Energy sector coupling: electric-thermal interaction through heat pumps

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Use of active demand response as possible solution to improve grid reliability

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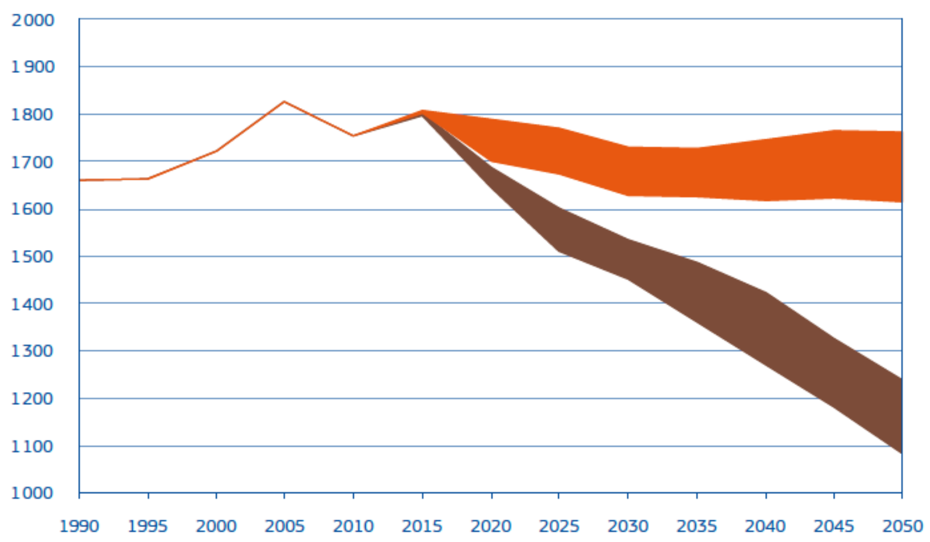
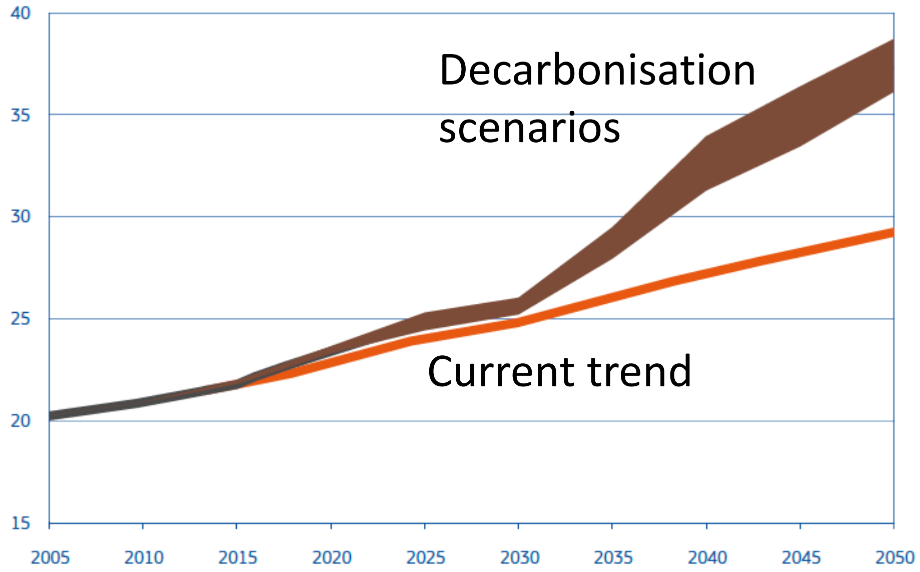
Future energy system 1/2

Decarbonised energy system: high share of intermittent, non-programmable, renewable energy sources

Reduction of energy demand



Electrification of end-uses



[1] 'Energy roadmap 2050' (COM(2011) 885 final of 15 December 2011

Future energy system 2/2

Action	**Problems**
USING FLEXIBLE GENERATION UNITS	High fuel consumption during peak periods has high environmental and economic costs
IMPROVING THE INFRASTRUCTURE	Update of transmission and distribution grids requires high investment costs
SHIFTING THE DEMAND	Requires change in user behaviour → comfort issues interconnection of data and control systems → privacy issues

Building Sector for Energy Saving

- The building sector (BS) requires about 40% of the total amount of energy consumption

The BS has a **wide energy saving potential** because most buildings are obsolete

Two ways can be followed to pursue the energy saving objective

Renovation or deep renovation of the building/plant system

Optimizing the management of the HVAC system

DR can be defined as a technology/algorithm/program which is used with the aim of CONTROL and/or SHIFT the energy use → **modify the shape of the energy load profile**

The definition is totally general but **in this context the energy use is related to the building.** The concept can be extended to a wide range of applications especially when the electricity is the energy vector (e.g. washing machines, etc).

Several studies in literature are focused on the **application of DR to HVAC systems, and to HEAT PUMPs in particular**.

The study and the understanding of the thermal behavior of the building are fundamental for **identifying appropriate management techniques.**

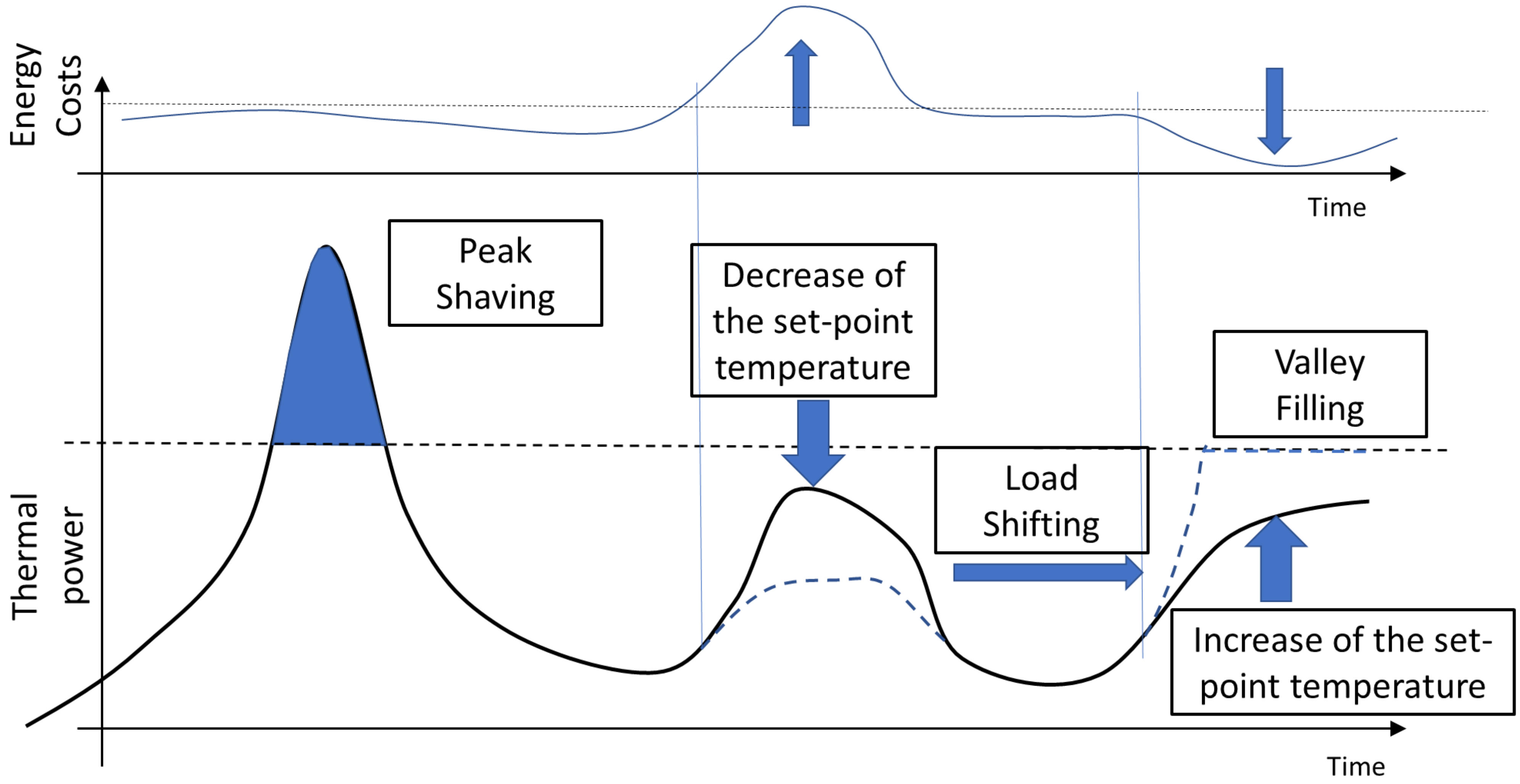
What is Demand Response?

