ANA2
ANA3

FROM RESEARCH TO INDUSTRY

INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

ADEME

Agence De l'Environnement et de la Maitrise de l'Energie

Laboratoire des Signaux & Systèmes

A parametric study to support the modelling of space heating demand in view of developing a load shedding algorithm

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3RD INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND 4TH GENERATION DISTRICT HEATING

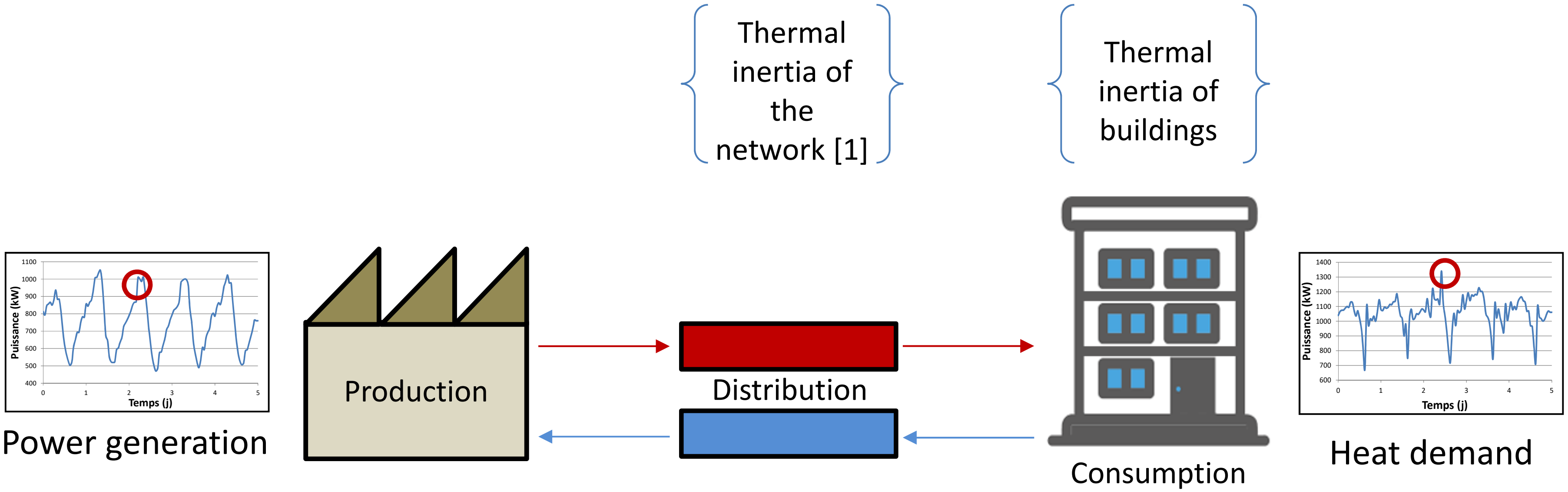
COPENHAGEN, 12–13 SEPTEMBER 2017

Slide 1

ANA2 The French Environmental and Energy Management Agency - ADEME
AOUN Nadine ADEME, 9/5/2017

ANA3 The French Alternative Energies and Atomic Energy Commission - CEA
AOUN Nadine ADEME, 9/5/2017

Advanced control of DHSs using heat demand flexibility



[1] L. Giraud – 2016, PhD Thesis "Dynamic modelling and advanced management of district heating systems"

Identification of a suitable building model for model-based operational optimization of a DHS scale

Building modelling approach

Reduced-order model identification using experimental data

Dynamic numerical simulation

Access to only limited data found at the sub-station

Which elements of the dynamic simulation model have a higher impact on the thermal inertia of the building

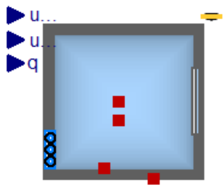
What structure should the identified reduced-order model have

?

Influence of model's parameters on the thermal dynamics

Introducing the dynamic simulation building model

Building simulation is performed in Modelica component-based language.
The base component is MixedAir of the Buildings Library [2]



MixedAir

Accounts for:

- Heat conduction
- Longwave infrared and solar radiation
- Heat convection
- Radiative and convective heat flux delivered by an external heating system
- Radiative, convective and latent internal heat gain
- Heat transfer by fluid inlets and outlets

Case study: Le Sallambô, 8-storey apartment building served by the DHS of Grenoble operated by CCIAG*

