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Chaotic Behavior of the Airflow in a Ventilated Room

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Where innovation starts

Background of Research
Buildings as Dynamic Complex Systems

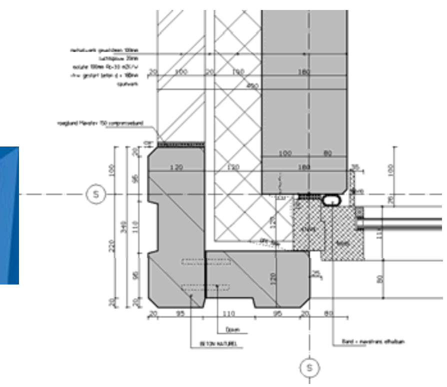
- **Where can we find dynamic complex systems in the built environment ?**

Everywhere and on several scales

~ km

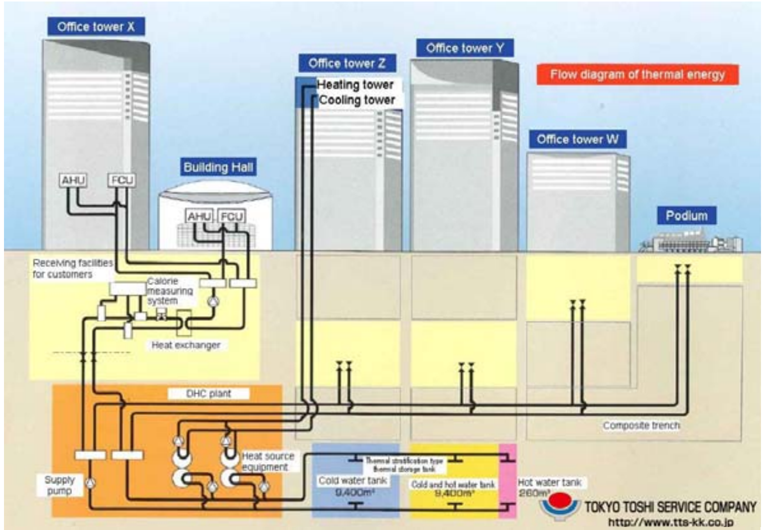
~ 10 m

~ 1 m



~ mm

Background of Research
~ 1 km ~ scale



Urban Area ~ km

Present dynamic complex systems:

Urban Systems & Control

* District heating
* Earth heating

Urban Physics

* Climate
* Pollution

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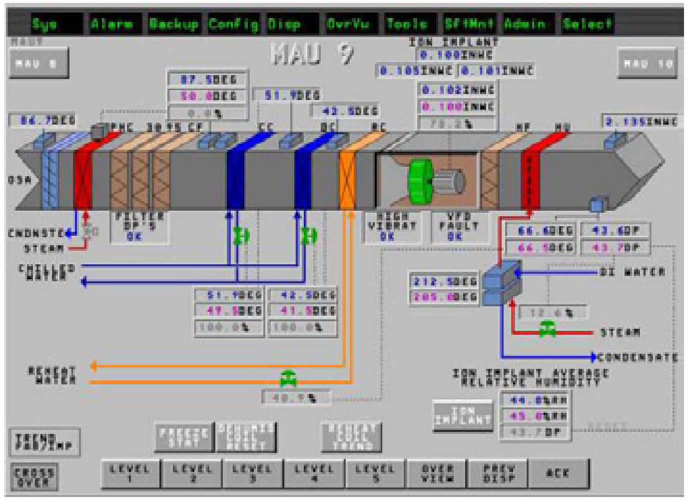
Background of Research
~ 10 m ~ scale



Building ~ 10 m

Present dynamic complex systems:
Building Systems & Control
* Central Air-conditioning
* Ground heat exchangers
Building Physics
* External boundary conditions

