

# Digital twins of prosumers

using socioeconomic factors and big data for optimization of customers' bill savings, and the adoption of concepts of self-consumption and prosumption

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**SIEMENS**



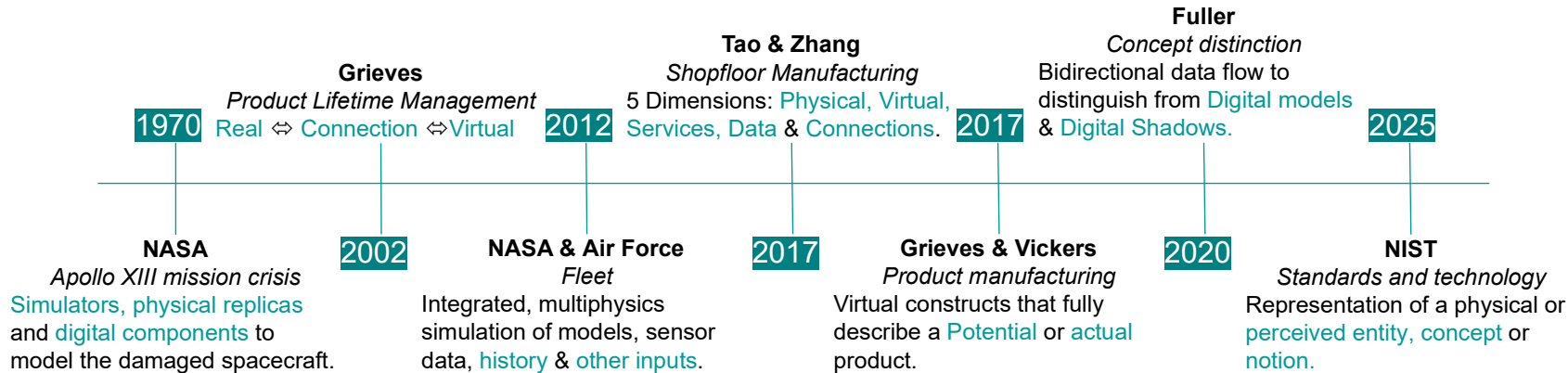
How can **digital twins** be designed and implemented to reflect the technical, economic, and social dimensions of **prosumers** to support **energy optimisation** and enables viable **business models**?

# Background

## Prosumer Digital Twins and their challenges

# Conceptual Foundation

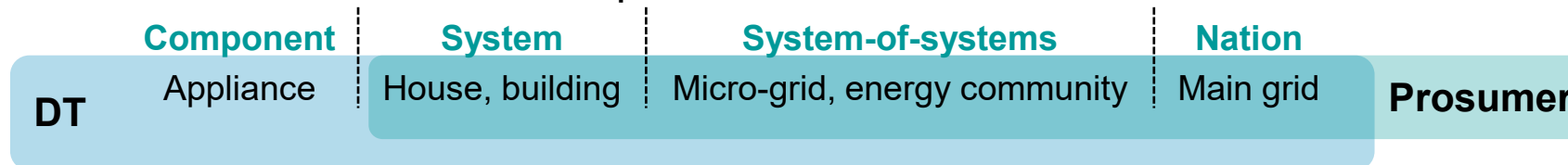
## What is a Digital Twin (DT)?



## What is a Prosumer?

Producer and Consumer

Implementation level:



Which factors are involved?

Which are the identified gaps?

# Conceptual Foundation

Which factors are involved?

- Social – Economic – Regulatory – Technical
- A comprehensive approach

Morning Time, am	What were you doing? <small>Please record your main activity for each 10-minute period.</small> Enter one main activity on each line.	What else were you doing? <small>Write in the most important activity you were doing at the same time</small> e.g. Looking after children, listening to the radio or having a drink	Where were you? e.g. At home, at friends, in car, on bus, train, cycling, walking
7:00 - 7:10	Sleeping		
7:10 - 7:20	↓		
7:20 - 7:30	Had a shower		At home
7:30 - 7:40	Made breakfast		↓
7:40 - 7:50	Ate breakfast	Read newspaper	↓
7:50 - 8:00	Did washing up		↓
8:00 - 8:10	Got my son dressed	Talked with my son	↓
8:10 - 8:20	Walked to school with son	↓	Walking
8:20 - 8:30	Dropped son off at school	↓	↓
8:30 - 8:40	Walked to bus stop		↓
8:40 - 8:50	Travel by bus to work	Read newspaper	On the bus
8:50 - 9:00	↓	↓	↓
9:00 - 9:10	↓	↓	↓
9:10 - 9:20	Walked from bus stop to main job		Walking
9:20 - 9:30	↓		↓
9:30 - 9:40	↓		↓
9:40 - 9:50	Main job		
9:50 - 10:00	↓		

Fig 6.1. UK- Time Use Survey (TUS)

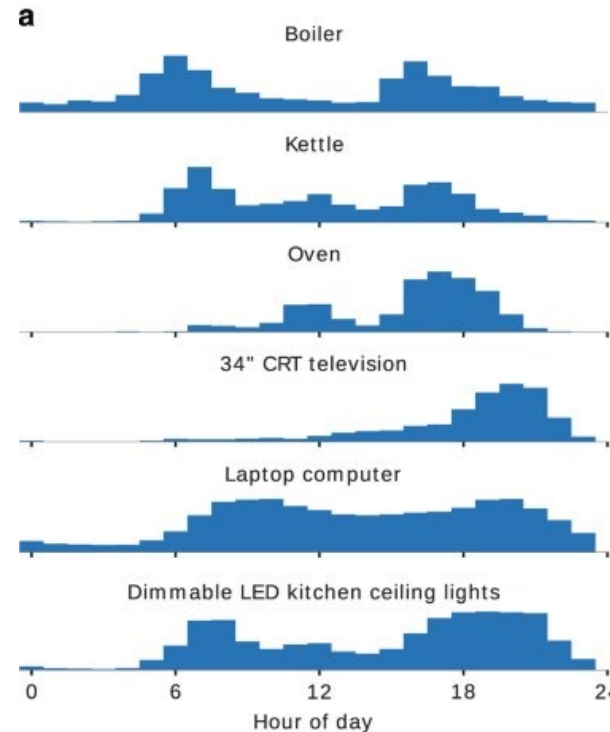


Fig 6.2. UK- Domestic Appliance Level Electricity (DALE)



Which are the identified gaps?

## Conceptual Foundation

Which are the identified gaps?

- Limited integration of behaviour and socioeconomic factors in DTs.
- Under-specified business models for DTs.
- Disjoint data realms: limited linkage of social and technical datasets.
- Scarcity of applications in residential/community prosumption.

Key Implications:

- Clarity of purpose needed when developing a DT
- Integration of non-technical factors, e.g. occupancy modelling, tariff structures
- Everyone should be involved: prosumers, operators, policy makers, and technology suppliers → **Huge challenge!**

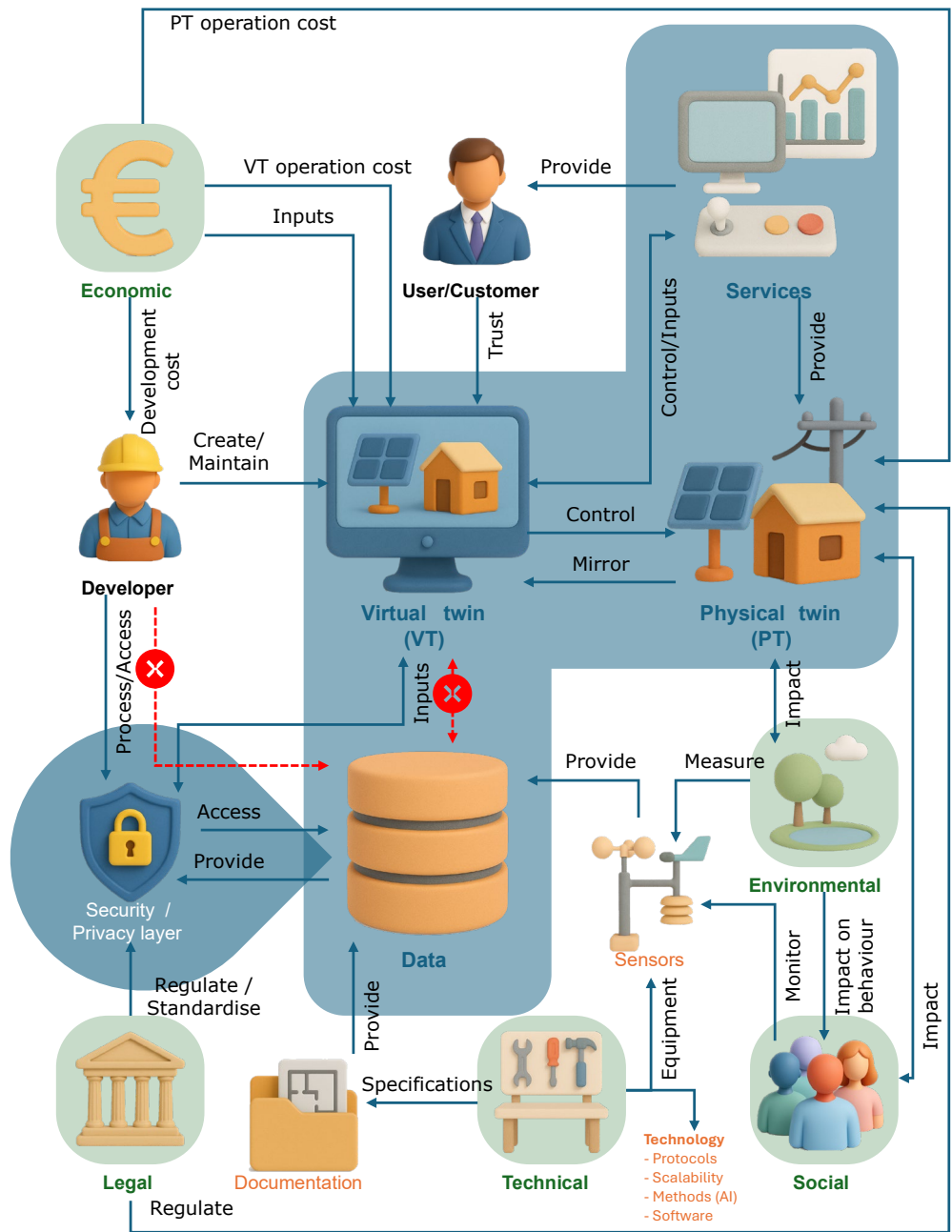


Fig 8. Digital twin components, factors, actors, and environment.