Model validated using the ANSI/ASHRAE Standard envelope test

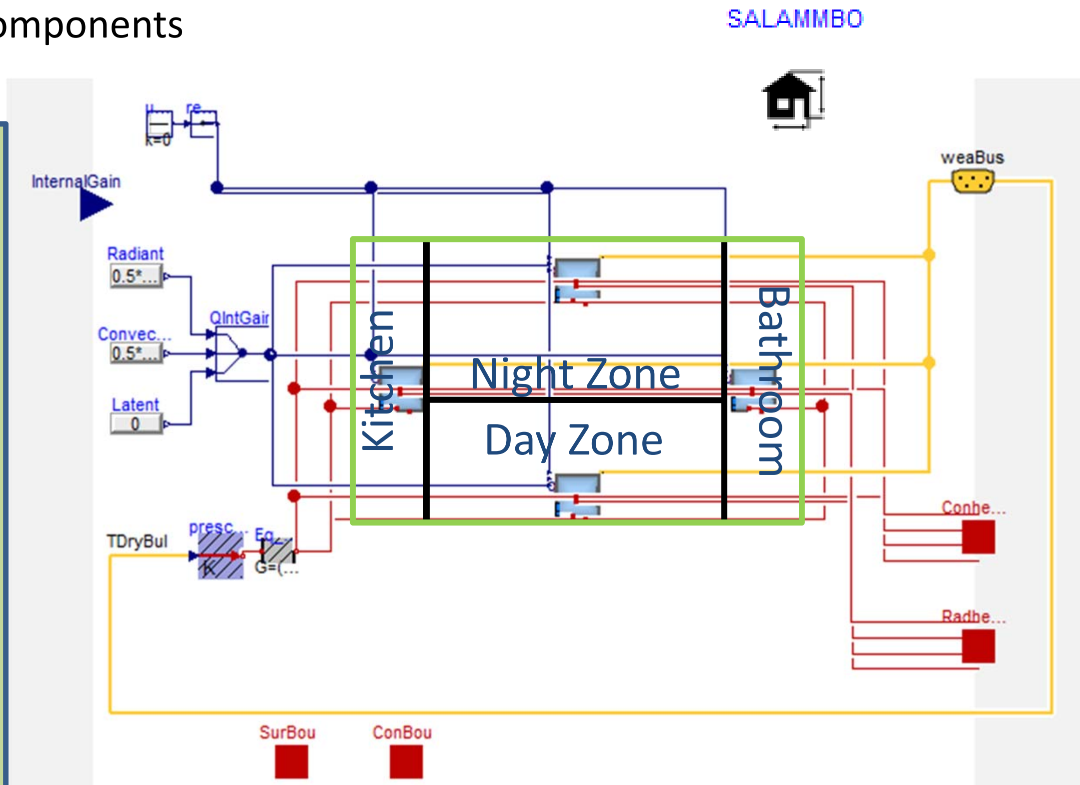
* CCIAG : Compagnie de Chauffage Intercommunale de l'Agglomération Grenobloise – DHS Operator of the city of Grenonble, second largest DHSs of France

[2] M. Wetter – 2013, "Modeling of heat transfer in rooms in the Modelica Buildings Library"

Influence of model's parameters on the thermal dynamics

Introducing the dynamic simulation building model

Each floor is assumed to have a 28.21x10.85 m^2 surface area and is modelled using 4 MixedAir components



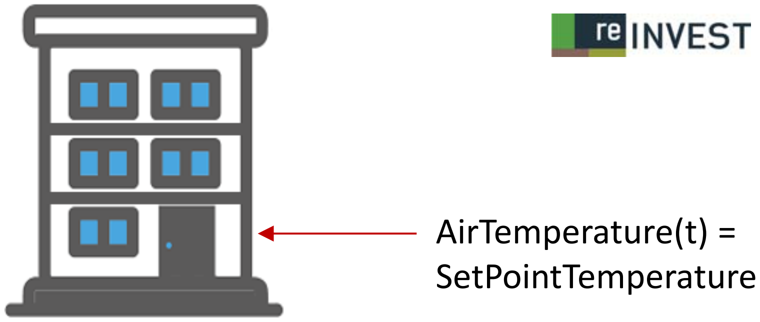
Main assumptions:

- Aeraulic flows are not modelled
- Ventilation and infiltration are modelled as a direct heat flux injected to the air node
- Thermal bridges are taken into account by multiplying the heat conductivity of construction material by a calibrated factor
- Internal heat gains are not modelled yet

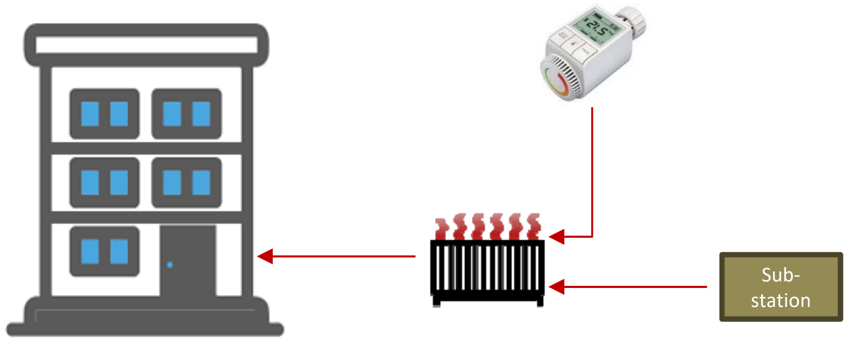
Influence of model’s parameters on the thermal dynamics

