# Analysis of IAQ based on modeling of building envelope coupled with CFD&HT room inflow

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# CONTENTS

# INTRODUCTION

## Objectives

◆ Test the combined heat, air and moisture transfer (HAM) models and volatile organic compound (VOC) pollutant transfer simulation.

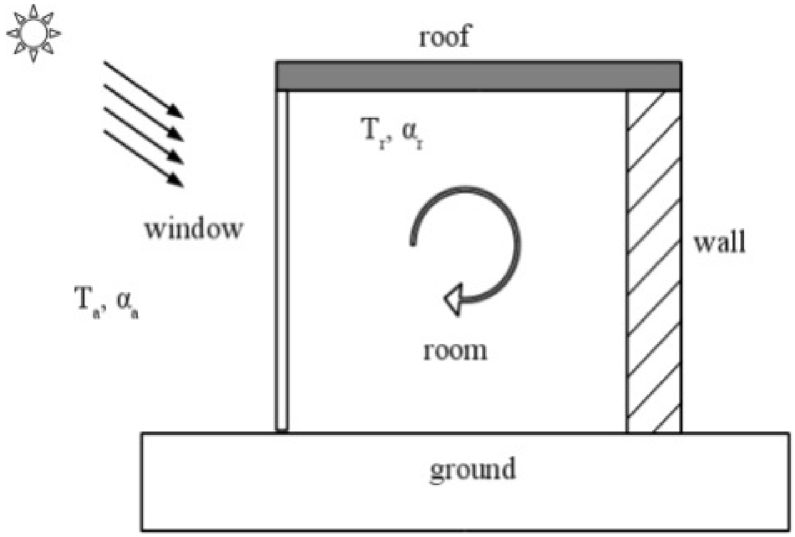
◆ Implementation of these models in the general building program (NEST) allowing HAM+VOC simulation coupled with CFD&HT (TermoFluids) coarse mesh simulation.

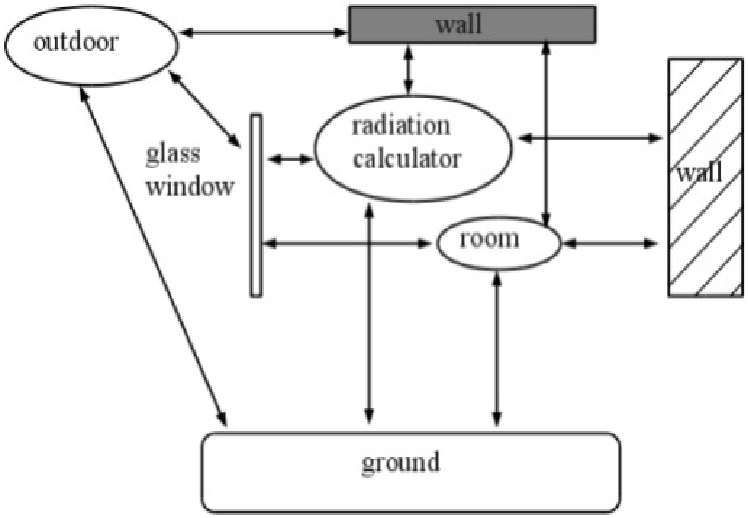
# INTRODUCTION

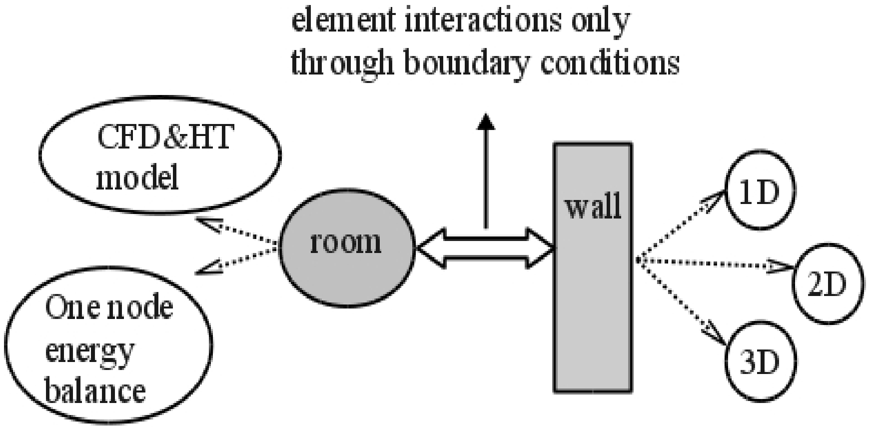
Moisture transport along with heat transfer, air flow and VOC transport through and within the building envelope is important for:

- maintaining a fresh and healthy indoor environment with proper temperature and humidity level.
- maintaining the quality of thermal insulation.
- predicting properly the energy loads over the year.
- avoiding condensation, mold formation and in turn the deterioration of the building structure.
- protecting the appearence of the building walls.