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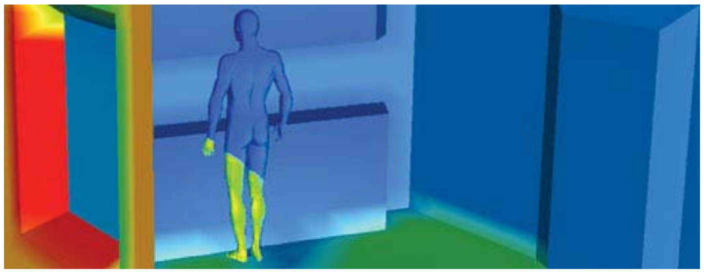
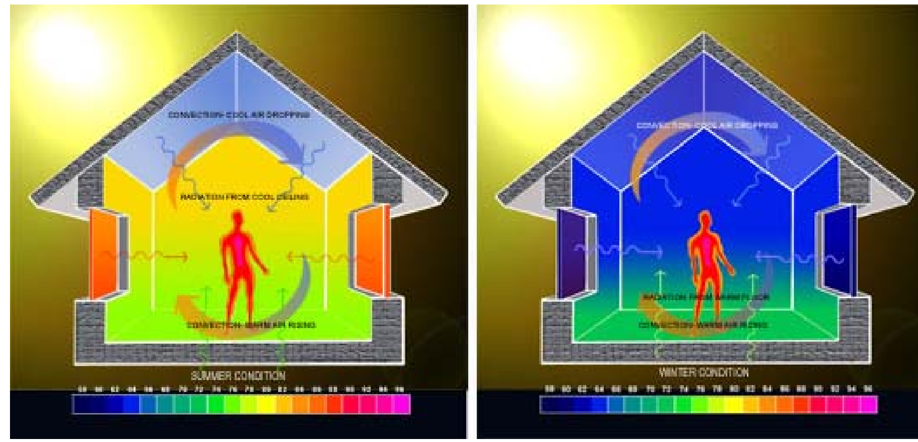
Background of Research
~ 1 m ~ scale





Indoor climate ~ 1 m

Present dynamic complex systems:
Indoor climate Systems
* Additional local Systems
Indoor climate Physics
* Health
* Thermal comfort

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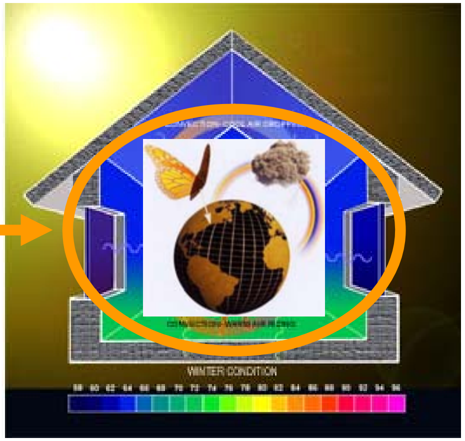
Problem statement
A 'butterfly effect' inside Buildings?



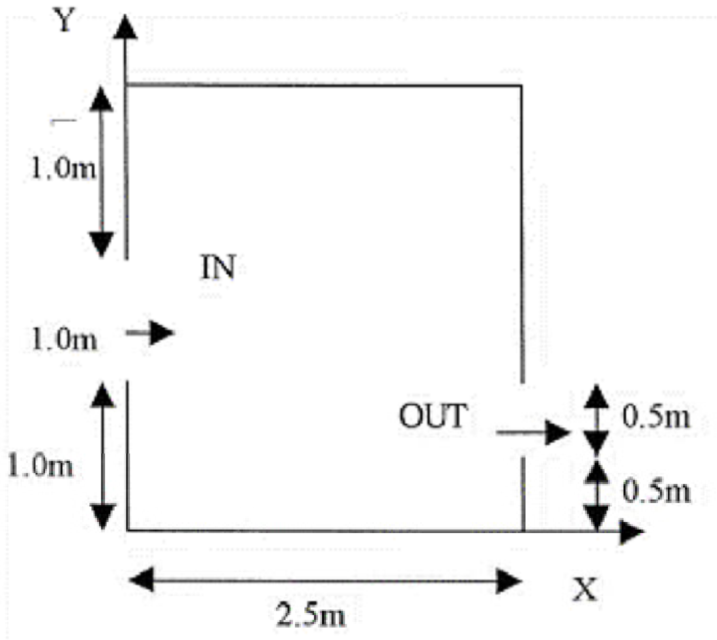
Butterfly effect :
Extreme sensitivity leads to an unpredictable system

How sensitive is the airflow in a ventilated room for very small parameter changes?

