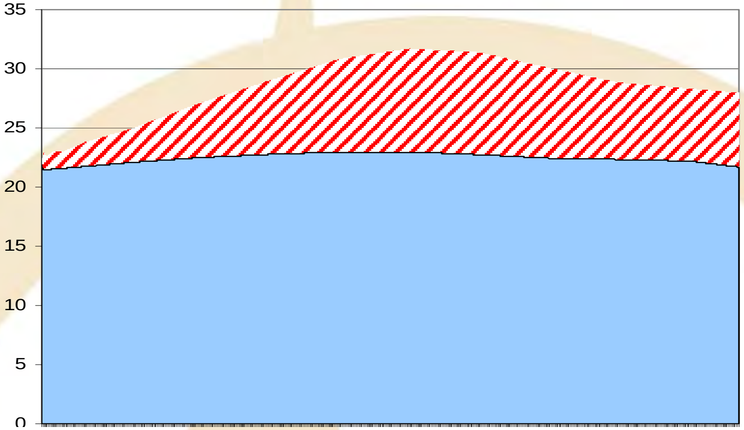
Irradiance (W/m^2)

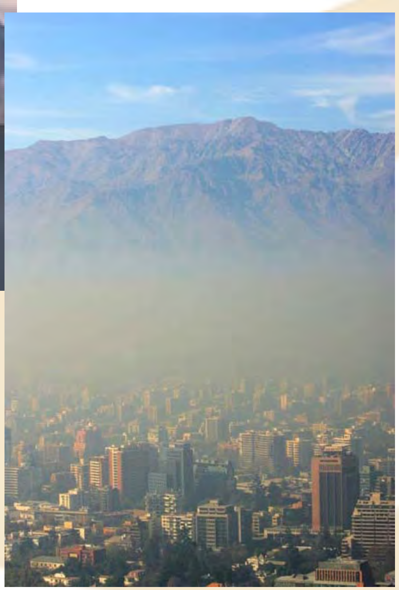
Number of persons

LIMITS of the main variables: temperature, speed of inlet air

Information to control system

Energy savings





Introduction & objectives

- Collect irradiance data from weather station for 1 year.
- Fit the irradiance data to a mathematical model.
- Approach the Finite Element model and impose the corresponding boundary conditions.
- Estimate the spatial and temporary temperature evolution of the model and analize different scenarios.

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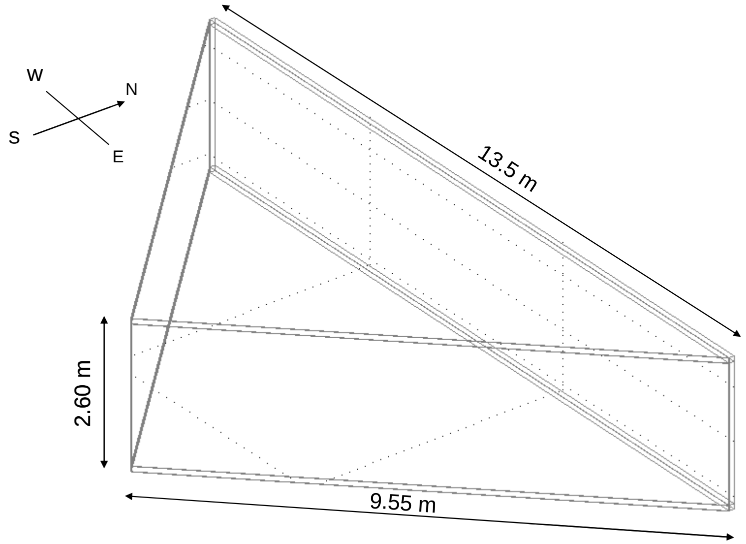
Enclosure construction details

Enclosure features



Enclosure volume:
118.46 m^3

Enclosure construction details

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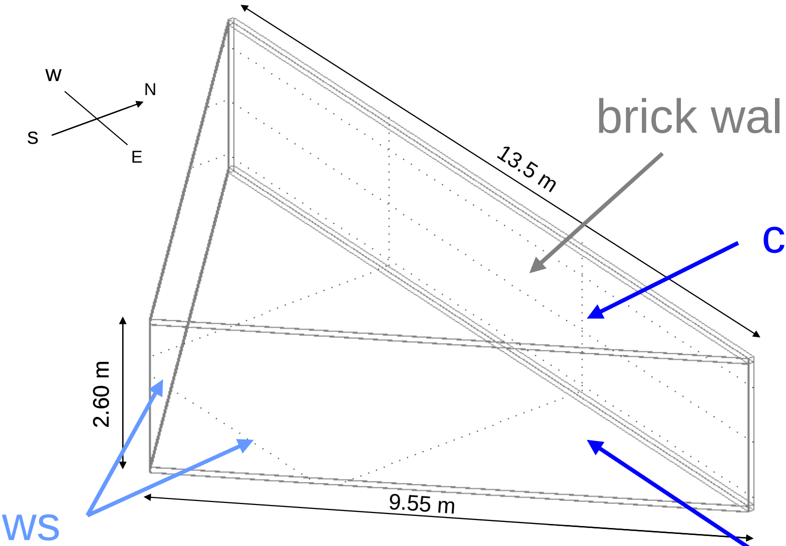

brick wall

concrete ceiling

glass windows
(1 cm. thickness)

concrete floor

Enclosure volume:
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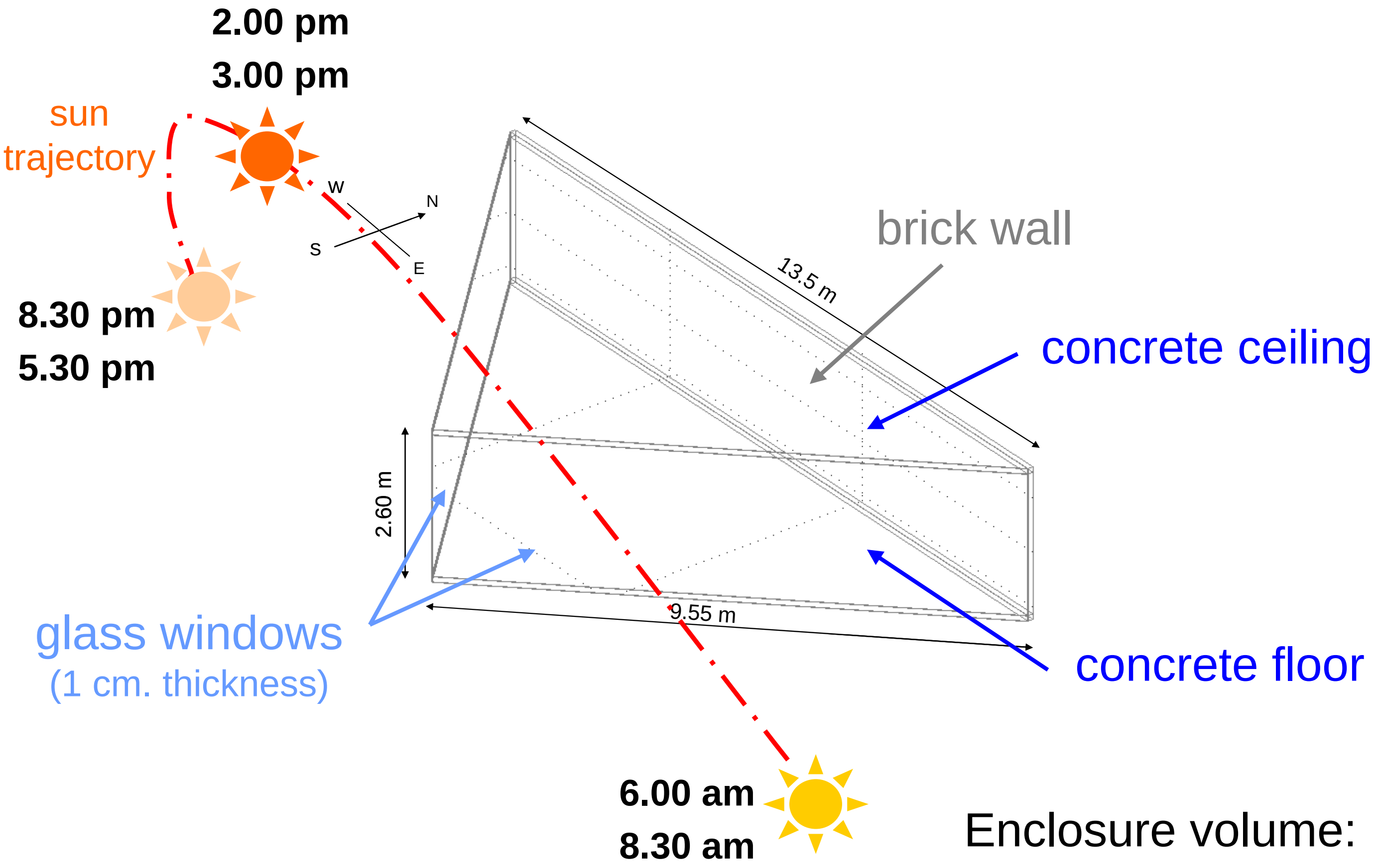
◪ Enclosure features and sun trajectory