# Modular framework






element interactions only through boundary conditions

# HAM+VOC model (wall flow model)

The **heat transfer equation** for a moist porous material, taking into account the enthalpy of convected moist air and condensation/evaporation within the material can be written as:

$$\rho_0 C\frac{\partial T}{\partial t}+\nabla\cdot\rho_a V(Cp_a+\omega Cp_v)T=\nabla\cdot(\lambda\nabla T)+h_{fg}\dot{m}_{ce}+\dot{m}_{ce}T(Cp_v-Cp_l)$$

where, $C$ is the effective specific heat capacity of moist material,
$h_{fg}$= 2.5x$10^6$ is the latent heat of water at 0°C, and
$m_{ce}$ is the amount of moisture condensation/evaporation.

# HAM+VOC model (wall flow model)

A pressure correction method is applied for calculating the zonal pressures by taking into account the **air mass flow** rates in and out of a zone.

The rooms surrounded by walls can be connected to each other or to the ambient with openings and doors. Unidirectional flow across an openings is calculated as a function of the pressure difference, discharge coefficient and a flow exponent

$$\dot{Q} = C_d(\triangle p)^n$$

# HAM+VOC model (wall flow model)

The **moisture transfer equation**, obtained by applying the Fick's law for vapour diffusion and Darcy's law for liquid transport, in terms of relative humidity and temperature, can be written as:

$$\theta\frac{\partial\phi}{\partial t}=\nabla\cdot\left(D_{\phi}\nabla\phi+D_{T}\nabla T\right)-\nabla\cdot\left(D_{l}\rho_{w}\vec{g}+\rho_{a}\vec{V}\omega\right)$$

where, $D_{\phi}=\delta_{v}p_{sat}+D_{l}\frac{\rho_{w}RT}{M\phi},\ D_{T}=\delta_{v}\phi\frac{\partial p_{sat}}{\partial T}+D_{l}\frac{\rho_{w}Rln\phi}{M}$

# HAM+VOC model (wall flow model)

The transient **VOC** diffusion is given by:

$$\frac{\partial C_m}{\partial t} = D_m \nabla^2 C_m$$

where, a partition coefficient $K_p = C_{mb}/C_{as}$ is assumed to relate the concentration at the boundary $C_{mb}$ of the material to the concentration in the immediate vicinity of the boundary $C_{as}$.

# HAM+VOC model (room airflow)

The **heat transfer equation** with the single well-mixed zone assumption can be written as:

$$\rho_a \tilde{V} \frac{d}{dt}((Cp_a + \omega Cp_v)T) = \sum_{j=1}^{n} \alpha_j A_j (T_{wj} - T_r) + \dot{m}_e Cp_a (T_e - T_r) +$$

$$\dot{m}_e Cp_a (\omega_e T_e - \omega_r T_r) + \sum_{j=1}^{n} \dot{m}_{wj} Cp_v T_{sj} + \dot{m}_g Cp_v T_g$$

where, a $C_a$ refers air, while $C_v$ refers vapour.

# HAM+VOC model (room airflow)

The **moisture balance** equation for a single well-mixed zone can be written as:

$$\rho_a \tilde{V} \frac{d\omega}{dt} = \sum_{j=1}^{n} \dot{m}_{wj} + \dot{m}_g + \dot{m}_e(\omega_e - \omega_r)$$

where, the left hand side term represents moisture accumulation while the right hand side terms represent moisture transfer from room walls, internal moisture generation and moisture transported by the infiltrating ambient air respectively.

# HAM+VOC model (room airflow)

The **<u>conservation equation for each pollutant</u>** emitted by the wall materials is written by considering a transient mass balance over the well-mixed room as:

$$\tilde{V}\frac{\partial C_r}{\partial t} = \dot{Q}_{ven}(C_{in} - C_r) + h_m A(C_r - C_{as}) + C_g$$

where, $h_m$ is the mass transfer coefficient,
$Q_{ven}$ is the ventilation rate,
$C_r$ is the room concentration,
$C_{as} = C_b/K_p$ is the concentration of the VOC at the material-air interface,
and $C_g$ is the generation of pollutant in the room.

# CFD&HT model

## Numerical methodology TermoFluids.

The Navier-Stokes equations, for the fluid inside the tank are written for all the control volumes of the domain as:

$$M\boldsymbol{u} = 0 \qquad (1)$$

$$\frac{\partial \boldsymbol{u}}{\partial t} = -C(\boldsymbol{u})\boldsymbol{u} + \nu D\boldsymbol{u} - \rho^{-1} G\boldsymbol{p} + \boldsymbol{f} \qquad (2)$$

$$\frac{\partial \boldsymbol{T}}{\partial t} = -C(\boldsymbol{u})\boldsymbol{T} + \lambda \rho^{-1} {c_p}^{-1} D\boldsymbol{T} \qquad (3)$$

where,

$C\,(\boldsymbol{u})$ and $D$ matrix are the convective and diffusive operators.

$G$ represents the discrete gradient operator.

$M$ is the divergence operator.

# CFD&HT model

## Numerical methodology TermoFluids.

- The velocity-pressure coupling is solved with a classical fractional step projection method.

