Project Acronym/ Acronimo del progetto:

INTEGRIDS

Project title:

Electric and thermal grids integration with energy flexible building

Titolo del progetto:

Studio dell'integrazione di reti elettriche e termiche con la flessibilità energetica degli edifici

Deliverable name	Pianificazione della fase sperimentale
Deliverable N°.	D5.2
Task	5.2
Author of the deliverable: Approved by:	Francesco Babich, Grazia Barchi, David Cennamo, Aaron Estrada, Mauro Pipiciello David Moser
Due date	30 september 2019

efre · fesr Südtirol · Alto Adige
Europäischer Fonds für regionale Entwicklung
Fondo europeo di sviluppo regionale
EUROPEAN UNION
AUTONOME PROVINZ BOZEN SÜDTIROL
PROVINCIA AUTONOMA DI BOLZANO ALTO ADIGE

Table of Contents

Executive summary

Il progetto finanziato dal Fondo Regionale per lo Sviluppo Economico "Integrids" ha il duplice obiettivo di esplorare l'interazione ed integrazione delle reti elettriche e termiche con la flessibilità degli edifici sia sviluppando modelli appropriati sia tramite la realizzazione di un laboratorio nell'area outdoor dell'Istituto di Energie Rinnovabili di Eurac Research. Il laboratorio Integrids avrà come scopo quello di connettere tramite un sistema di comunicazione dedicato i tre laboratori identificati come PV Integration, Energy Exchange e Multi-lab più una stazione meteo dedicata. Attualmente questi laboratori, già presenti o in fase di costruzione presso l'area outdoor di "advanced energy systems" di Eurac Research sono in grado di generare profili di produzione fotovoltaica, emulare il consumo tramite carichi elettronici, emulare il comportamento di un sistema di teleriscaldamento e teleraffreddamento con pompe di calore reversibili nonché testare condizioni di comfort e domanda per edifici.
Tramite l'infrastruttura che si svilupperà nel progetto Integrids, questi tre laboratori saranno in grado di scambiare dati tra loro sia di grandezze misurate, sia in futuro di controlli, alfine di effettuare test combinando più di un laboratorio alla volta. I dati scambiati saranno gestiti tramite un server centralizzato dove ci sarà un database sia di inviare le quantità di interesse da monitorare e controllare ad un unico database a cui si potrà accedere per effettuare esperimenti off-line. Il medesimo sistema centralizzato ospiterà anche sia tramite un opportuno supervisore centralizzato capace di inviare comandi da un laboratorio all'altro in base a controlli condizionali dipendenti da diversi obiettivi, quali ad esempio la massimizzazione di energie rinnovabili, la minimizzazione dei costi o delle perdite...
In definitiva l'infrastruttura del laboratorio Integrids permetterà ai tre laboratori di creare una sorta di microrete virtuali in cui non saranno possibili scambi di potenza ed energia o di calore, ma la gestione dei flussi avverrà tramite scambio di dati di produzione e consumo.
In questo report vengono descritti i tre laboratori e la tipologia di esperimenti che potranno essere svolti utilizzando l'infrastruttura INTEGRIDS.

1 Introduction

One of the main objectives of the INTEGRIDS project is to build a new laboratory infrastructure which extends the EURAC outdoor energy system facilities in order to test in the future some of the concepts proposed in the project.

The infrastructure will be mainly able to virtually connect the three existing labs, which are:

- *The PV Integration Lab*
- *The Energy Exchange Lab*
- *The Multi-Lab*

Under the framework of the INTEGRIDS project, the three existent (or under construction) laboratories are expected to work as a virtual micro-grid able to perform off-line and online experiments.

A proper communication infrastructure will be deployed to share data from one laboratory to one another. The three labs will create a sort of virtual microgrid, where no direct interaction in terms of energy/power exchange will be performed.

A dedicated database will be also developed to store all the data provided by the three laboratories and by a dedicated weather station.

A centralized energy management control will send operational signals (e.g. instructions) to the respective control system of each lab to operate for common objectives. On the other hand, the meteo station will provide weather related data to the laboratories to allow them to perform their respective operations.

The core purpose of the INTEGRIDS infrastructure is to be able to simulate as realistically as possible the interaction between the different components of different grids.

