An empirical methodology for rating building thermal mass as energy storage system

Chrysa Politi

Email: chrysapol@metal.ntua.gr

A. Peppas, K. Kollias, M. Taxiarchou, D. Mantelis, L. Karalis

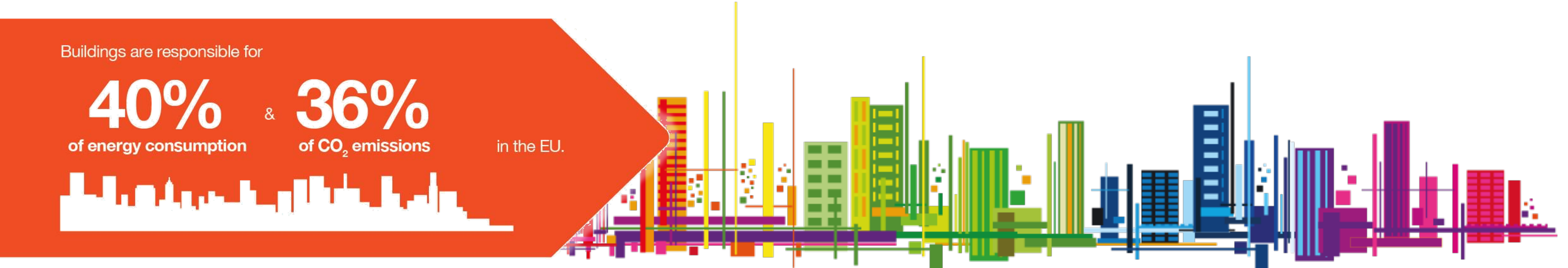
Laboratory of Metallurgy
School of Mining and Metallurgical Engineering,
National Technical University of Athens, Greece

Introduction (1)

- **55% of world's population in 2018** resided in **urban areas** and it is projected to reach **68% by 2050**.

- According to Revised Renewable Energy Directive (2018/2001/EU) **Renewable energy target** for the EU for 2030 is set to reach **at least 32%.**

- **Storage of renewable energy** in various stable forms has become a **high priority** in the research agenda.



Introduction (2)

- **Thermal mass** maintains **thermal comfort**, stabilizes **heating/cooling loads** and mitigates **peak power demand**.

- **Integration of prediction algorithms** increases **computational costs** and the **complexity** of the systems.

Necessity of an **empirical methodology** to **define** a **real building case** by utilizing **minimum input** parameters and **no uncertain factors**.

The Concept (1)

Residential space heating while respecting thermal comfort, offers the **highest potential** for **Demand-Side Flexibility (DSF)**.

DSF by turning up its Heating, Ventilation, and Air Conditioning (**HVAC**) system at night and turn down in the morning, or vice versa.

Optimal performance of space heating leads to :

- ✓ increased system reliability

- ✓ reduced operating costs

- ✓ low system emissions

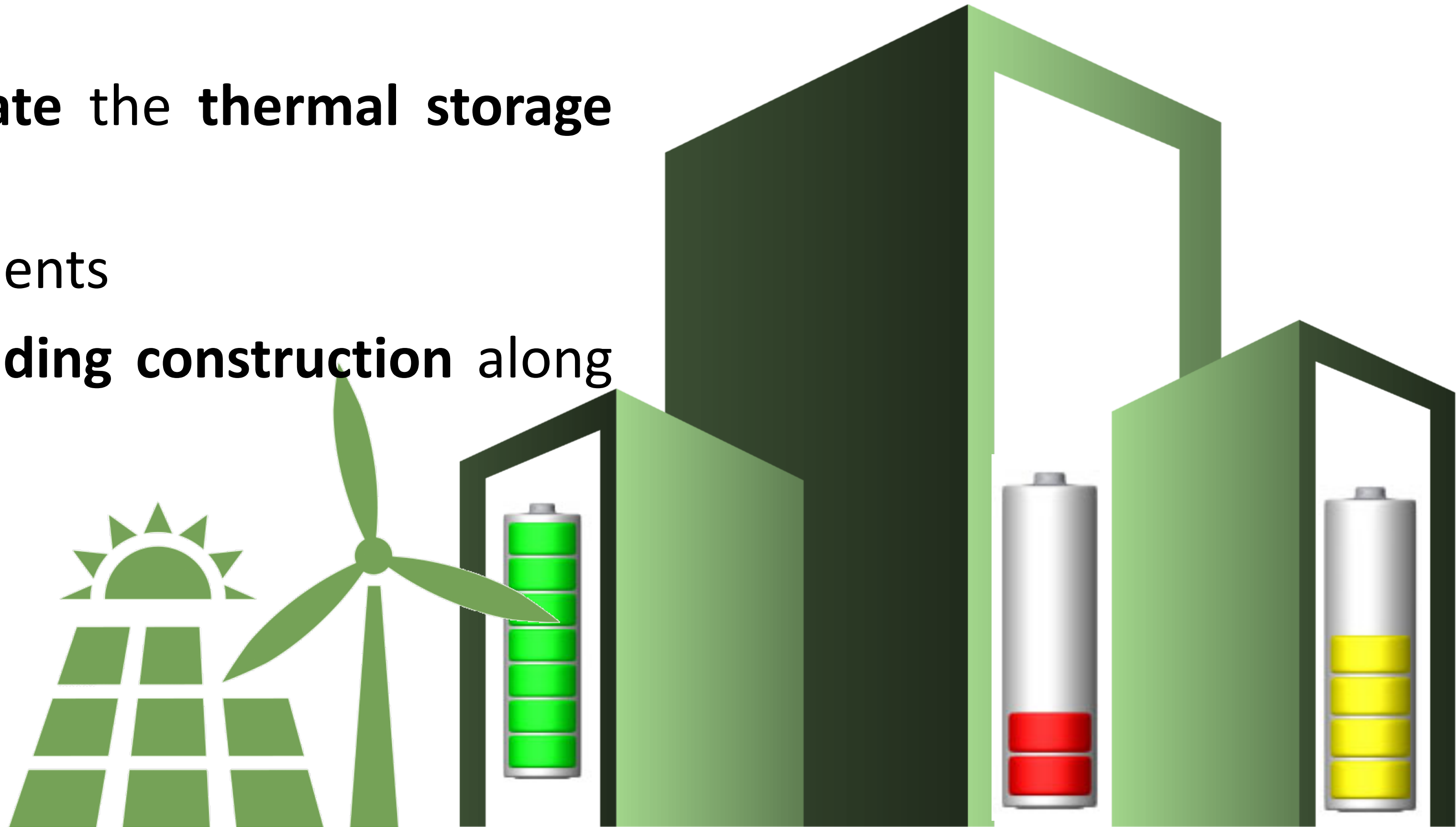
Moreover, it **activates the thermal mass** of the building.