- A first–order backward Euler scheme for the pressure gradient.

- For the temporal discretization of the Navier-Stokes equations, a third-order gear-like scheme is used for the derivative, convective and diffusive terms.

# CFD&HT model

## Numerical methodology TermoFluids.

The spatial discretization schemes are conservative:

convective operator is skew-symmetric $(C_c\ (\boldsymbol{u}_c) = -\ C_c^{*}\ (\boldsymbol{u}_c))$

diffusive operator ($D_c$) is symmetric and positive-definite, and

negative conjugate transpose of the discrete gradient operator is exactly equal to the divergence operator. $(-(\Omega_c G_c^{\ *}) = M_c)$

LES models employed:

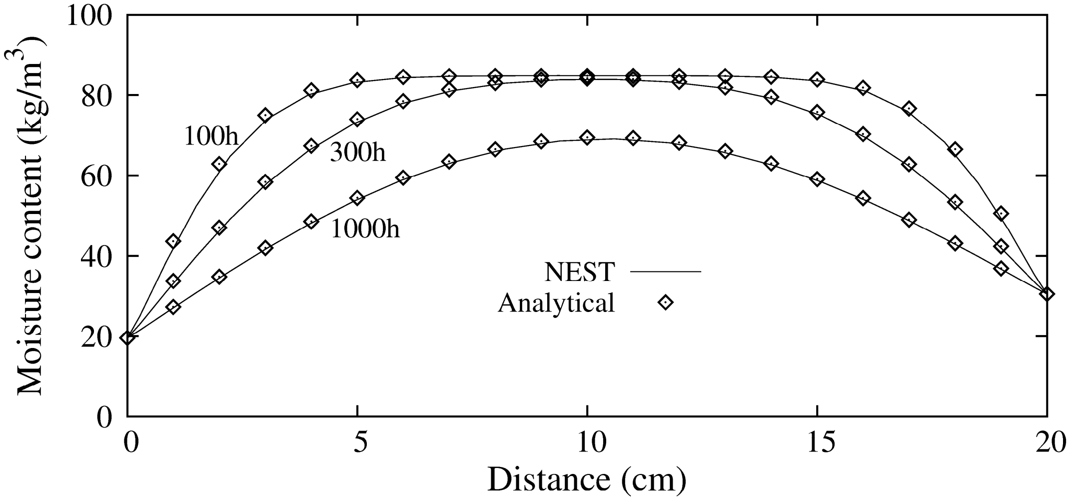
Wall-Adapting Local Eddy-viscosity (WALE) model (Nicoud, 1999).

QR model (Verstappen, 2003).

Variational Multiscalce (VMS) model (Hughes, et al. 2000).

# BENCHMARK TEST CASES

## 1) Isothermal moisture transfer through wall



65% of relative humidity on one side

45% of relative humidity on other side

T is constat and equal 25$^o$C

**HAMSTAD BENCHMARK EXERCICE #2**

# BENCHMARK TEST CASES

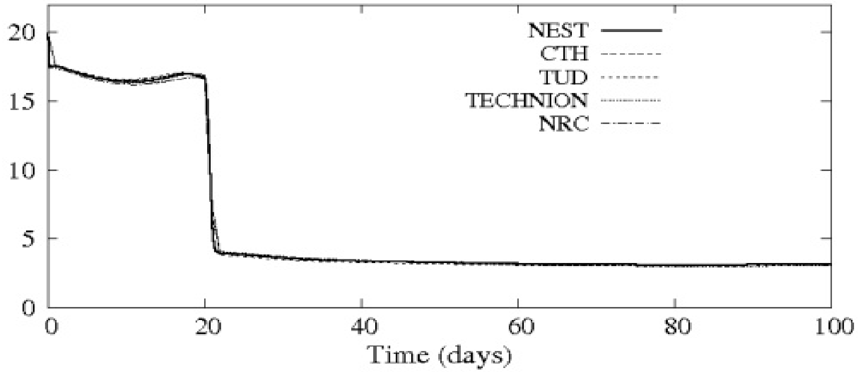
## 2) Air transfer in a “lightway wall”