2 Collected measurements and nomenclature

To manage all the measurements acquired from the laboratories inside the Integrids net we chose a coherent approach for every lab to simplify data management and system maintenance.

We decided to use a nomenclature inspired by ISA-5.1-1984 (R1992) [2] standard. This type of nomenclature was used to built the Exchange lab, so we decided to use the experience done and we did some modification to remove constraints, due to technical .

The aim of the naming convention is to quicken the identification of the components and their associate signals and to simplify the management of the data produced by the sensors.

Each component name is composed by a Component Identifier (CI) and a Signal Identifier (SI).

The Component Identifier is used to uniquely identify each component, ranging from main machines to single sensors using a three structure. The code is composed in this manner:

P.SS(S):TT(T)NN

- P.SS(S). This part is composed as follows: first letter identifying the primary level to indicate where the component is located, after the dot there is the second level of the plant to indicate the component of the device. This part of the name is almost free, the only constraint is to have a clear meaning and to be not too long and not too short.

- TT(T). This part is the functional category to specify the function of the component. To choose this part of the code a list exists (see below) with the used codes.
- NN. This is used to distinguish multiple components of the same type in the same area.

TT(T) Legend	
AS	Air sensor
BU	Gas burner
BV	Balancing valve
CH	Chiller
CTR	Controller
CHV	Check valve
DC	Dry cooler
EM	Electricity meter
ER	Electric resistance
EV	Expansion vessel
FC	Fixed speed compressor
FC	Flow controller
FM	Flow meter
FP	Fixed speed pump
GB	Gas boiler
GM	Pyranometer
HE	Heat exchanger
HM	Heat meter
HYM	Hygrometer
HP	Compression heat pump
HV	Hand valve
IM	Current meter
MC	Machine controller
MV	Motorised valve
M2V	Motorised 2 way valve
M3V	Motorised 3 way valve
ORC	Organic Rankine Cycle engine
PI	Pressure indicator
PM	Pressure meter
PS	Pressurization system
RM	Pyrheliometer

RV	Release valve
SC	Solar collector
SF	Solar field
SV	Safety valve
TC	Temperature controller
TI	Temperature indicator
TK	Tank
TM	Temperature meter
TS	Traditional Substation
VC	Variable speed compressor
VC	Virtual component
VF	Variable speed fan
VM	Voltage meter
VP	Variable speed pump
WS	Weather station
YF	Y Filter

Signals in a lab include analogue and digital signals (possibly including specific transmission protocols), typically used for measurement acquisition and system control. The aim of this nomenclature is to have:

one signal = one process variable = one variable to store the data.

The Signal Identifier (SI) is a composition of two parts: the first one is the Component Identifier and the second one is a code of this form: QF(A)(N).

Every signal will have this format:

P.SS(S):TT(T)NNQF(A)(N)

- QF(A): the first letter (Q) indicates the physical quantity associated to the signal, the second letter (F) describes the signal function within a control loop and the last letter (A) is optional to provide additional information referred to the measured quantity.

The functional specifier, F-field, is used to clarify if the signal is a measured (Y), reference/set-point (R) or a command/control[1] (U).

The additional modifier, A-field, is used to specify details/variants of the measured quantity.

This table is an example of codes used until now.

QF(A) Legend		
Q - Physical Quantity	**F - Control Function**	**A - Additional Information (optional)**

[1] This is typically called "manipulated variable" in control theory.

T	Temperature	R	Reference	A	Absolute value (default for all the Q-field quantities except for Q = “F”)
F	Flow rate	U	Control	D	Differential (e.g., for Q = “P”) / Diffuse (for Q = “G”)
P	Pressure	Y	Measurement	G	Gauge
Q	Thermal power			V	Volumetric (default for Q = “F”)
E	Thermal energy			M	Mass
R	Thermal resistance			R	Relative
I	Electrical current				
V	Voltage				
Z	Electric resistance				
J	Electrical power				
K	Electrical energy				
G	Radiation				
W	Wind				
H	Humidity				
O	Opening				
S	Speed				
X	Length				
L	Level				
D	Deformation				
M	Mass				
N	Number				
B	Binary value (on/off)				

Analizyng the various components inside the labs that will give data to Integrids we chose the signals names in the following tables.