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Irradiance data

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- Irradiance data from weather station

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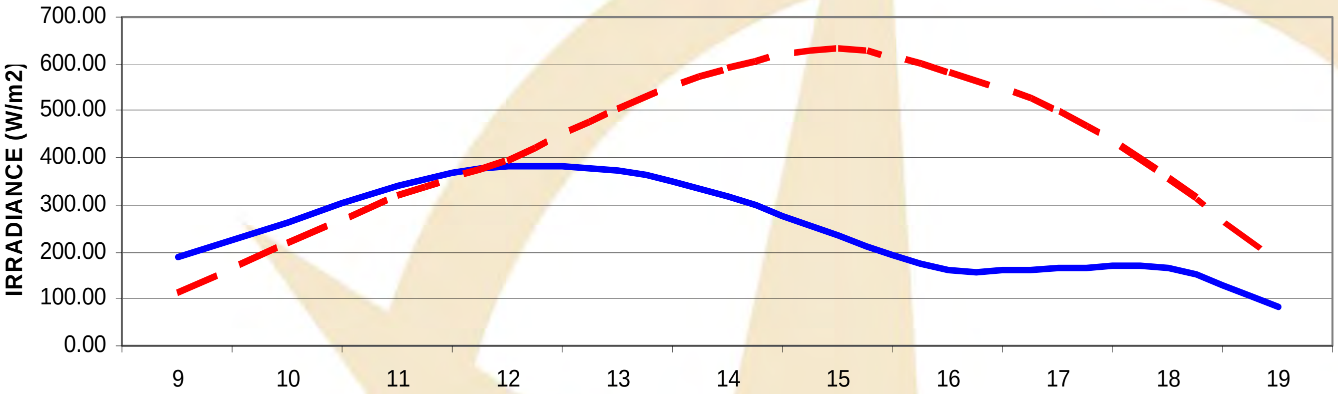
Irradiance data from weather station

Summer irradiance



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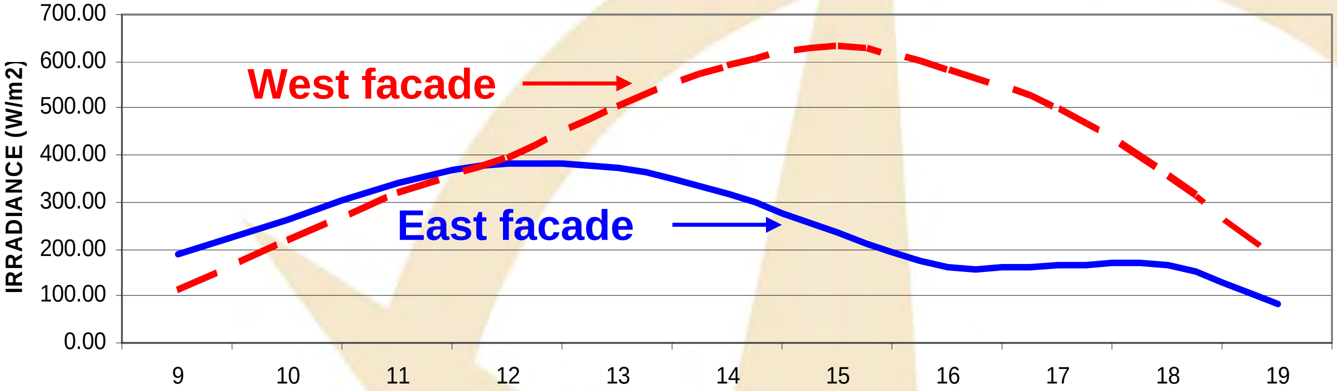

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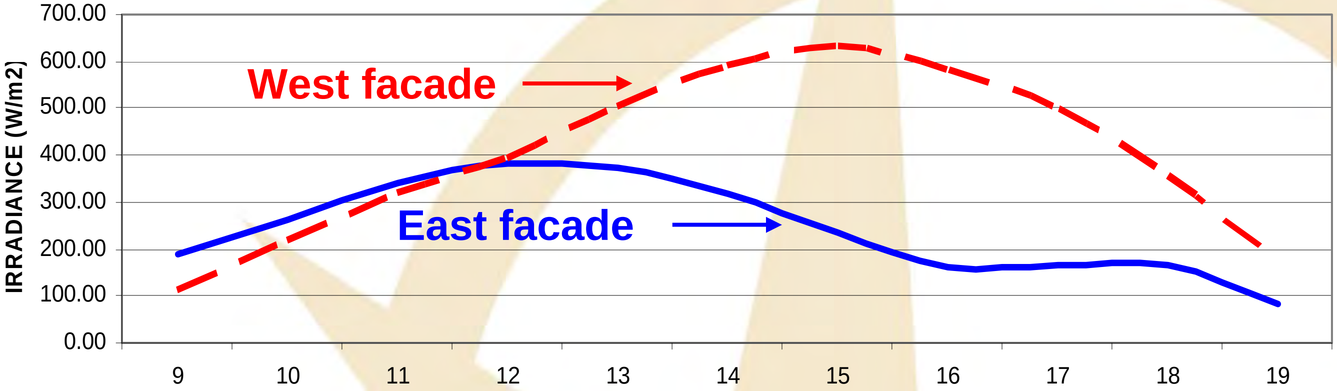
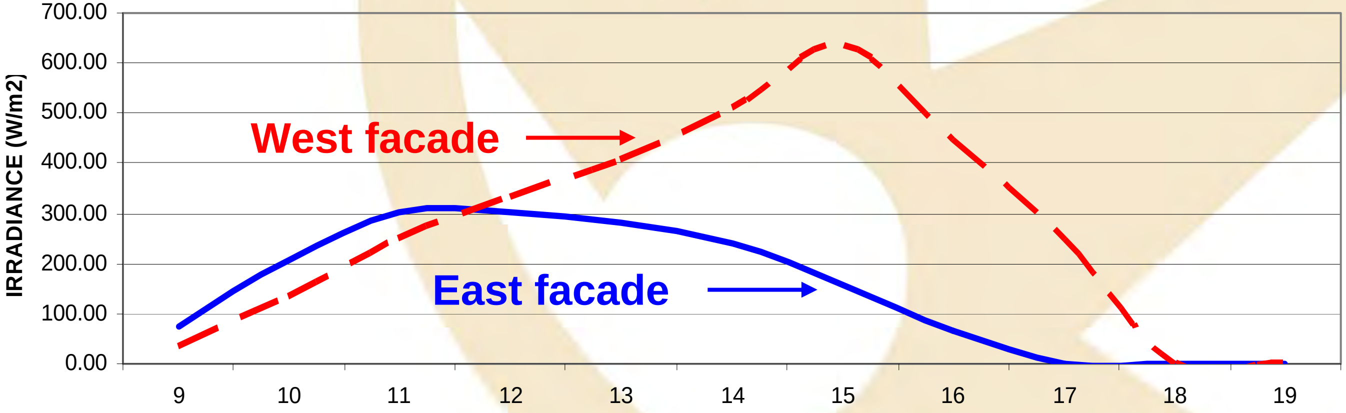


Winter irradiance



Simulation scenarios

- Modelling taking into account:

Simulation scenarios

◨ Modelling taking into account:

- Time of the day
  - Morning (9.00 am to 12.00 m)
  - Noon (12.00 m to 4.00 pm)
  - Later (4.00 pm to 7.00 pm)

Simulation scenarios

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- Weather season
  - Summer
  - Winter

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  - Later (4.00 pm to 7.00 pm)
- Weather season
  - Summer
  - Winter
- Existence or not of air conditioning
- Number of persons
  - 1,2,5 and 10 persons.

Irradiance curve fitting

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Irradiance curve fitting

- Mathematical model fitted to the initial data in order to be introduced in Comsol.
- Polynomial curves.