Methodology

- Select reference case from literature
- Modeling (Comsol)
- Verify results
- Investigate parameter sensitivity
  - Air supply temperature
  - Hot/cold air supply switching

Reference case



$$\frac{\partial u}{\partial t} = -\frac{\partial (uu)}{\partial x} - \frac{\partial (vu)}{\partial y} - \frac{\partial p}{\partial x} + \frac{1}{\mathrm{Re}}\nabla^2 u$$

$$\frac{\partial v}{\partial t} = -\frac{\partial (uv)}{\partial x} - \frac{\partial (vv)}{\partial y} - \frac{\partial p}{\partial y} + \frac{1}{\mathrm{Re}}\nabla^2 v + \frac{Gr}{\mathrm{Re}^2}T$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

$$\frac{\partial T}{\partial t} = -\frac{\partial (uT)}{\partial x} - \frac{\partial (vT)}{\partial y} + \frac{1}{\mathrm{Re}\,\mathrm{Pr}}\nabla^2 T$$

Sinha et al. 2000 Energy and Buildings 32, pp121-129

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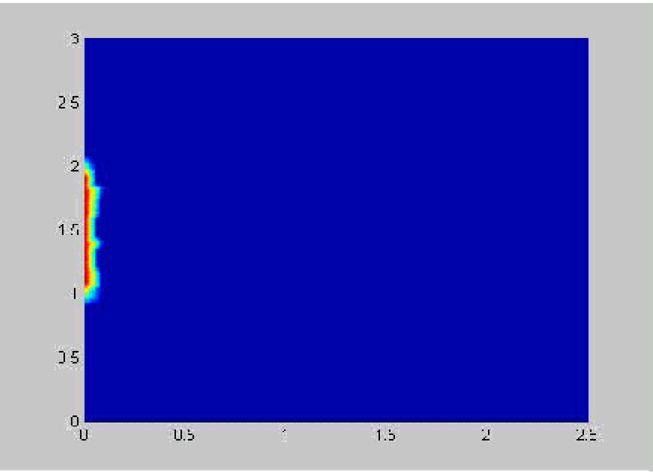
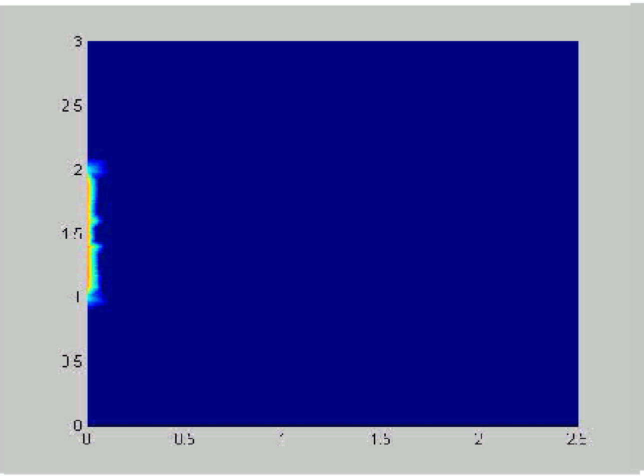
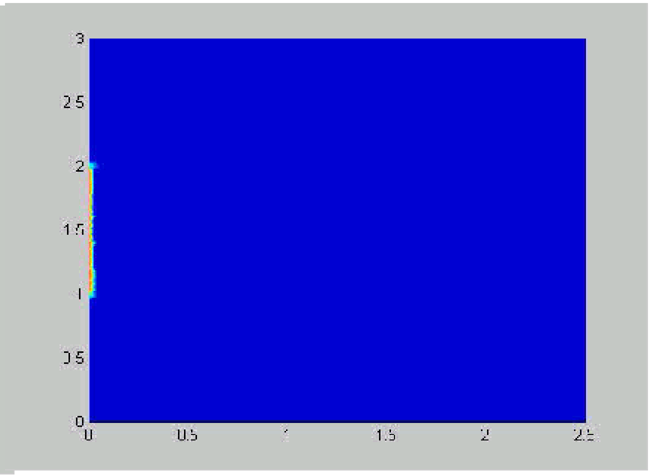
Simulation using Comsol