The Concept (2)

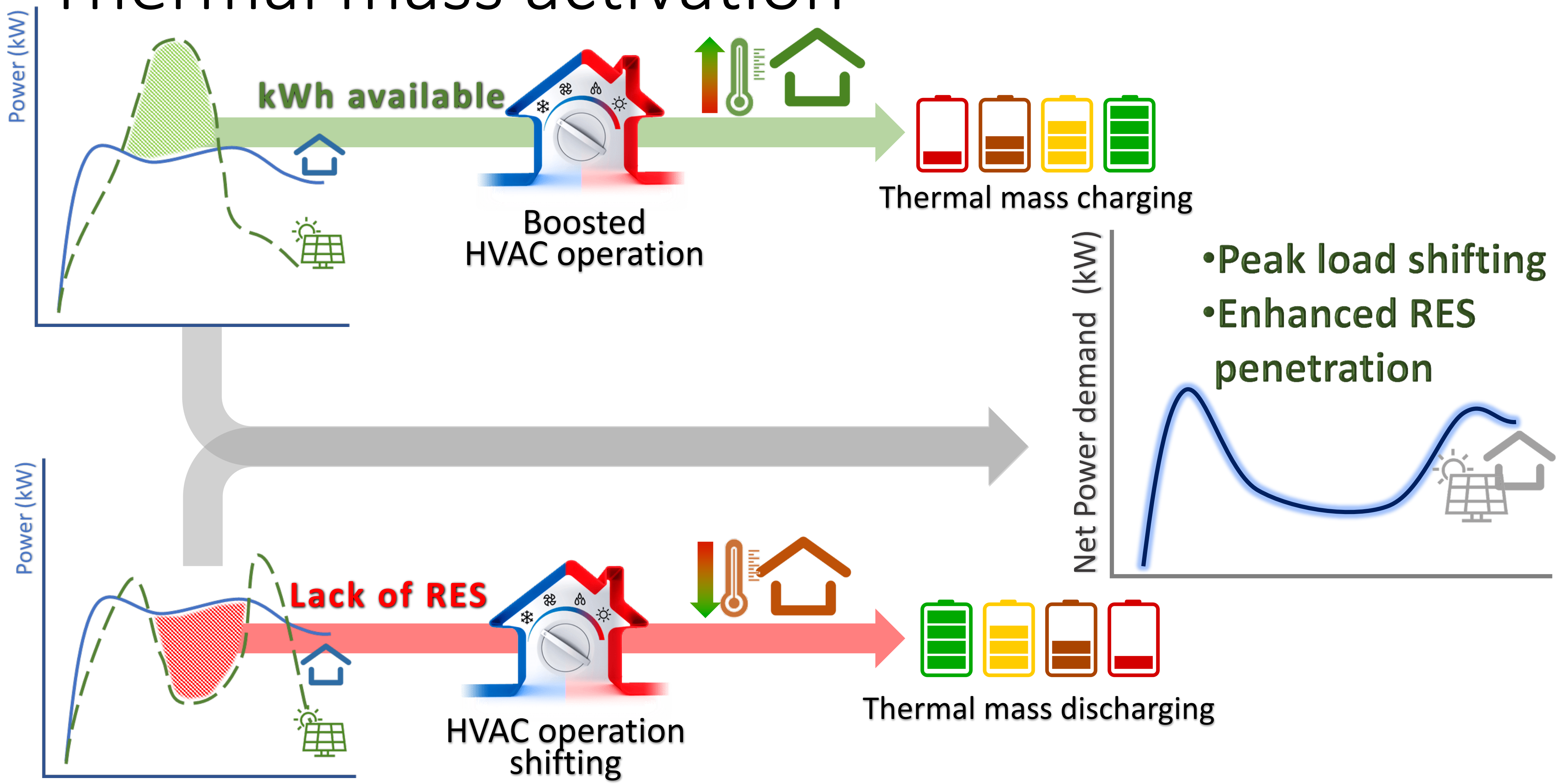
Building’s thermal mass is a solution to **store thermal energy**, **stabilize heating and cooling loads** and **mitigate peak power demand**.

Efficient and **flexible** way to **rate** the **thermal storage capability** by using:

- room temperature measurements
- basic information of the **building construction** along with its **HVAC equipment**