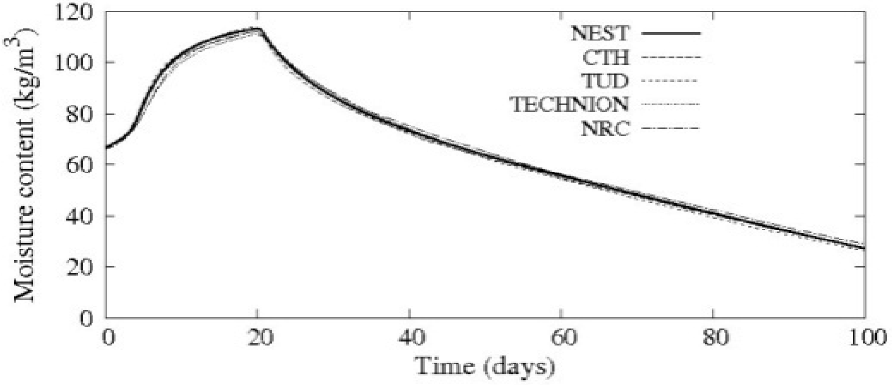
200 mm thin layer

Moisture transfer caused by airflow

Initial and boundary T=20ºC

Indoor humidity 70%
Outdoor humidity 80%





**HAMSTAD BENCHMARK EXERCICE #3**

# BENCHMARK TEST CASES

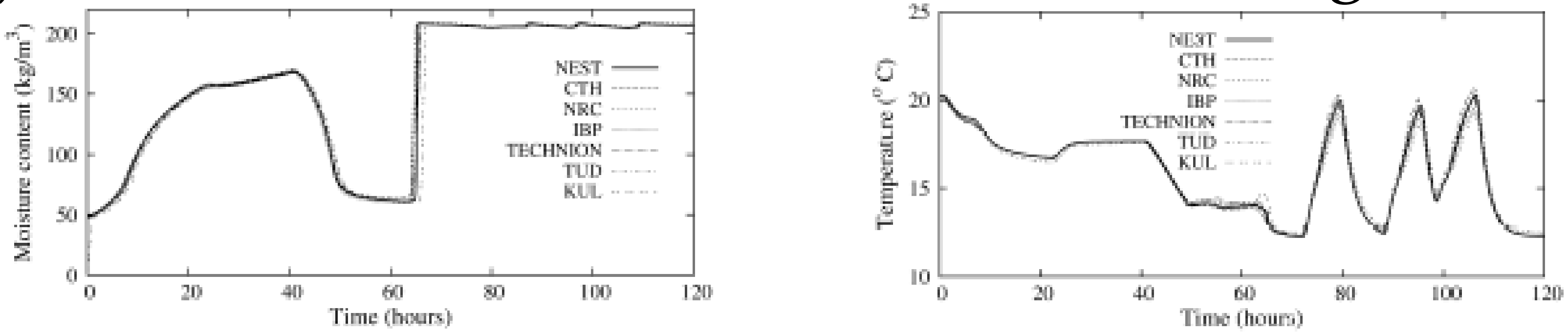
## 3) Non-Isothermal moisture transfer in a composite wall

- 2 layer wall of a 100mm hygroscopic thin and 20 mm non hygroscopic thick.
- the exterior layer has fast liquid transfer properties.
- the wall is subjected to changes in outdoor temperature, relative humidity, rain loads at exterior surface.
- the vapour pressure of the interior side is also varied.

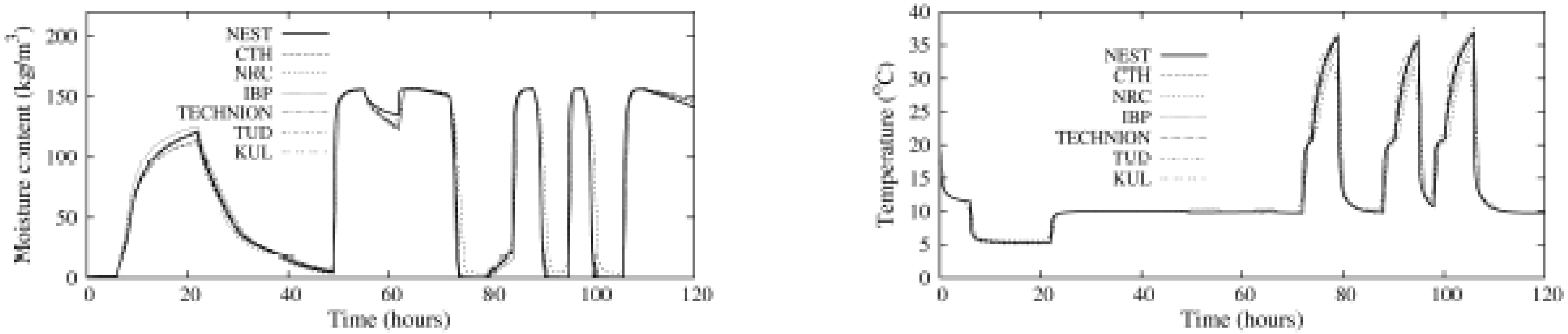
Severe climatic load generates different phenomena of heat and moisture transfer like heating, cooling, alternating drying and wetting due to rain load along with fast liquid transfer properties of the first layer.

# BENCHMARK TEST CASES

## 3) Non-Isothermal moisture transfer through walls



Moisture content and temperature variation at internal surface with time.



