Modeling, Identification and Control of Experimental Platform for Energy Management in Intelligent Buildings

Part of COHYBA Project

Contrôle Hybride pour les Bâtiments Verts

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Internship at

LJK-IMAG

as part of the requirements to obtain the degree of

Master of Science in System, Control and Information Technology

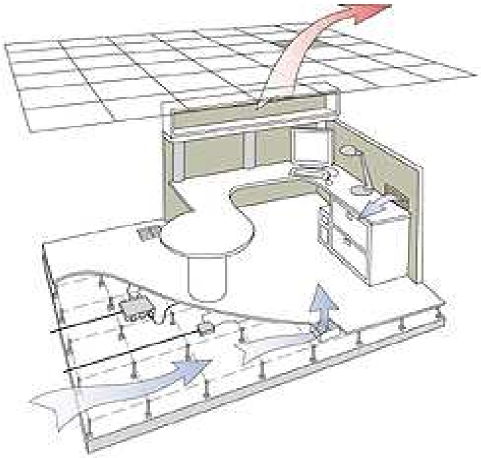
ENERGY consumption in Buildings has reached up to

40%

of the TOTAL energy use in developed countries

rapidly INCREASING

Underfloor Air Distribution (UFAD)



Serious Alternative To Conventional CEILING-BASED Air Distribution Systems

Experimental Building

CEILING PLENUM

- Temperature sensor

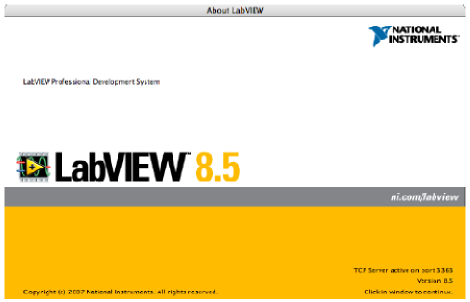
RETURN PIPE

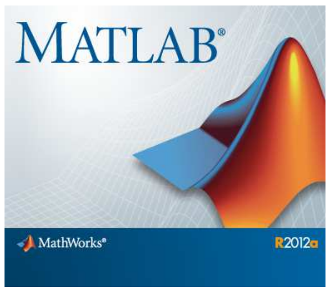
ROOMS AREA

- Fan
- Lamp as heat source
- 2 Door
- Temperature sensor
- Exhaust on the ceiling

UNDERFLOOR PLENUM

- Cooler system
- Temperature sensor

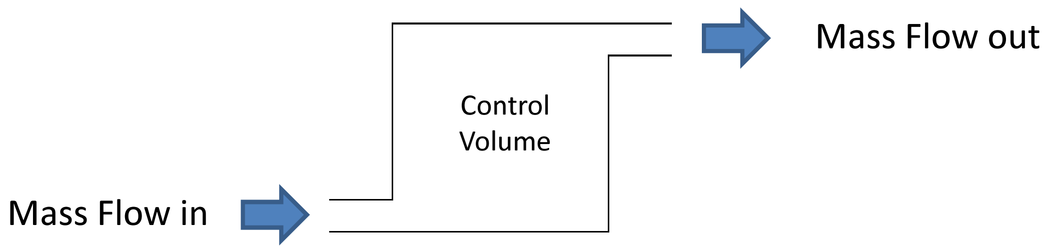




THEORETICAL MODEL

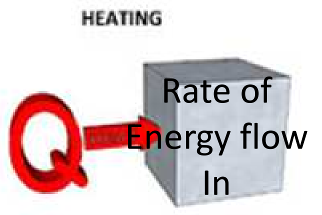
Law of Conservation of Mass

Rate of change of Mass in control volume = Mass Flow in – Mass Flow out

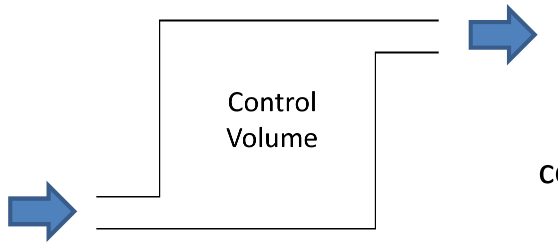


Law of Conservation of Energy

Rate of change of Energy in control volume = Rate of Heat added + Rate of Work done + Rate of energy flow In control volume – Rate of energy flow Out of control volume