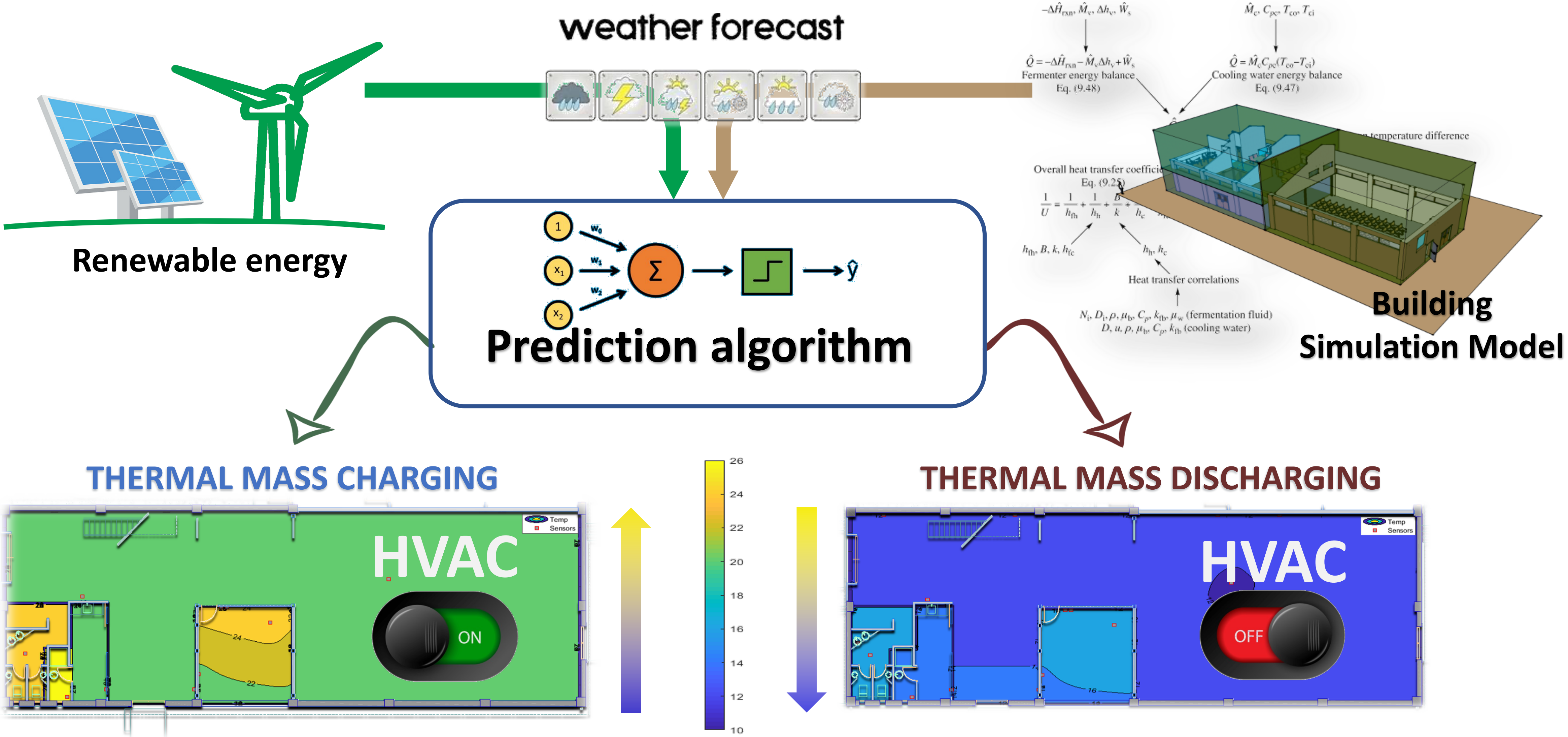


Thermal mass activation



EU Research Project: The concept

SABINA:
SmArt BI-directional
multi eNergy gAteway



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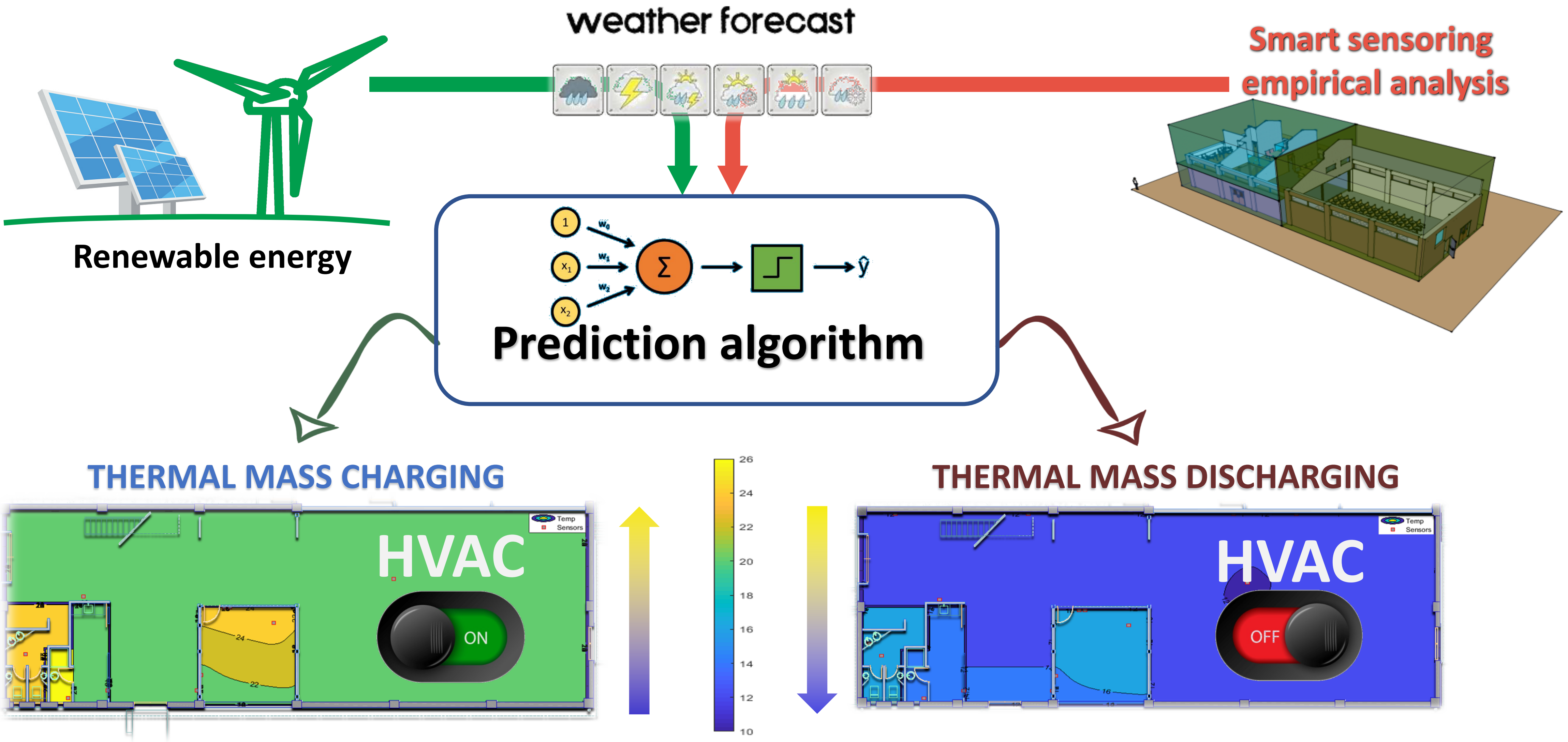
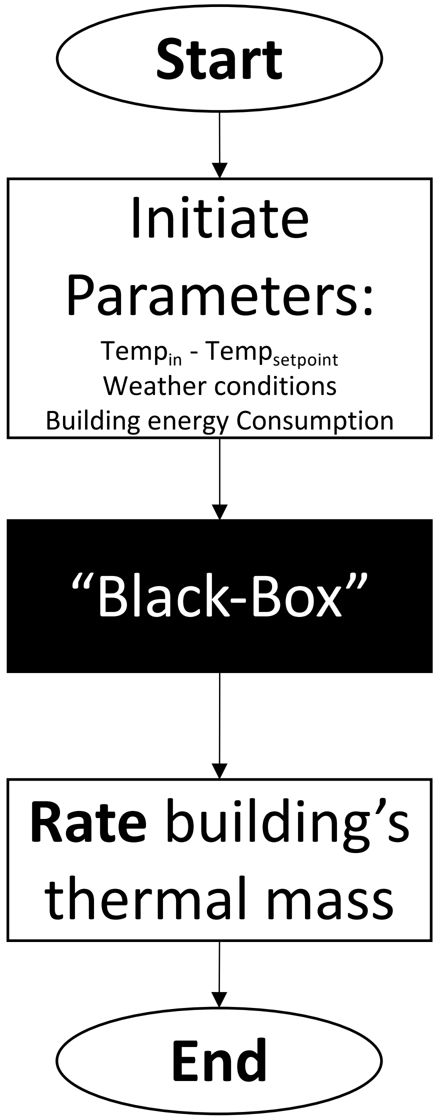
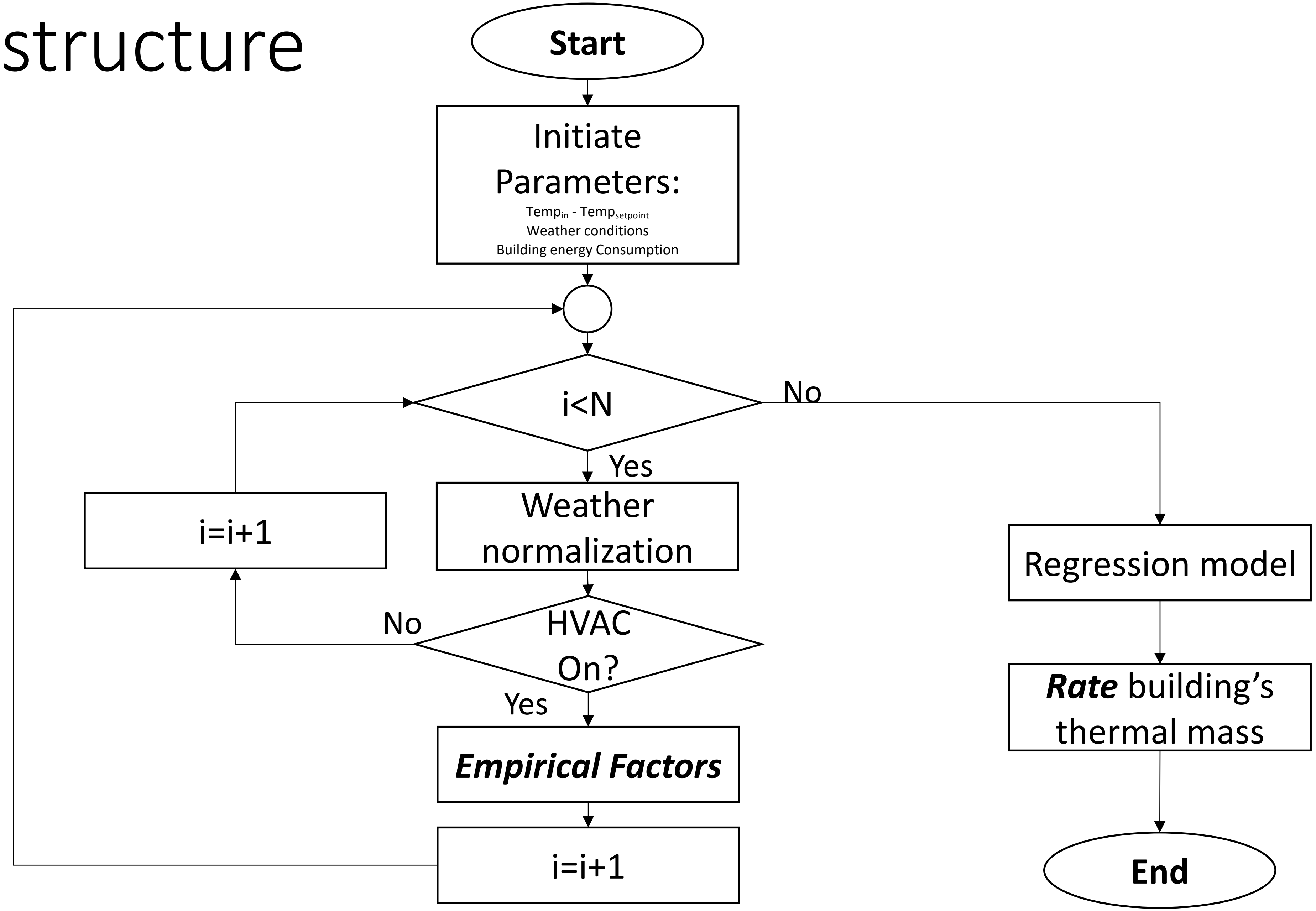