In the literature there are several definitions of Energy Flexibility of buildings, among which:

"The Energy Flexibility of a building is the ***ability to manage its demand and generation*** *according to local climate conditions, user needs, and energy network requirements. Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding energy networks."*

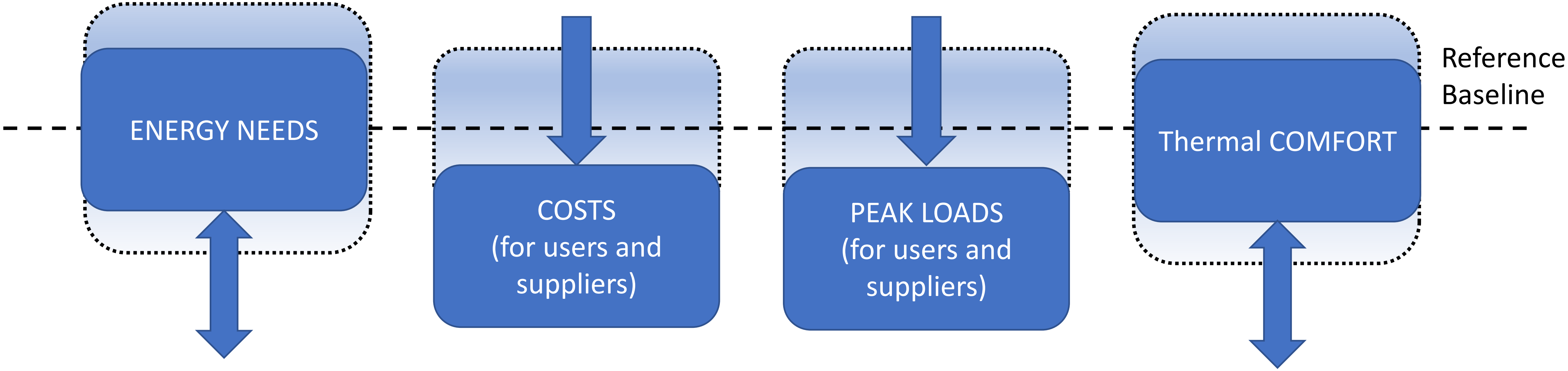
This definition place the building in a central role.

The Energy Flexibility of the building



The Energy Flexibility of the building

Energy Flexibility of the building and ADR usually give:



Connections between variables of the problem

Despite the literature suggests many definition for the energy flexibility, one of the main points or questions about this field is **which is the best way for the quantitative evaluation of this characteristic?**

All the definitions start from the assumption that **the flexibility has not to jeopardize the operation of the system from technical and comfort on the user side**.

The study of the EF of the building can be useful to understand **how much the building load can be modulated**

The main issue of the Energy Flexibility

The **energy flexibility of the building is affected by many variables** as already specified in literature and found in the present study:

- climate conditions
- user habits
- type of building (envelope)
- type of plant system (emission units, etc…)

…

Variables and boundary conditions of the EF

The chosen approach is a "**quantified methodology**" proposed by Heussen et al. [2] and Reynders et al. [3]

The **Demand Response** Technology/Approach uses a "**Virtual storage capacity**"

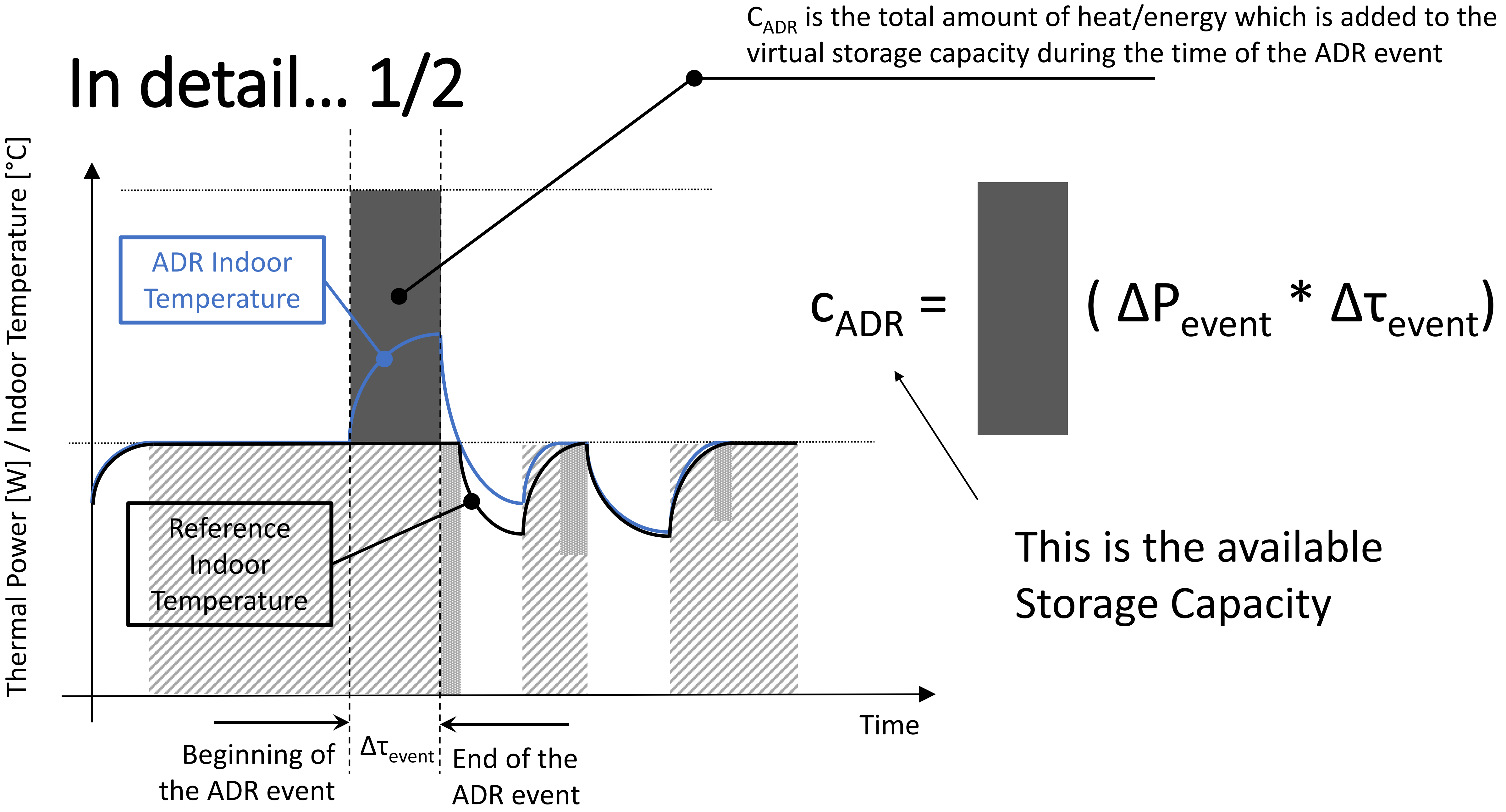
The energy flexibility can be defined by the use of three **quantitative indexes**

- **C_{ADR}** available storage capacity
- **η_{ADR}** efficiency of the virtual storage
- **PSC** power shift capability

Another important **definition** in this context is the "**ADR event**" and its properties

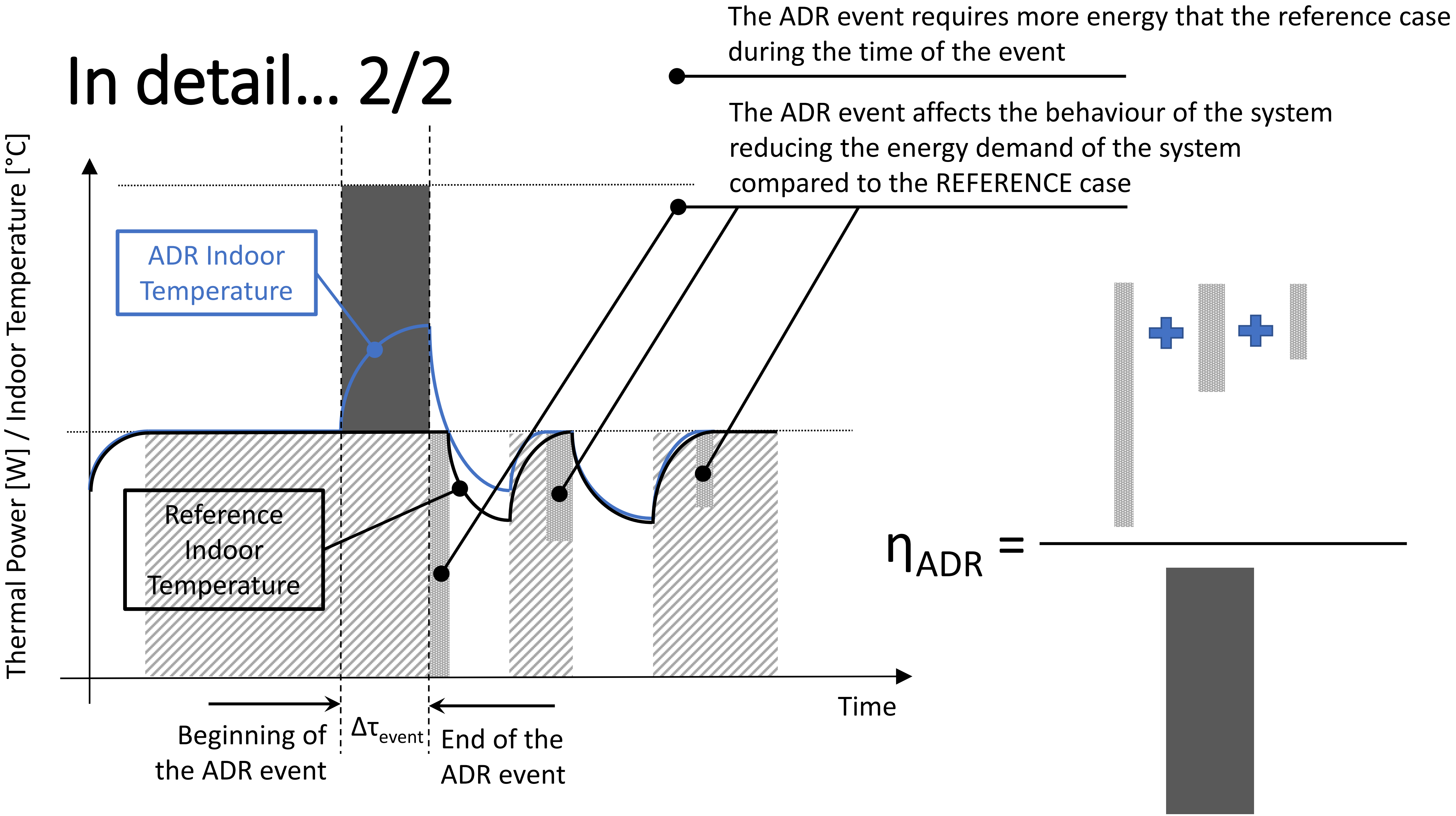
Approach used in the case study for the evaluation of the Energy Flexibility of the Building