# Proposal: A multifactor Digital Twin

## 5-Dimension Model

- Virtual twin
- Physical twin
- Data
- Services
- Connections
- + Security / Privacy



Security → trust

Local data → address database gaps

# Auxiliary tools

Platform selection

Tool development

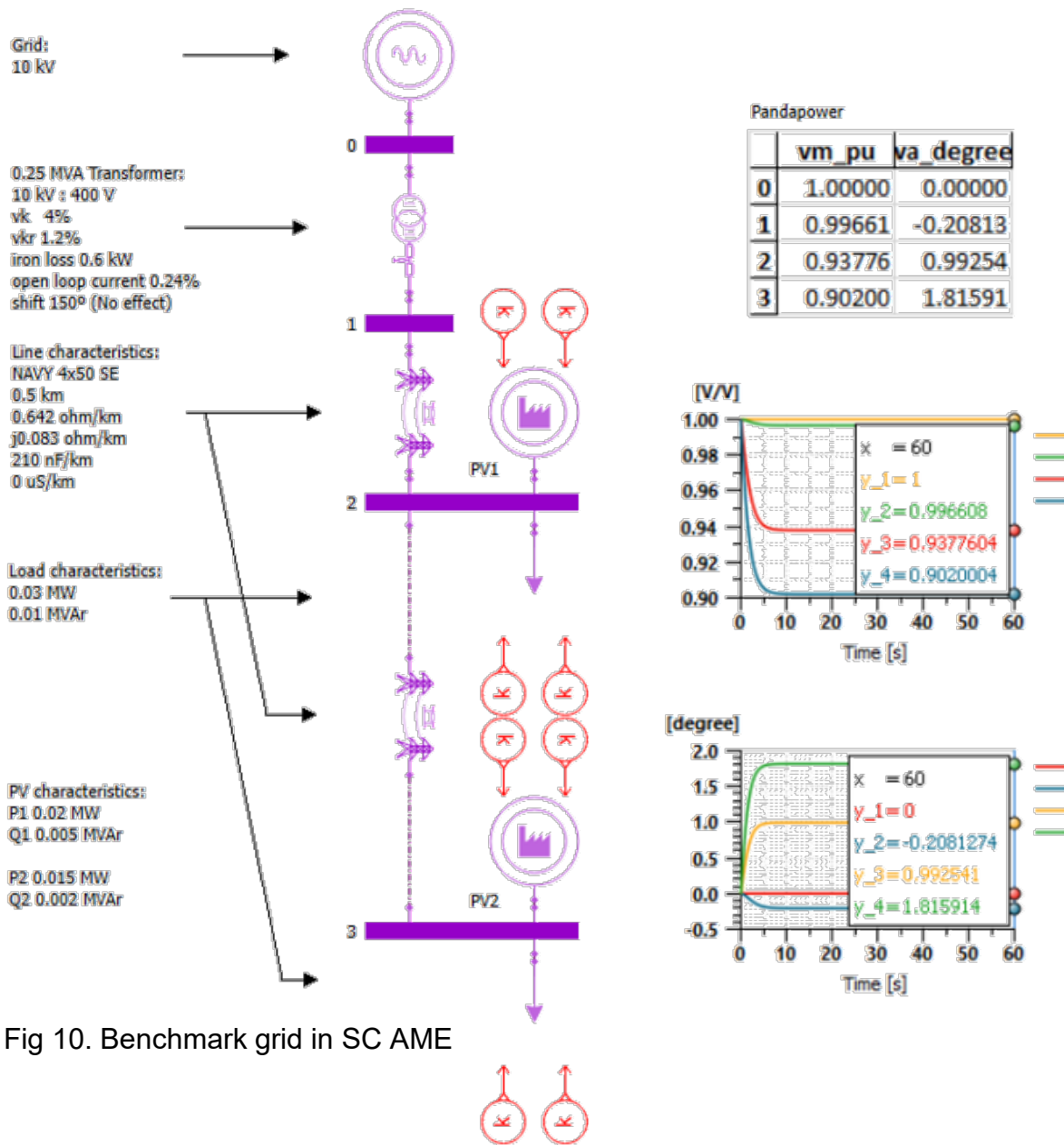


Fig 10. Benchmark grid in SC AME

# Simcenter Amesim



- Multiphysics out-of-the-box
- Compatible with other tools
- Incorporates optimization algorithm
  - Genetic algorithm

## Grid modelling

Modified components to converge to the solution.

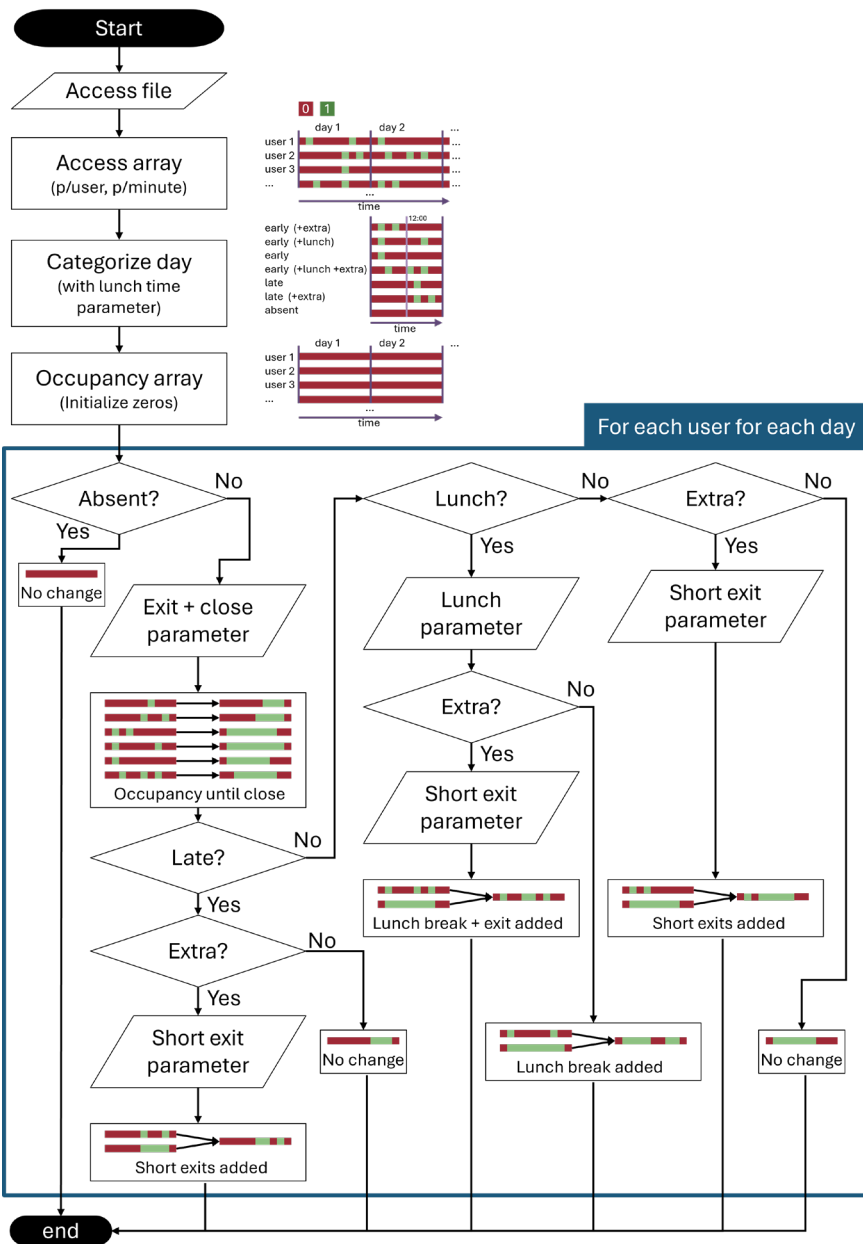
$$I_2 = -I_1 = \frac{V_1 - V_2}{Z}$$

adding a state variable and a parameter

$$\dot{I}_2 = -\dot{I}_1 = \frac{V_1 - V_2}{Z} - I_2$$

Solve the load flow problem in a **non-iterative** approach with the same solver engine as the rest of the physics.