Rate of Energy flow In control volume



Rate of Energy flow Out of control volume

- CONDUCTION
- CONVECTION
- RADIATION

Rate of energy flow = Rate of Mass Flow x [enthalpy + Kinetic Energy + Potential Energy]

Apply laws of Thermodynamics on the Experimental Building

Initial Model

$$\dot{E}_i = \rho C_v V_i \frac{dT_i}{dt} = -\alpha_{pl_i}(T_i - T_{pl}) - \alpha_{c_i}(T_i - T_c) - \sum_{k \in \{ow_i\}} \alpha_{i,k}(T_i - T_{out}) - \sum_{j \in \{iw_i\}} \alpha_{i,j}(T_i - T_j)$$

$$+ \sum_{s_i} \delta_{s_i} \epsilon \sigma A_{s_i}(T_{s_i}^4 - T_i^4) + C_p \dot{m}_{pl_i}(T_{pl} - T_i) + \sum_j \delta_{d_{ij}} C_p \rho A_{d_{ij}} \sqrt{2R}\, \delta_{i \leq j}(T_j - T_i)^{3/2}$$

Heat Exchange by Conduction through the WALLs surrounding the room i

Mass Flow Rate forced by the Underfloor FAN

$$\alpha = k \frac{A}{\Delta x}$$

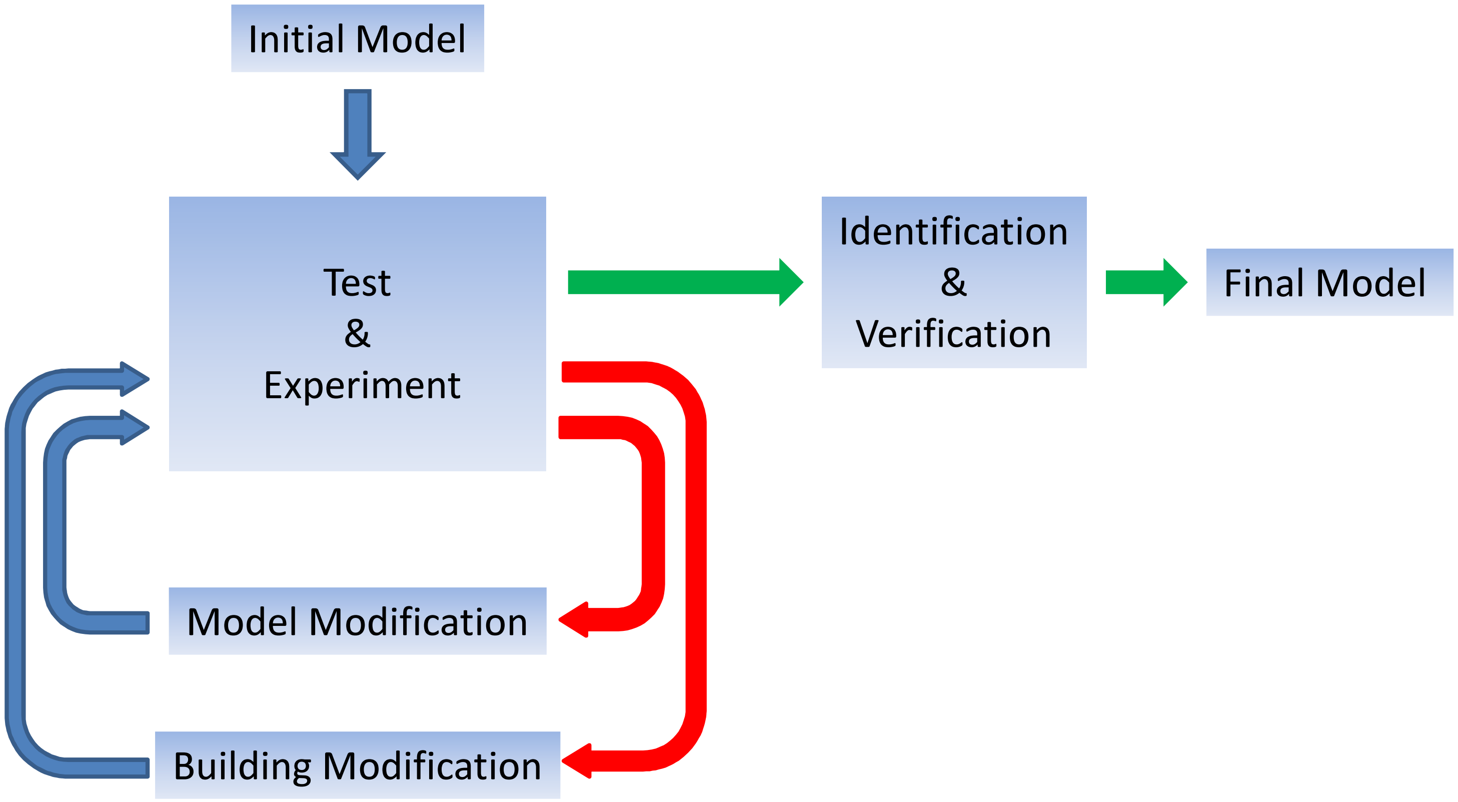
mass flow rate going from a

high temperature room to a low temperature room

Radiation From the HEAT SOURCE

when the DOOR between them is open

Modeling Procedure



Modification of Initial Model

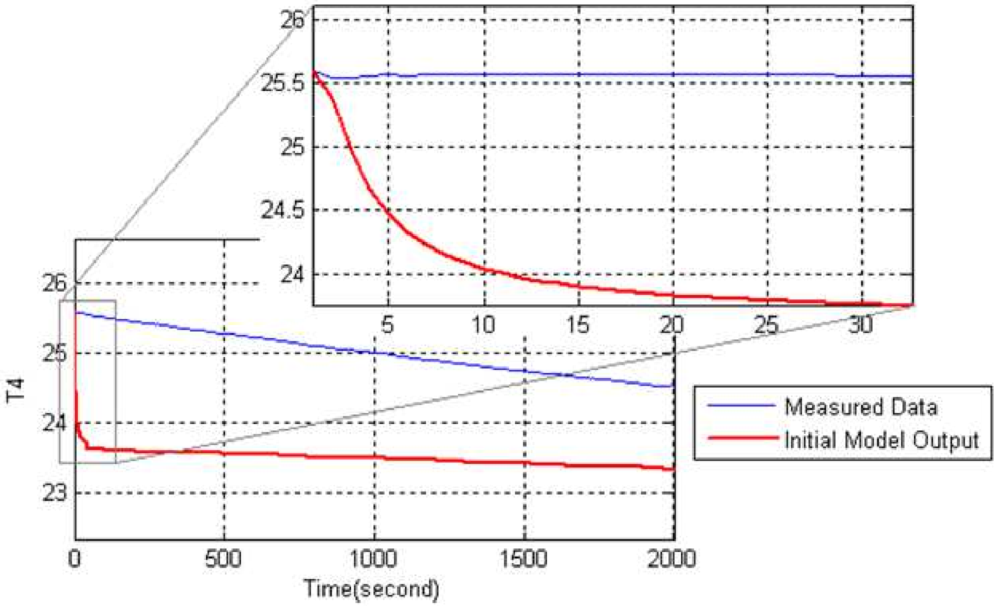
Test Description

Heat up Room 4, to study how it goes back to equilibrium temperature

Test Condition

Doors close
Heat source OFF
Fans OFF
Under floor set to 17 °C

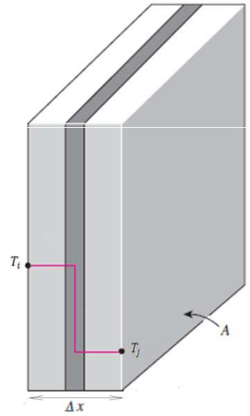
This behavior
Needs
200000 times
Lower
Conductivity Factor