All foreseen signals are in the list to have a stable series of data for every experiment. If some experiments needs a subset of data for further analysis we will manage this in the experiment configuration marking signals as active or not without eliminationg them from the data saving list.

PBS First	**PBS Second**	**Component**	**Physical quantity**	**Signal Type**	**Index**	**DB String**
P	SSS	TTT	Q	F	N	
SA	Charge	Hz	I	Y		SA.Charge:HzIY

SA	Charge	Hz	V	Y		SA.Charge:HzVY
SA	String	Hz	I	Y		SA.String:HzIY
SA	String	Hz	V	Y		SA.String:HzVY
SA	Load	Hz	I	Y		SA.Load:HzIY
SA	Load	Ve	I	Y		SA.Load:VeIY
SA	Pyr	Hz	G	Y		SA.Pyr:HzGY
SA	Pyr	Ve	G	Y		SA.Pyr:VeGY
WS	TRH	TM	T	Y		WS.TRH:TMTY
WS	TRH	HYM	H	Y		WS.TRH:HYMHY
SA	AI10	AI	V	Y	10	SA.AI10:AIVY10
SA	AI11	AI	V	Y	11	SA.AI11:AIVY11
SA	AI12	AI	V	Y	12	SA.AI12:AIVY12
SA	AI13	AI	V	Y	13	SA.AI13:AIVY13
SA	AI14	AI	V	Y	14	SA.AI14:AIVY14
SA	AI15	AI	V	Y	15	SA.AI15:AIVY15
SA	AI16	AI	V	Y	16	SA.AI16:AIVY16
SA	AI17	AI	V	Y	17	SA.AI17:AIVY17
SA	AI18	AI	V	Y	18	SA.AI18:AIVY18
SA	AI19	AI	V	Y	19	SA.AI19:AIVY19
SA	AI20	AI	V	Y	20	SA.AI20:AIVY20
SA	AI21	AI	V	Y	21	SA.AI21:AIVY21
SA	AI22	AI	V	Y	22	SA.AI22:AIVY22
SA	AI23	AI	V	Y	23	SA.AI23:AIVY23
SA	AI24	AI	V	Y	24	SA.AI24:AIVY24
SA	AI25	AI	V	Y	25	SA.AI25:AIVY25
SA	AI26	AI	V	Y	26	SA.AI26:AIVY26
SA	AI27	AI	V	Y	27	SA.AI27:AIVY27
SA	AI28	AI	V	Y	28	SA.AI28:AIVY28
SA	AI29	AI	V	Y	29	SA.AI29:AIVY29
SA	AI30	AI	V	Y	30	SA.AI30:AIVY30
SA	AI31	AI	V	Y	31	SA.AI31:AIVY31
SA	Ve	C1	T	Y		SA.Ve:C1TY
SA	Ve	P1	T	Y		SA.Ve:P1TY
SA	Ve	C2	T	Y		SA.Ve:C2TY
SA	Ve	P2	T	Y		SA.Ve:P2TY
SA	Hz	C2	T	Y		SA.Hz:C2TY
SA	Hz	P1	T	Y		SA.Hz:P1TY
SA	Hz	C1	T	Y		SA.Hz:C1TY
SA	Hz	P2	T	Y		SA.Hz:P2TY
SA	RTD	TM	T	Y	8	SA.RTD:TMTY8
SA	RTD	TM	T	Y	9	SA.RTD:TMTY9
SA	RTD	TM	T	Y	10	SA.RTD:TMTY10
SA	RTD	TM	T	Y	11	SA.RTD:TMTY11
MPPT	Ve	Batt	V	Y		MPPT.Ve:BattVY
MPPT	Ve	String	V	Y		MPPT.Ve:StringVY
MPPT	Ve	String	I	Y		MPPT.Ve:StringIY