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Summer irradiance

East facade

$$5.74\cdot10^{-5}x^{9}-2.11\cdot10^{-3}x^{8}+0.027x^{7}-0.13x^{6}-0.0894x^{5}+2.8178x^{4}$$
$$-11.4836x^{3}+19.675x^{2}+68.0458x+106.835$$

West facade

$$2.467\cdot10^{-4}x^{9}-0.0115x^{8}+0.219x^{7}-2.146x^{6}+11.227x^{5}-28.553x^{4}$$
$$+18.761x^{3}+44.859x^{2}+38.910x+23.081$$

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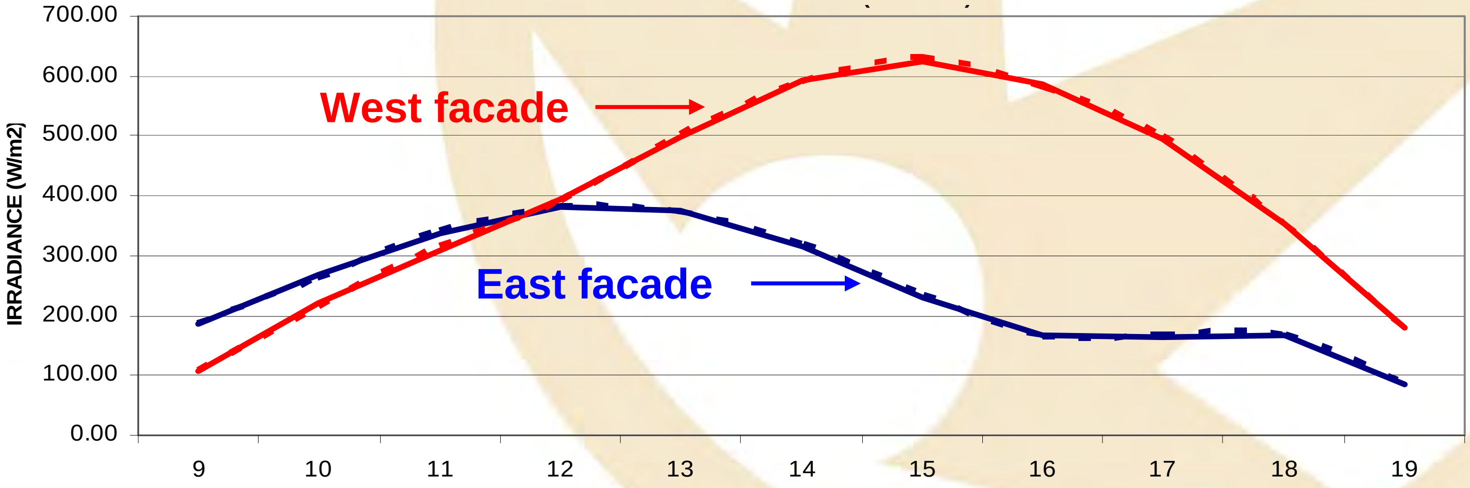

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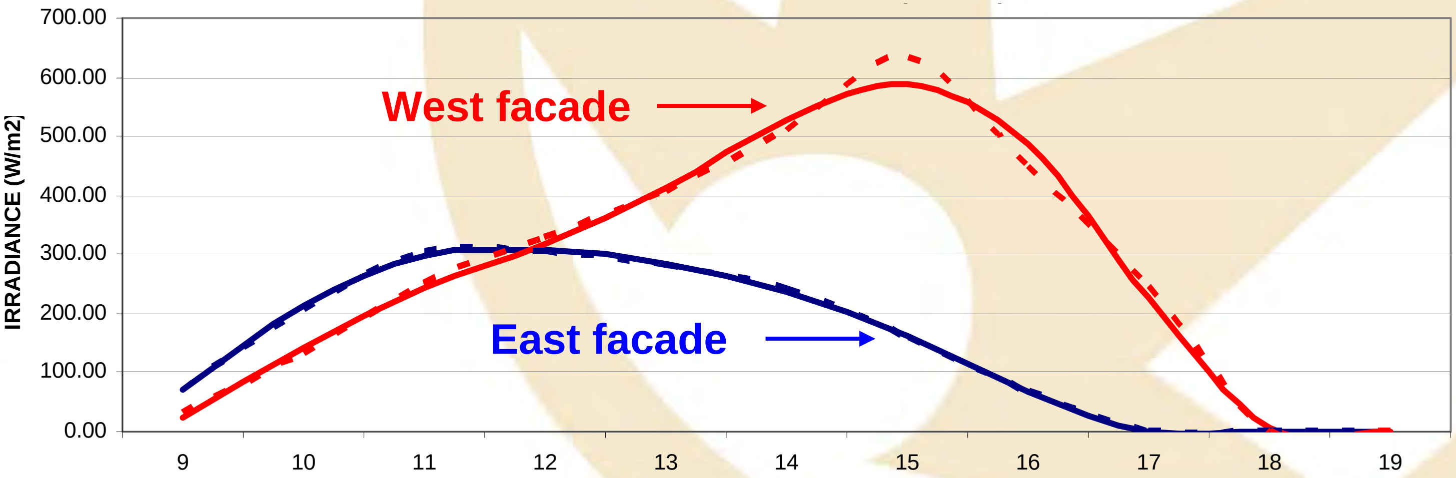
Winter irradiance

East facade

$$1.598\cdot 10^{-4}x^{9}-0.008x^{8}+0.177x^{7}-1.965x^{6}+11.912x^{5}-36.571x^{4}$$
$$+33.981x^{3}+54.017x^{2}+23.841x-14.832$$

West facade

$$-6.39\cdot 10^{-5}x^{9}+8.99\cdot 10^{-4}x^{8}+0.026x^{7}-0.762x^{6}+6.463x^{5}-24.772x^{4}$$
$$+30.239x^{3}+37.999x^{2}-5.974x-30.031$$



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Restrictions and boundary conditions approach

Comsol approach

- Heat transfer module (3D)
  - Fluid-thermal interaction
    - Turbulent Non-isothermal Flow, k - **ε**
      - General heat transfer (htgh)
      - k - ε Turbulence Model (chns)

Restrictions and boundary conditions approach

Comsol approach

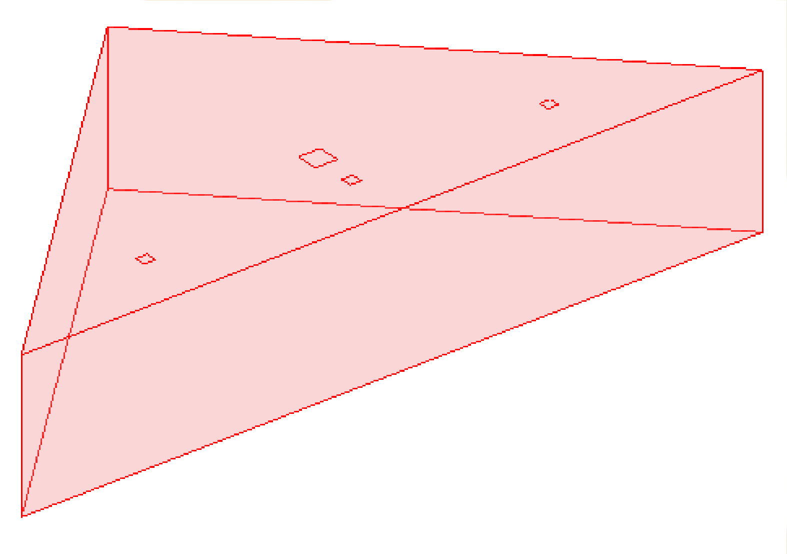
- Subdomain settings, (chns and htgh)

Restrictions and boundary conditions approach

Comsol approach

- Subdomain settings, (chns and htgh)

Air (library material)
rho (p0[1/Pa], Tf[1/K]) [kg/m³] (density)
eta (Tf[1/K]) [Pa·s] (dynamic viscosity)



Restrictions and boundary conditions approach

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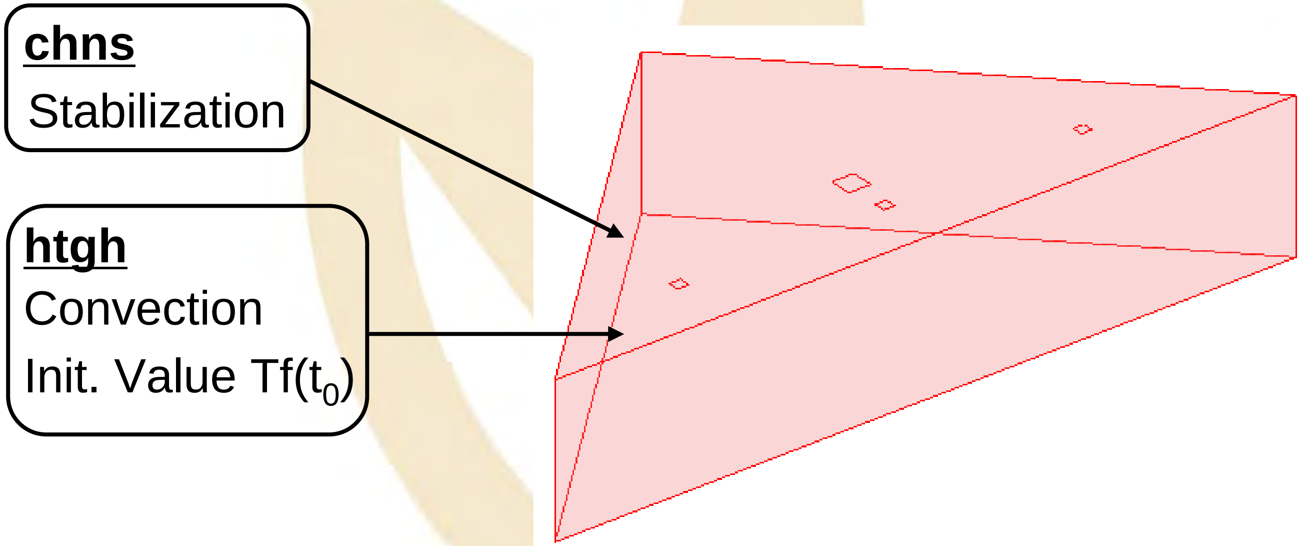

chns
Stabilization

htgh
Convection
Init. Value Tf(t_0)