Model structure



Model structure



N: measurements

Variable-Base Degree Days (VBDD)

The **weather** has a **significant impact** on **thermal performance** of buildings, as well as on **renewables**.

Degree-day methodology is a **simple** and **proper** method for **energy analysis** of buildings.

VBDD method contributes to the exclusion of the **location** and the **climate conditions**.

Heating Degree Days (HDD) [°C/h]

$$HDD_h(t_{bal}) = \frac{\sum_{hours}(T_{bal} - T_o)}{24h}$$

Balance-Point Temperature [°C]

$$T_{bal} = Setpoint - \frac{\dot{Q}_{occ} + \dot{Q}_{lit} + \dot{Q}_{equ} + \dot{Q}_{sol}}{K_{tot}}$$

ASHRAE 2009 Handbook - Fundamentals

Empirical factors for thermal mass rating

The set of empirical factors aims to **rank the capability of building’s thermal mass to store thermal energy** in relation with its **installed HVAC equipment**.

Cooling-Heating Rate [$^oC/h$]

$$CHR = \frac{T_{setpoint} - T_{i_{start}}}{\left| t_{setpoint} - t_{start} \right|}$$

Calculates the duration for increasing the inner temperature of the building 1^{o}C.

Assesses the electrical energy consumption required for reaching the selected setpoints.

$$ERR = \frac{\int_{start}^{setpoint} C_{HVAC}(t)dt}{A_{gnd}}$$

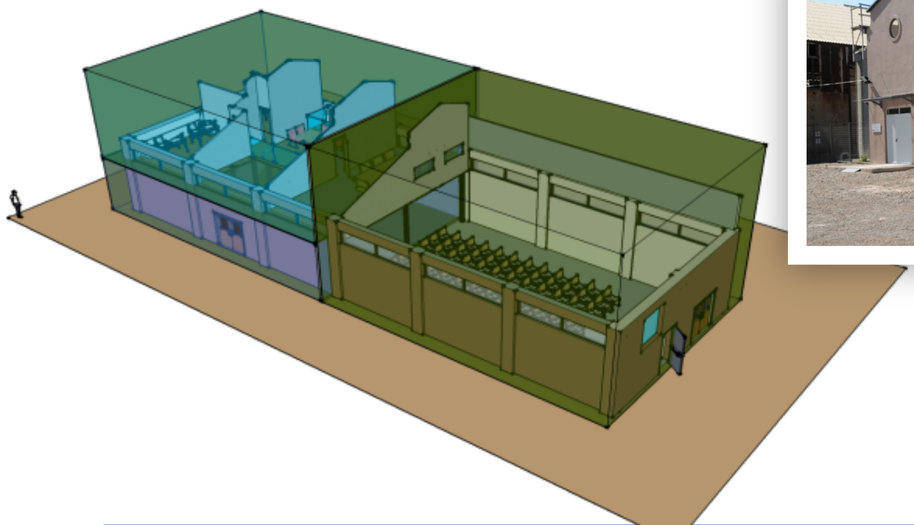
Equipment Response Rate [kWh/m^2]