Reformed definition of Energy Stored in the Rooms

Energy stored in the Air inside of the room + Energy stored in all components of the room

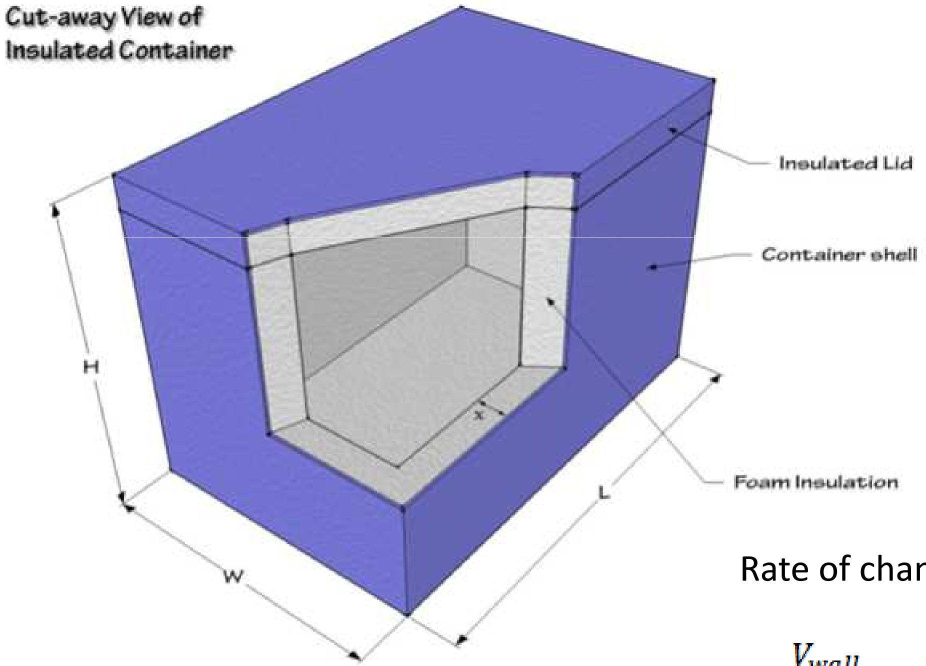
$\rho_{air} V_{air} C_v T_{air}$ $\rho_{wall} V_{wall} C_p T_{wall}$



$(\rho_{air} V_{air} C_v + \rho_{wall} \frac{V_{wall}}{2} C_p) T_{air}$ = Total Energy store

Add Convection into Model

Heat Lost or Gain through the walls of an Insulated Container



$$Q = A\left[\frac{T_o - T_i}{\frac{x}{k} + \frac{1}{H_i} + \frac{1}{H_o}}\right]$$

Rate of change of Energy in the container

$$\left(\rho_{air} V_{air} C_v + \rho_{wall} \frac{V_{wall}}{2} C_p\right) \frac{dT_{in}}{dt} = -\frac{A_{wall}}{\frac{x}{k} + \frac{1}{H_i} + \frac{1}{H_o}} (T_{in} - T_{out})$$

Modified Model

$$\dot{E}_i = R_i \frac{dT_i}{dt} = -\alpha_{pl_i}(T_i - T_{pl}) - \alpha_{c_i}(T_i - T_c) - \sum_{k \in \{ow_i\}} \alpha_{i,k}(T_i - T_{out}) - \sum_{j \in \{iw_i\}} \alpha_{i,j}(T_i - T_j)$$

$$+ \sum_{s_i} \delta_{s_i} \epsilon \sigma A_{s_i}(T_{s_i}^4 - T_i^4) + C_p \dot{m}_{pl_i}(T_{pl} - T_i) + \sum_j \delta_{d_{ij}} C_p \rho A_{d_{ij}} \sqrt{2R} \delta_{i \le j}(T_j - T_i)^{3/2}$$