MPPT	Ve	Charge	J	Y		MPPT.Ve:ChargeJY
MPPT	Ve	Energy	K	Y		MPPT.Ve:EnergyKY
MPPT	Ve	BattMax	V	Y		MPPT.Ve:BattMaxVY
MPPT	Ve	BattMin	V	Y		MPPT.Ve:BattMinVY
MPPT	Ve	SOC	L	Y		MPPT.Ve:SOCLY
MPPT	Ve	Batt	T	Y		MPPT.Ve:BattTY
MPPT	Ve	Loc	T	Y		MPPT.Ve:LocTY
MPPT	Ve	Batt	L	Y		MPPT.Ve:BattLY
MPPT	Ve	Charge	L	Y		MPPT.Ve:ChargeLY
MPPT	Hz	Batt	V	Y		MPPT.Hz:BattVY
MPPT	Hz	String	V	Y		MPPT.Hz:StringVY
MPPT	Hz	String	I	Y		MPPT.Hz:StringIY
MPPT	Hz	Charge	J	Y		MPPT.Hz:ChargeJY
MPPT	Hz	Energy	K	Y		MPPT.Hz:EnergyKY
MPPT	Hz	BattMax	V	Y		MPPT.Hz:BattMaxVY
MPPT	Hz	BattMin	V	Y		MPPT.Hz:BattMinVY
MPPT	Hz	SOC	L	Y		MPPT.Hz:SOCLY
MPPT	Hz	Batt	T	Y		MPPT.Hz:BattTY
MPPT	Hz	Loc	T	Y		MPPT.Hz:LocTY
MPPT	Hz	Batt	L	Y		MPPT.Hz:BattLY
MPPT	Hz	Charge	L	Y		MPPT.Hz:ChargeLY

Table 1: PV Integration Stand Alone experiment

PBS First	PBS Second	Component	Physical quantity	Signal Type	Index	DB String
P	SSS	TTT	Q	F	N	
W	DL	S1	T	Y		W.DL:S1TY
W	DR	S1	T	Y		W.DR:S1TY
W	DL	S2	T	Y		W.DL:S2TY
W	DR	S2	T	Y		W.DR:S2TY
W	DL	S3	T	Y		W.DL:S3TY
W	DR	S3	T	Y		W.DR:S3TY
W	DC	S5	T	Y		W.DC:S5TY
W	TL	S1	T	Y		W.TL:S1TY
W	TR	S1	T	Y		W.TR:S1TY
W	TL	S2	T	Y		W.TL:S2TY
W	TR	S2	T	Y		W.TR:S2TY
W	TL	S3	T	Y		W.TL:S3TY
W	TR	S3	T	Y		W.TR:S3TY
W	TC	S5	T	Y		W.TC:S5TY
W	CC	RTD	T	Y		W.CC:RTDTY
W	CC	RTD	T	Y		W.CC:RTDTY
W	DL	A1	T	Y		W.DL:A1TY
W	DR	A1	T	Y		W.DR:A1TY
W	DL	A2	T	Y		W.DL:A2TY
W	DR	A2	T	Y		W.DR:A2TY
W	DR	A3	T	Y		W.DR:A3TY
W	DL	A3	T	Y		W.DL:A3TY
W	DL	S4	T	Y		W.DL:S4TY
W	DR	S4	T	Y		W.DR:S4TY
W	TL	A1	T	Y		W.TL:A1TY
W	TR	A1	T	Y		W.TR:A1TY
W	TL	A3	T	Y		W.TL:A3TY
W	TR	A3	T	Y		W.TR:A3TY
W	TL	S4	T	Y		W.TL:S4TY
W	TR	S4	T	Y		W.TR:S4TY
W	CC	C14	T	Y		W.CC:C14TY
W	Pyra	GM	G	Y		W.Pyra:GMGY
W	Anem	AS	W	Y		W.Anem:ASWY
W	CC	AI	V	Y	1	W.CC:AIVY1
W	CC	AI	V	Y	2	W.CC:AIVY2
W	CC	AI	V	Y	3	W.CC:AIVY3
W	CC	AI	V	Y	4	W.CC:AIVY4
W	CC	AI	V	Y	5	W.CC:AIVY5
W	CC	AI	V	Y	6	W.CC:AIVY6
W	CC	AI	V	Y	7	W.CC:AIVY7
W	CC	AI	V	Y	8	W.CC:AIVY8
W	CC	AI	V	Y	9	W.CC:AIVY9
W	CC	AI	V	Y	10	W.CC:AIVY10