Re = 50; Gr =0



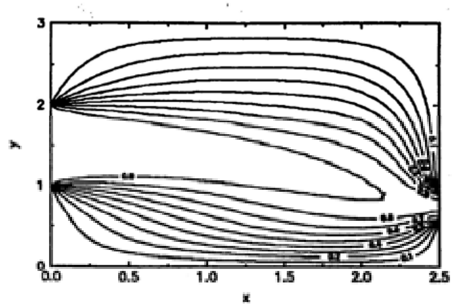
Re = 1000; Gr =0



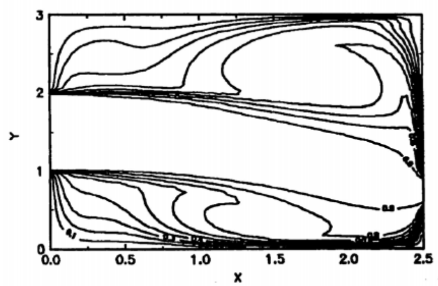
Re = 1000; Gr =~10^7

Verification

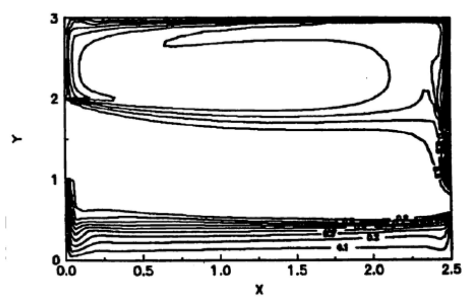
Sinha et al. 2000



a) Re = 50 , Gr=0

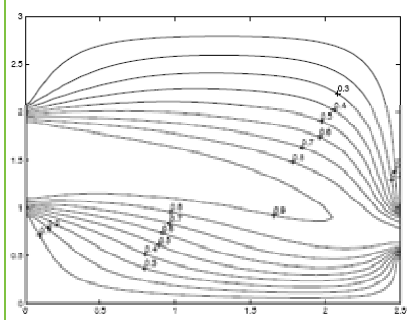


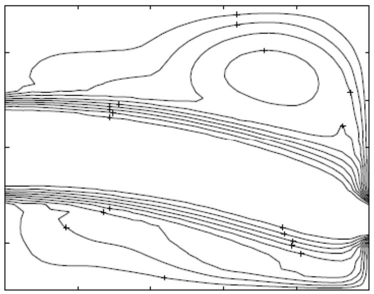
b) Re =1000 , Gr =0

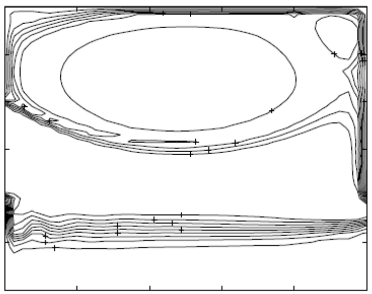


c) Re = 1000 , Gr =2.5 10 ^{7}