Heat exchange through the WALLs surrounding the room i

$$R_i = (\rho_{air} V_i C_v + \rho_{wall} \frac{V_{wall_i}}{2} C_p) \qquad \alpha_{ab} = \left[\frac{A_{ab}}{\frac{x}{k} + \frac{1}{H_a} + \frac{1}{H_b}} \right]$$

Definition

Temperatures of the Rooms ⇒ Output

Fans ⇒ Control Input

Outside/Underfloor/Ceiling's Temperatures ⇒ Exogenous Input

Doors/ Heat source ⇒ Disturbances

Building Modification During the Tests

Change Temperature Sensors and Transducers ➡ Increase the Accuracy of Data

Wiring Arrangement Correction ➡ Reduce the Noise effect

Sealing and Isolation ➡ Eliminate unwanted Air Flow from the Gaps

Control the Exhaust opening Proportionally with the Fans ➡ Eliminate Air Flow from Ceiling

Adapt Model to Experimental Building

$$\dot{E}_i = R_i \frac{dT_i}{dt} = -\alpha_{pl_i}(T_i - T_{pl}) - \alpha_{c_i}(T_i - T_c) - \sum_{k \in \{ow_i\}} \alpha_{i,k}(T_i - T_{out}) - \sum_{j \in \{iw_i\}} \alpha_{i,j}(T_i - T_j)$$

$$+ \sum_{s_i} \delta_{s_i} \epsilon \sigma A_{s_i}(T_{s_i}^4 - T_i^4) + C_p \dot{m}_{pl_i}(T_{pl} - T_i) + \sum_j \delta_{d_{ij}} C_p \rho A_{d_{ij}} \sqrt{2R}\delta_{i \leq j}(T_j - T_i)^{3/2}$$

Grey BOX model

For Room 1 :

$$\dot{T}_1 = \alpha_1(T_1 - T_{pl}) + \gamma_1(T_1 - T_c) + \delta_1(T_1 - T_{out}) + \varphi_1(T_1 - T_2) + \theta_1(T_1 - T_4) +$$

$$S_1\mu_1(T_{s_1}^4) + S_1\vartheta_i(T_1{}^4) + F_1\beta_1(T_1 - T_{pl}) + D_{12}\omega_1(T_2 - T_1)^{3/2} + D_{14}\tau_1(T_4 - T_1)^{3/2}$$

10 Unknown parameters for each room should be Identified
40 in Total

Identification Strategy to Adapt Model to Experimental Building
Recursive Least Square algorithm