Restrictions and boundary conditions approach

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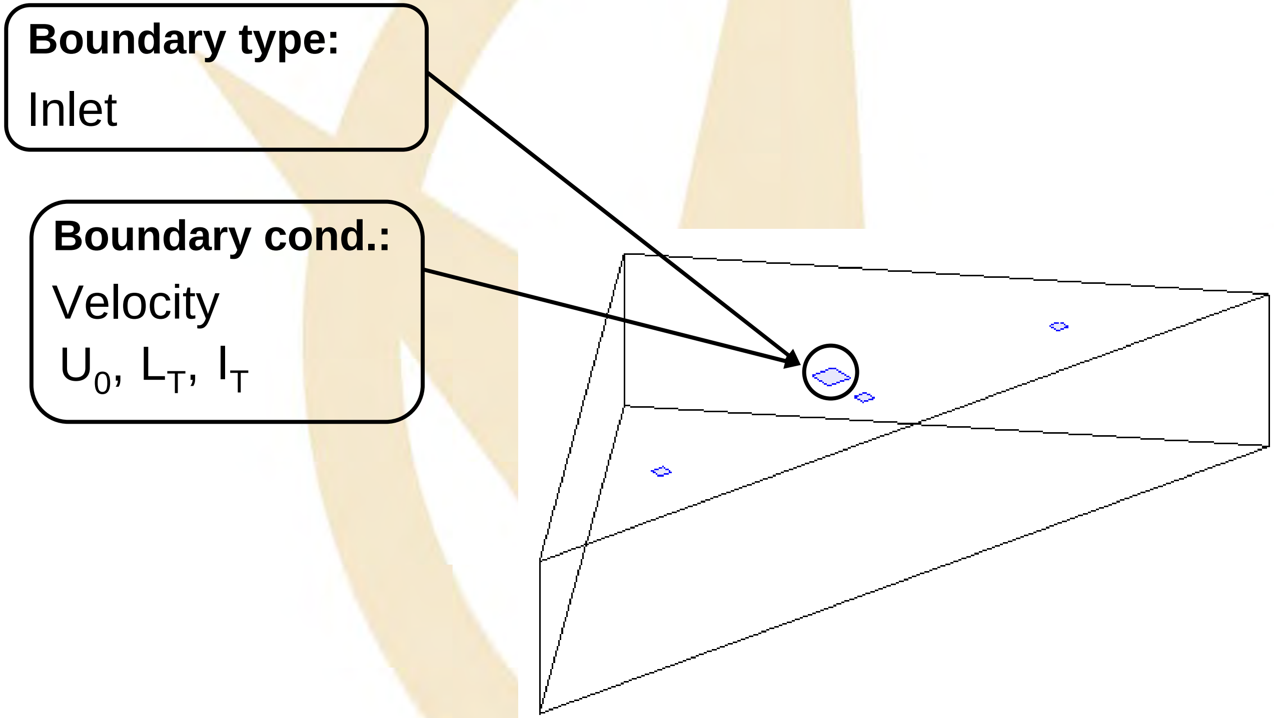
Comsol approach

- Boundary settings, **chns**



Boundary type:

Inlet

Boundary cond.:

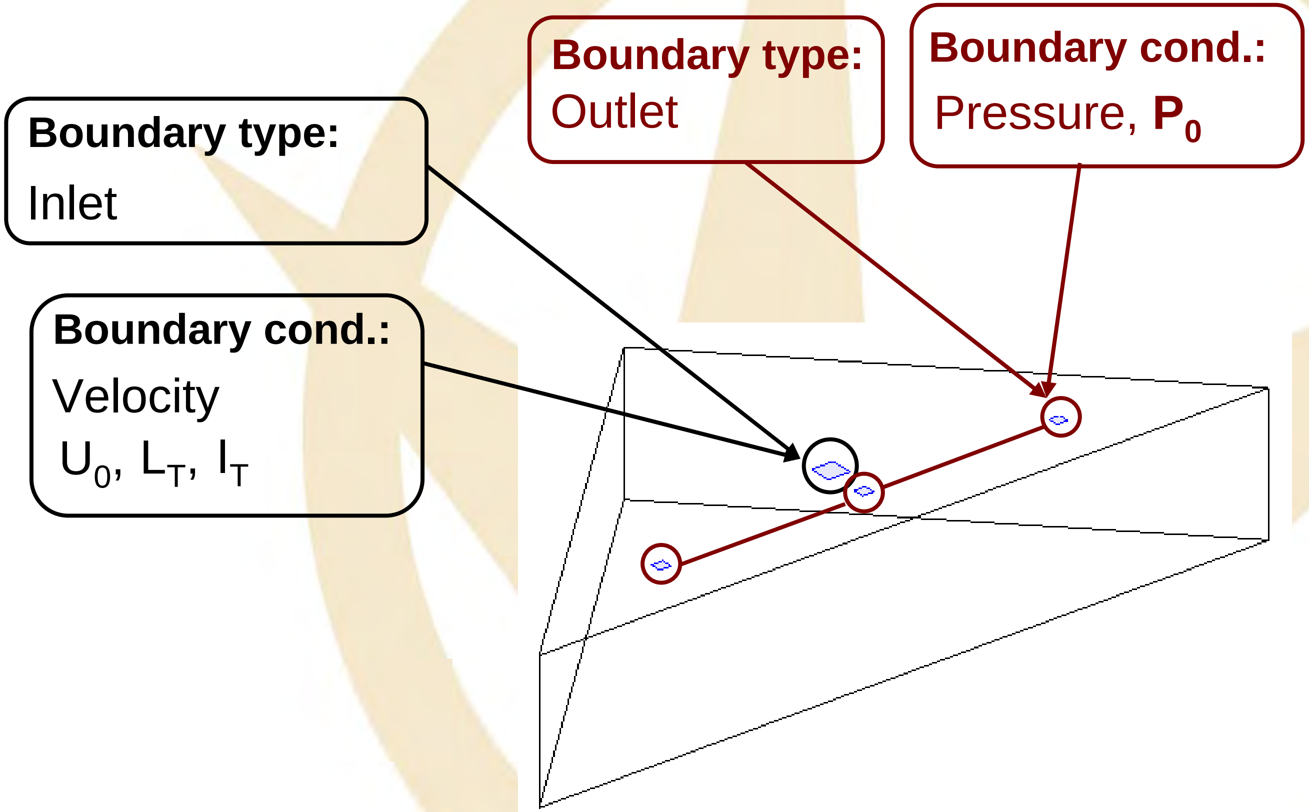
Velocity

U_0, L_T, I_T

Restrictions and boundary conditions approach

◪ Comsol approach

- Boundary settings, **chns**



Boundary type:
Inlet

Boundary cond.:
Velocity
U_0, L_T, I_T

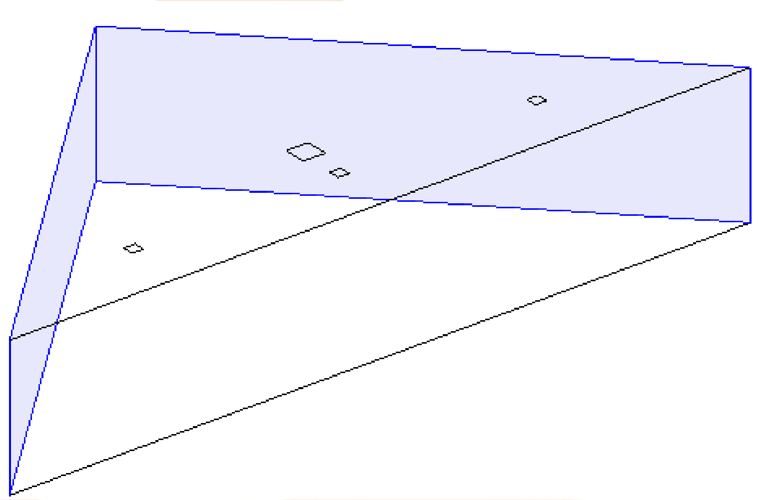
Boundary type:
Outlet

Boundary cond.:
Pressure, $\mathbf{P_0}$

Restrictions and boundary conditions approach

Comsol approach

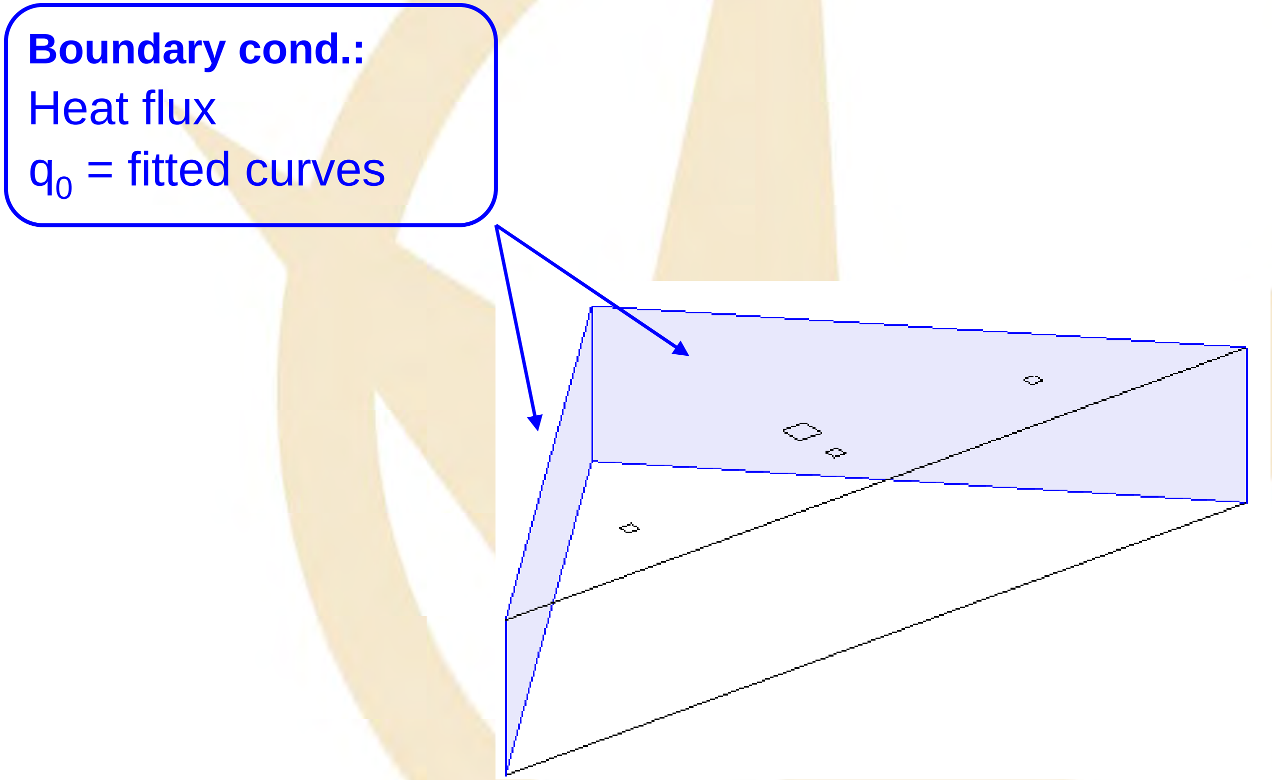
- Boundary settings, **htgh**



Restrictions and boundary conditions approach

◪ Comsol approach

- Boundary settings, **htgh**



Boundary cond.:
Heat flux
q_0 = fitted curves

Restrictions and boundary conditions approach

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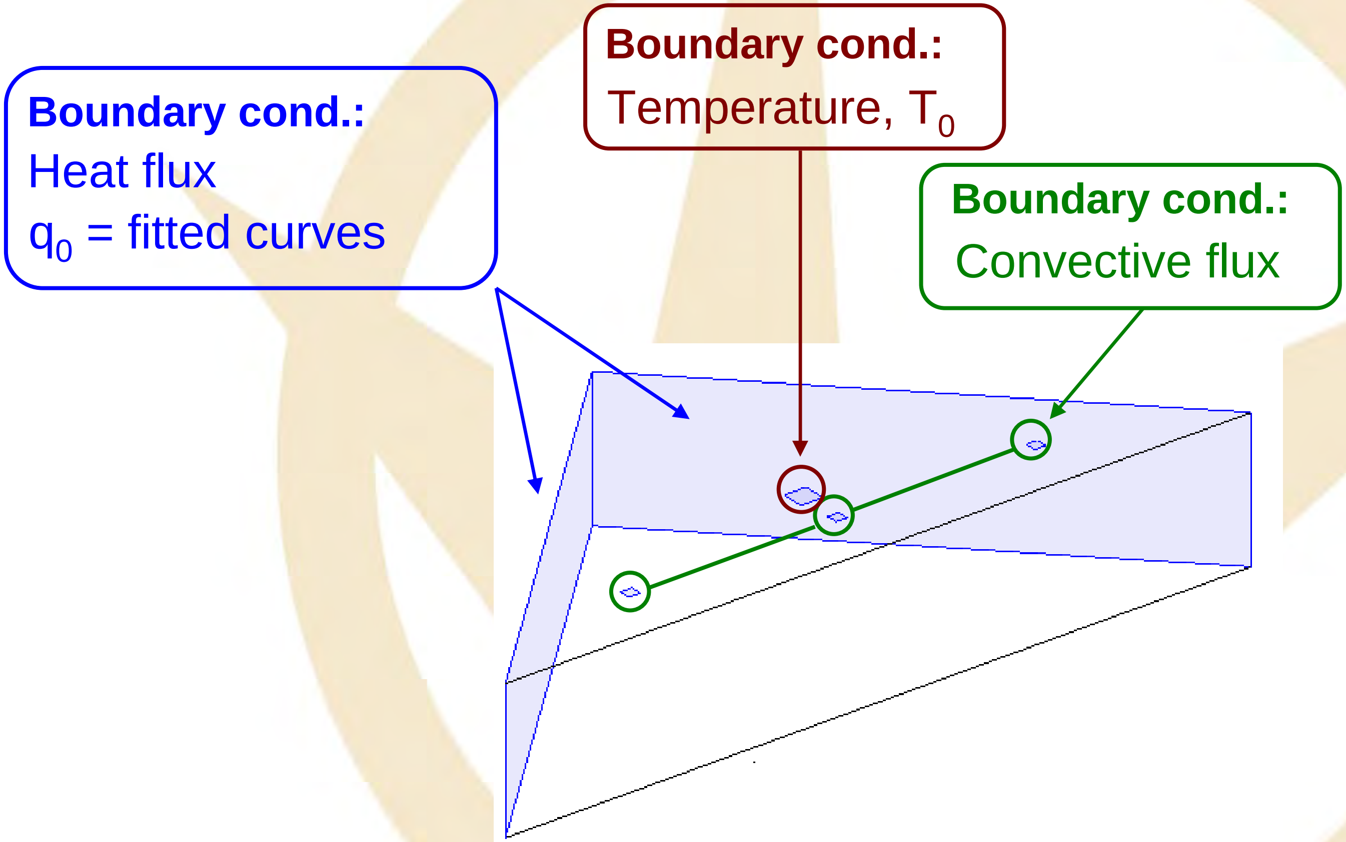
- Boundary settings, **htgh**