- With negligible delay



# Occupancy Model (UTBM example)

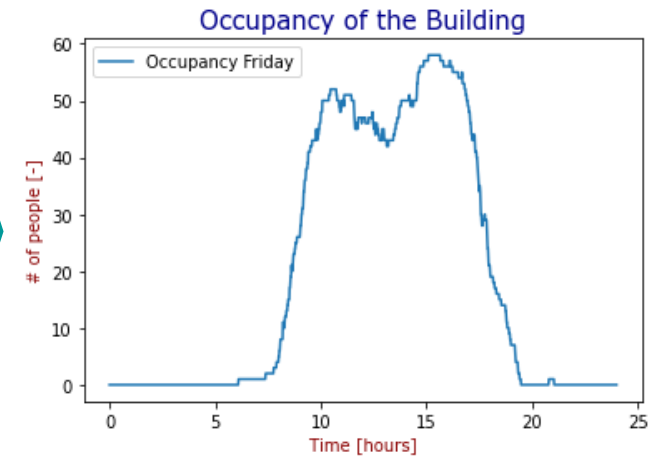
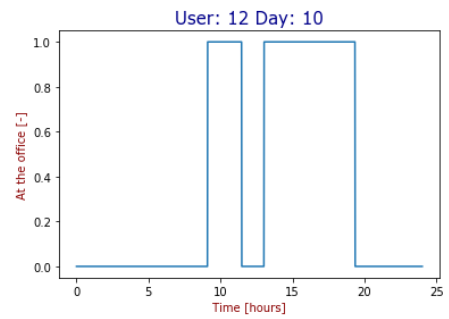
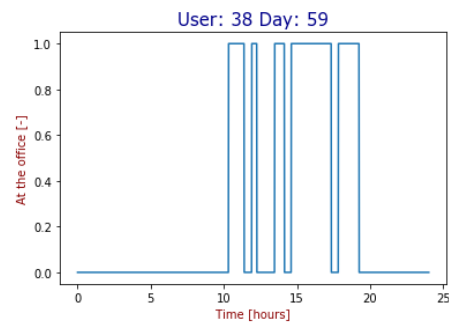
From door access to occupancy estimations.

## Parameters:

- Building closing times
- Usual exit time
- Duration and variability of breaks

## Challenge:

- Data anonymity and privacy
- Scope: Entrance access information (not per-office)



# Methodology

# Developed Digital Twins

## NOVA, Portugal



Fig 14.1. NOVA campus Caparica

Source: [www.fct.unl.pt](http://www.fct.unl.pt)

## UTBM, France

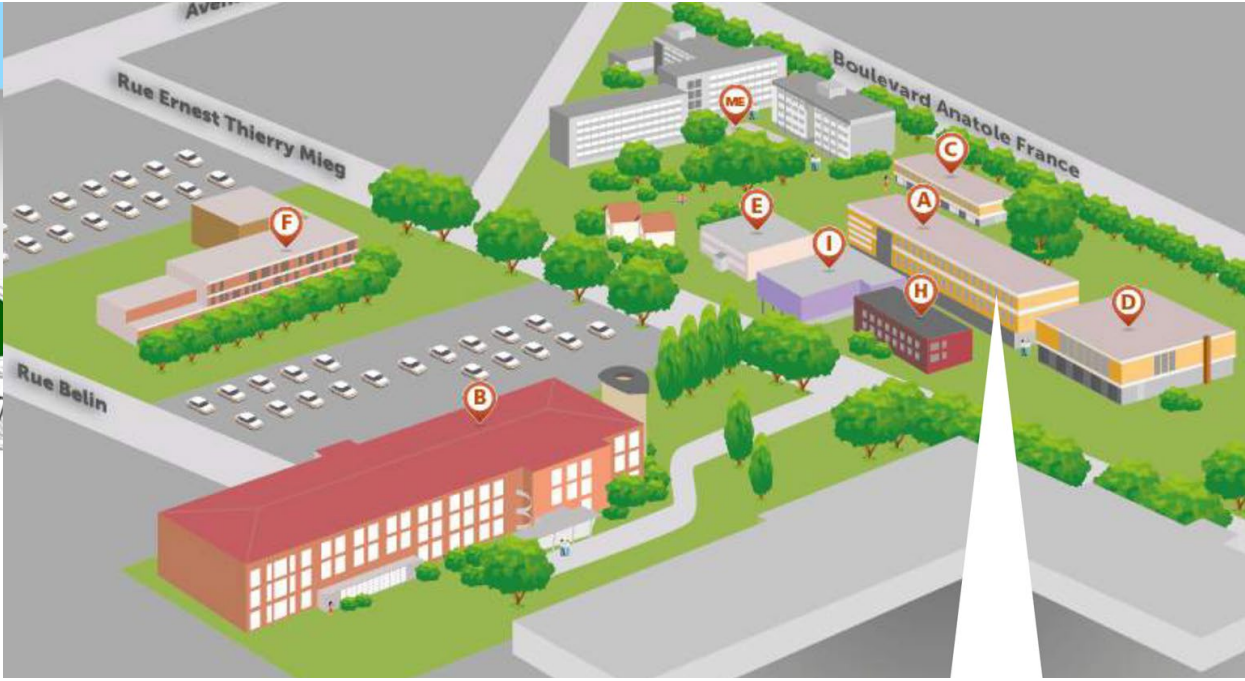


Fig 14.2. UTBM campus Belfort

Source: [www.utbm.fr](http://www.utbm.fr)

# Nova & UTBM

## NOVA

### Assets:

- Chiller-based cooling system during the summer
- Water tank for a fire-system

### Data:

- Aggregated building consumption
- Temperature measurements from sensor in corridor
- Weather data
- Physical description of the building

## UTBM

### Assets:

- Two solar photovoltaic arrays with a DC to AC converter.
- Electric vehicle charger.
- Hydrogen platform: electrolyzers, fuel cells.

### Data:

- Building access information.
- Electric consumption of building, electric vehicle, PV
- Hydrogen devices measurements.
- Local weather station