In detail… 1/2



C_{ADR} is the total amount of heat/energy which is added to the virtual storage capacity during the time of the ADR event
Thermal Power [W] / Indoor Temperature [°C]
ADR Indoor Temperature
Reference Indoor Temperature
Time
Beginning of the ADR event
$\Delta\tau_{event}$
End of the ADR event
$c_{ADR} = $ (ΔP_{event} * $\Delta\tau_{event}$)
This is the available Storage Capacity

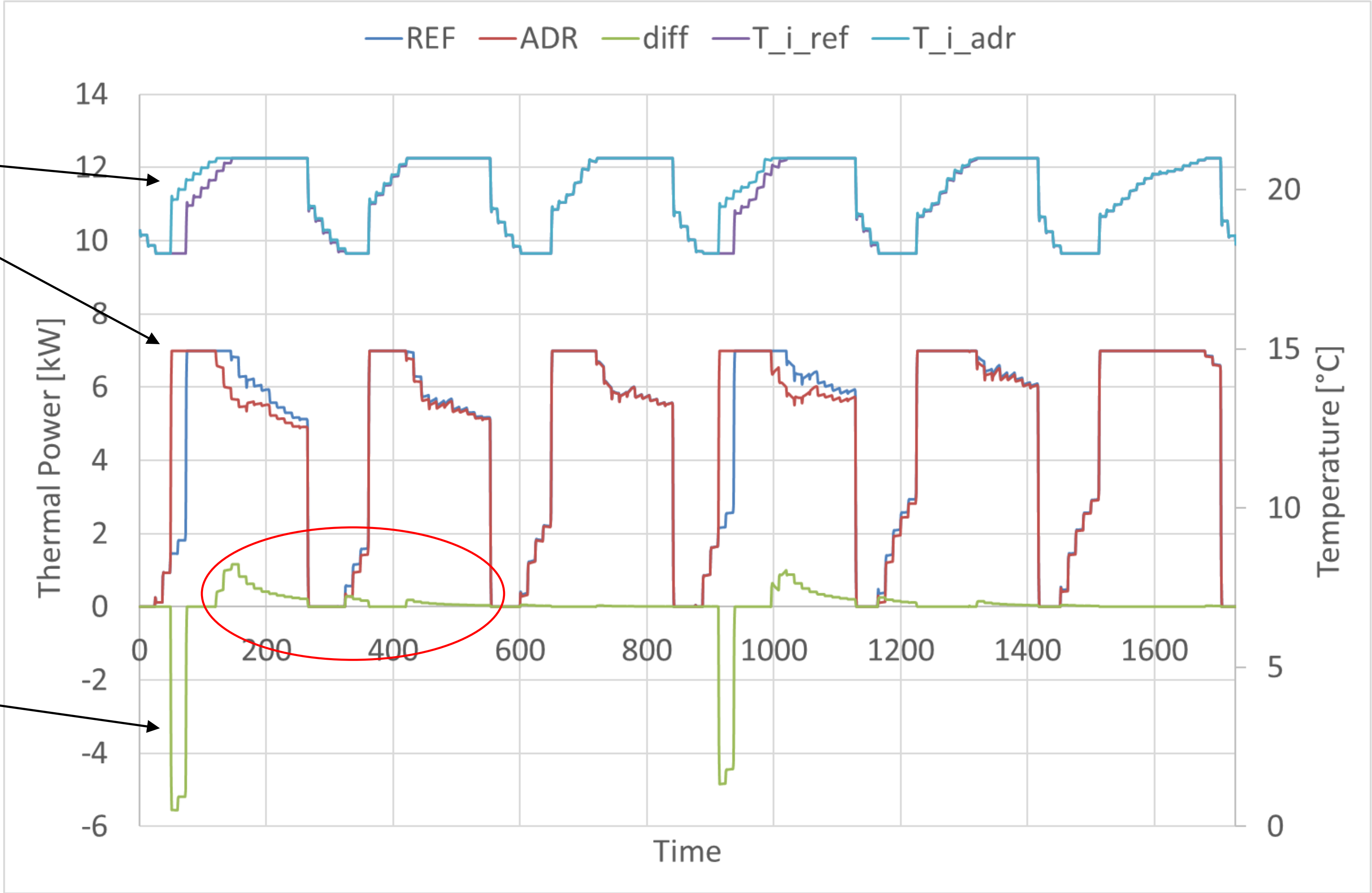
In detail... 2/2



The ADR event requires more energy that the reference case during the time of the event
The ADR event affects the behaviour of the system reducing the energy demand of the system compared to the REFERENCE case
Thermal Power [W] / Indoor Temperature [°C]
ADR Indoor Temperature
Reference Indoor Temperature
Time
Beginning of the ADR event
Δτevent
End of the ADR event
ηADR =

The Design Thermal Power is limited to 7 kW in the simulations

Difference between the reference case and the case with the ADR event (C_ADR)



Example of analysis

Objectives of the Case Study – Active Demand Response of Distributed Heat Pumps

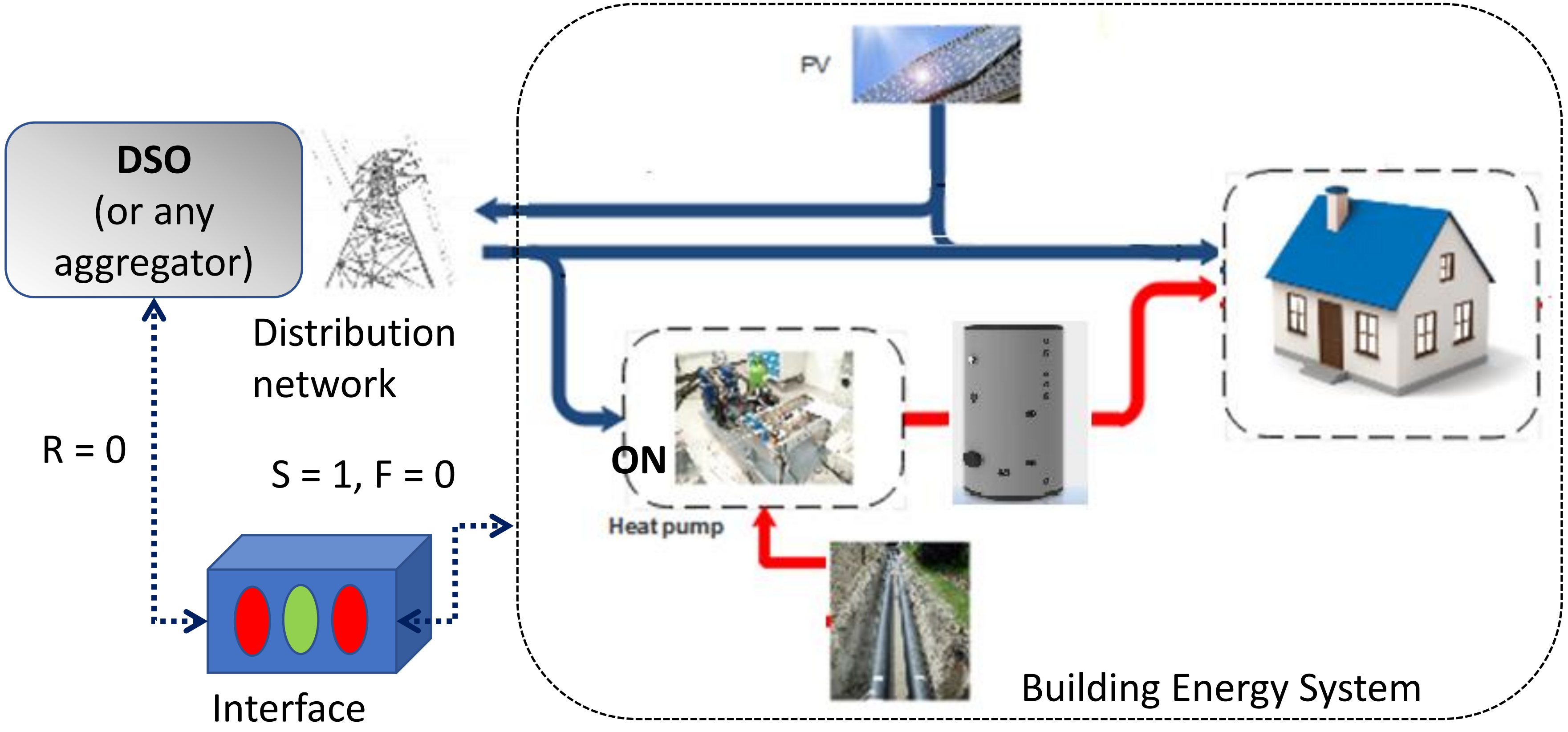
The work investigate the thermal behaviour of the building considering the energy point of view