Boundary cond.:
Heat flux
q_0 = fitted curves

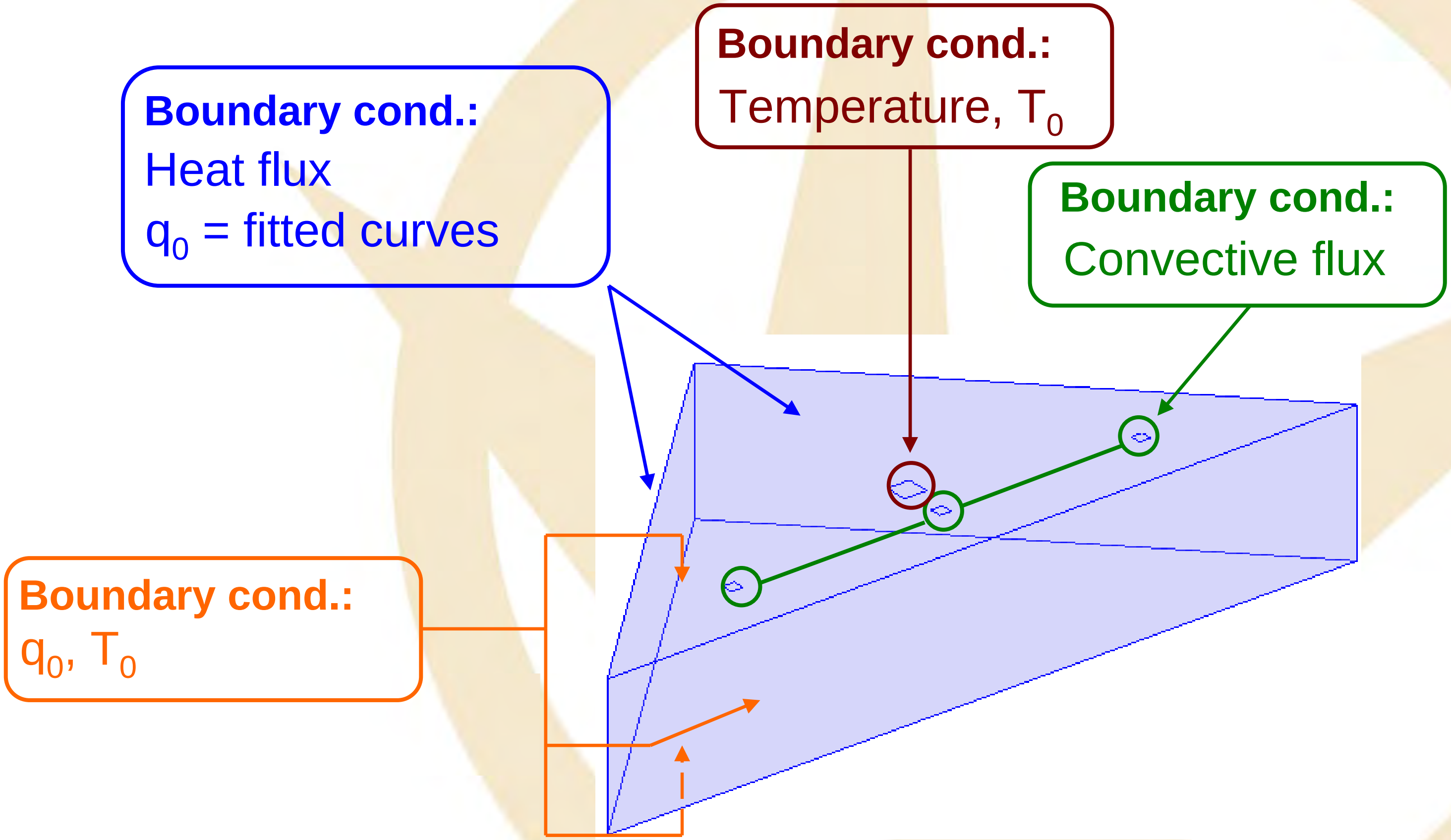
Boundary cond.:
Temperature, T_0

Boundary cond.:
Convective flux

Restrictions and boundary conditions approach

Comsol approach

- Boundary settings, **htgh**



Boundary cond.:
Heat flux
q_0 = fitted curves

Boundary cond.:
Temperature, T_0

Boundary cond.:
Convective flux

Boundary cond.:
q_0, T_0

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Comsol approach

- Differential equations

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}$$

$$\rho a_y=\rho F_y-\frac{\partial p}{\partial y}+\frac{\partial}{\partial y}\left(2\mu\frac{\partial v}{\partial y}+\left(\zeta-\frac{2}{3}\mu\right)\nabla^T\vec{u}\right)+\frac{\partial}{\partial z}\left(\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right)+\frac{\partial}{\partial x}\left(\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right)$$

$$\rho a_x=\rho F_x-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(2\mu\frac{\partial u}{\partial x}+\left(\zeta-\frac{2}{3}\mu\right)\nabla^T\vec{u}\right)+\frac{\partial}{\partial y}\left(\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right)+\frac{\partial}{\partial z}\left(\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right)$$

$$\rho a_z=\rho F_z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial z}\left(2\mu\frac{\partial w}{\partial z}+\left(\zeta-\frac{2}{3}\mu\right)\nabla^T\vec{u}\right)+\frac{\partial}{\partial x}\left(\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right)+\frac{\partial}{\partial y}\left(\mu\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right)$$

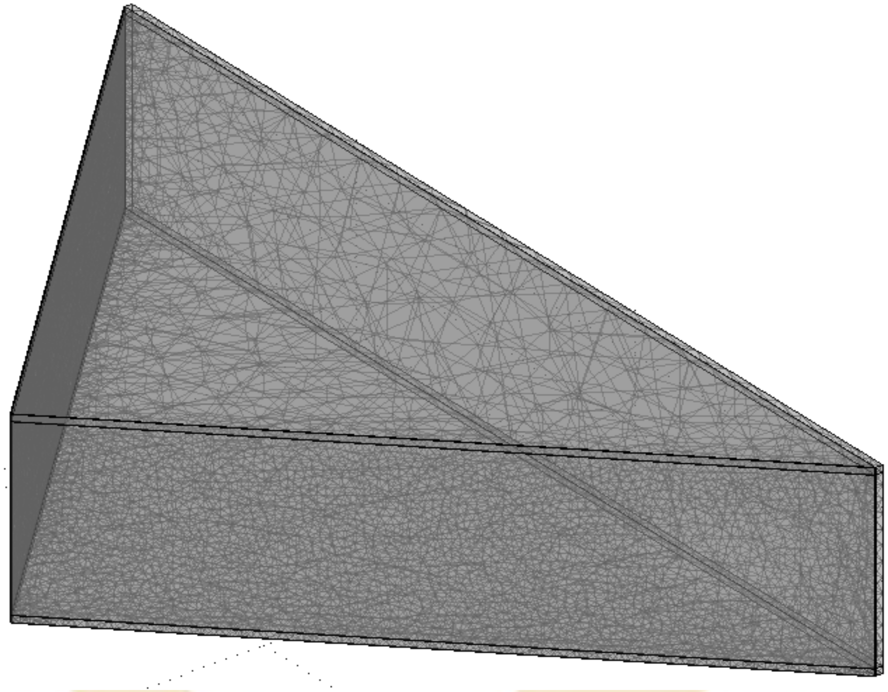
$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\frac{\partial Q}{\partial t}+\Phi_d-\nabla^T\vec{q}_r=\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)+\frac{\rho}{2}\frac{D}{Dt}\left(u^2+v^2+w^2\right)+\rho\frac{DE}{Dt}$$

Finite Element mesh

Enclosure’s Finite Elements mesh

Tetrahedral elements

60883 elements
99069 dof



Results. Experimental validation

- Temperature comparissons at reference points.

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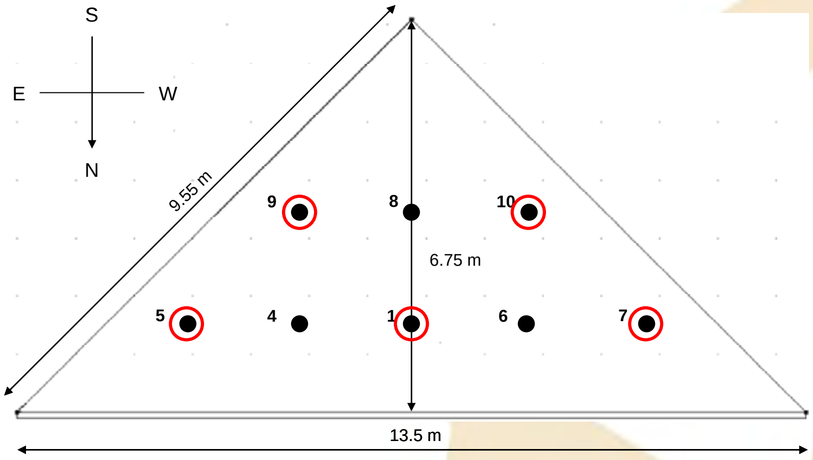

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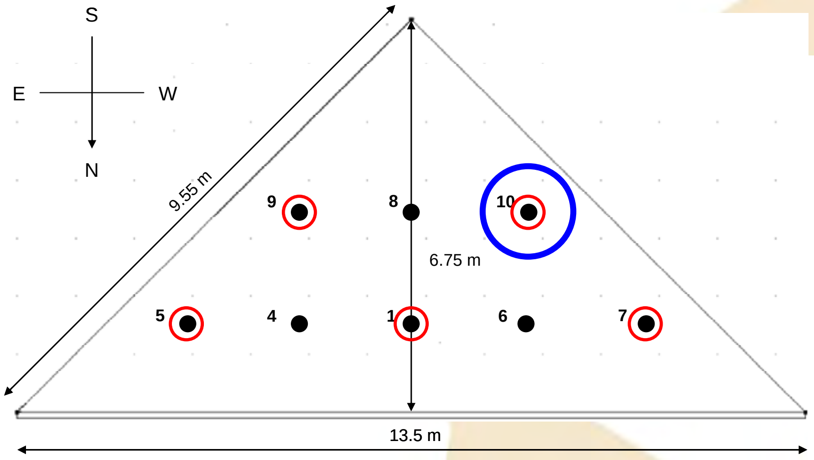
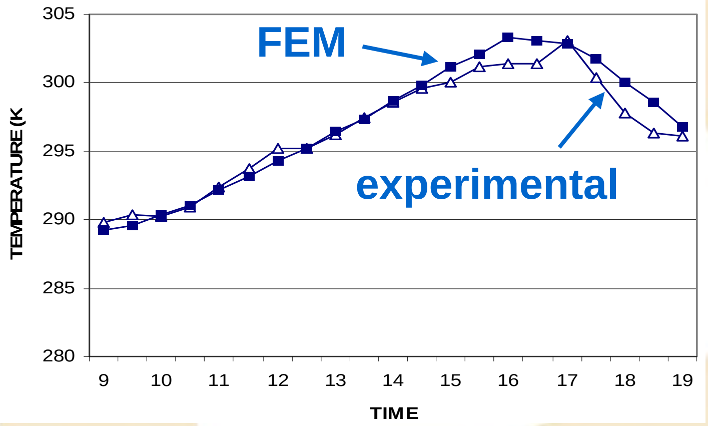