Comsol







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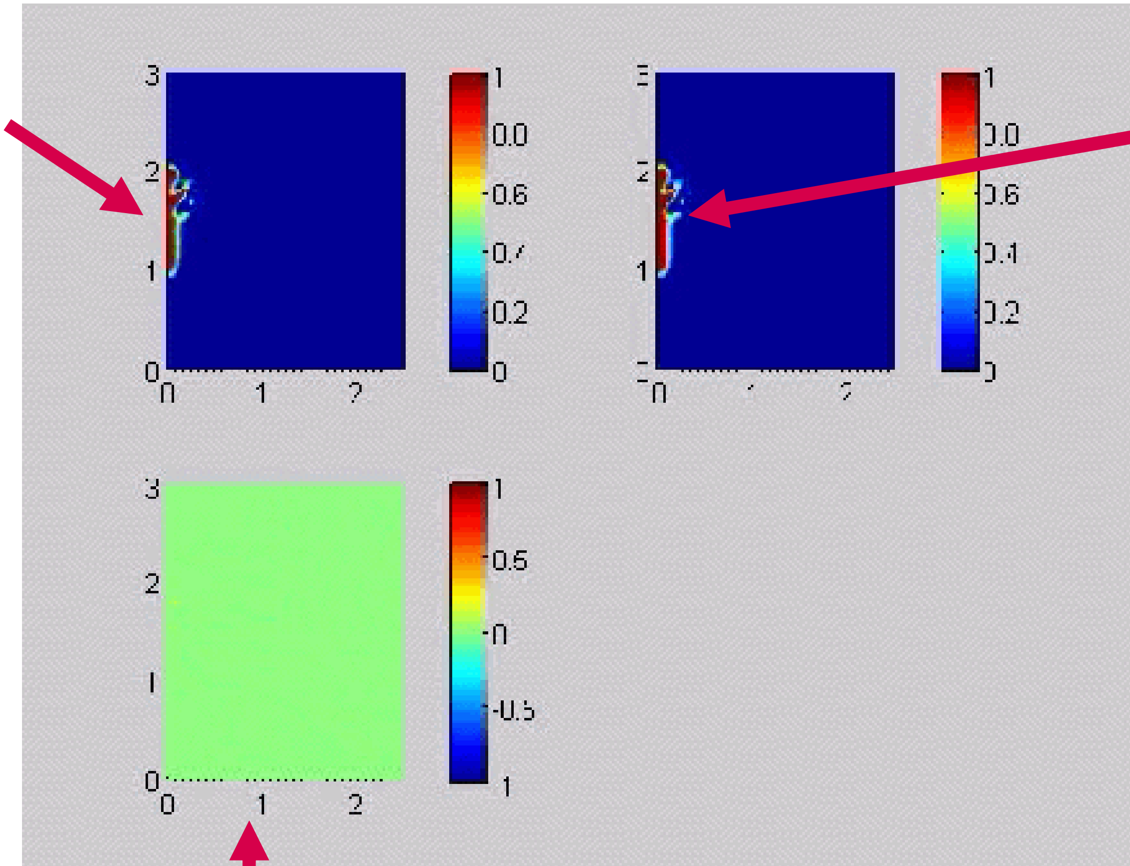
Air supply sensitivity

Air supply = 1

Air supply = 0.98

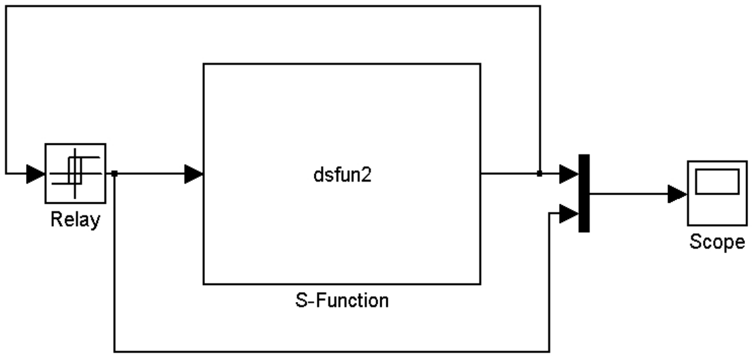


Difference between top figures

Switching model Comsol/SimuLink

- **Using SimuLink & S-Functions**

(Schijndel, A.W.M. van, 2005, Implementation of FemLab in S-Functions, 1ST FemLab Conference Frankfurt, pp324-329)