W	CC	AI	V	Y	11	W.CC:AIVY11
W	CC	AI	V	Y	12	W.CC:AIVY12
W	CC	AI	V	Y	13	W.CC:AIVY13
W	CC	AI	V	Y	14	W.CC:AIVY14
W	CC	AI	V	Y	15	W.CC:AIVY15
W	CC	AI	V	Y	16	W.CC:AIVY16
W	CC	AI	V	Y	17	W.CC:AIVY17
W	CC	AI	V	Y	18	W.CC:AIVY18
W	CC	AI	V	Y	19	W.CC:AIVY19
W	CC	AI	V	Y	20	W.CC:AIVY20
W	CC	AI	V	Y	21	W.CC:AIVY21
W	CC	AI	V	Y	22	W.CC:AIVY22
W	CC	AI	V	Y	23	W.CC:AIVY23
W	CC	AI	V	Y	24	W.CC:AIVY24
W	CC	AI	V	Y	25	W.CC:AIVY25
W	CC	AI	V	Y	26	W.CC:AIVY26
W	CC	AI	V	Y	27	W.CC:AIVY27
W	CC	AI	V	Y	28	W.CC:AIVY28
W	CC	AI	V	Y	29	W.CC:AIVY29
W	CC	AI	V	Y	30	W.CC:AIVY30
W	CC	AI	V	Y	31	W.CC:AIVY31
W	CC	DO	B	R	0	W.CC:DOBR0
W	CC	DO	B	R	1	W.CC:DOBR1
W	CC	DO	B	R	2	W.CC:DOBR2
W	CC	DO	B	R	3	W.CC:DOBR3
W	CC	DO	B	R	4	W.CC:DOBR4
W	CC	DO	B	R	5	W.CC:DOBR5
W	CC	DO	B	R	6	W.CC:DOBR6
W	CC	DO	B	R	7	W.CC:DOBR7
MPPT	T	Batt	V	Y		MPPT.T:BattVY
MPPT	T	Charge	L	Y		MPPT.T:ChargeLY
MPPT	B	Batt	L	Y		MPPT.B:BattLY
MPPT	B	Charge	V	Y		MPPT.B:ChargeVY

Table 2: PV Integration mock up facade experiment

3 Data management

This section reports how we manage data storage from different laboratories and how we plan to integrate information in order to perform different experiments on INTEGRIDS. Such tasks are accomplished through a unique application interface that serves as bridge between all the involved systems.

3.1 System description

Each laboratory system is able to produce different data as output that can be used later on in order to perform experiments. Moreover, each system uses specific database technologies while signal conventions might be slightly different, depending strictly on each laboratory. As result, integrating data across laboratories becomes difficult because: (1) each system needs to implement the same connection interface to access to each database, and; (2) data structures are different, and each system needs to know exactly how to process such data once retrieved.

In order to overcome such problems, we implemented am Application Programming Interface (API) that works as a bridge between each laboratory system to store data, allowing also to read produced data, making it possible to integrate information to perform different experiments. This means that all laboratory systems implement a unique connection interface to the API by following the same rules to read/write data, while the API knows how to process, store and retrieve data from each database technology. Having an API also minimizes modifications whenever there are changes about data storage or retrieval (e.g. use of a new database technology); in that case none of the laboratory systems need to be re-adapted with new changes.