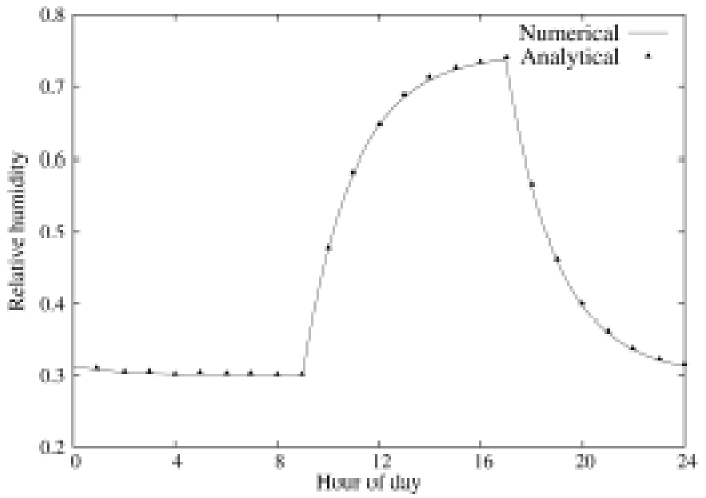
Moisture content and temperature variation at external surface with time.

**HAMSTAD BENCHMARK EXERCICE #4**

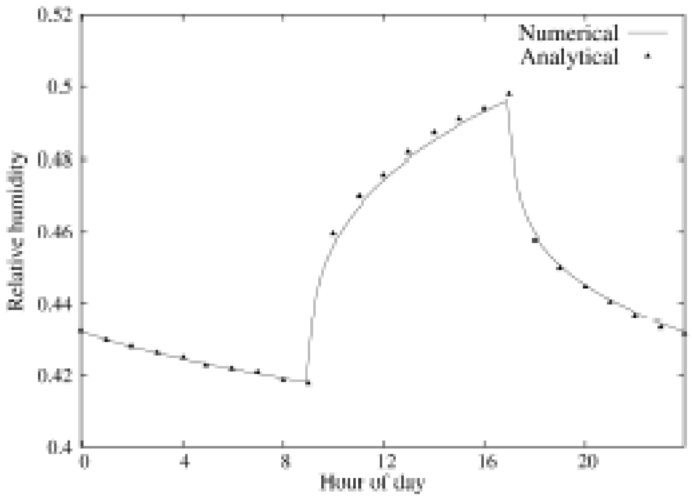
# BENCHMARK TEST CASES

## 4) Room and wall moisture transfer

- A rectangular box.
- Isothermal conditions with moisture transfer until cyclic steady state is reached.



CASE A Room relative humidity with vapour tight walls.

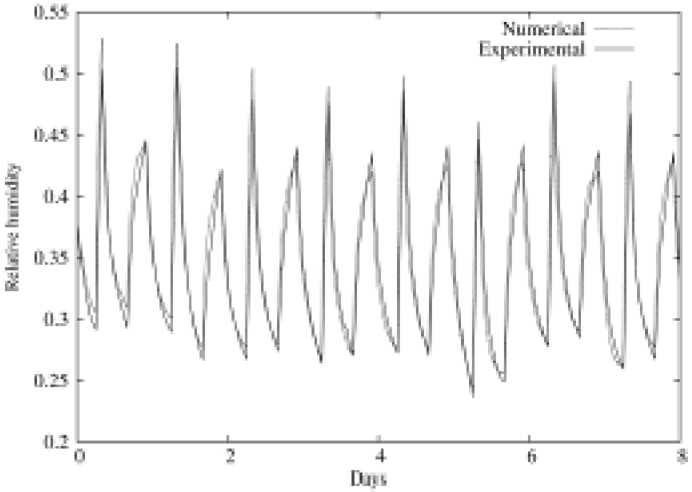


CASE B Room relative humidity with moisture buffering walls.

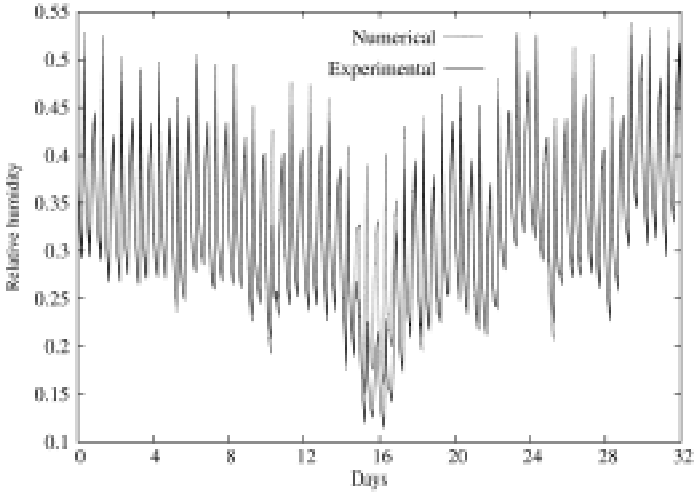
# BENCHMARK TEST CASES

## 5) BESTEST 1

- A rectangular box with two windows.
- Internal conditions changes due to solar radiation.