point 10



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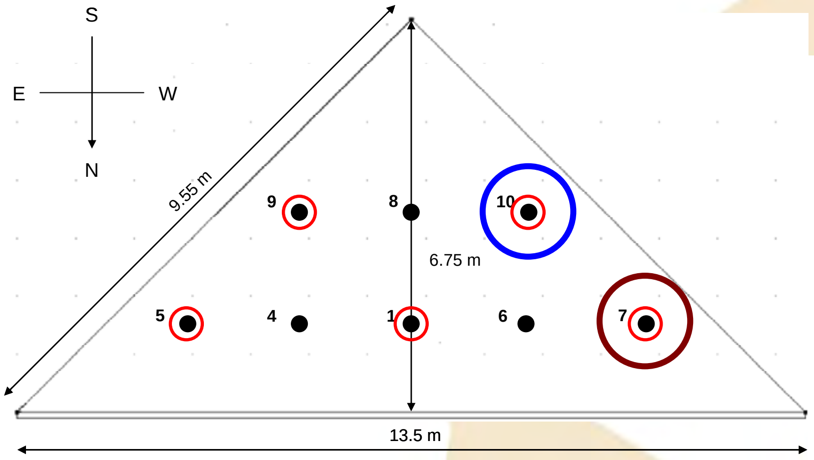
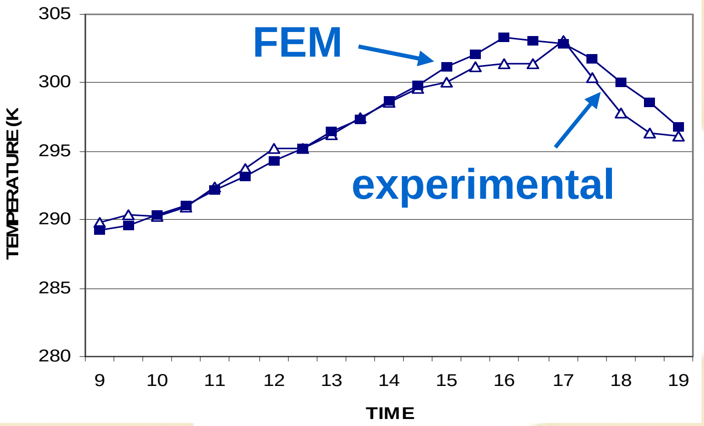
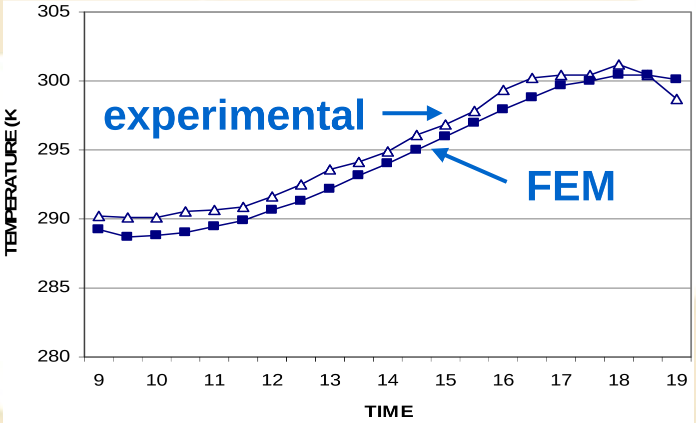


point 10



point 7



Good approximation between experimental results and FEM

Results. Temperature evolution

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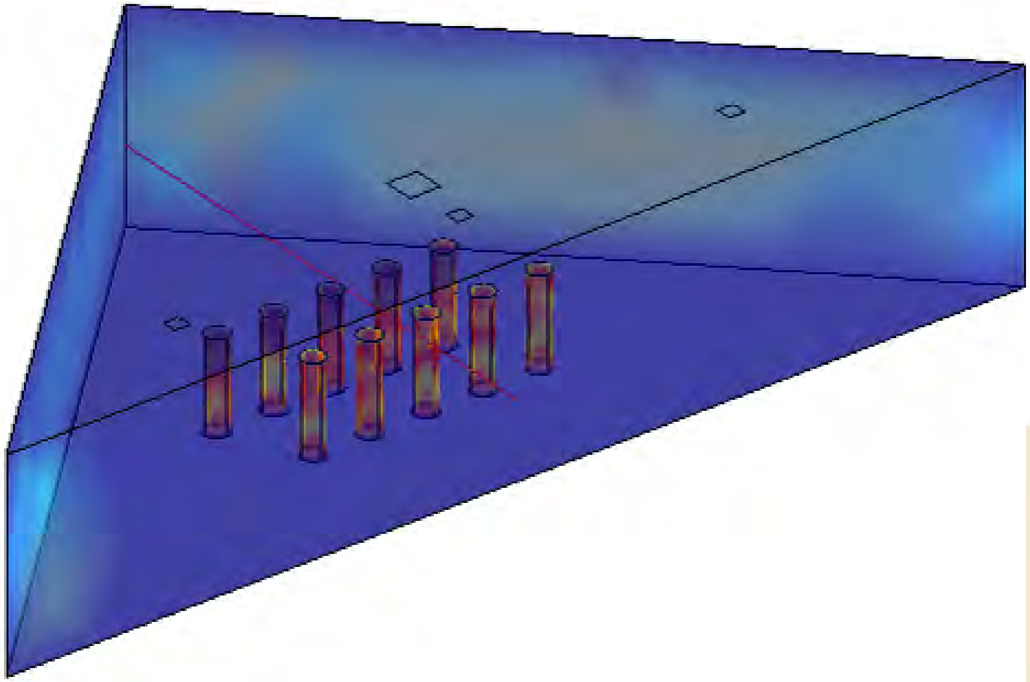
- Temperature distribution of the enclosure. Ten people



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◨ Temperature evolution. Summer.

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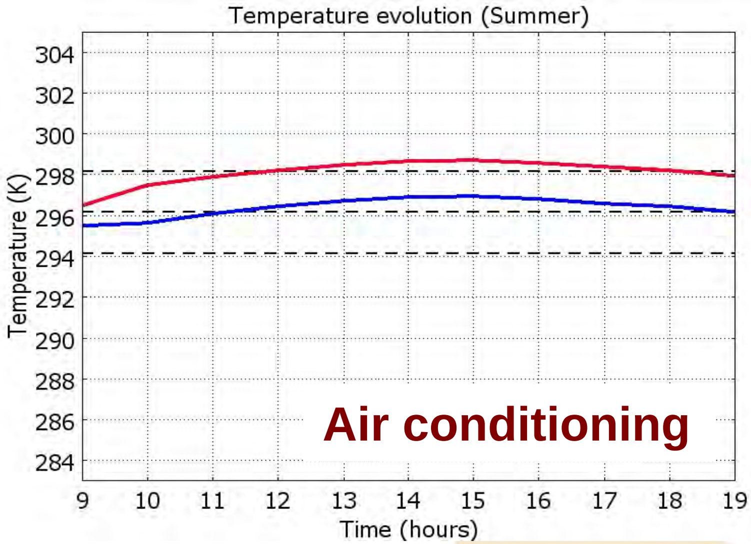