Introducing the heating systems models

A- Ideal indoor air temperature control



B- Explicit modelling of the sub-station, pipes, thermostatic radiator valves and radiators developed in the Modelica DistrictHeating Library *[3]



** A Modelica library of DHS’s components including pipes, sub-stations and regulation systems developed at CEA-INES

[3] L. Giraud et al – 2015 “Presentation, validation and application of the DistrictHeating Modelica library”

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Influence of model's parameters on the thermal dynamics

Defining the variable parameters and setting the simulations matrix

Insulation level	High (RT2012-20%***) Consumption = Reference		Medium (RT2005) Consumption = 3.75xReference
Internal mass	Building with internal insulation	Building with external insulation	Building with external insulation + furnishing slabs
Heating system	Ideal control (IC)	Low temperature radiators (Rad50)	Medium temperature radiators (Rad70)

en[illegible] w[illegible]
separating the 4 thermal zones of
a floor and light partition walls
inside the zones

25 [illegible]
Wood : 25 kg/m², 18 mm thick
Ceramic : 5 kg/m², 10 mm thick
Light material : 15 kg/m², 120 mm thick

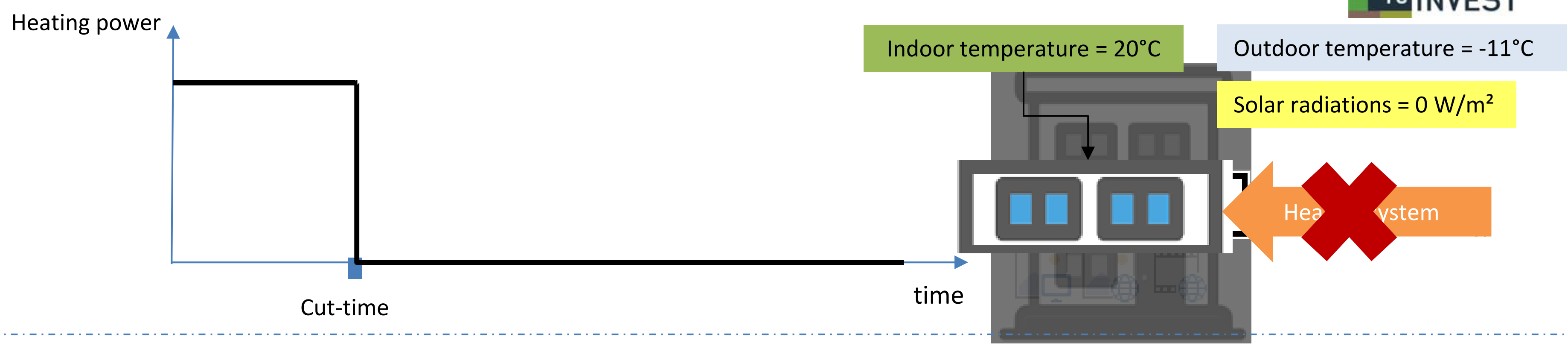
18 simulations

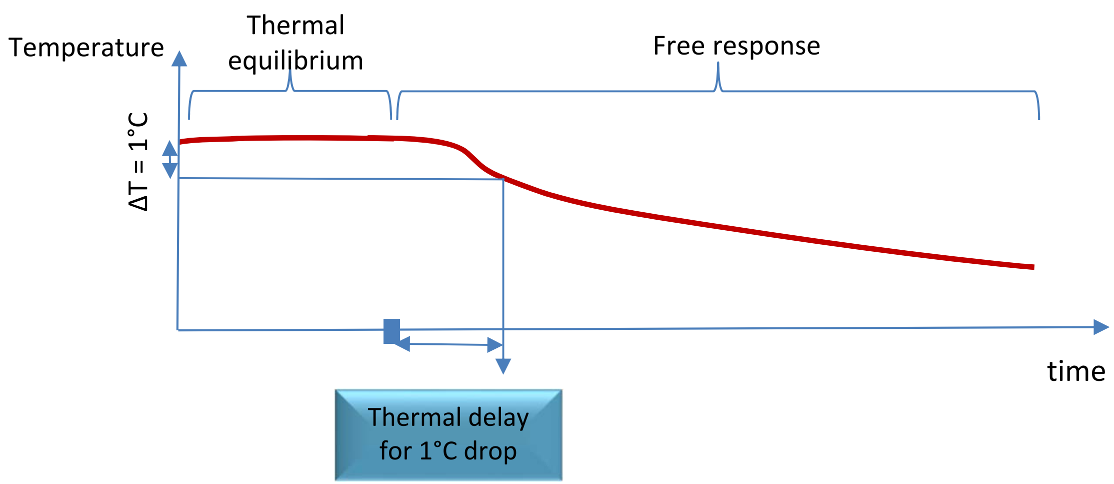
*** A building that satisfies the requirements of the latest French legislation issued in 2012, and consumes 20% less than the legislation's limits.