# Nova Digital Twin

# Nova Digital Twin

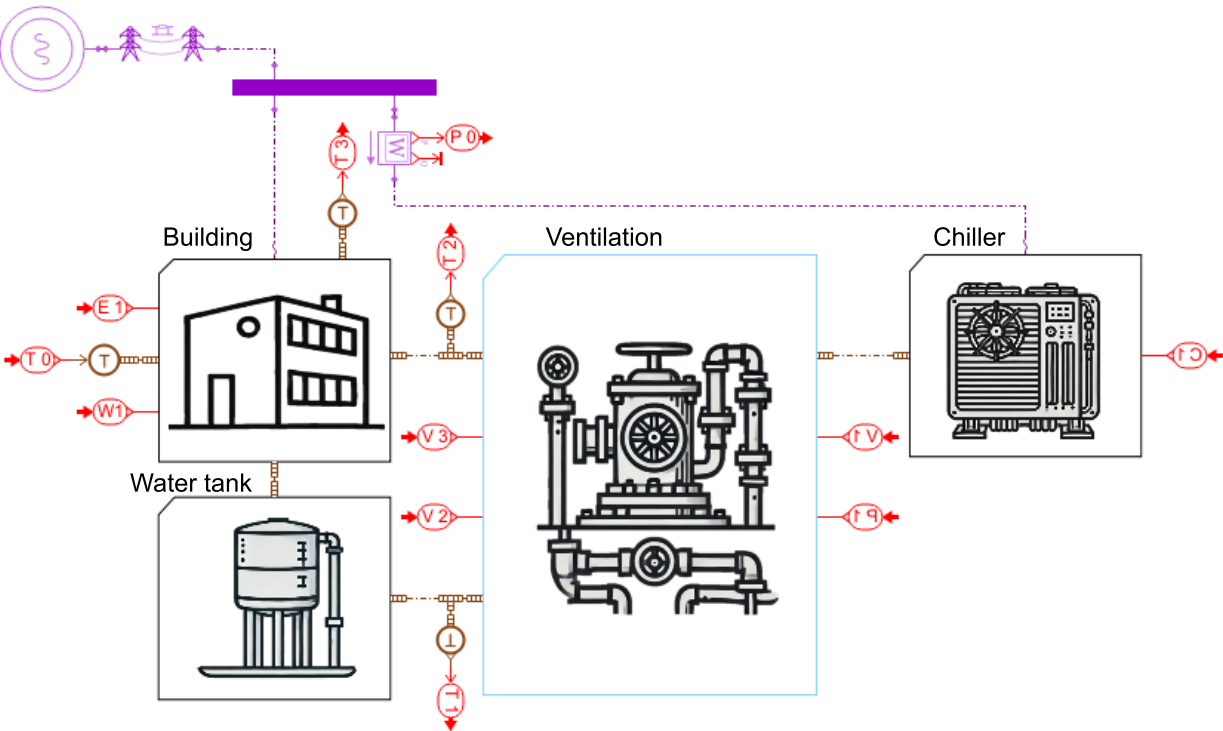


Fig 18.1 Nova digital twin



Fig 18.2 Nova building

# Nova Digital Twin

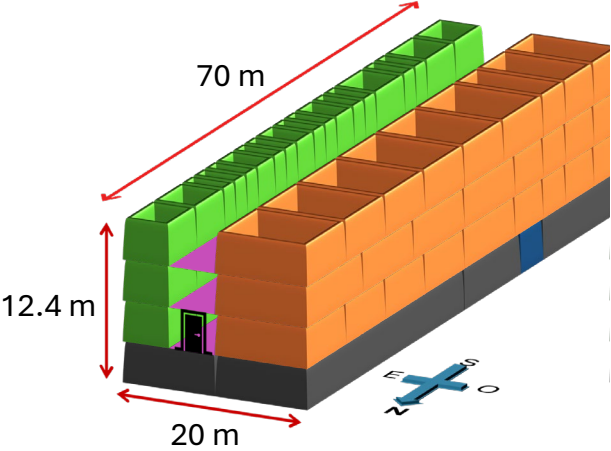


Fig 19.1 Building structure

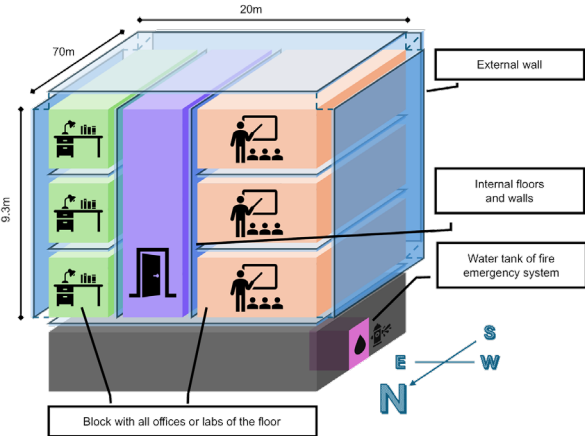


Fig 19.2 Simplified building

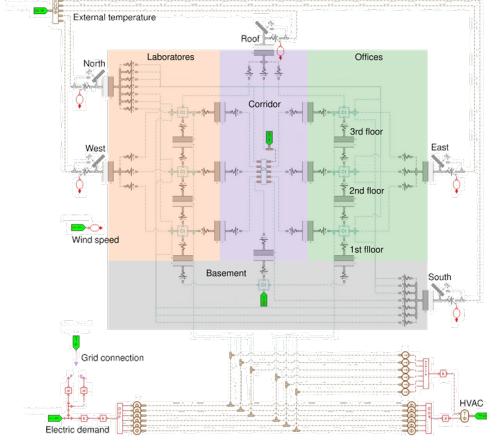


Fig 19.3 Building model

## Physical System

Understanding of the system and its boundary conditions.

## Simplification

Reduction of the system accounting for model complexity and data limitations.

## Abstraction

Description within the Simcenter Amesim of the system with interactions with the environment.