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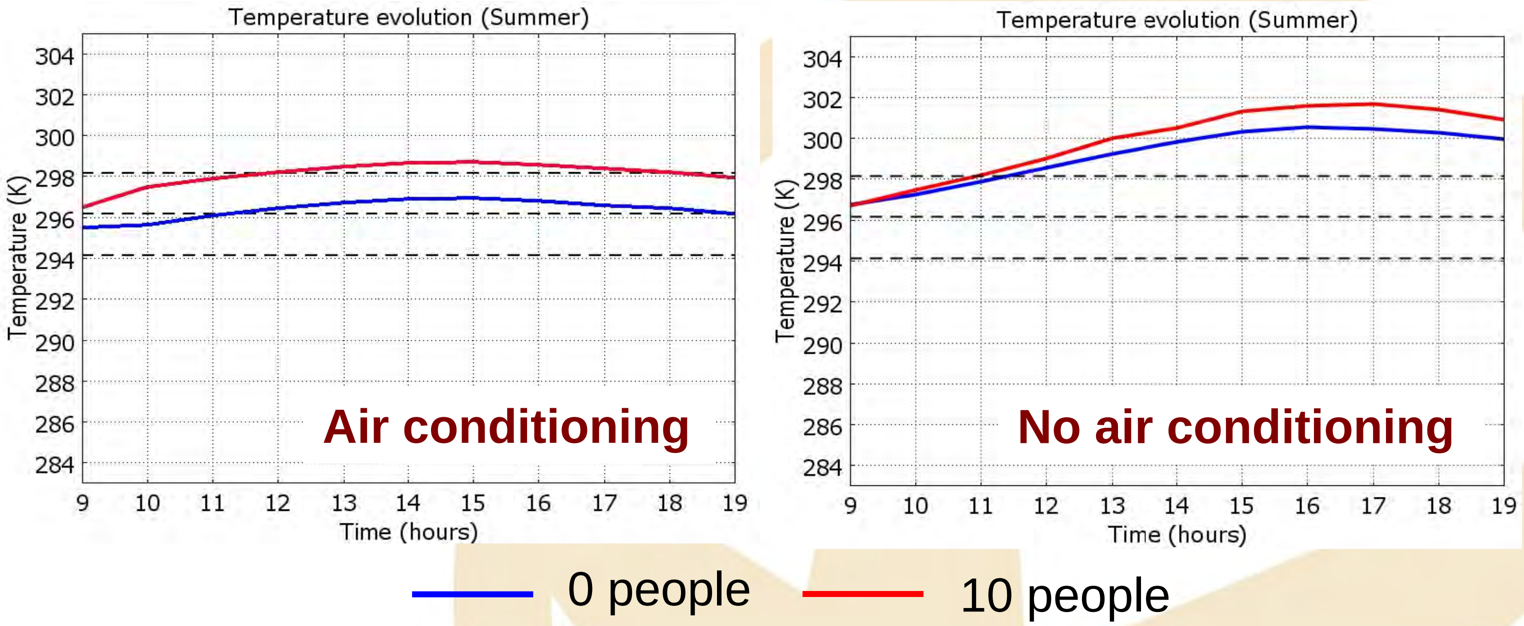
Results. Temperature evolution

Temperature evolution. Summer.



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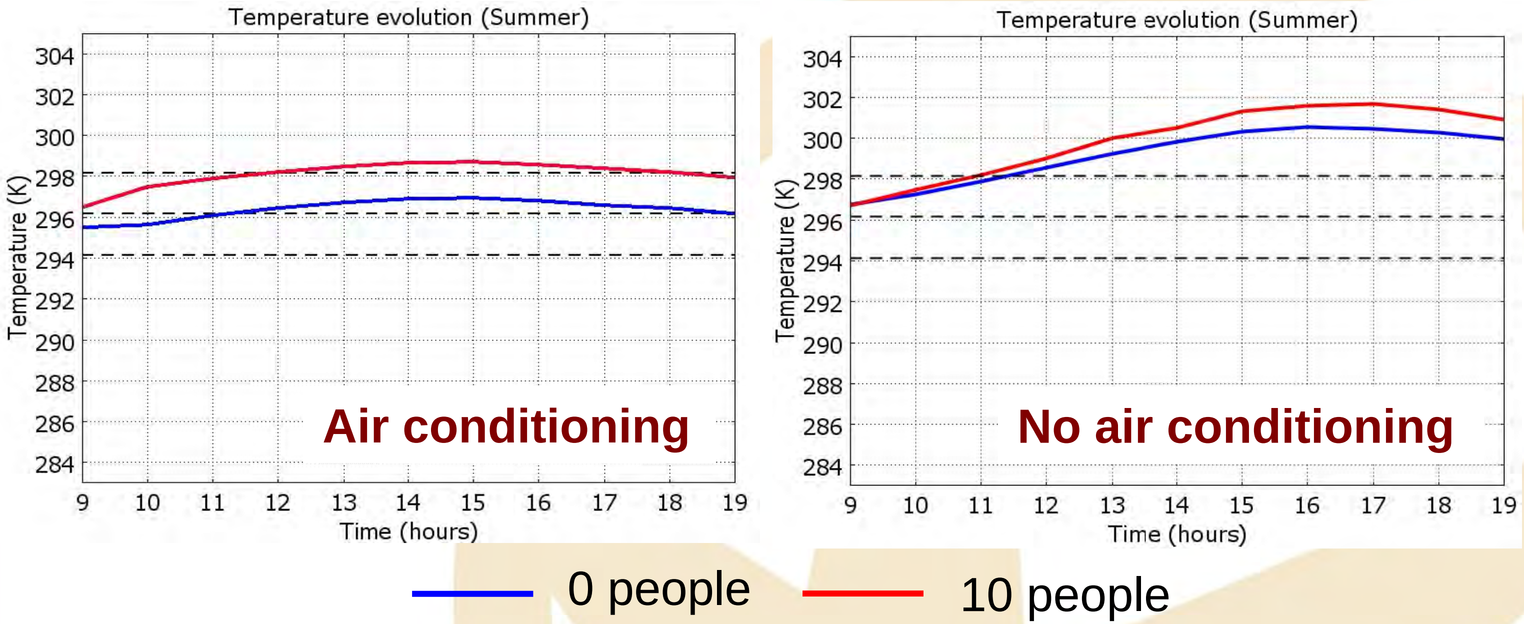

- Enclosure’s temperature 10 people > enclosure’s temp. 0 people
- The trend of the temperature evolution is similar to the irradiance curve.
- With air conditioning the temperature remains within the comfort range.

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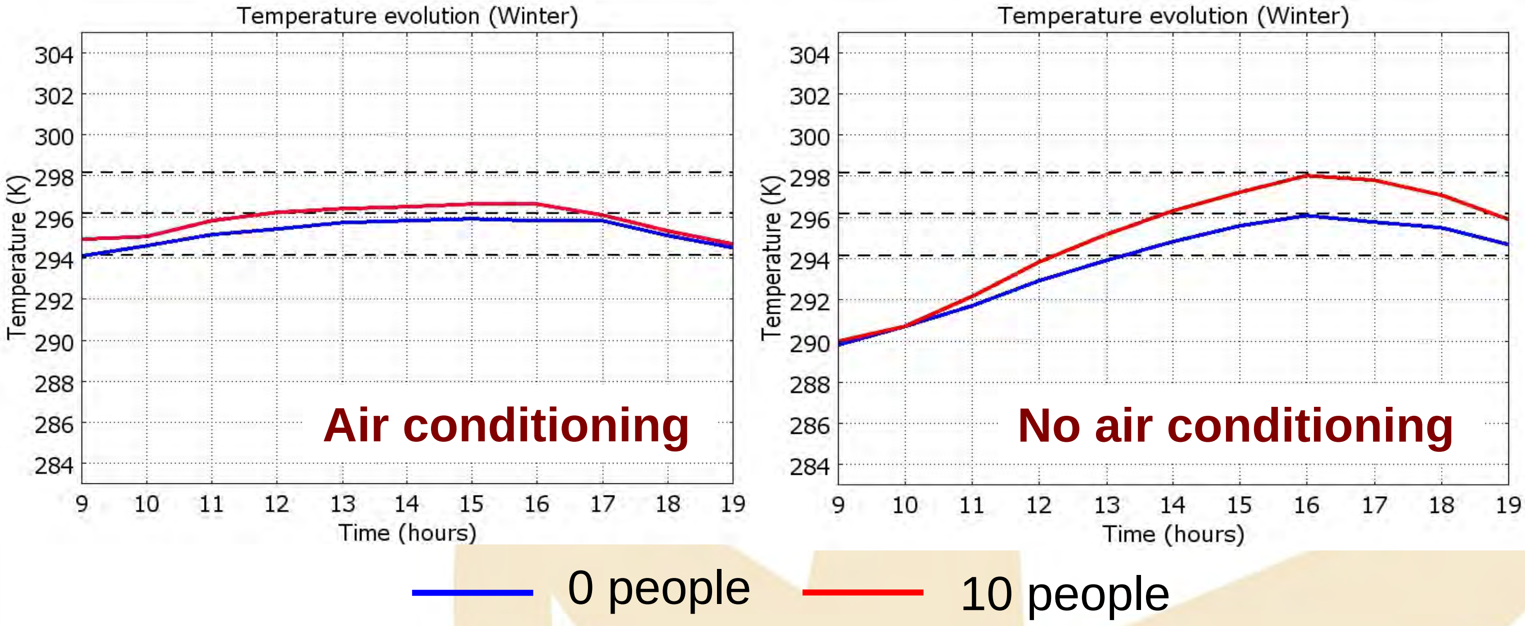
Results. Temperature evolution

Temperature evolution. Winter.



- The trend of the temperature evolution is similar to the irradiance curve.
- With air conditioning the temperature remains within the comfort range.

Conclusions

- Influence of the irradiance in the temperature evolution into the enclosure.
- Setting the irradiance curves to assign a heat source to modelling in Comsol.
- Good approximation between experimental and numerical results.
- Trend of the temperature evolution similar to the irradiance curve.

Thermal modelling for the implementation of an energetic efficiency control system in a room of meetings of singular geometry

Thanks !

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