[4] H. Johra et al – 2017 – "Influence of internal thermal mass on the indoor thermal dynamics and integration of phase change materials in furniture for building energy storage: A review"

Influence of model's parameters on the thermal dynamics

Describing the experimental protocol and the comparative quantity





Air temperature

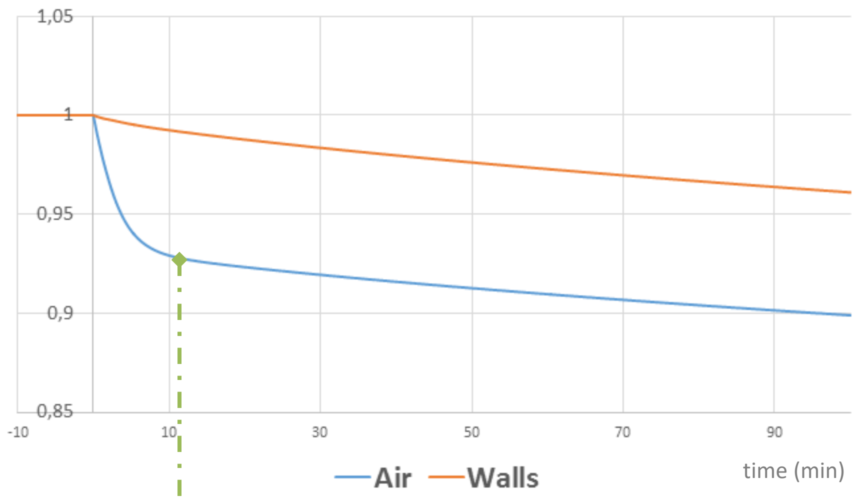
Walls temperature

Perceived temperature

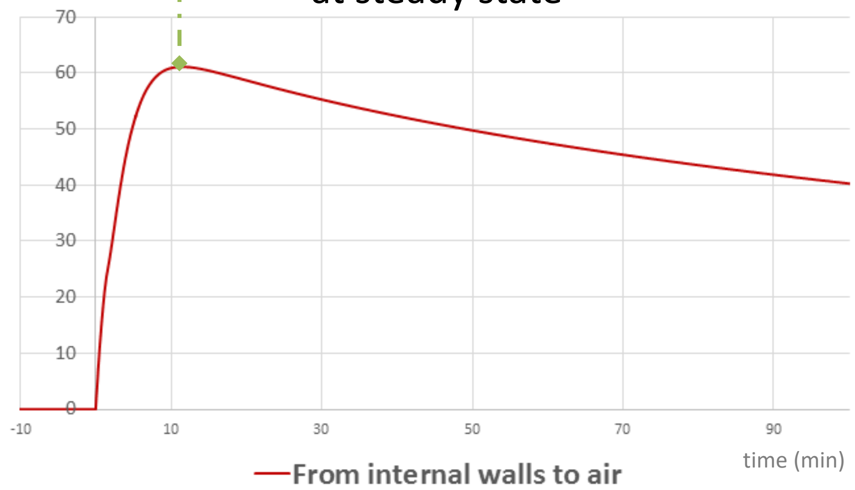
Influence of model's parameters on the thermal dynamics

Results and preliminary conclusions

Normalized temperature



Heat flux % to total heating power at steady state



Insulation level	RT2012 – 20% (Well insulated)
Internal mass	External insulation + Furnishing
Heating system	**Ideal Control (IC)**

ANA1

The graph shows **the average temperatures of the 4 zones of an intermediate floor weighted by their surface fractions** in a **normalized** form:

$$T_{norm}(t) = 1 - \frac{T_{set\ point} - T(t)}{T_{set\ point} - T_{outdoor}}$$

- $T_{set\ point} = 20°C$
- $T_{outdoor} = -11°C$
- time=0s ➔ Heating power cut-time, start of the free response

- Air temperature curve is steep at the beginning of the drop.
- Air temperature curve gets *flatter* as soon as the heat flux given by the internal surfaces to the mixed air inside the zone reaches its peak.

Slide 9

ANA1

If we analyze few results, the first think we notice in all different cases is that convective and radiative temperatures have distinct dynamics. In this graph we have a case of direct air temperature control, we see the evolution from the beginning of the simulation (that is time = -50 min) through the instant at time = 0 when we cut the control signal, and the free response to the end of the simulation. The plot shows normalized temperatures so values range between 1 (initial temperature at the cut time) and 0 (the final temperature).
Convective temperature is characterized by a steep drop in the few minutes following the cut time. It means the air looses its heat quickly as its temperature is greater than walls temperature. From the moment when the convective temperature equals the radiative temperature, its curve becomes flatter.