# Nova Digital Twin: Subsystems

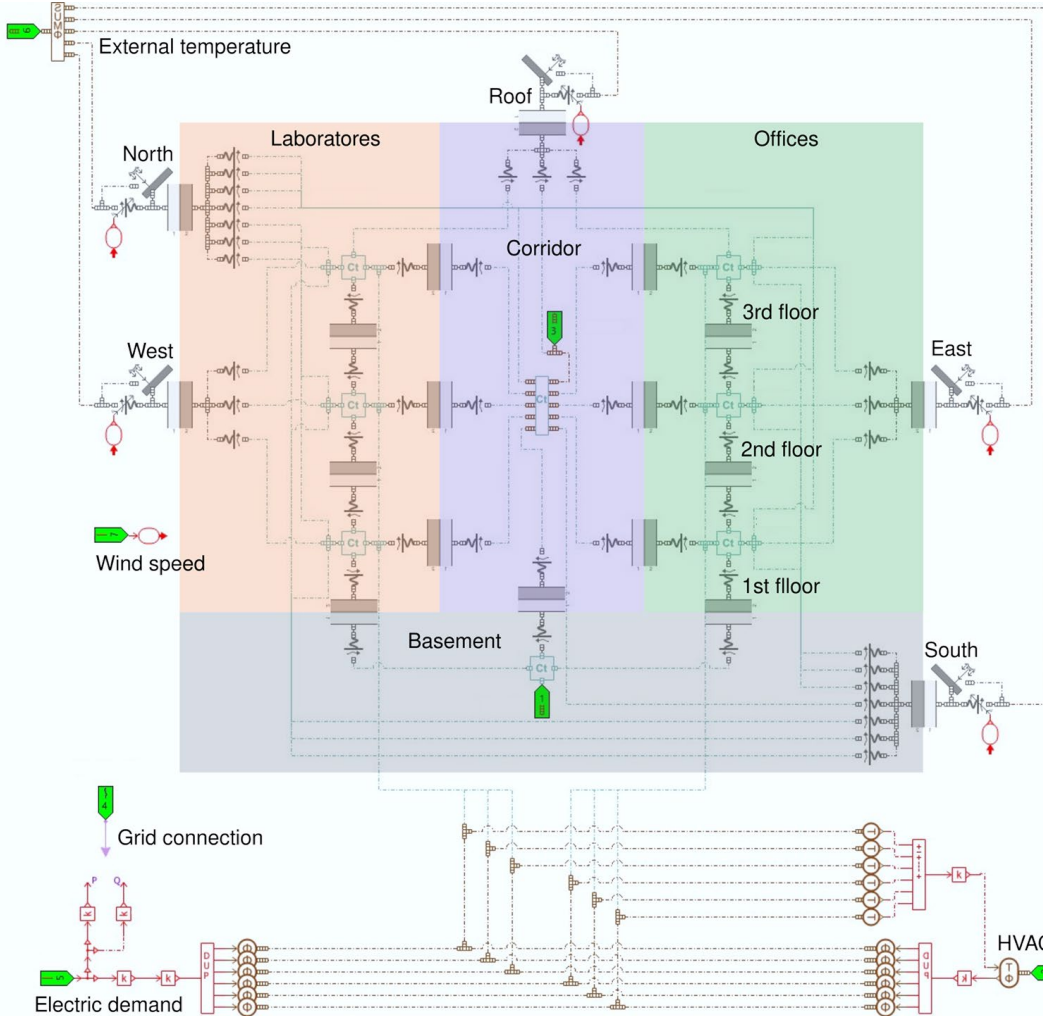


Fig 20.1. Building model

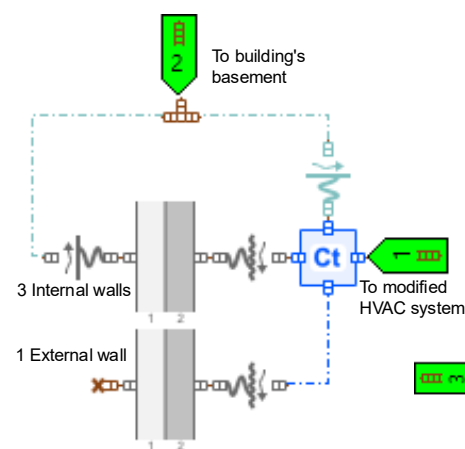


Fig 20.2. Water tank model

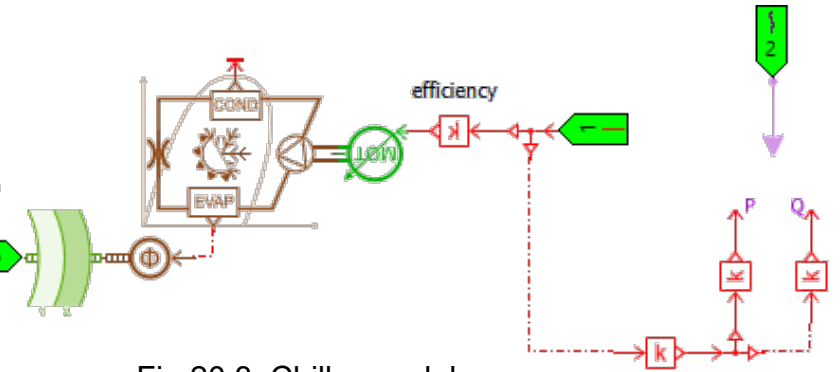


Fig 20.3. Chiller model

Spaces and objects

→

$$\frac{dT}{dt} = \frac{1}{C_{th}} \sum_i \dot{Q}_i$$

Two-layered walls

→

$$C_1 \frac{dT_1}{dt} = \dot{Q}_1 - \frac{T_1 - T_2}{R_{12}}$$

$$C_2 \frac{dT_1}{dt} = \dot{Q}_2 + \frac{T_1 - T_2}{R_{12}}$$

Thermal resistance

→

$$\dot{Q}_{ab} = \frac{T_a - T_b}{R_{ab}}$$

Solar irradiance

→

$$\dot{Q}_{solar} = \alpha \cdot A \cdot I \cdot \cos\theta$$

# Nova Digital Twin: Subsystems

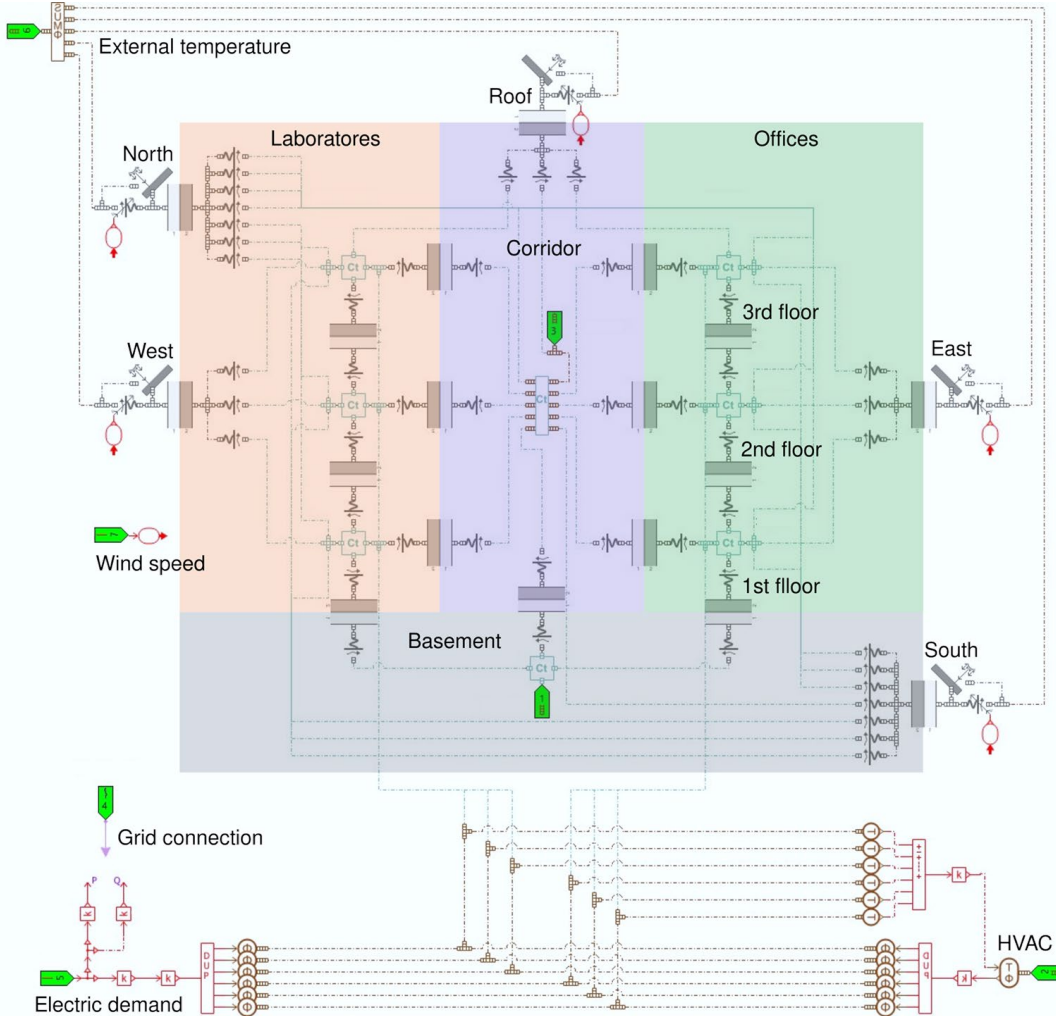


Fig 20.1. Building model

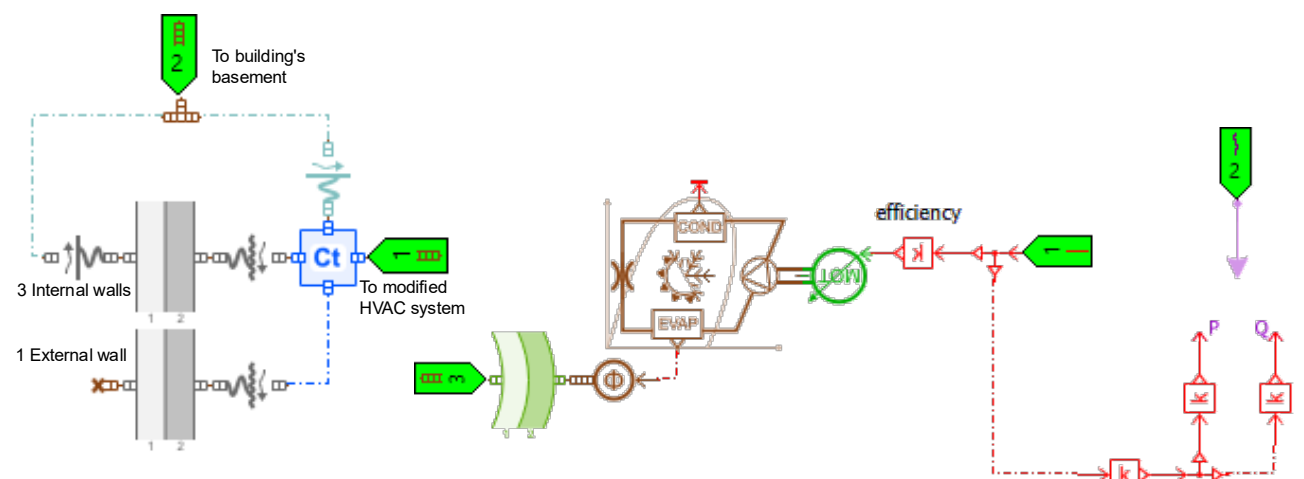


Fig 20.2. Water tank model

Fig 20.3. Chiller model

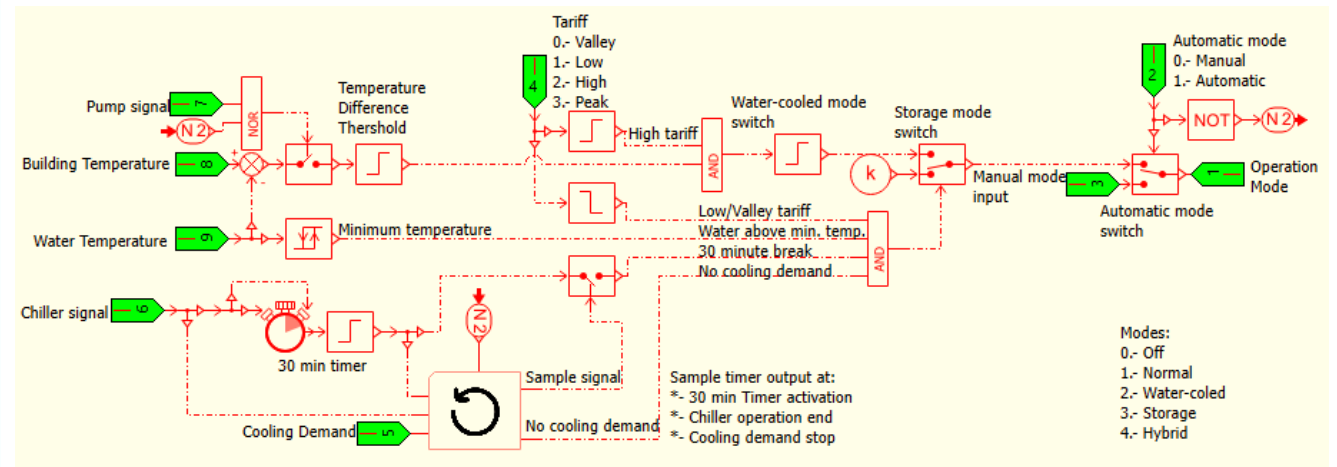
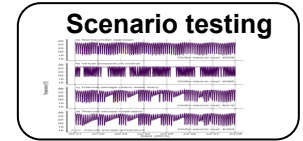
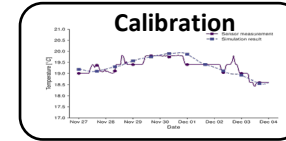


Fig 20.4. Building model



## Effect of initial conditions

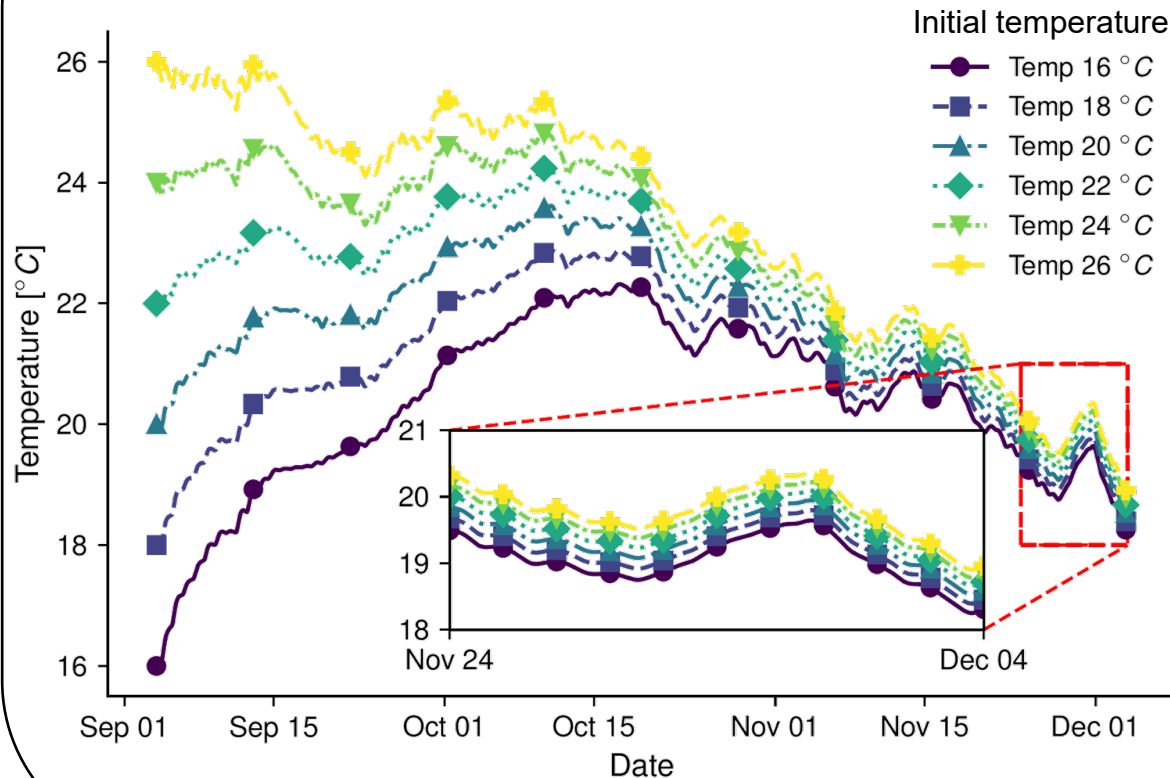
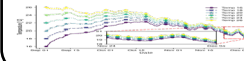


Fig 22. Effect of initial temperature on simulations

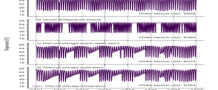
- The effect of initial conditions diminishes
- Use of previous data to settle the values
- Use of optimisation algorithms to find starting values