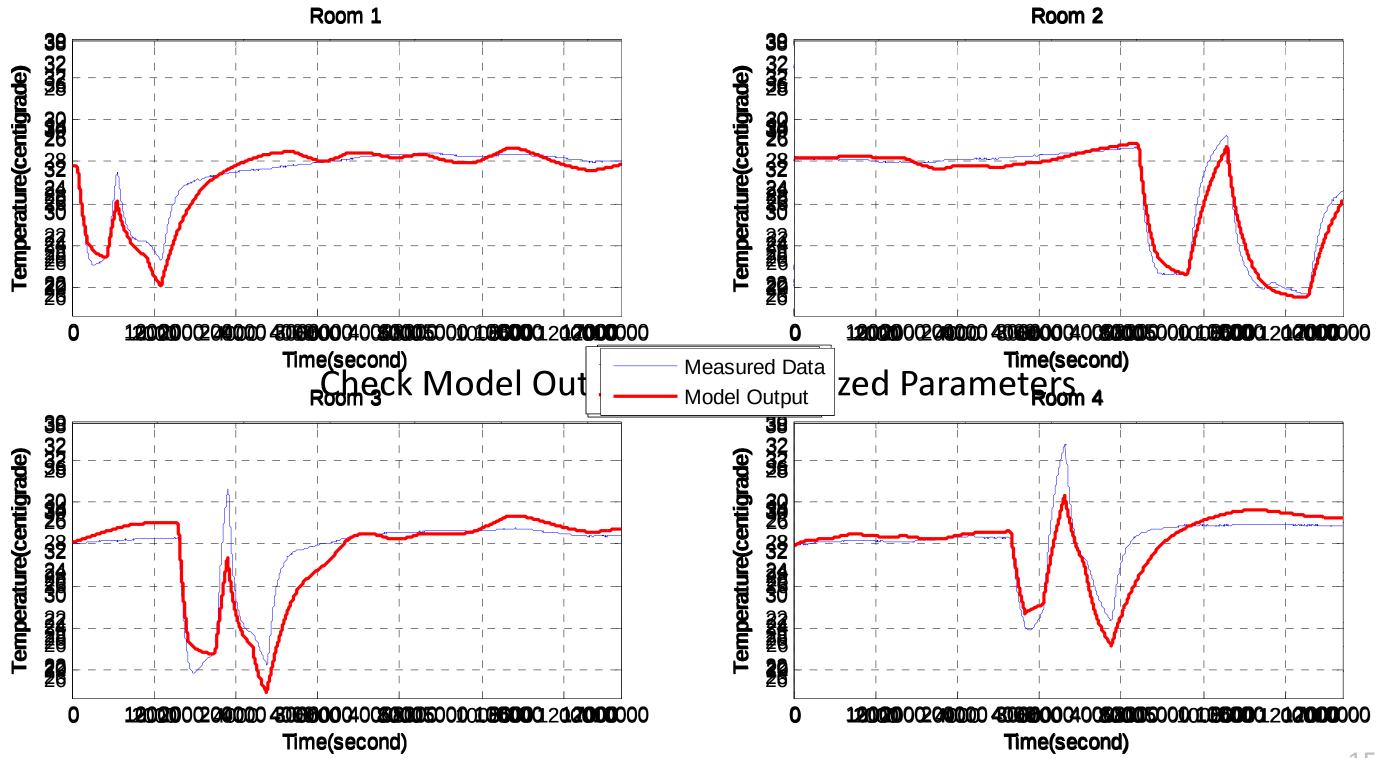
Test Description

Capture the main behavior of system

Tests Condition

Under Floor set to 17 °C

Outside Temperature varying around 30°C



Check Model Out... zed Parameters

Verification of Parameters

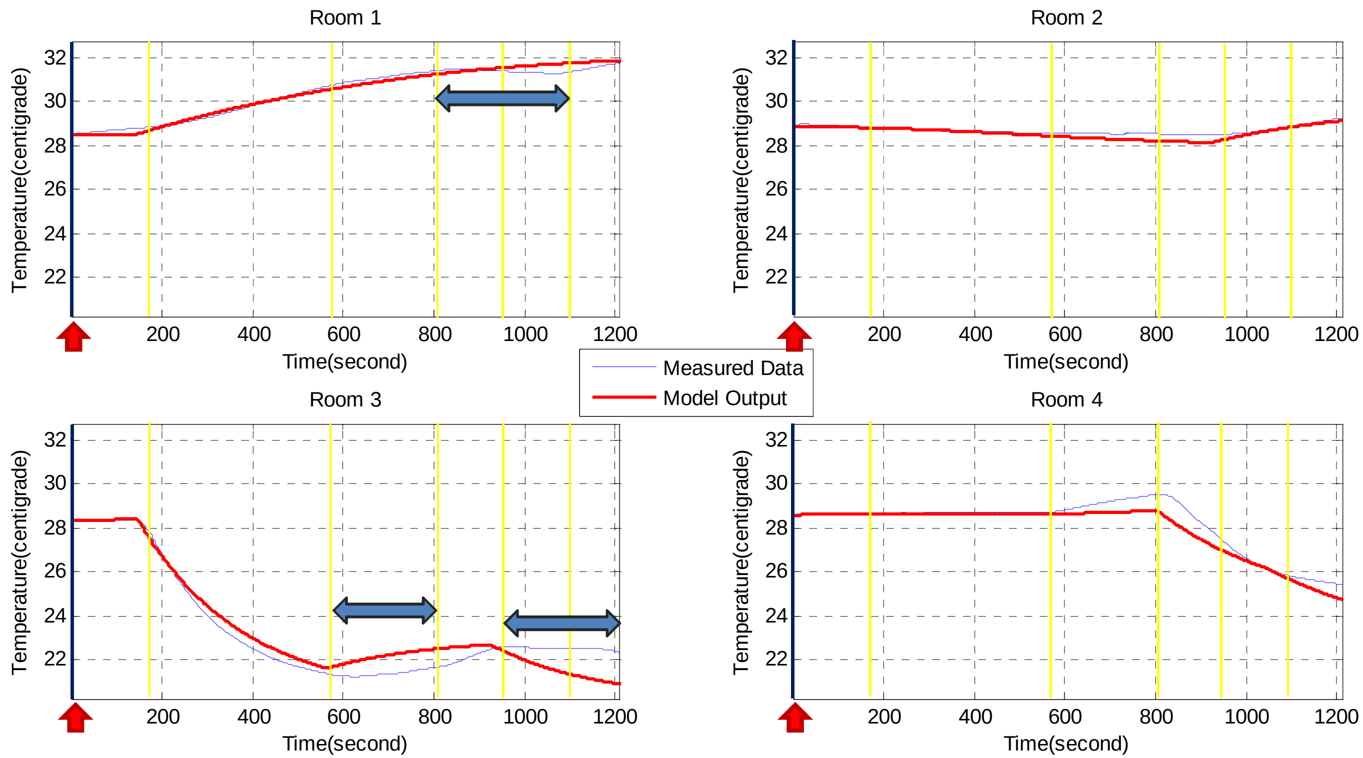
A- the lamp in room 1 and the fan in room3 are turned ON

B- the lamp in room 3 is turned ON and the door between 1 and 4 is opened

C- the fan in room 4 is turned ON

D- the lamp in room 3 is turned OFF and the door between 1 and 2 is opened

E- the door between 1 and 4 is closed



The control strategy that we applied on the experimental building was based on

Robust Controlled Invariance

Keep the States in an Interval With using of Control Input For ANY external Conditions