A **two reference cases has been defined** (two baseline for the set-point temperature of the rooms inside of the building)

The $\mathbf{C_{ADR}}$ and $\boldsymbol{\eta_{ADR}}$ have been calculated and discussed

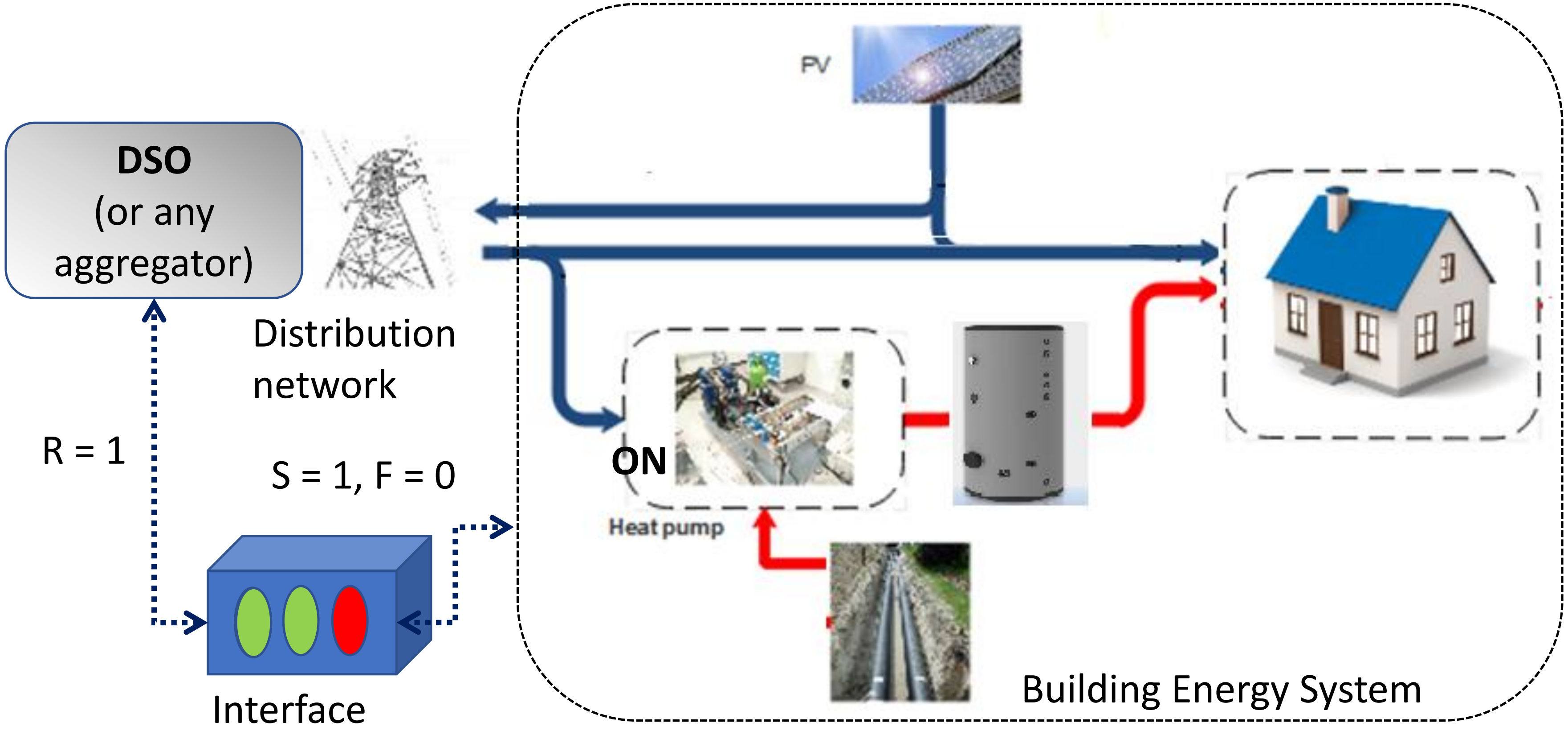
Some conclusions have been obtained from the simulations to **provide suggestions to be used in the control algorithms**

The final step (not addressed in this context) of the work is to carry out a program or a code for the management of smart thermostats coupled with a gateway collector managed by the energy supplier



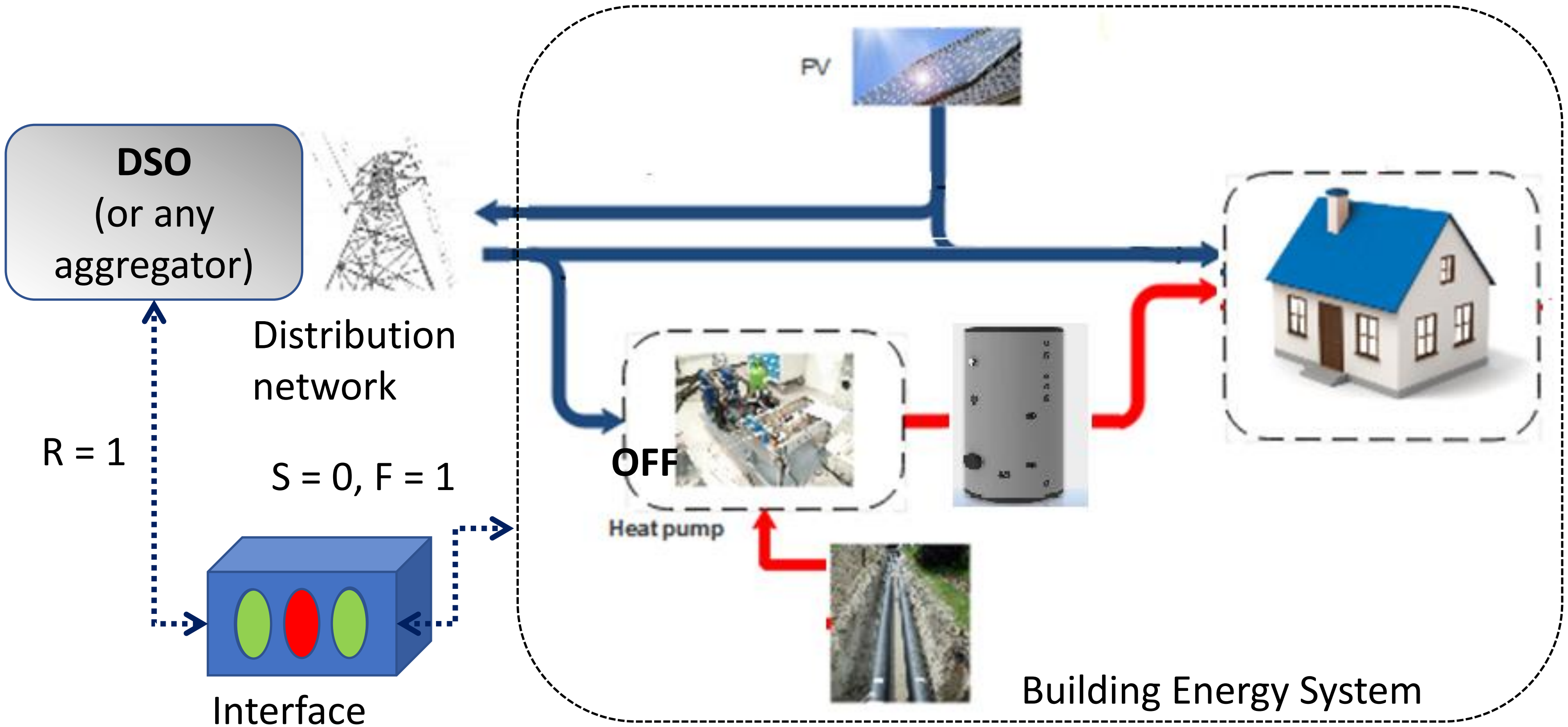
State signal S (1 if heat pump is on, 0 if off)
Flexibility signal F (1 if heat pump can be switched on/off upon request; 0 otherwise)
Request signal R (1 if aggregator requires switching event; 0 otherwise)

Concept of the system 1/3
"Active Demand Response of distributed heat pumps"



BES not flexible in this moment (due to e.g. high PV self-consumption or low state of charge of the water tank)

Concept of the system 2/3
"Active Demand Response of distributed heat pumps"



Switching event occurs: heat pump switched off by aggregator!