# Results

Effect of initial conditions



Scenario testing



## Calibration

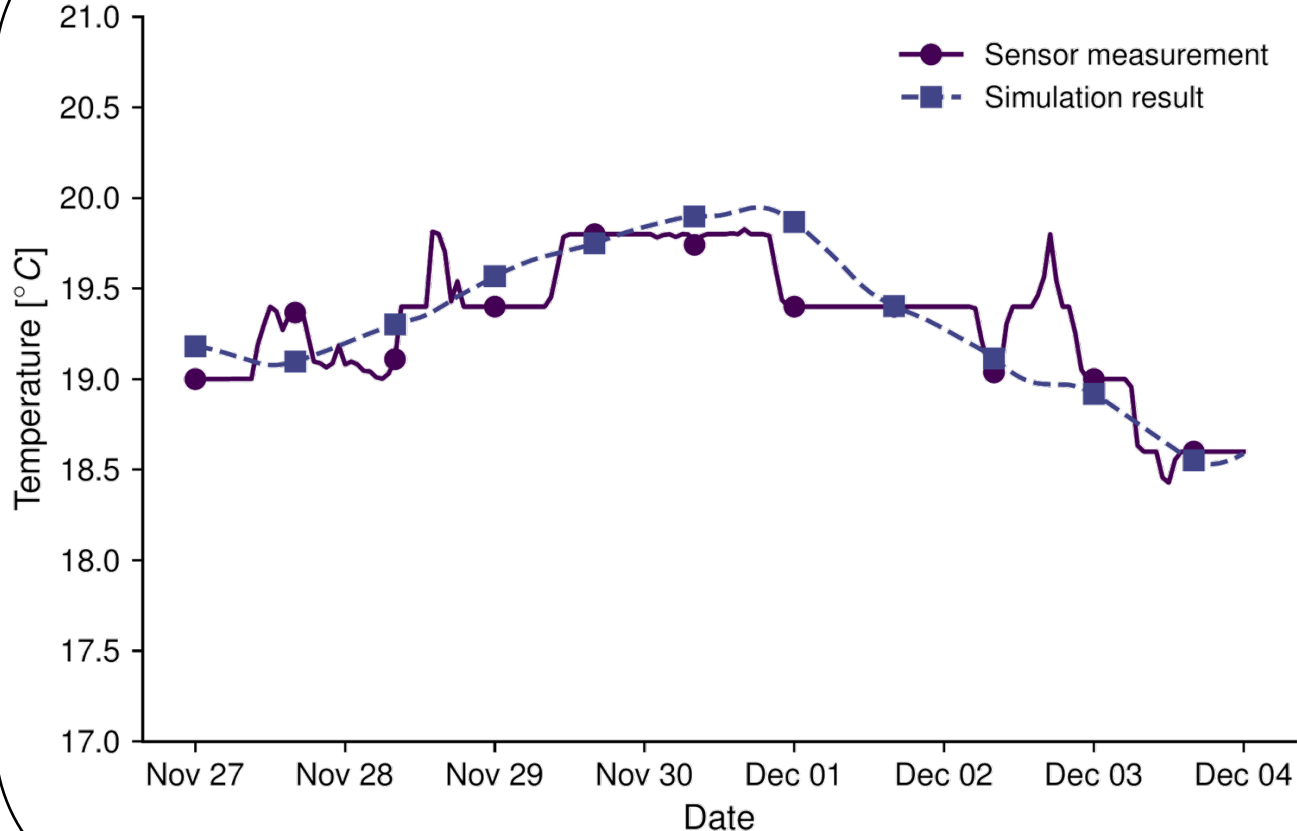


Fig 23.1. Model calibration results

- Simplified building envelope leads to a loss of dynamics.
- Model trained on weather station data does not exactly represent the conditions outside.
- Acceptable average behaviour.

## Validation

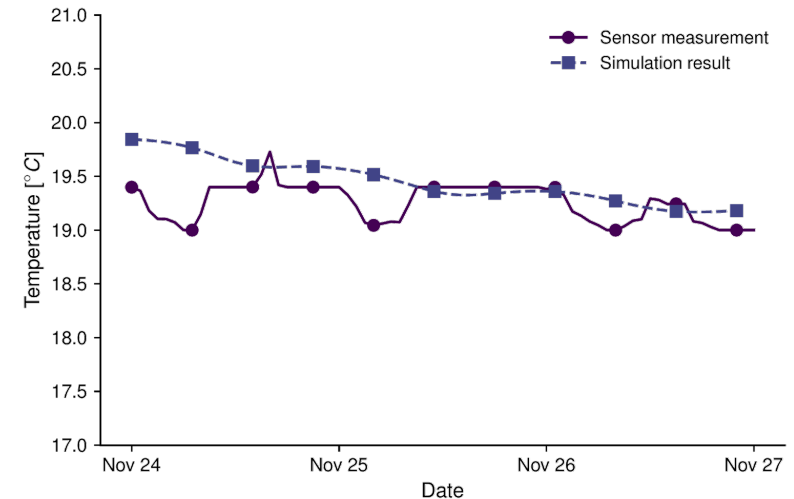
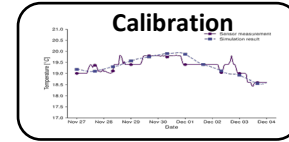
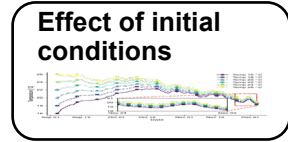


Fig 23.2. Model validation results



## Scenario testing

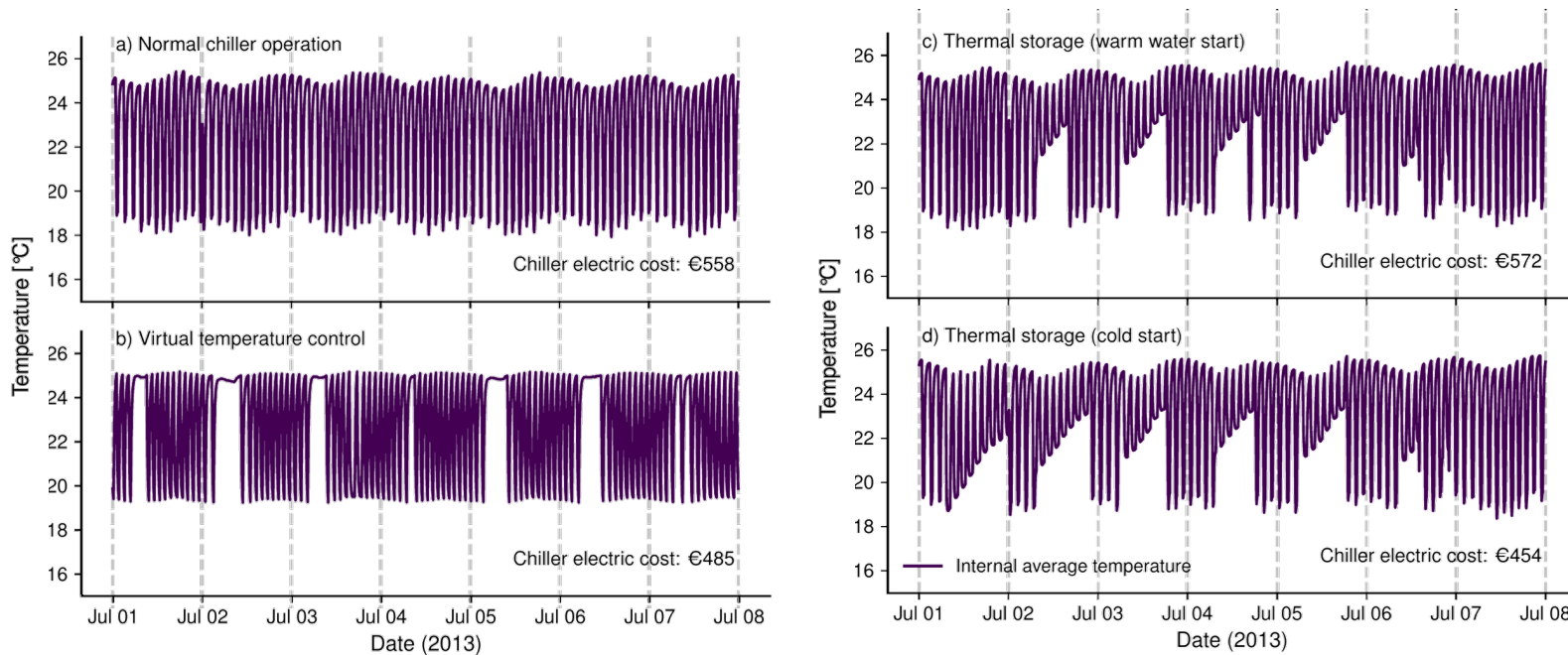


Fig 24. Model under different simulated scenarios

Savings: ~ €2000 (6 months)

~ €2700 (6 months)

- Comfort-aware demand reduction
- Thermal storage for peak management and tariff-responsive operation (time-of-use optimisation). Flexible control with direct economic implications