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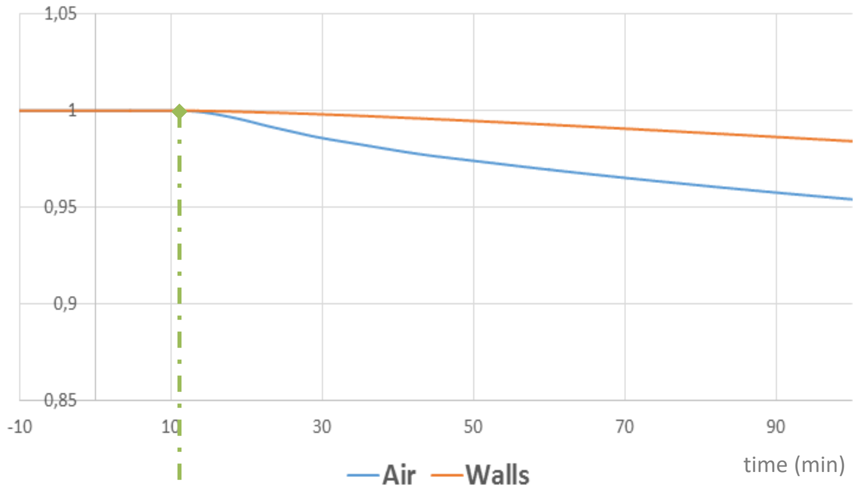
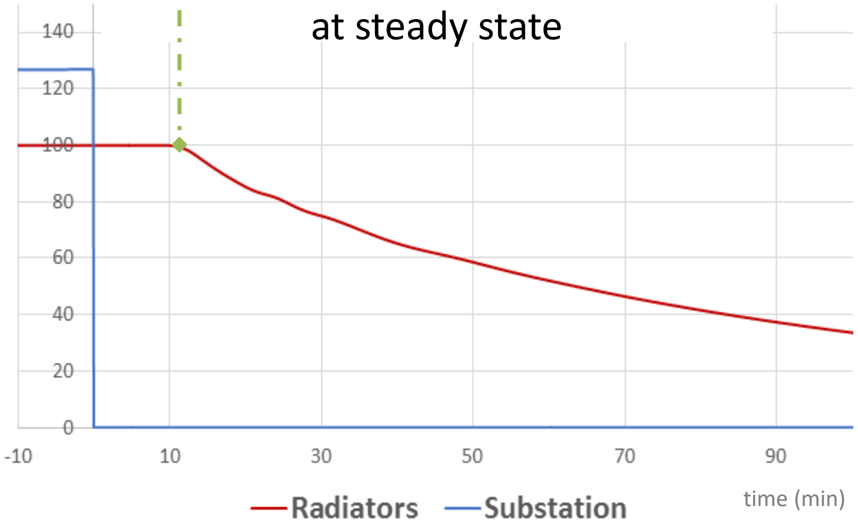
Influence of model's parameters on the thermal dynamics