Concept of the system 3/3
“Active Demand Response of distributed heat pumps”

The Case Study in brief

The work has been carried out for a building of 12 units

Each flat has a useful area of about 100 m^2

The building envelope has three different levels of insulation

- **Old Building** (70's – without thermal insulation)
- **Existing Building** (90's – with about 4 cm of thermal insulation)
- **New building** (after the EPBD, about 10 cm of thermal insulation)

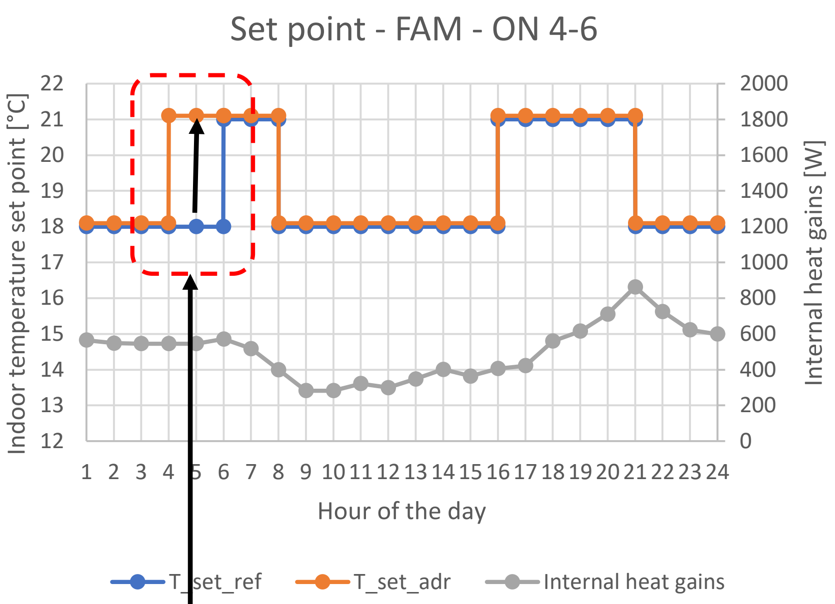
Two schedules for the user habits have been considered in the analysis (different set point temperature od the indoor temperature)

Only **Passive Thermal Storage** (building envelope) has been taken into account in the work

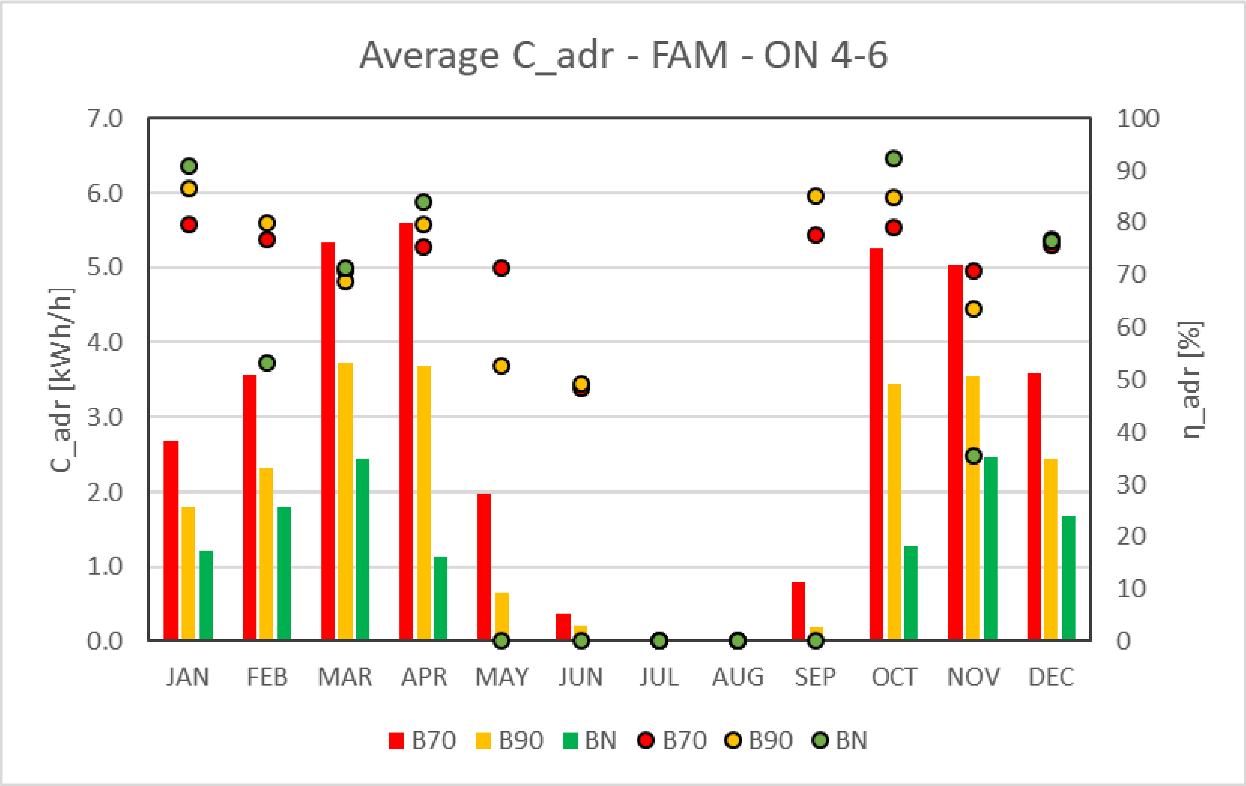
- Reference cases
  - OC → heating is sw. ON from 6 a.m. to 9 p.m. (continuous operation)
  - FAM → heating is sw. ON, 6 – 8 a.m. and 4 – 9 p.m.
    → cooling is sw. ON h24

- ADR events
  - Heating is forced
    1. ON → 4 – 6 a.m. (18°C → 21°C)
    2. OFF → 8 – 10 a.m. (21°C → 18°C)
  - Cooling is forced
    1. ON → 26°C (50%) → 24°C (60%)
    2. OFF → 26°C (50%) → 27°C (45%)

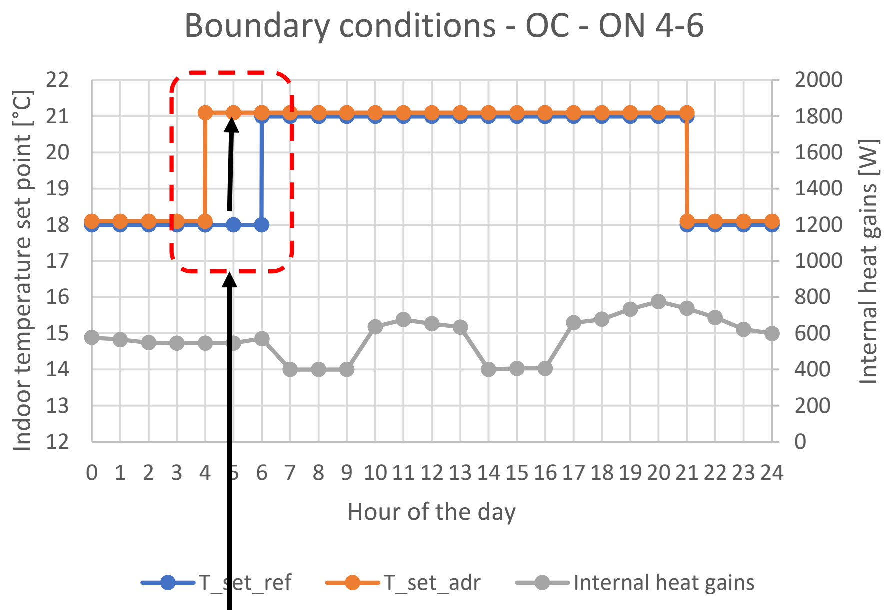
Boundary conditions used in the simulations



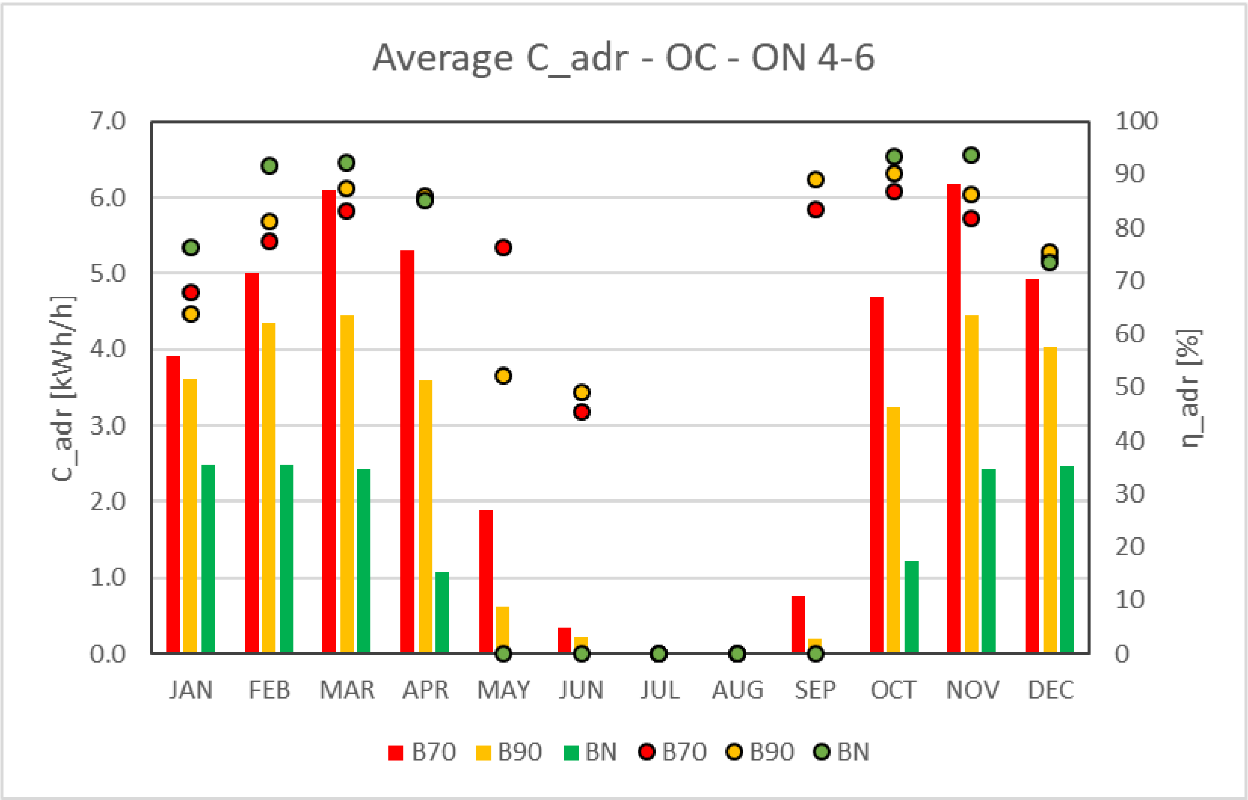
ADR event:
The set-point temperature is increased from night set-back of 18°C to 20°C