# UTBM Digital Twin

# UTBM Model

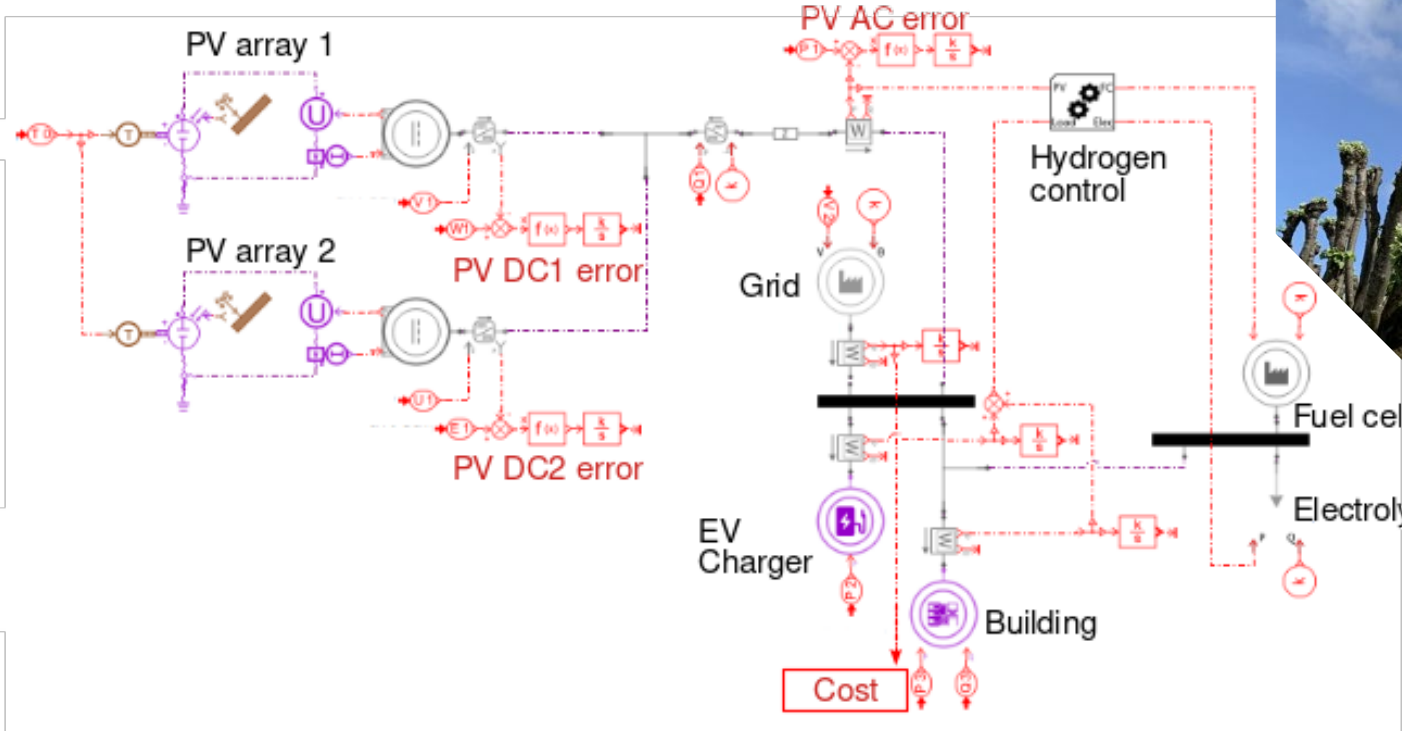
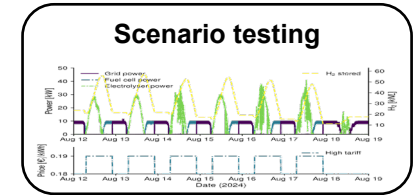
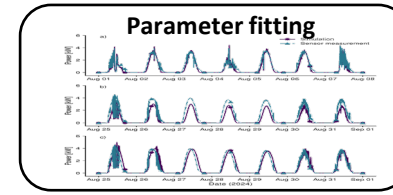


Fig 28.1 UTBM digital twin



Fig 28.2 UTBM building



## Occupancy model

Building level as office access is not monitored.

The parameters of the model were tweaked to match the behaviour of occupancy observed during the direct measuring periods.

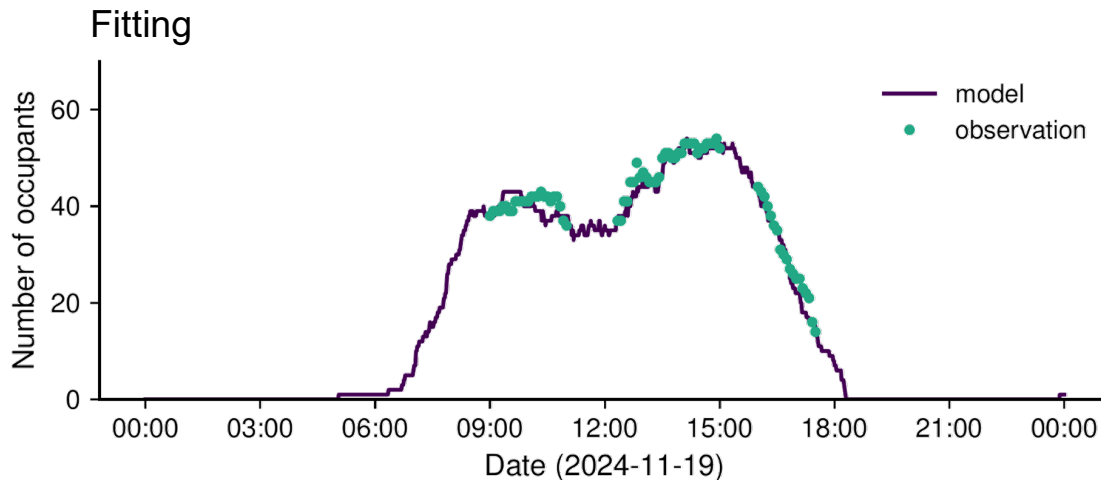


Fig 29.1. Model Fitting

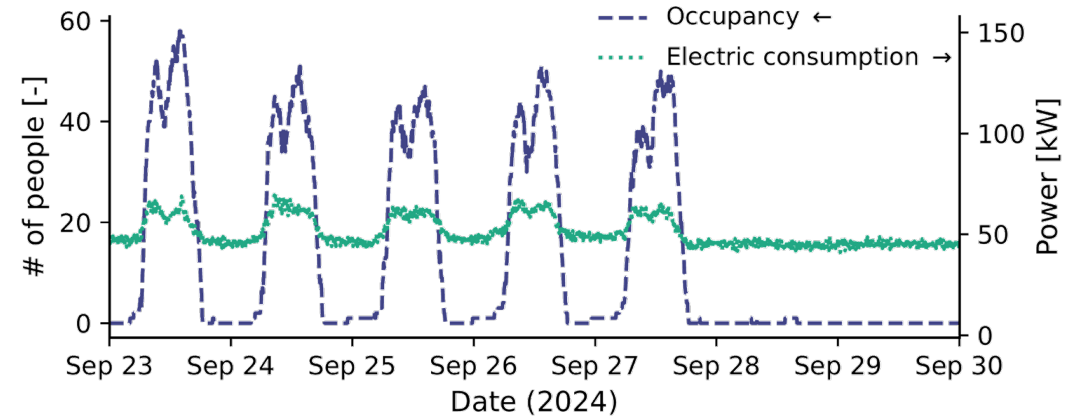
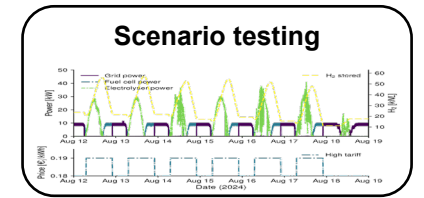
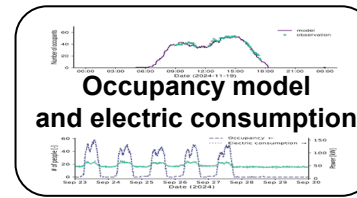