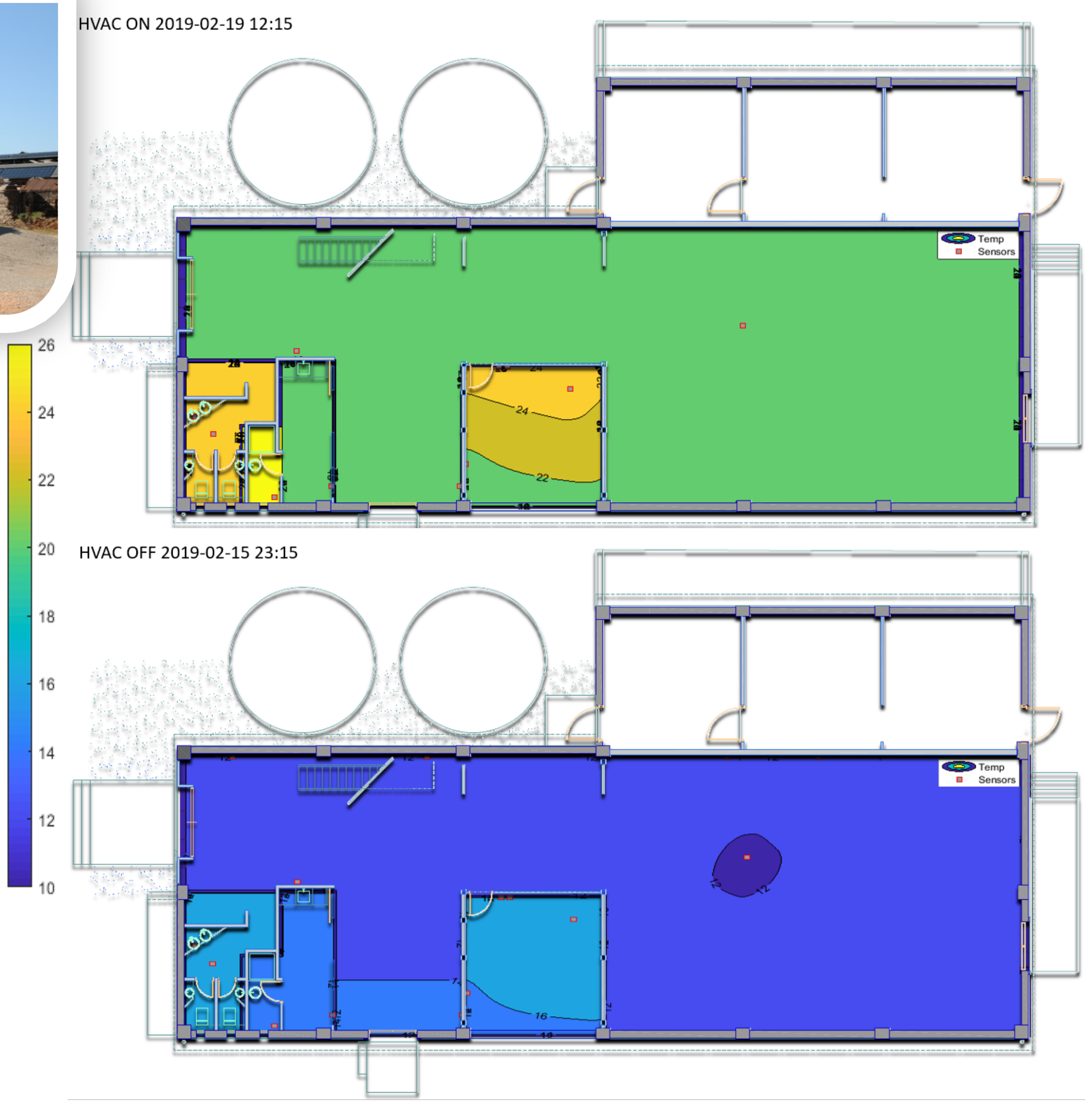
Building Ranking Coefficient [$^oC{\cdot}kWh/h{\cdot}m^2$]

$$BRC = \frac{CHR}{ERR}$$

Correlates the building thermal capabilities with the installed heating infrastructure.

The demo site (1) : Building





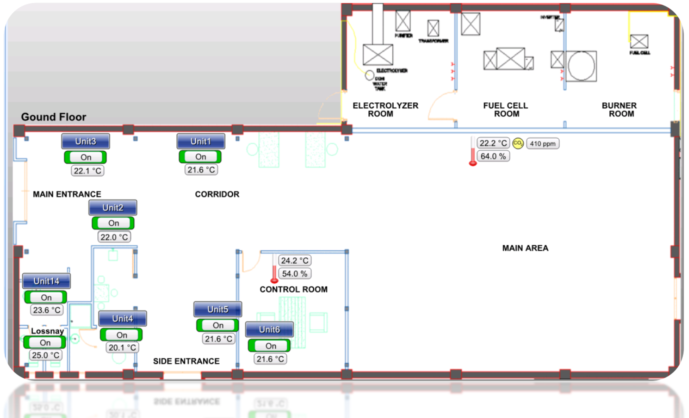
Building main characteristics	
Building envelope materials	Concrete with double brick walls and metallic roof insulated with 25.4mm polyurethane
Energy consumption	133 kWh/m^2
HVAC systems	Heat Pump-Air Handling Unit 01(32kW load) Ventilation Refrigerant Flow Units(25kW load)

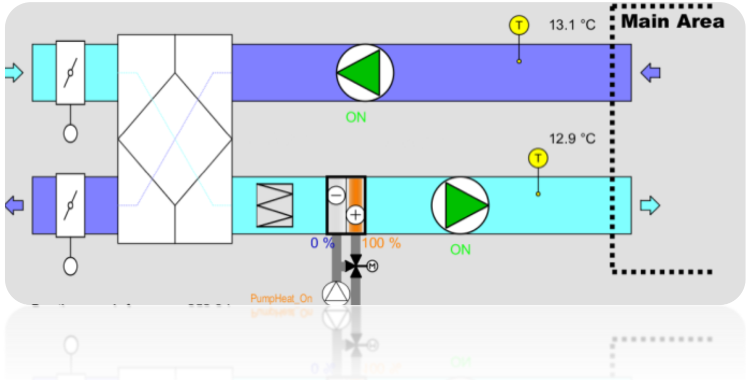
The demo site (2) : Heating /Cooling Systems

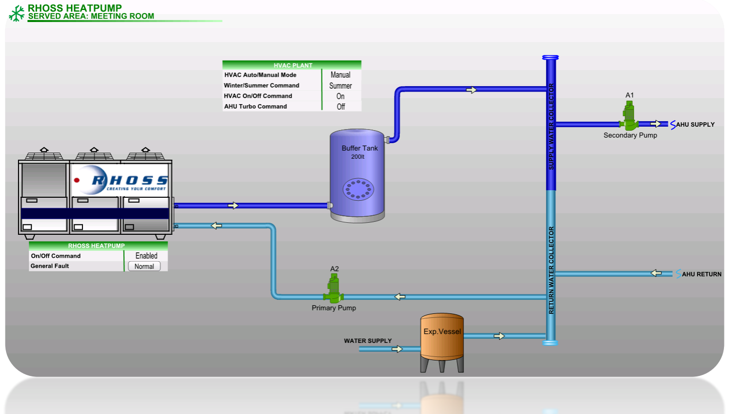
The building uses **two** separate HVAC systems:

- 2 Exterior Variable Refrigerant Flow **(VRF)** units and 14 floor mounted fan-coil units **(FCU)** → 25 kW maximum electrical load

- Air Handling Unit **(AHU)** and a closed-loop air/water Heat Pump **(HP)**. → 32 kW maximum electrical load