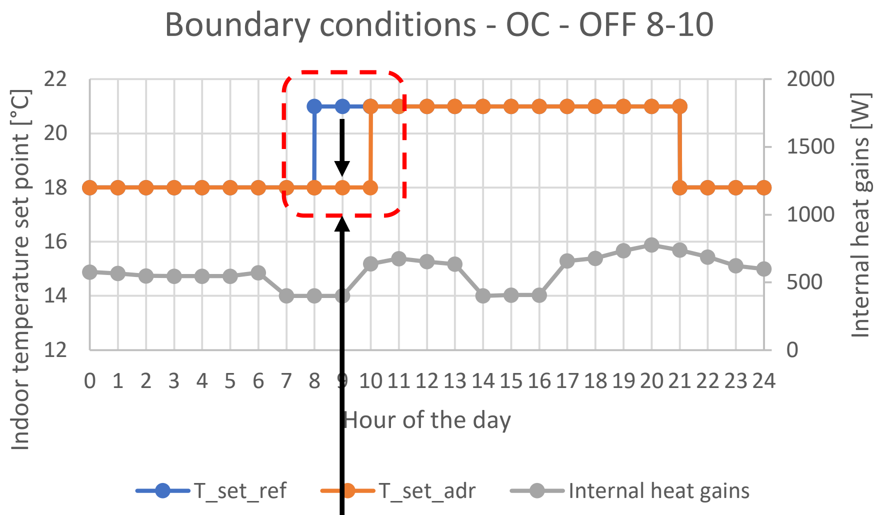
Upward flexibility in the heating season – CASE **UH1**



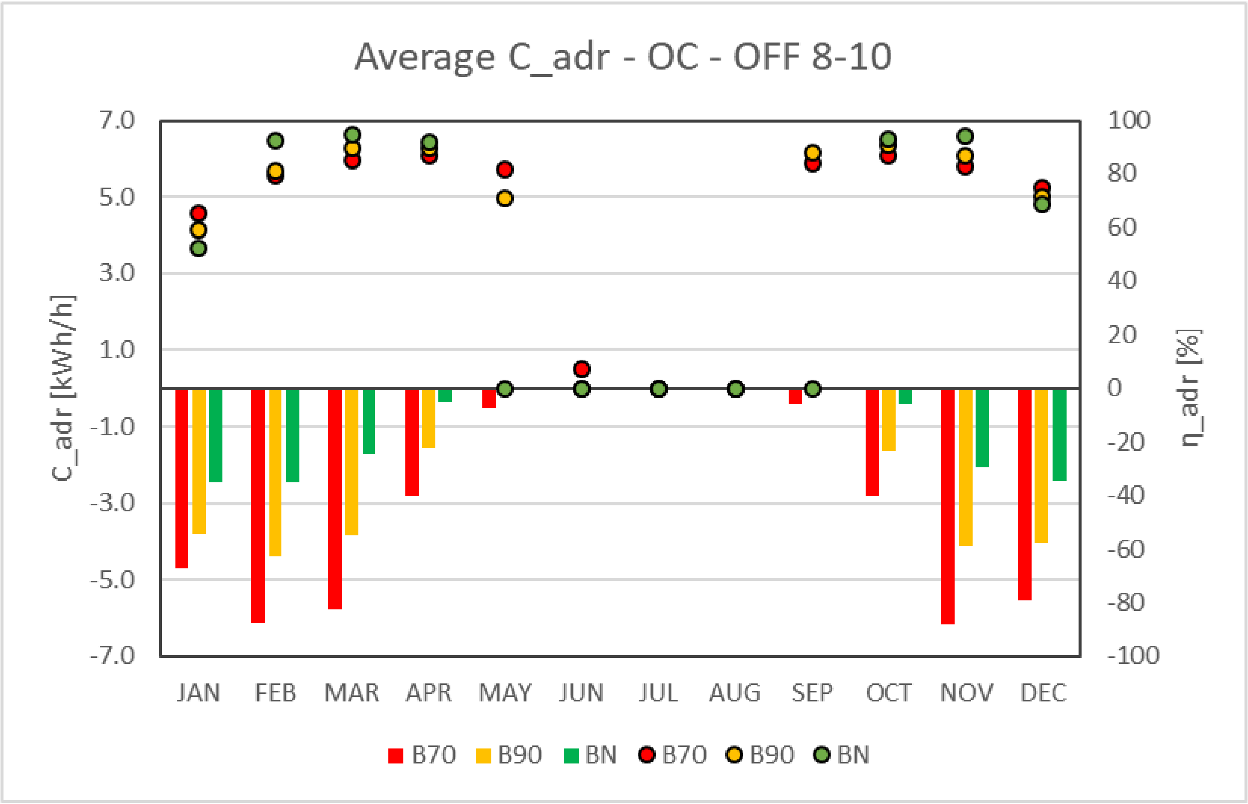
ADR event:
The set-point temperature is increased from night set-back of 18°C to 20°C



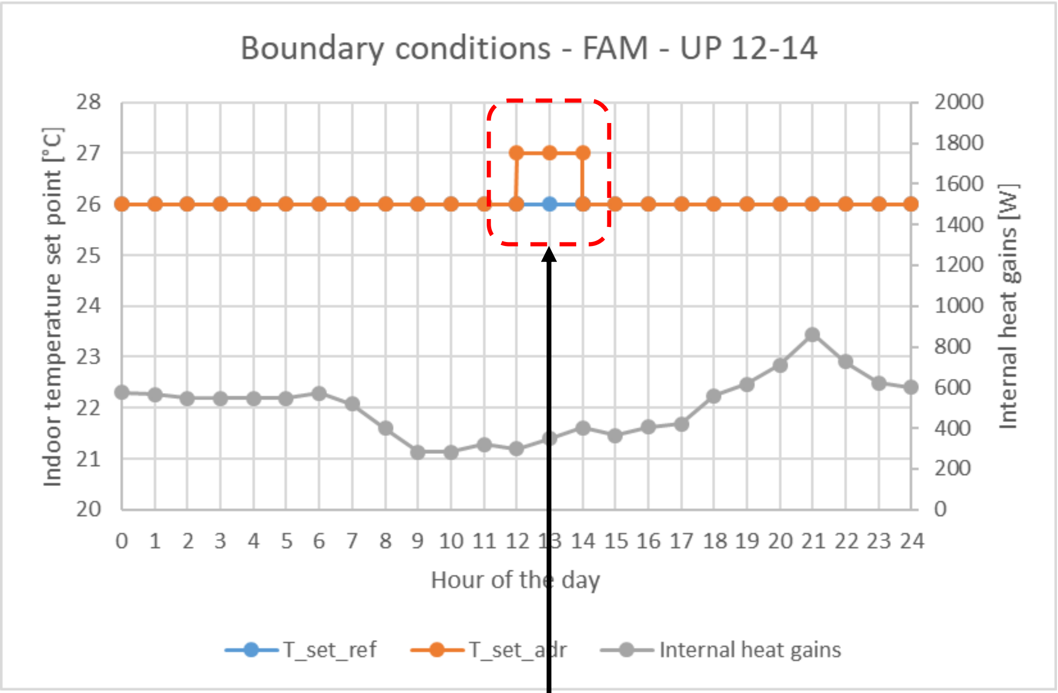
Upward flexibility in the heating season – CASE **UH2**