Room relative humidity over some days

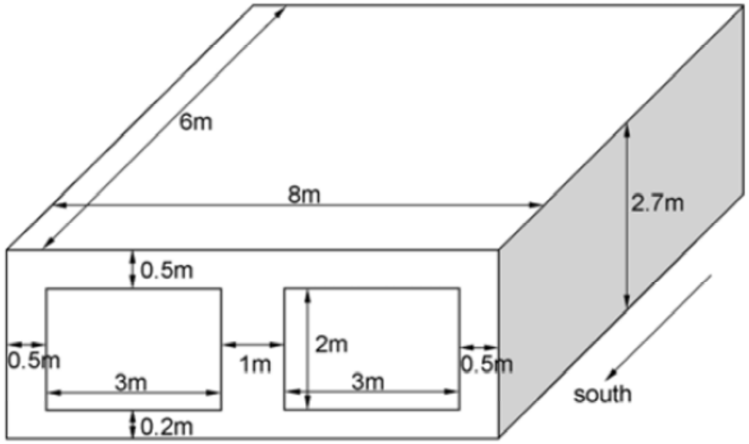


Room relative humidity during the whole period

# BENCHMARK TEST CASES

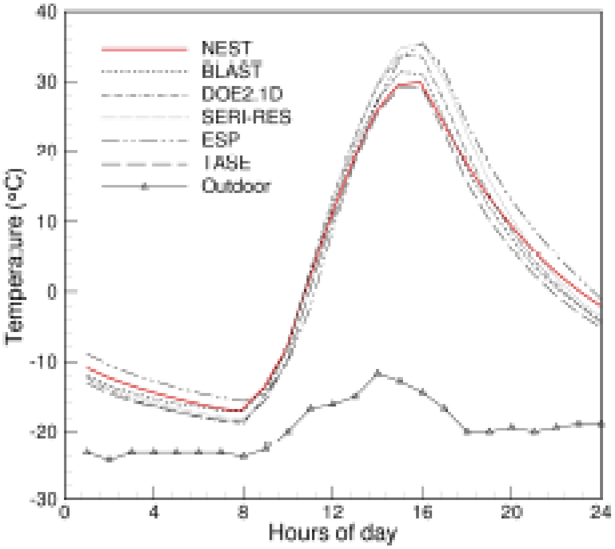
## 6) BESTEST CASE 2

- Location: Denver Colorado
  (Latitude: 39.8, Longitude: 104.9, Altitude: 1609).
- High temperature amplitudes and significant solar radiation.
- Internal gains= 200W.
- Air change rate, ACH=0.5.

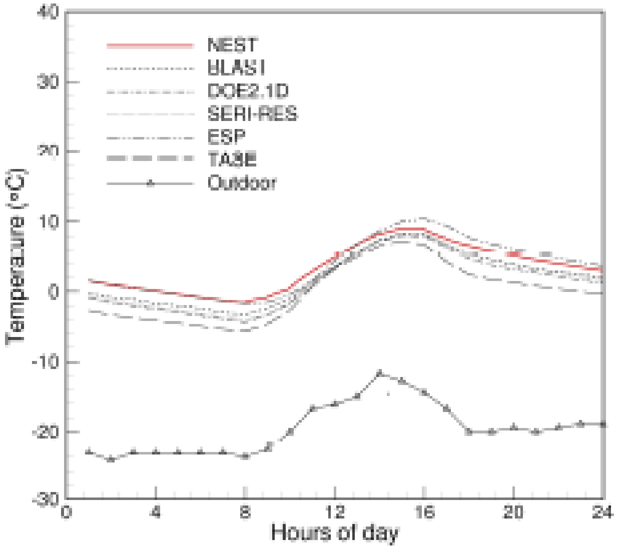


# BENCHMARK TEST CASES

## 6) BESTEST CASE 2



Indoor temperature variation on 4th January for a lightweight structure.

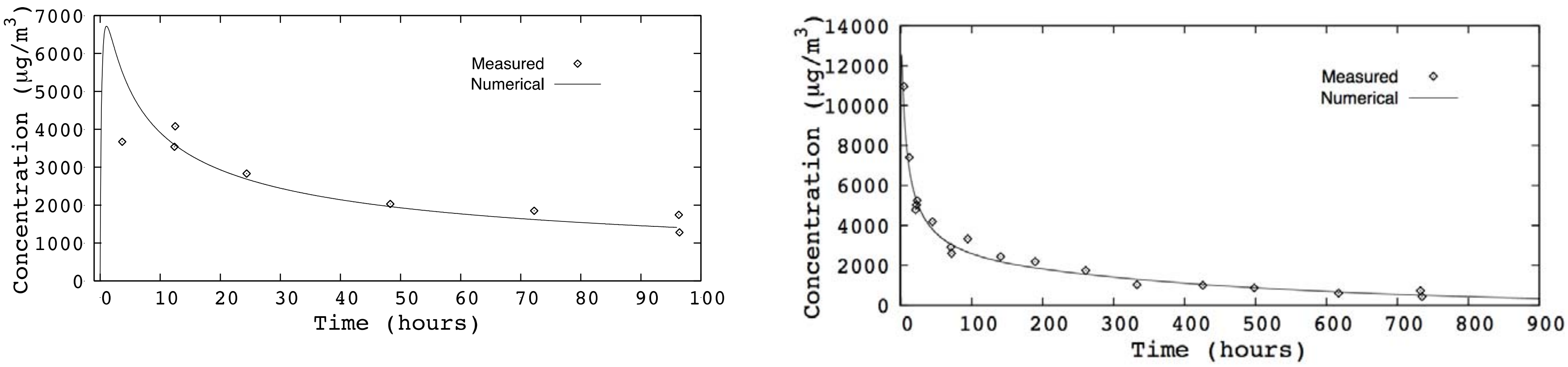


Indoor temperature variation on 4th January for a heavyweight structure.