The demo site (4): Renewable Energy Plants

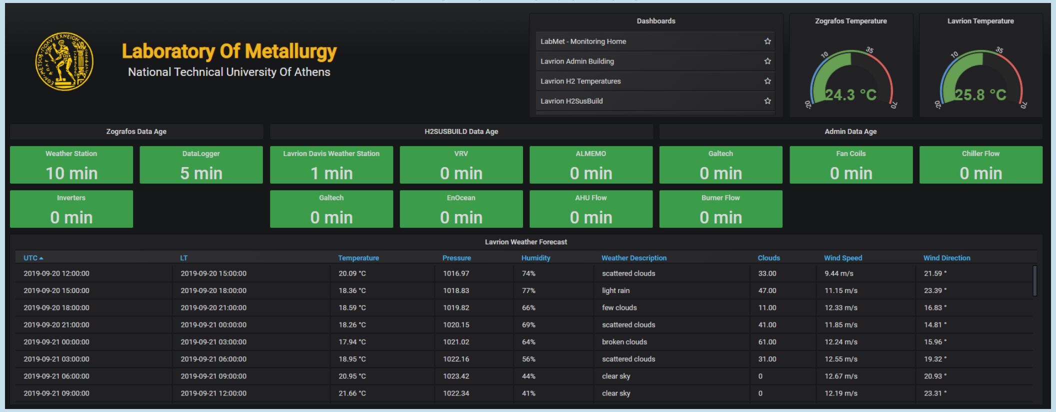
624 photovoltaic (PV) thin-film CIGS panels (total panel area 475 m^2, total installed power 46.8 kW)

6 wind turbines (downwind technology, blade diameter 5.5 m, total installed power 36 kW)

54 photovoltaic (PV) monocrystalline cell technology (total panel area 250 m^2, total installed power 15.1kW)