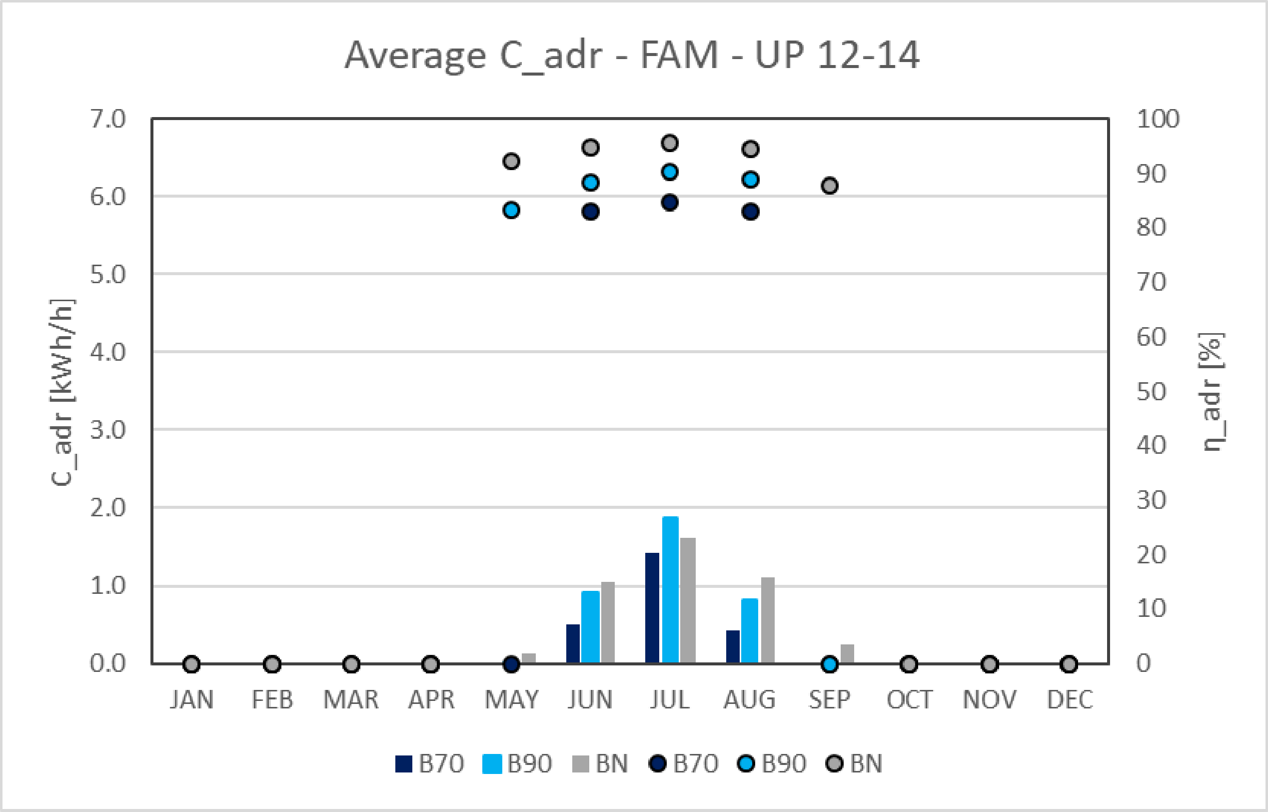
ADR event:
The set-point temperature is decreased from 20°C to 18°C in the first two hours of the morning



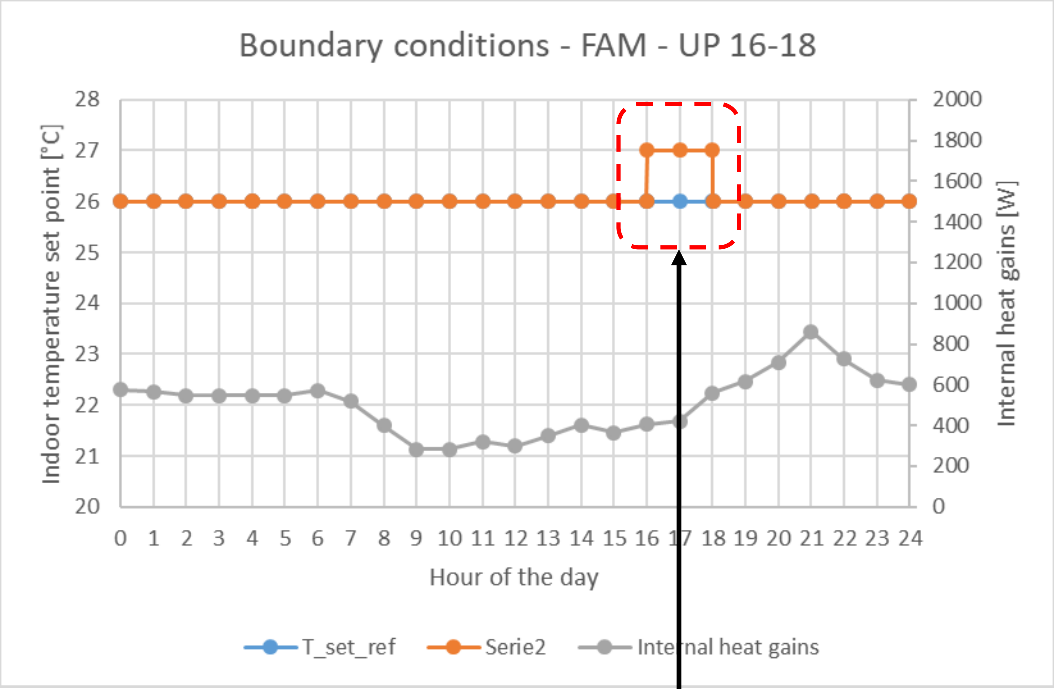
Downward flexibility in the heating season – CASE **DH1**



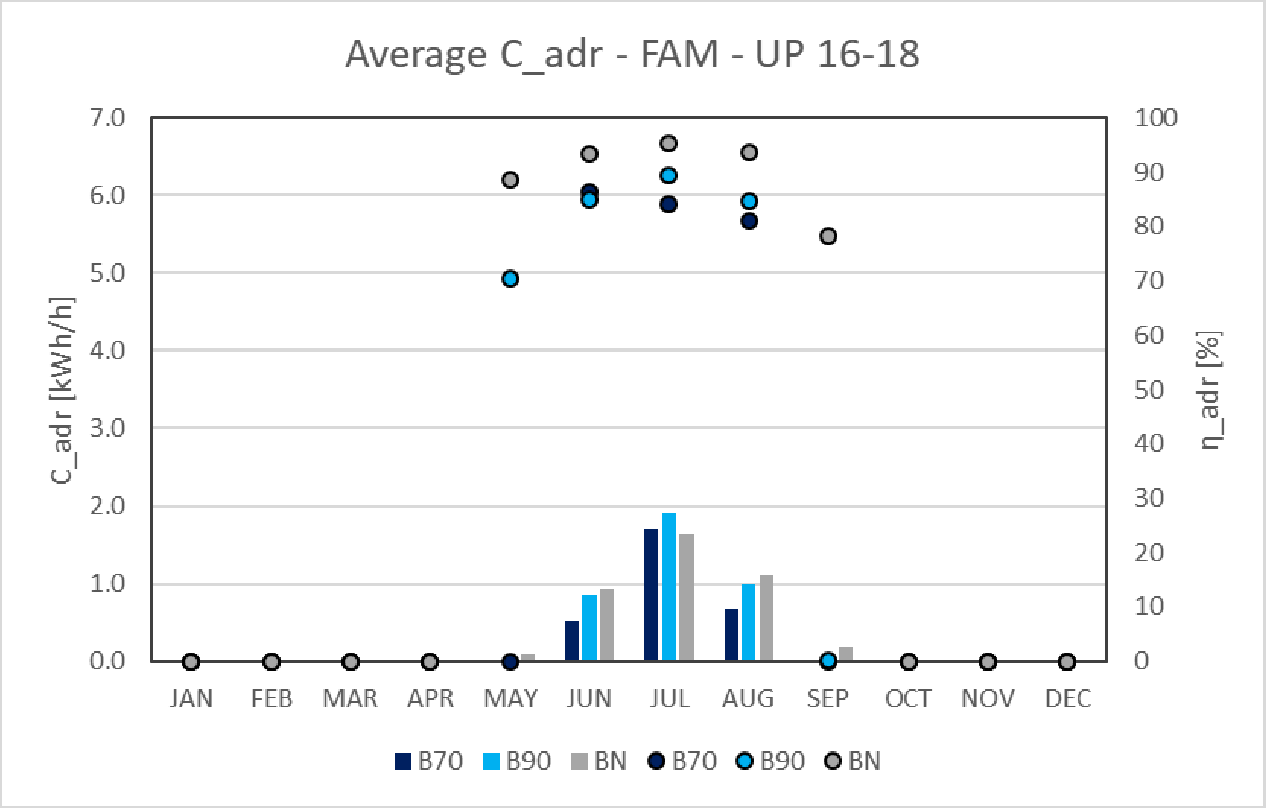
ADR event:
The set-point temperature is increased from 26°C (50%) to 27°C (45%) from 12 a.m. to 2 p.m. (sw. OFF is forced)



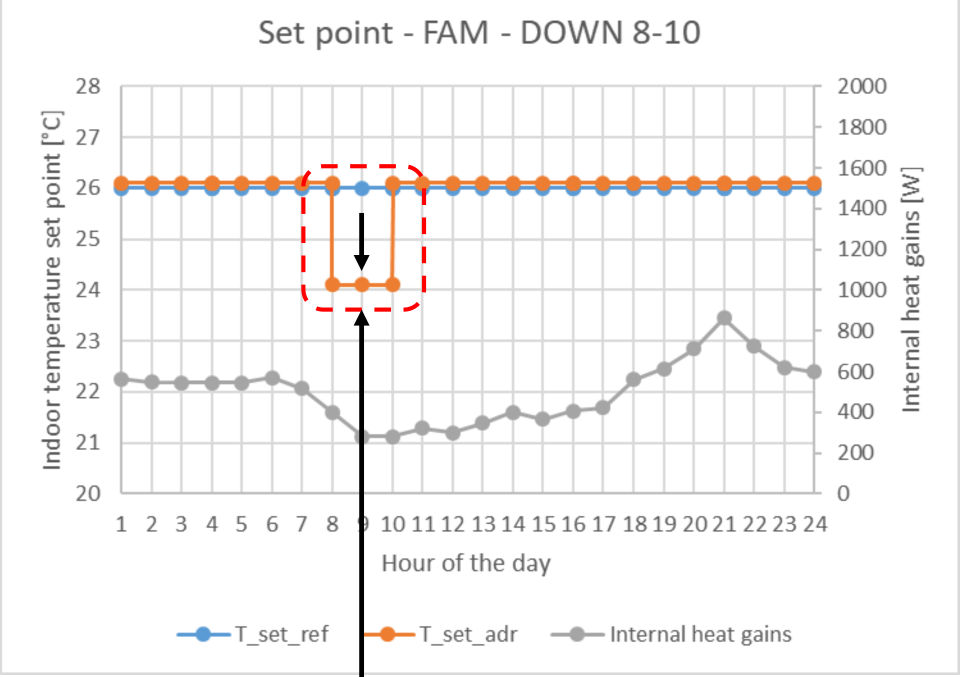
Upward flexibility in the cooling season – CASE **UC1**