# BENCHMARK TEST CASES

## 6) Pollutants transfer trough walls

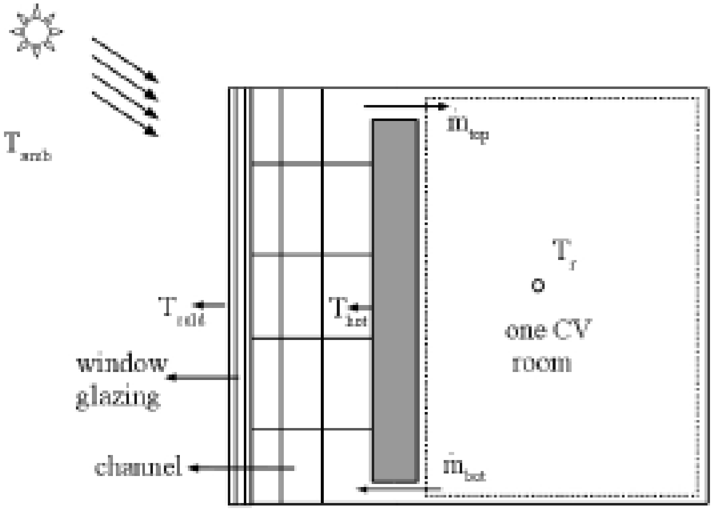
- Small chamber emitting pollutans inside.
- TVOC are hexanal, -pinene, camphene and limonene.



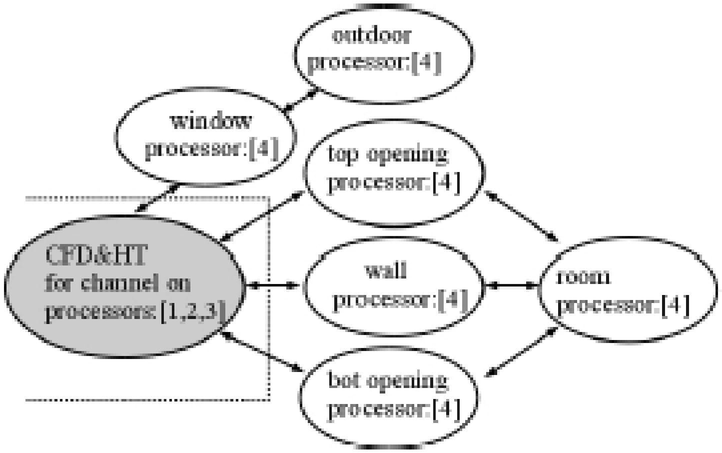
Evolution of the pollutant concentration in the chamber with time with two particle boards PB1 and PB2.

# BENCHMARK TEST CASES

## 7) Ilustrative case



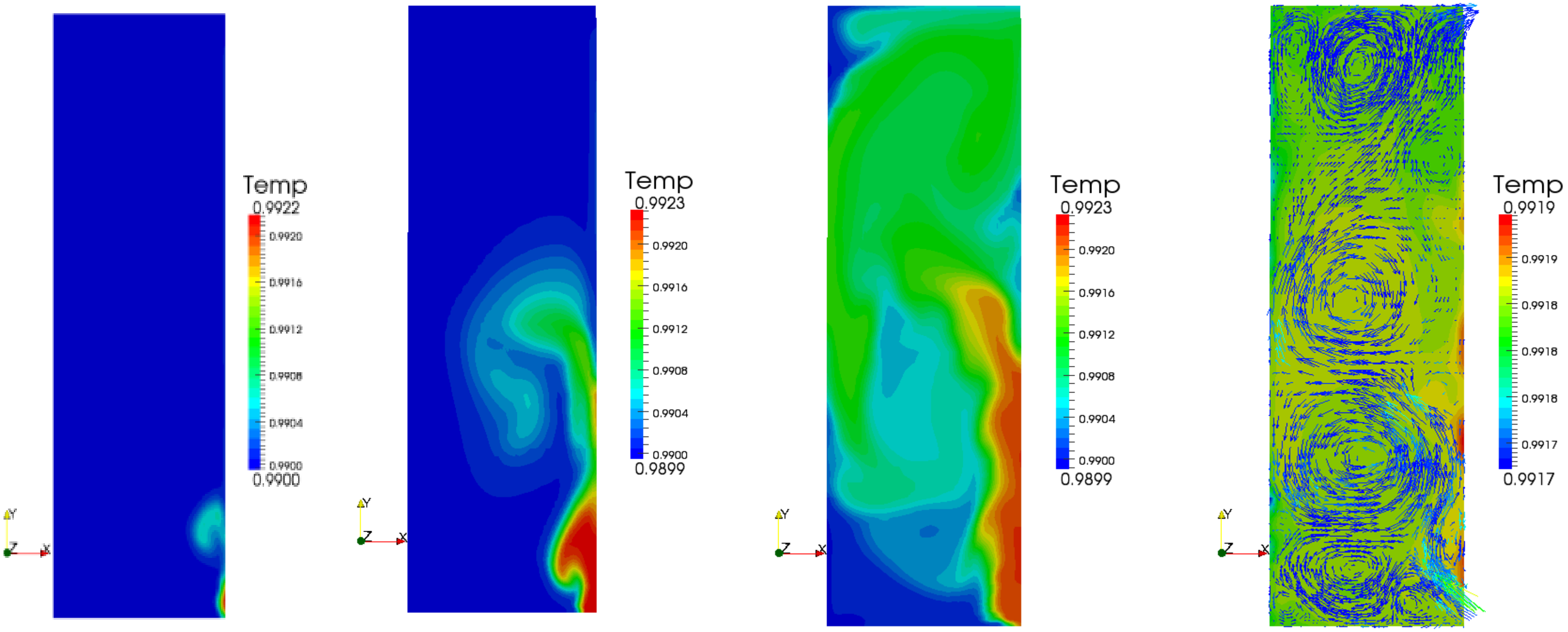
Schematic of the illustrative case.