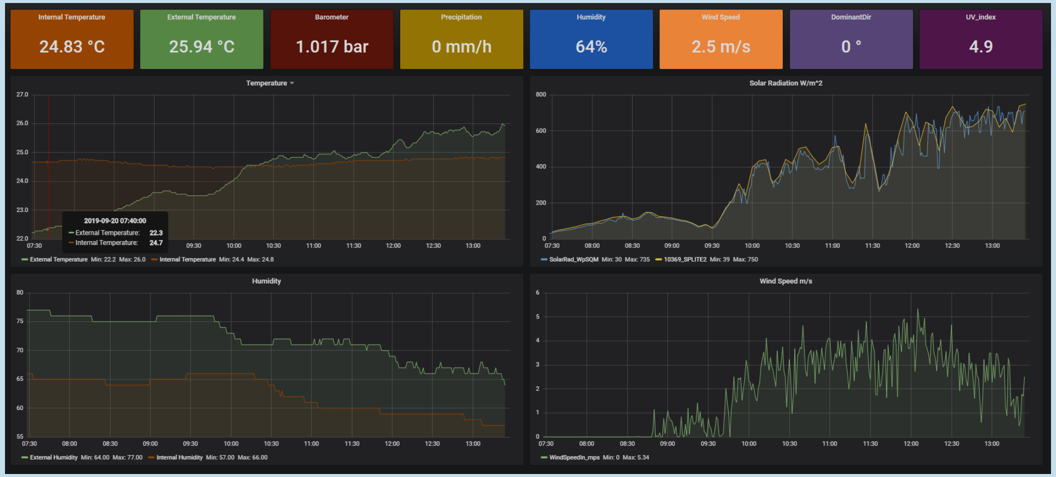
The demo site (3) : Monitoring system

Overall Status

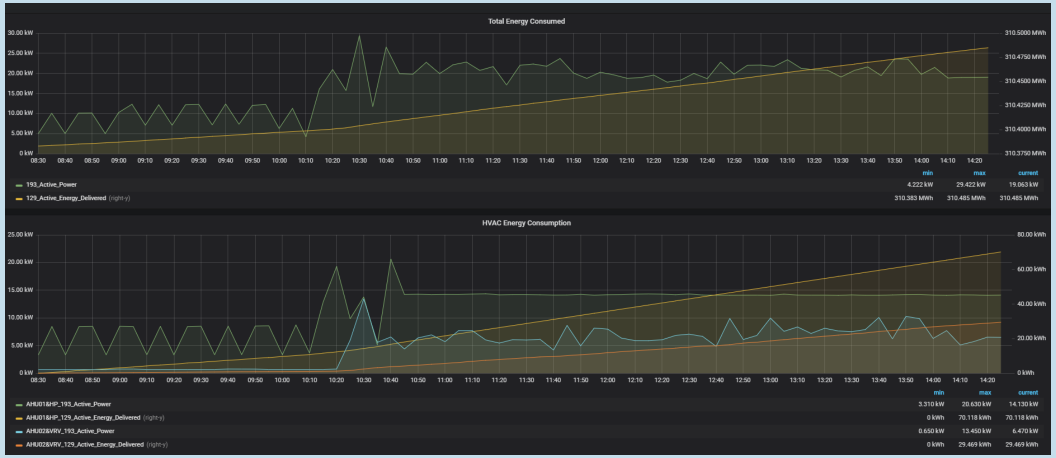


LTCP District

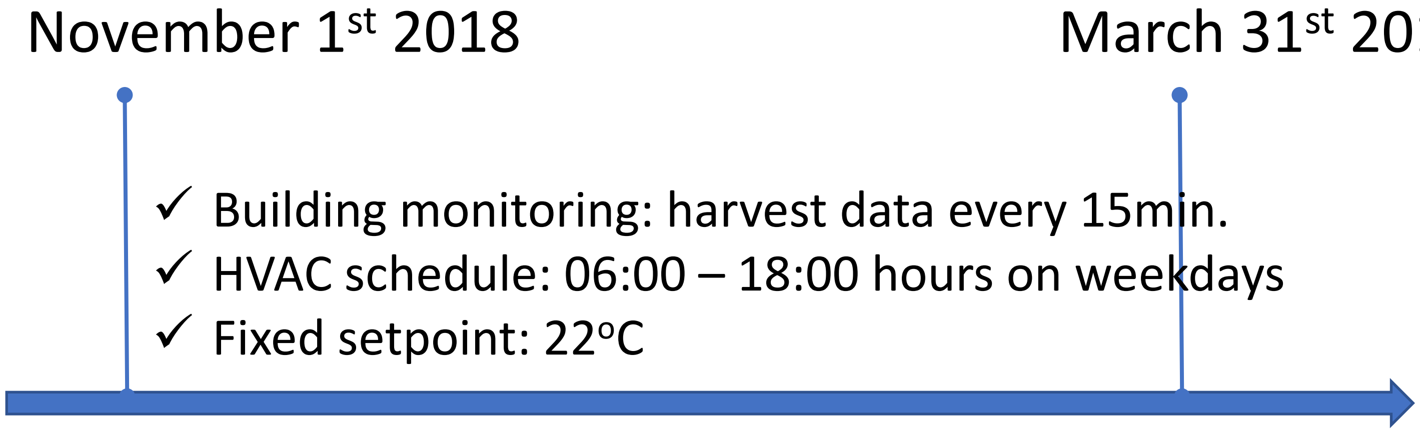
Weather data



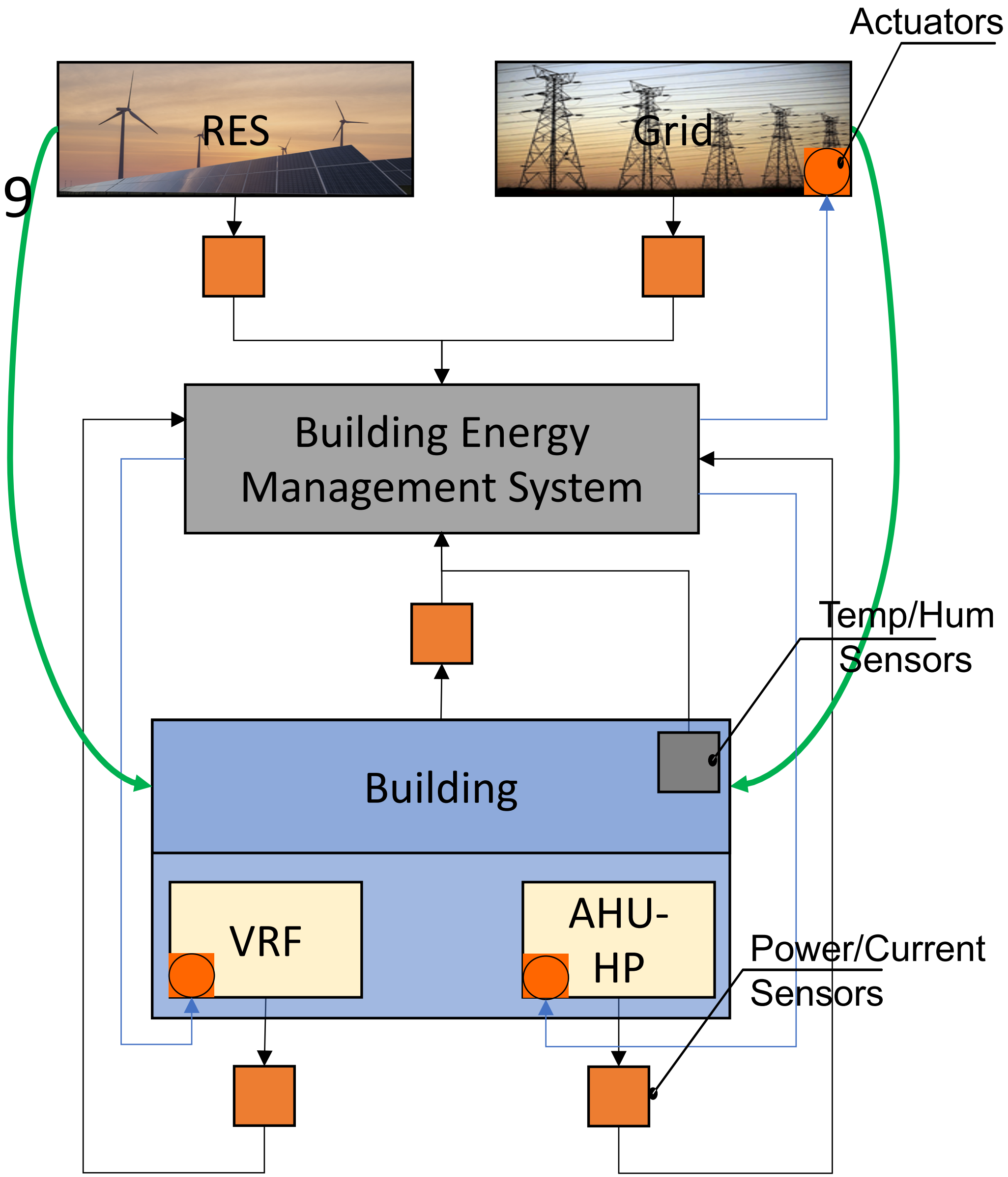
Building Energy Consumption



Case Study



- ✓ Building monitoring: harvest data every 15min.
- ✓ HVAC schedule: 06:00 – 18:00 hours on weekdays
- ✓ Fixed setpoint: 22^{o}C



The collected data include:

- Inner temp. [^{o}C], from 25 sensors;
- Ambient temp. [^{o}C], global irradiance in W/m^2 and wind speed in m/s measurements, from the weather station;
- Energy consumed by HVAC systems [kW], from 3 power meters;
- Energy generated by RES [kW], from 3 power meters.

Note: The system is continuously connected to the grid in order to ensure the uninterruptible electrical supply of the infrastructure .

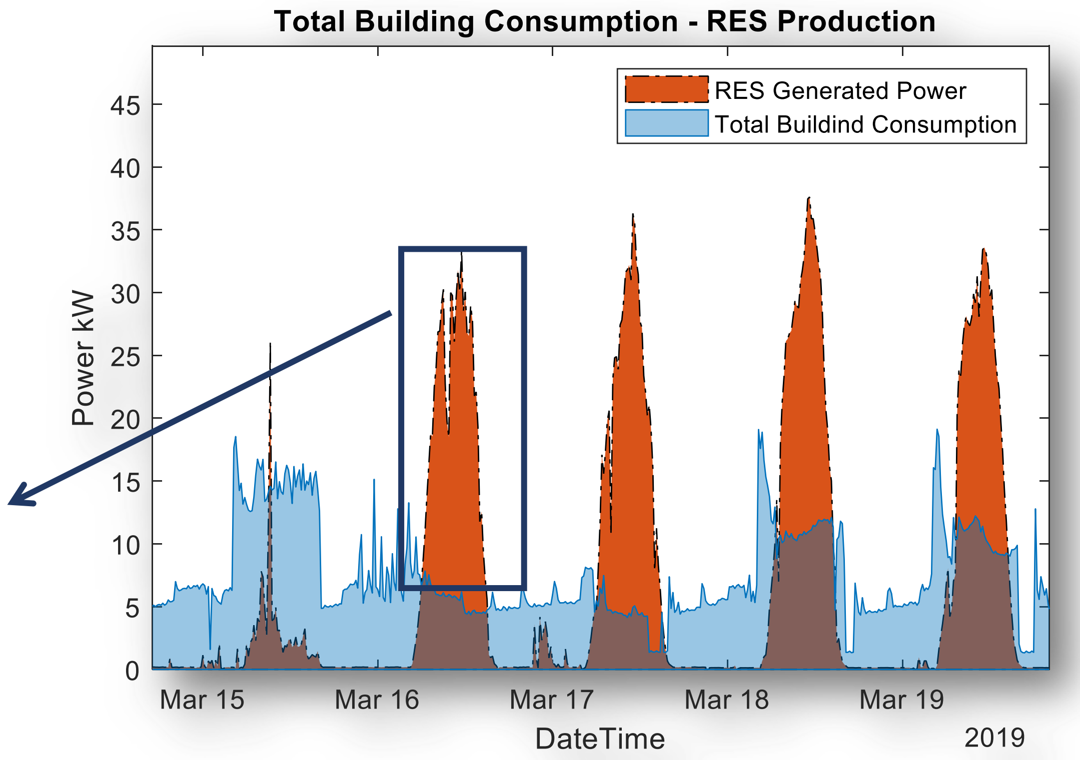
RES availability (1)

The availability of excess renewable energy to be stored is assessed.