Fig 29.2. Occupancy and electric consumption

# Results



## Calibration

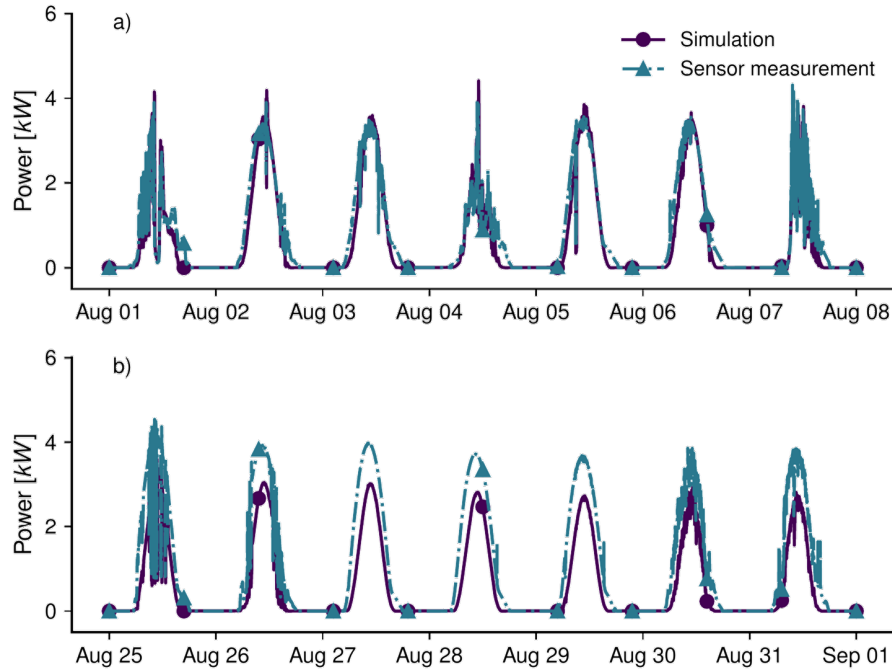


Fig 30.1. Model fitted with 1<sup>st</sup> week's data

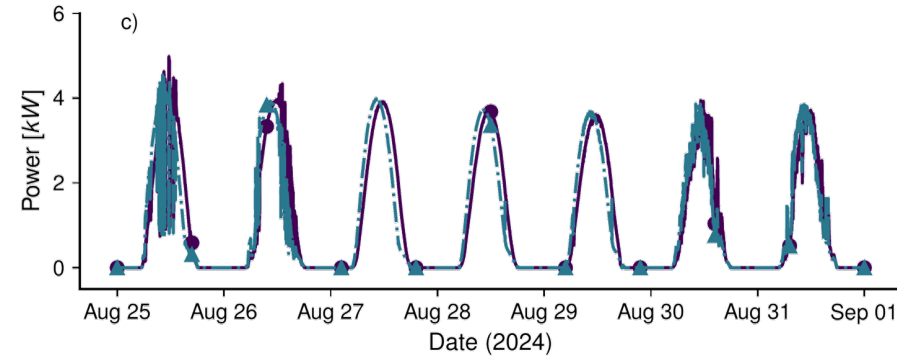
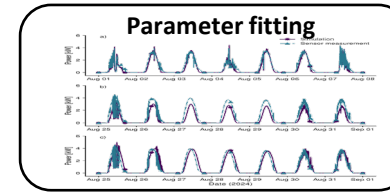
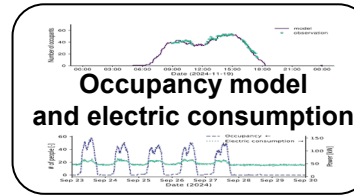


Fig 30.2. Recalibrated with previous week's data

- PV adjust of series and parallel resistances for single diode model as well as diode ideality factor.
- Weekly recalibration kept the model updated.
- Previous week data use for recalibration with positive results.

# Results



## Scenario testing

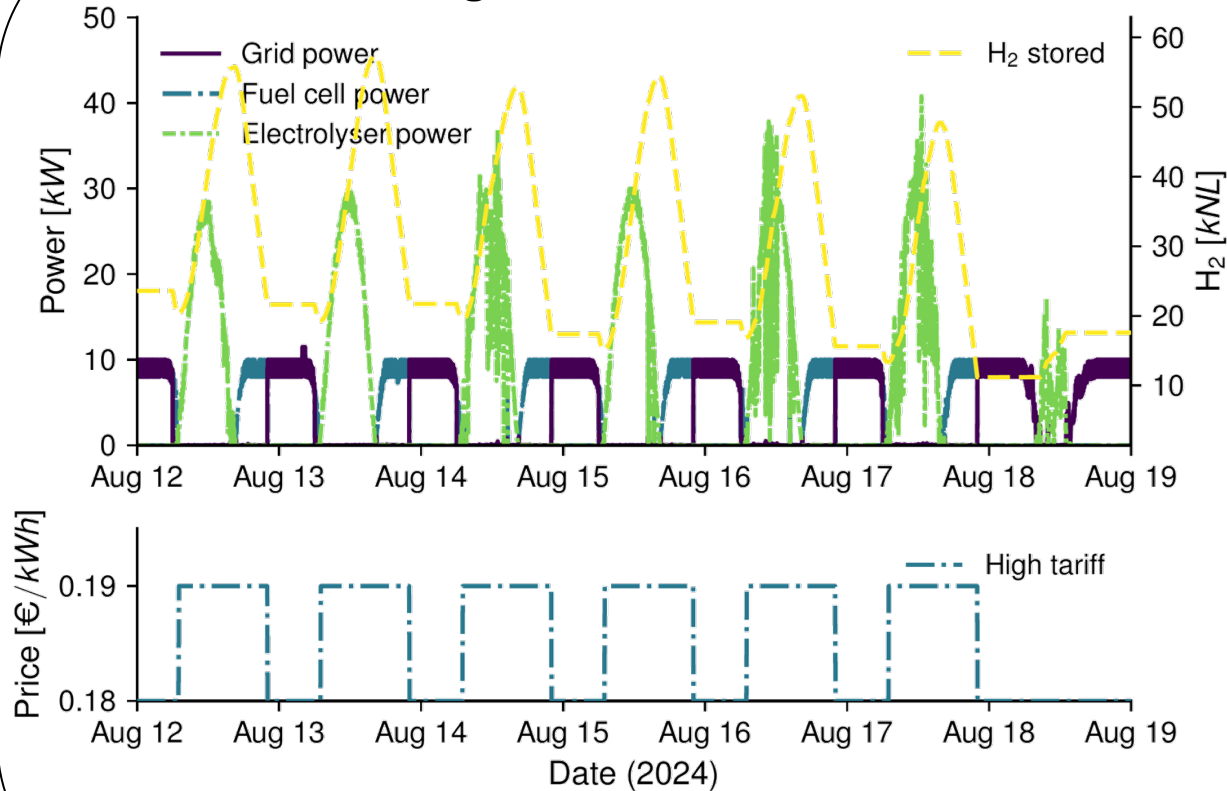


Fig 31. Hydrogen storage of solar energy scenario

PV generation increased to create situations of excess energy.

(Retrofits, expansions, or sizing optimisation for prosumers).

- Store as hydrogen or sell with a feed-in-tariff. Cost reductions with 50kW PV:
  - Unused excess energy: ~10% (€20)
  - Hydrogen storage: ~50% (€100)
  - Feed-in-Tariff: ~80% (€160)

Store energy

$$P_{fc} = -\Delta P, \quad P_{el} = 0$$

$$\dot{H}_{out} = \frac{P_{fc}}{\eta_{fc}} \cdot k$$

$$H_{stored}(t) = H_{stored}(t) - \int \dot{H}_{out}(t) dt$$

Use stored hydrogen

$$P_{el} = \Delta P, \quad P_{fc} = 0$$

$$\dot{H}_{in} = \eta_{el} \cdot P_{el} \cdot k$$

$$H_{stored}(t) = \int \dot{H}_{in}(t) dt$$

# Business model

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
<ul style="list-style-type: none"> <li>➤ Facilities Management</li> <li>➤ Energy Service Companies</li> <li>➤ Internet of things (IoT)/Weather Data Providers</li> <li>➤ Simcenter Amesim Support (Siemens)</li> </ul>	<ul style="list-style-type: none"> <li>➤ Digital twin calibration and validation</li> <li>➤ Scenario simulation and optimisation</li> <li>➤ Predictive control strategy implementation</li> <li>➤ Continuous monitoring and updating of DT</li> </ul>	<ul style="list-style-type: none"> <li>➤ Reduction of cooling energy costs</li> <li>➤ Optimisation of self-consumption and prosumption</li> <li>➤ Virtual sensor deployment without additional hardware</li> <li>➤ Scenario-based energy planning and cost forecasting</li> </ul>	<ul style="list-style-type: none"> <li>➤ Subscription-based service</li> <li>➤ Performance-based incentive sharing</li> <li>➤ Periodic reporting and dashboard access</li> <li>➤ Technical support and consultancy</li> </ul>	<ul style="list-style-type: none"> <li>➤ Building managers</li> <li>➤ Campus operators</li> <li>➤ Public sector facility managers</li> </ul>
<h3>Key Resources</h3> <ul style="list-style-type: none"> <li>➤ Calibrated DTs</li> <li>➤ Weather and building consumption data</li> <li>➤ Energy price tariffs</li> <li>➤ Simulation and optimisation infrastructure</li> </ul>		<h3>Channels</h3> <ul style="list-style-type: none"> <li>➤ Online platform</li> <li>➤ Technical workshops and training sessions</li> <li>➤ Reports and scenario analyses</li> </ul>		
<h3>Cost Structure</h3> <ul style="list-style-type: none"> <li>➤ Model development and maintenance</li> <li>➤ Data acquisition and processing</li> <li>➤ Software licensing (e.g., Simcenter Amesim)</li> <li>➤ Cybersecurity and data protection measures</li> </ul>		<h3>Revenue Streams</h3> <ul style="list-style-type: none"> <li>➤ Subscription fees (fixed or tiered)</li> <li>➤ Performance-based savings sharing</li> <li>➤ Consultancy fees for optimisation and scenario testing</li> </ul>		

Table 25. Business Model of Prosumer Digital twin

## Takeaways

- Real-time data access is not the only way to keep a model updated.
- Policies, tariffs and regulations are central to incentivize change and need to be considered for DT optimisation.
- Different sources of value: like self-sufficiency and resilience.
- Measurements and models are connected: find the right optimisation method to link them.
- Alternatives to the grid as an intermediary: existing infrastructure and other forms of energy
- Limited sensors are a challenge but not a definite barrier
- Digital twins enable reaching objectives in specific situations and offer insights into the system

# Conclusions

## Conclusion

### Initial Goal:

To design, implement, and evaluate Digital Twins that integrate technical, and socioeconomic factors for optimising prosumer energy performance and exploring viable business models.

### Achievements:

- Validated causal grid modelling library
- Digital twin implementations in data scarcity conditions with different energy forms
- Parametrized occupancy model algorithm for entrance-controlled buildings

### Findings:

- Digital Twins can work under real-world data constraints
- Technical and socioeconomic integration is feasible and insightful
- DTs unlock operational, economic, and social value for prosumers

### Practical impacts:

- **Energy optimisation:** measurable reductions in grid imports and operational costs
- **Flexibility services:** identification of demand-shifting and peak reduction potential
- **Hydrogen integration:** insights into when hydrogen contributes meaningfully (policy-dependent)
- **Decision-support:** DT scenarios support prosumers, planners, and researchers



# Collaboration



# Thank you.

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