Results and preliminary conclusions

Normalized temperature



Heat flux % to total heating power at steady state

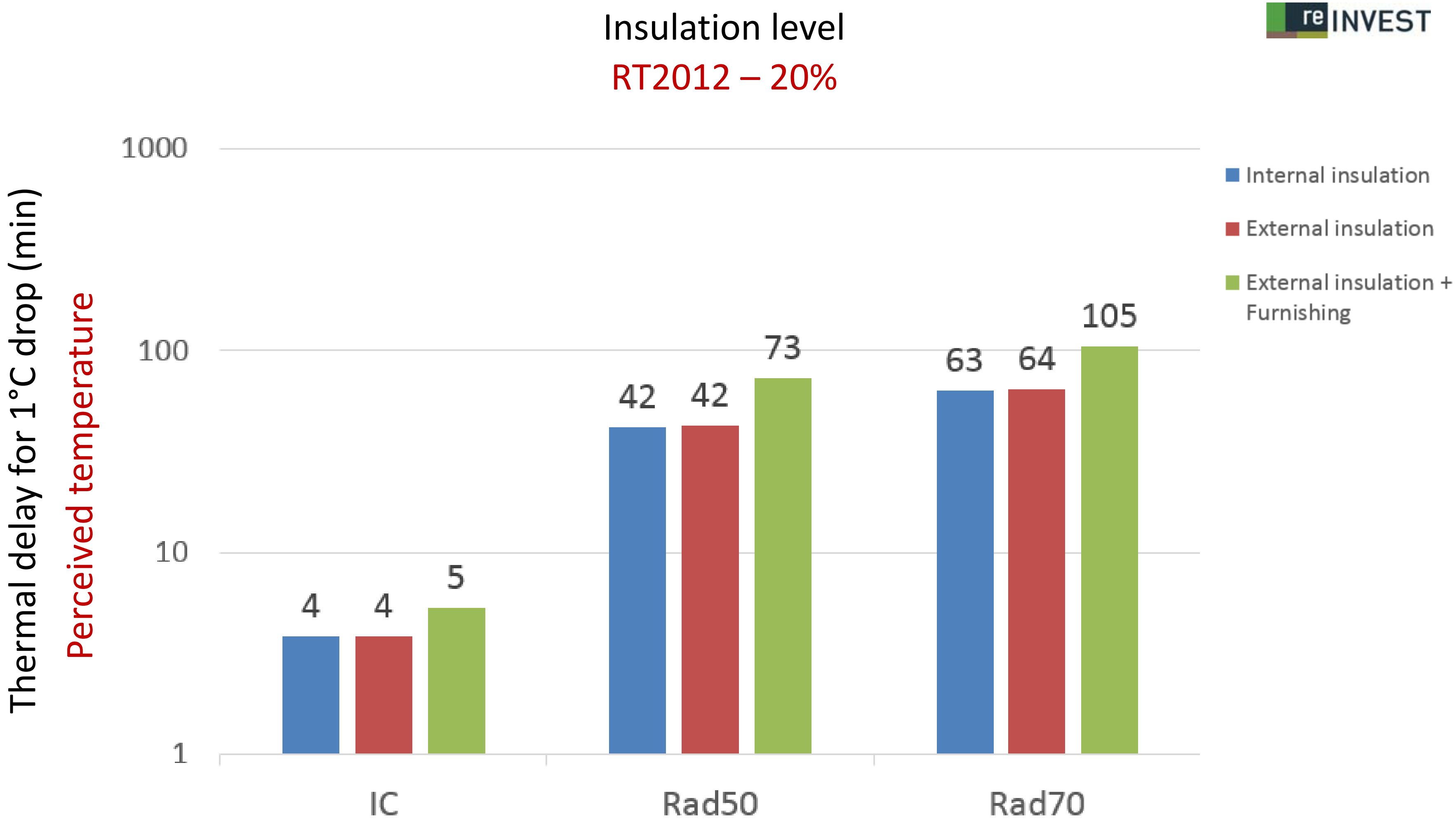


Insulation level	RT2012 – 20% (Well insulated)
Internal mass	External insulation + Furnishing
Heating system	**Medium temperature radiators (Rad70)**

- When the heating system is explicitly modelled, the thermal delay is significantly increased due to the thermal inertia of water in the heating circuit between the sub-station and the radiator

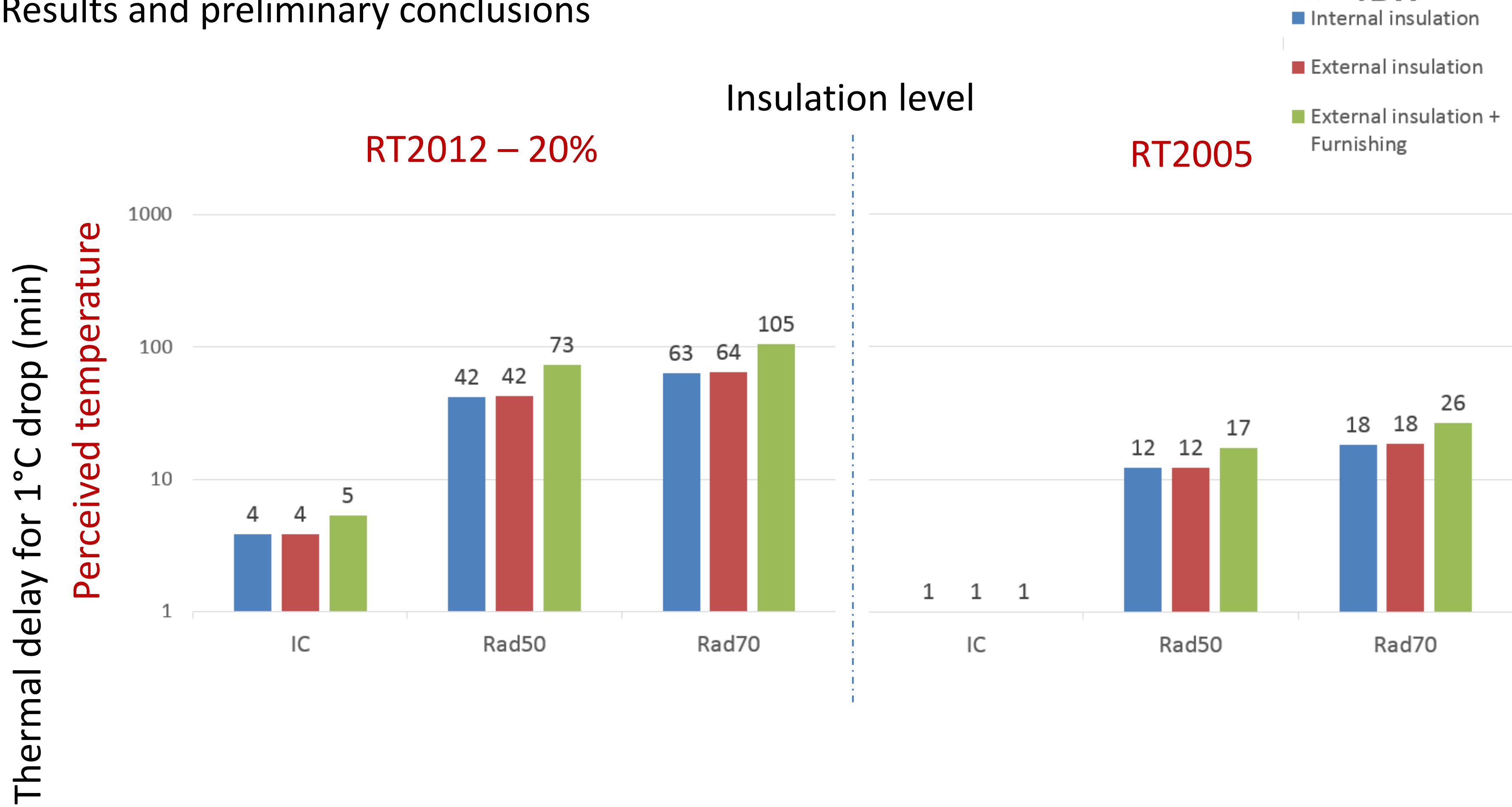
Influence of model's parameters on the thermal dynamics