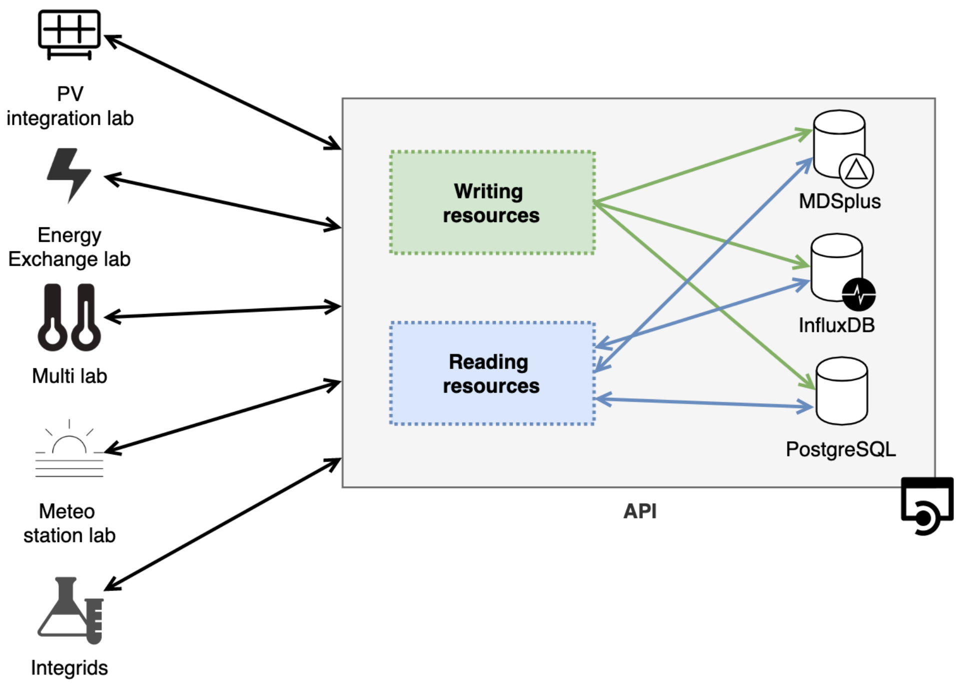


Figure 1. Representation of the API implementation to access data from and to different database technologies.

3.2 System features

The API system was implemented following a Representational State Transfer (REST) architecture, in which no sessions are allowed. Instead, the API implements security authentication and authorization through token validation. This means that each laboratory system can access to specific resources, preventing writing/reading data from unauthorized sources.

The API defines resources to access to different database technologies through specific uniform resource locations (URL). In order to differentiate between data storage and reading, the API defines different access methods (GET, POST, etc.). Depending on the method, resources accept different inputs, returning a status code and some output as result; inputs and outputs are in JavaScript Object Notation (JSON) format.

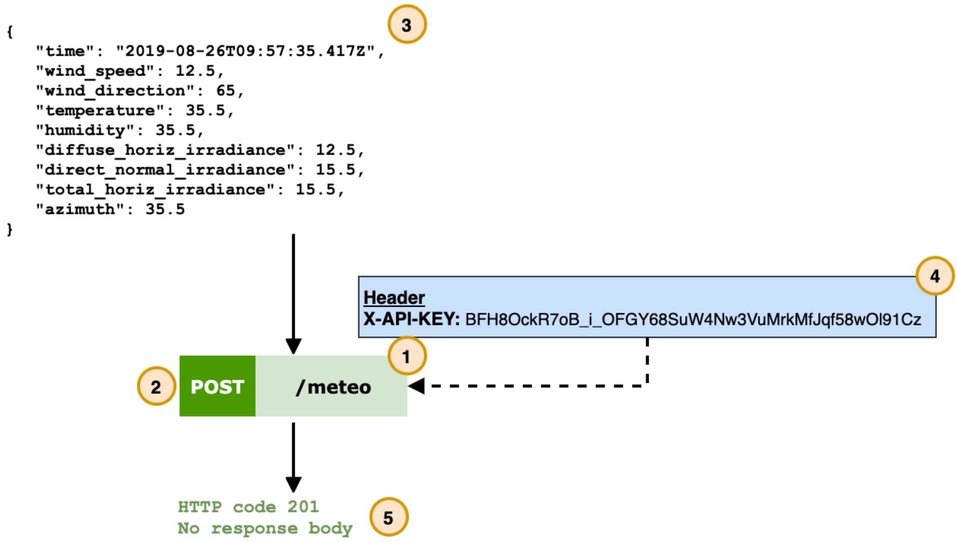


Figure 2. Example of resource endpoint to write data from Meteo Station laboratory. Each resource has: (1) a specific URL; (2) a method verb; (3) an input in JSON format; (4) a token specification for authorization purposes, and; (5) A status code and body as response.

The application is implemented with Flask, a web framework developed in Python, using also the Flask-Restplus library to create APIs and generate documentation for different input/output for each resource. We use Gunicorn as Web Server Gateway Interface (WSGI) to deploy the system.