Model

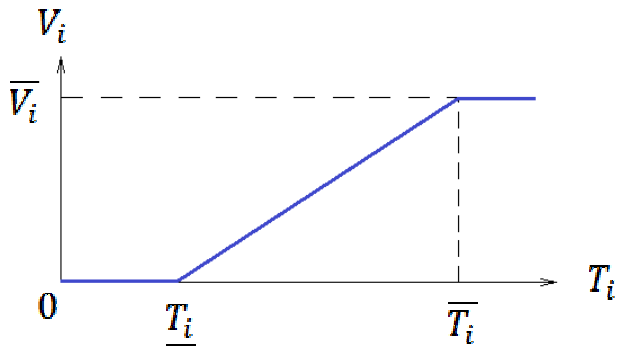
↓

Monotonicity Property *

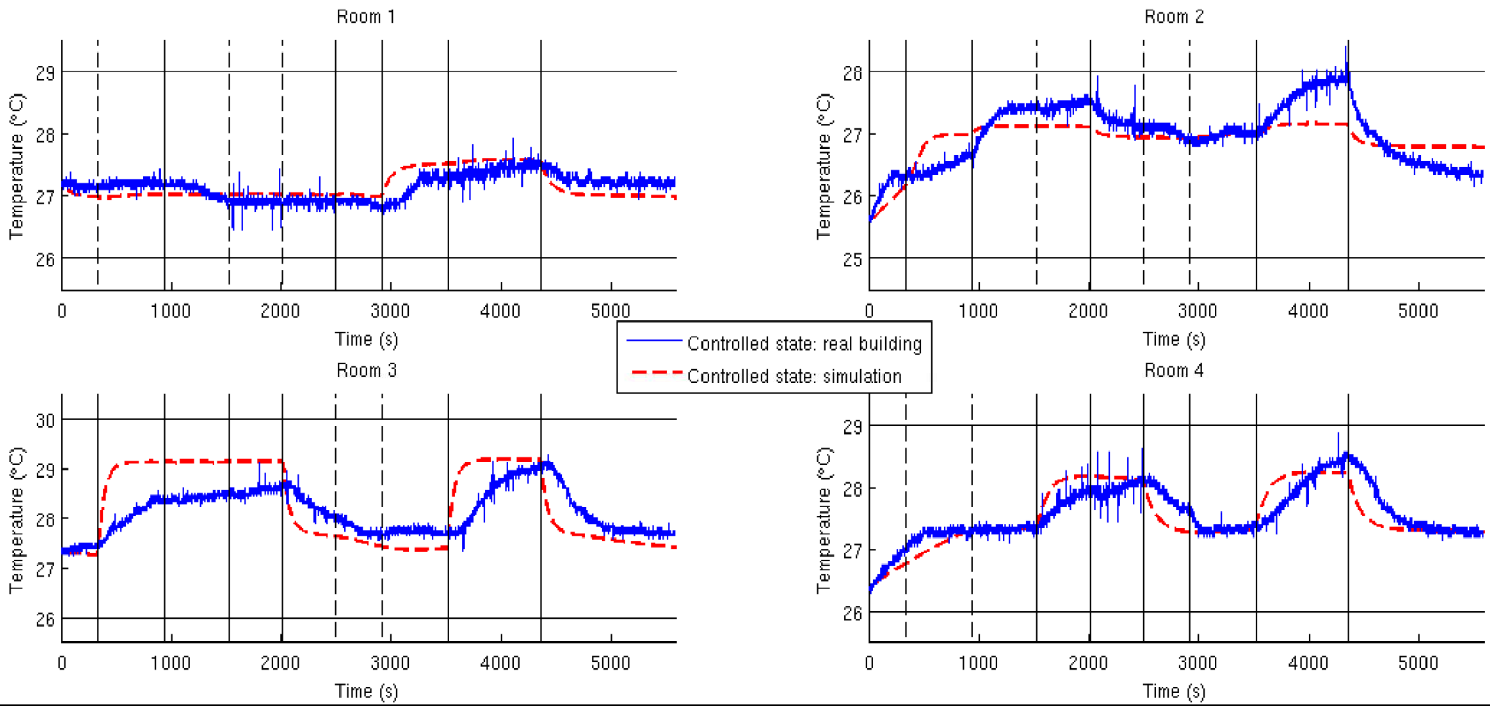
↓

Find the Limits of
Robust Controlled Invariance

* P.-J. Meyer, A. Girard, E. Witrant and H.Nazarpour Robust Controlled Invariance for UFAD Regulation. In Proceedings of the Conference on Buildsys, 2013



V_i
$\overline{V_i}$
0
$\underline{T_i}$
$\overline{T_i}$
T_i



Room 1
Room 2
Room 3
Room 4
Temperature (°C)
Time (s)
0
1000
2000
3000
4000
5000
Controlled state: real building
Controlled state: simulation

Find a Simple Model
Modification and Improvement due to some Experiments Results
Identification of Parameters of the Model
Verification
Implementation of a Controller

We Achieved the Desired Goals

This Internship was Directly related to a PhD work

A Paper Published from the Results of this Internship*

* P.-J. Meyer, A. Girard, E. Witrant and H.Nazarpour Robust Controlled Invariance for UFAD Regulation. In Proceedings of the Conference on Buildsys, 2013

Any Questions ?