Energy production of the RES in relation to energy consumption of the building

During daylight, energy production exceeds building’s demand

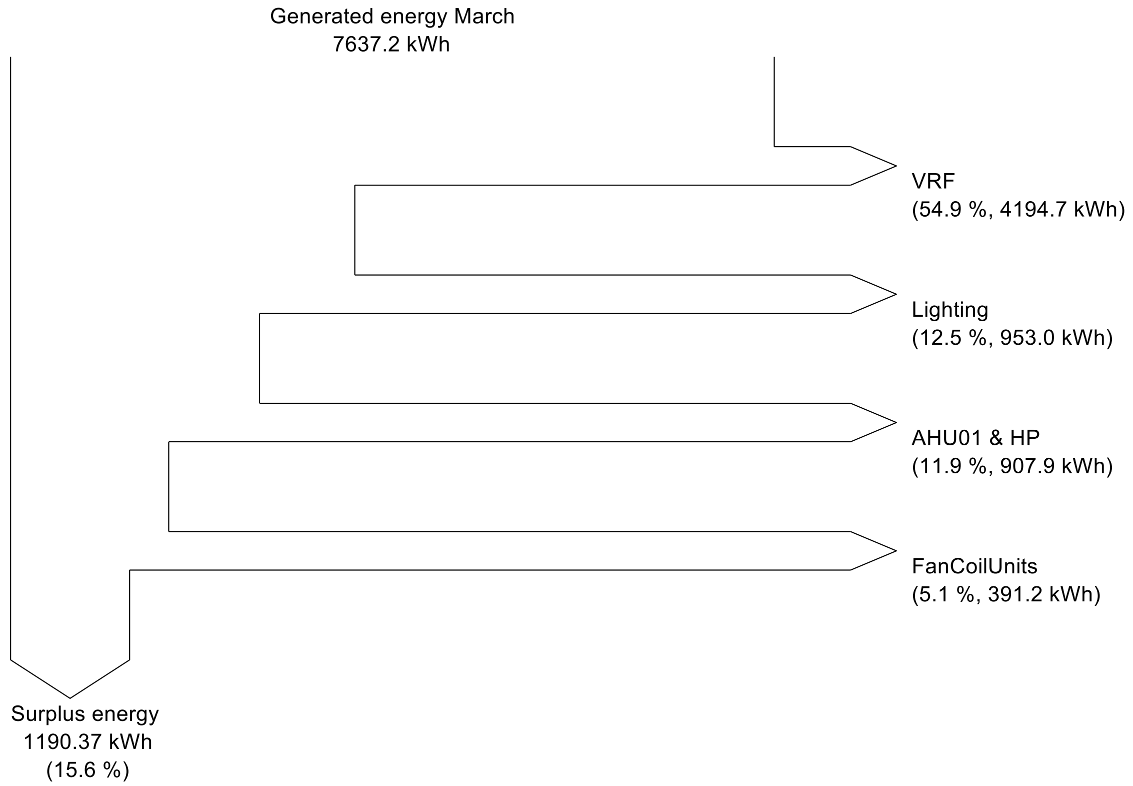
Surplus energy available to be stored to the thermal mass of the building



RES availability (2)

- Considering the heating period, the RES production was unable to fully cover building's demands.

- Exclusively, March presented **surplus energy 1,19MWh**.



Energy flow pathways of generated and consumed energy.

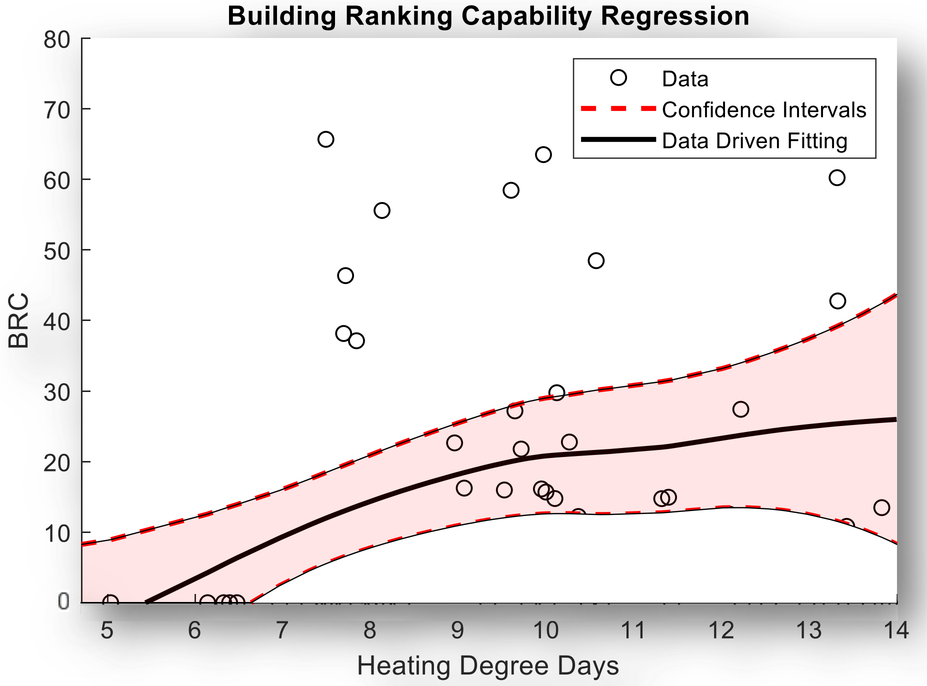
Analysis of the Results

Results lead to two **major observations**:

- **BRC** factor is increased accordingly to **HDD**
- **Fitting curve** indicates the **impact** of climate conditions on building’s performance

The gradient of the curve expresses the thermal mass capability:

- As the **gradient** of the curve approaches **zero**, the **impact** of the HDD approaches **zero**
- The **higher** the BRC is, the **greater potential** for **thermal mass exploitation.**



Results of the regression analysis with a confidence level of **95%**

Conclusion (1)

- By **exploiting thermal mass**, the buildings can moderate the **discrepancy of supply and demand**.

- Thermal mass allows the **utilization of DSF** at residential buildings and will **increase the penetration of RES** in the total energy consumption mix.

- The **quantification** of the available **thermal mass** is proved **complex** and **expensive** .

Conclusion(2)

This approach provides the following **competitive advantages**:

- **Minimum set of parameters** and **sensor infrastructure**
- **Variable measuring equipment** without affecting the accuracy
- **Interrupted / inconsistent data** without affecting the results

The **outcomes** lead to **empirically rate** building capability to store energy to its thermal mass.

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