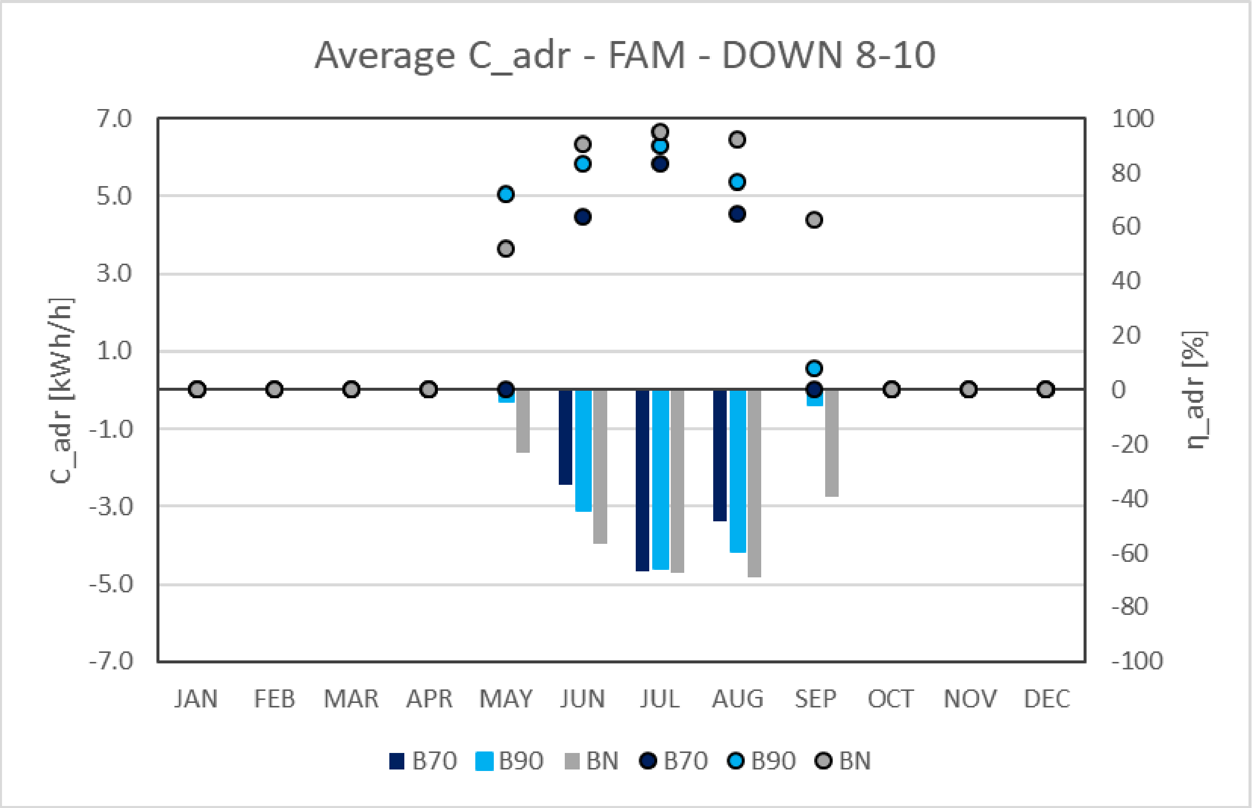


ADR event:
The set-point temperature is increased from 26°C (50%) to 27°C (45%) from 4 p.m. to 6 p.m. (sw. OFF is forced)



Upward flexibility in the cooling season – CASE **UC2**

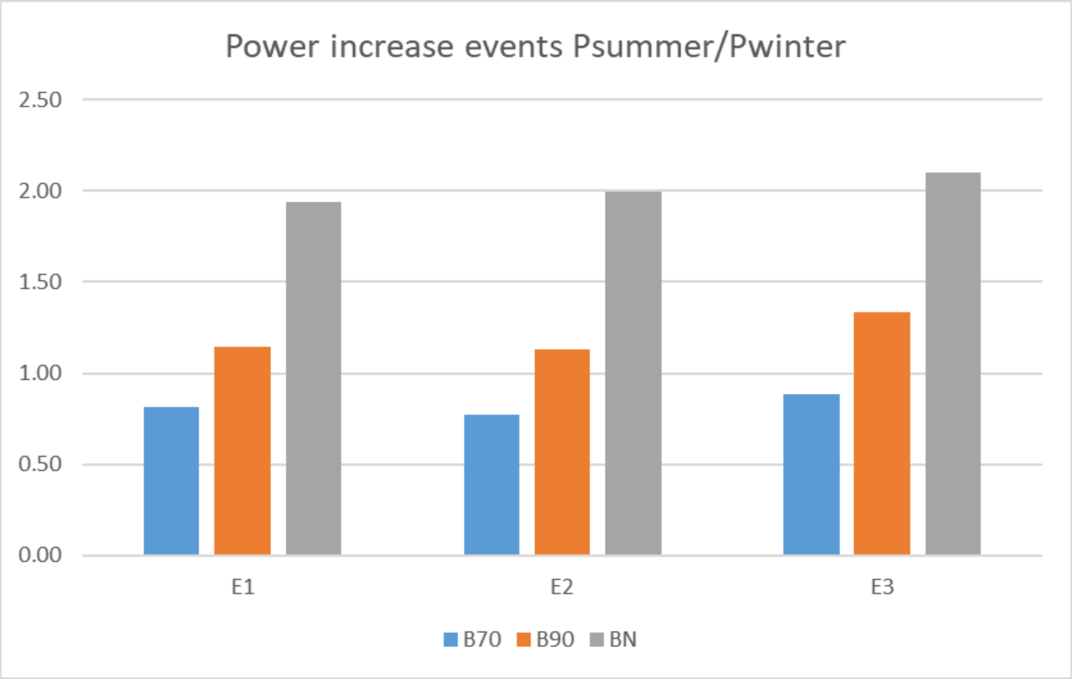


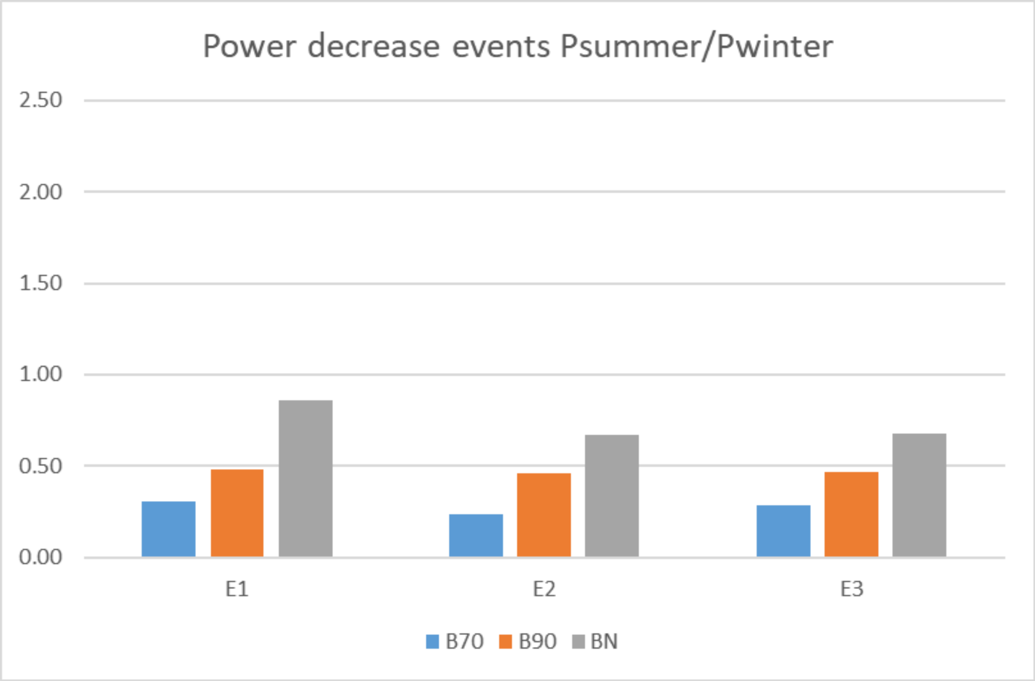


ADR event:
The set-point temperature is decreased from 26°C (50%) to 24°C (60%) from 8 a.m. to 10 a.m. (sw. ON is forced)

Downward flexibility in the cooling season – CASE **DC1**

The values in the graphs represent the ratio between the increase/decrease of the thermal power demand during the period of the events





Effect of the Building on Thermal Power demand over Different Events

The smart control system has to activate the distributed heat pumps with the aim of:

- **Cost saving**
- **Reducing the overload of the grid during the peak hours**
- **Shifting the thermal load**

The simulation is useful to **address the suppliers** to select the best moment of the day where **use the "events" as function of the user behaviour** (time, duration, increase or decrease of the set-point temperature)

The **EF indicators** used in this work showed that: EF depends on **user habits** (schedule), **climate** conditions, **time** and **type (up/down) of event**, **quality** of the **envelope** and **design thermal power.**

The costs has not taken into account in this part of the study, the main objective was the thermal behaviour of the envelope (analysis carried out for different quality of the envelope)

Conclusions

… thank you for your attention

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