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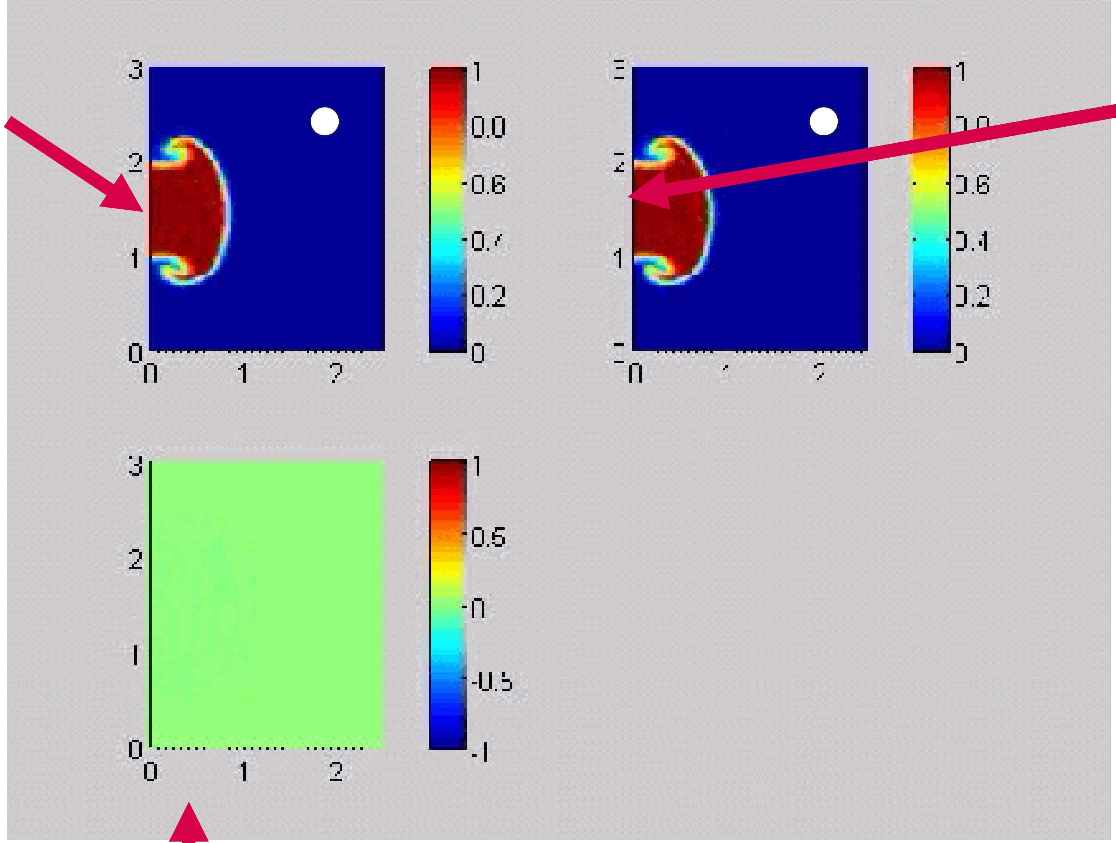
Switching sensitivity without buoyancy

Switching:
<0.30 hot air
>0.50 cold air



Switching:
<0.32 hot air
>0.48 cold air

Difference between top figures

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Conclusions

With buoyancy

- Chaotic behavior is already observed by changing the supply air temperature from 22 °C into 21.9 °C.

Without buoyancy

- Minor chaotic behavior is observed by a small change in the air supply control parameters

Question

- What does this mean for the predictability of the indoor climate?

Thank you !