Results and preliminary conclusions



Influence of model's parameters on the thermal dynamics

Results and preliminary conclusions



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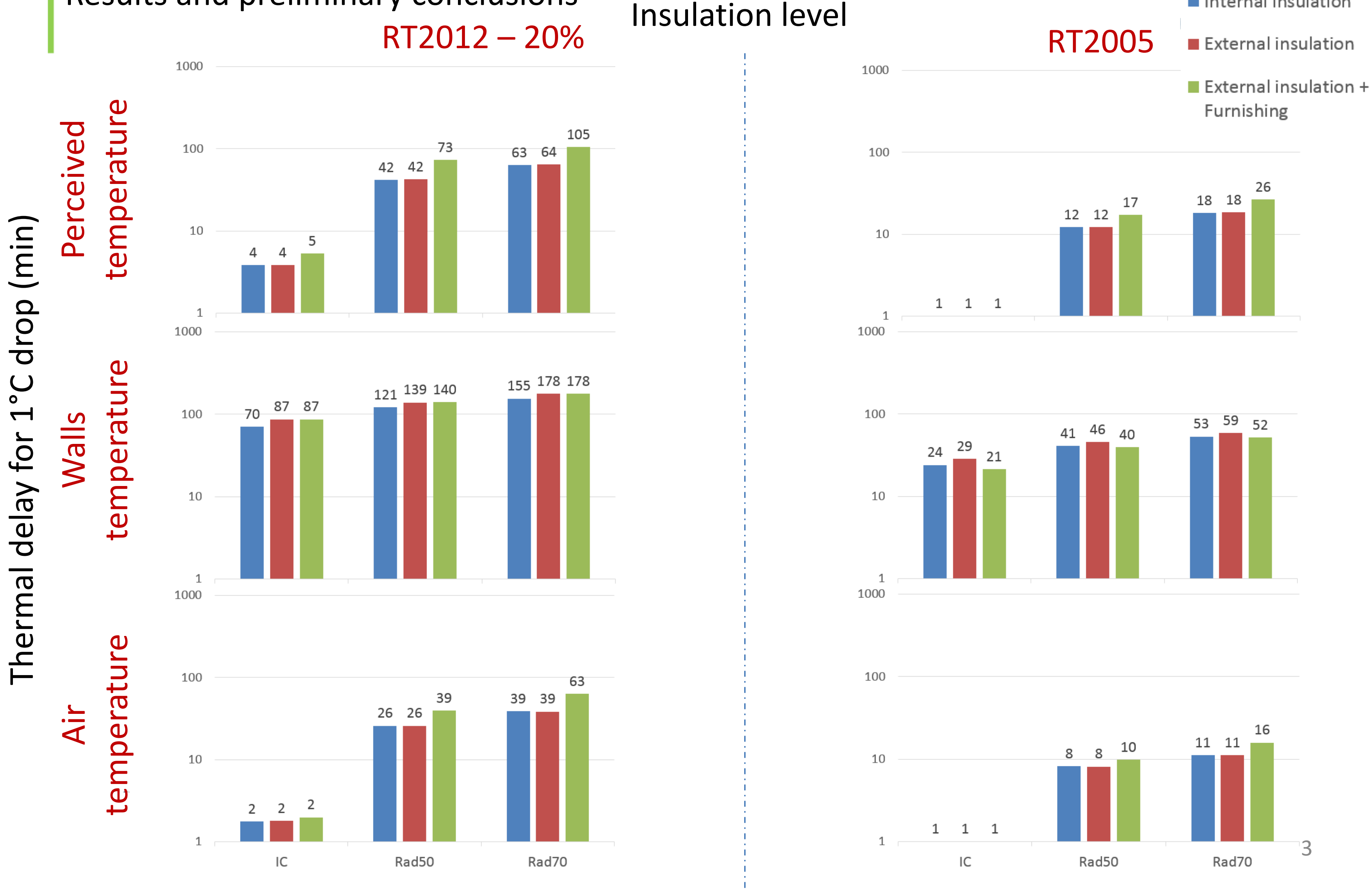
Influence of model's parameters on the thermal dynamics