Partition of elements on different processors.

# BENCHMARK TEST CASES

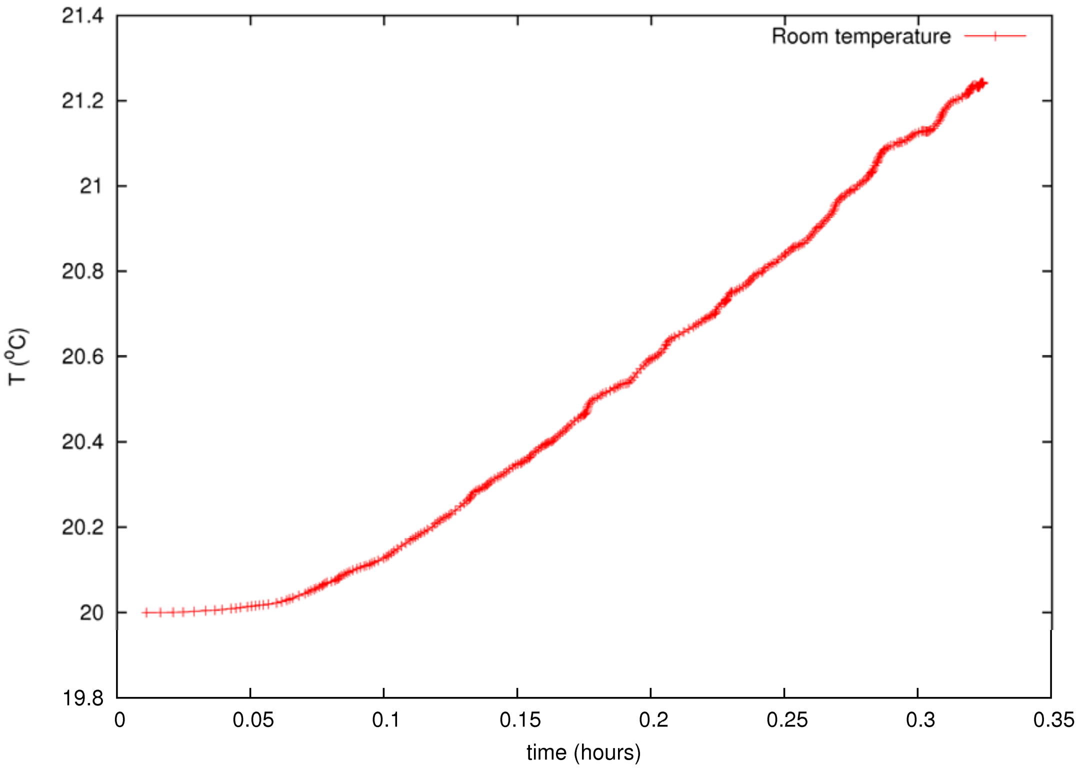
## 7) Ilustrative case



Temperature evolution at 40, 80, 120 and 300 s

# BENCHMARK TEST CASES

## 7) Ilustrative case



Room temperature evolution.

# CONCLUSIONS

- A modular object-oriented tool (NEST) with parallel infrastructure is presented.
- Heat, Air  Moisture transfer model based and VOC transport have been implemented in the building simulation software NEST.
- Verification and validation exercises have been carried out.
- It is possible to integrate CFD & HT models for required elements of a building system.
- Different models are implemented for different elements allowing different levels of complexity in the same simulation.
- An illustrative coupled simulation (CFD & HT model for channel + global model for room) has been presented.

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