Results and preliminary conclusions



Conclusions and upcoming steps

The study quantitatively proves the importance of:

- Distinguishing the air temperature from the walls temperature and considering an intermediate temperature for control.
- Explicit modelling of the heating system
- Including internal mass

Upcoming steps:

- Investigation of the case of floor heating.
- Classification of the set of existing buildings into several categories and proposition of a suitable reduced-order model structure for each category

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Thank you

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Influence of model's parameters on the thermal dynamics

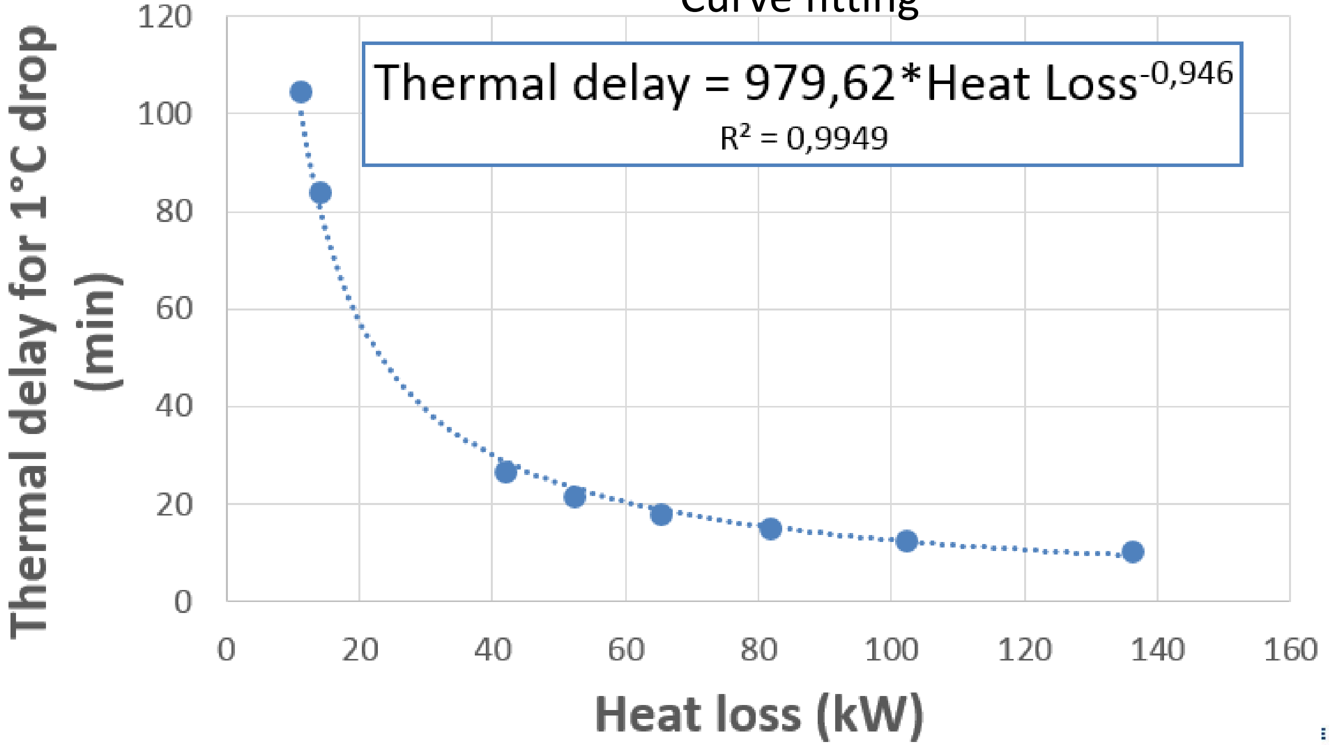
Results and preliminary conclusions

Theoretically

$$\text{Thermal delay} \propto \text{Time constant} \equiv \frac{\text{Thermal capacity}}{\text{Heat losses}}$$

Insulation level	**8 different levels**
Internal mass	External insulation + Furnishing
Heating system	Medium temperature radiators

Curve fitting



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Identification of a suitable building model for model-based operational optimization of a DHS scale

4DH

Heat Roadmap Europe

reINVEST

- Building modelling approaches
  - Direct detailed modelling
  - Reduced-order model identification using experimental data
    - Access to a wide range of data: Temperatures at several points, heat flux, occupants presence….
    - Access to only limited data: Heat consumption from sub-station's meters, set-point temperature, outdoor temperature.
    - In-situ measurements
    - Dynamic numerical simulation

Which elements of the dynamic simulation model have a higher impact on the thermal inertia of the building

What structure should the identified reduced-order model have

?

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