4 Single laboratory experiments

In this chapter we report a brief recall to the single laboratory description which is useful to better understand the type of experiments that can be performed in each single laboratory. For clarity we mention that some of them have been designed or developed outside INTEGRIDS project, however they will be part of INTEGRIDS infrastructures and database.

4.1 Energy Exchange lab

This section reports the description of some tests foreseen to be carried out at the EURAC pilot laboratory “Energy Exchange”. The main goal of these tests is to compare different control strategies applied to prosumer substation of fifth generation district heating and cooling (5GDHC) networks. These networks employ decentralised water source heat pumps at the building site. Unlike traditional high-temperature district heating, 5GDHC systems exploit a network operating at a temperature close to the ground (10-25°C) achieving negligible thermal losses and allowing for bidirectional thermal energy flow [1]

In the following we will name this deterministic approach as “basic” control. A more complex approach consists in integrating forecasts/prediction into the control logic. In this way, it is possible to anticipate the system behaviour and to act with proper advance in order to avoid critical operating conditions. For example, energy storages can pre-charged in view of high demand periods (or in view of periods of higher energy prices at the available sources). In order to be able to predict the future evolution of the system, a suitable model is needed. This model can then be run multiple times on a certain horizon while varying the available free control parameters (such as set point values), in order to find their optimal values. This process can be made efficient through special optimization algorithms. Once optimal control parameters have been identified, control can be adjusted, and another iterative step can start. In this way, control is progressively updated at discrete instants. The ideal period of these iterations depends on the change velocity of the system, while it is limited by the time needed to run the model within the optimizer. As such, this approach is typically named model predictive control (MPC). While we denote deterministic control as “basic” control, we use the expression “advanced” control for MPC and other similar solutions.

4.1.1 The Energy Exchange Lab description

The Energy Exchange Laboratory of Eurac Research installed at the NOI tech-park in Bolzano (Italy). The system can be set in different configurations using different energy sources and sinks in order to reproduce a small-scale 5GDHC network. Though a general description of the laboratory was provided in Deliverable D5.1, this subsection shortly reviews its main content with a focus on heat pump (HP) substations. The laboratory includes:

- The poly-generation producer substations where the thermal energy can be supplied by a parabolic trough collector field or a gas boiler by means of a diathermic oil circuit. Moreover, the thermal energy can be supplied to a water circuit through a heat exchanger, it can be converted in electricity in a micro-ORC unit or it can be used to run an absorption chiller for chilling water production.
- A distribution network made by a compact connection of insulated stainless-steel pipelines with a total length of about 100 meters. It can be set up in different configurations thanks to several ports where the producer substations and prosumer substations can be connected by means of flexible pipes. Moreover, it includes a centralised water-based thermal energy storage (TES) of 2000 litres.
- The prosumer substations including two electrical driven water-source heat pumps operating with the refrigerant R410a (HP1 and HP2 in Figure 1) and a substation for traditional high-temperature district heating (DH).
- A heat rejection circuit, consisting of a dry-cooler and a buffer water-based TES. It is used to emulate the building loads by providing a suitable return temperature to the 5GDHC prosumer substations.

The Energy Exchange Laboratory configuration considered in this study and shown in Figure 1 includes part of the components listed above. In particular, the thermal network is set up by considering a traditional two-pipe distribution with supply and return pipelines connected at the end by means of a bypass. This bypass is needed in order to satisfy the mass balance of the system when a difference of the mass flow rates between the producer substation and the prosumer substations occurs. The producer substation is operated in balanced mode where the thermal energy extracted by the heat pumps from the network is provided instantaneously by the gas boiler to the water circuit by means of a flat-plate heat exchanger. The thermal energy is supplied at the beginning of the DHC network through the so-called “PS2” port. The two 5GDHC prosumer substations are operated and connected to the DHC network by means of flexible pipes through the so-called “P1.1” and “P2.1” ports. As far as the prosumer substations are concerned, it can be seen that some components of a typical 5GDHC substation are missing. In particular, both the domestic hot water (DHW) and the space heating (SH) tanks are not physically present in the laboratory. The behaviour of these components is emulated by means of real-time models in order to supply to the heat pumps a suitable return temperature as in a real substation. The emulation process and modelling approach are described in the next sections.

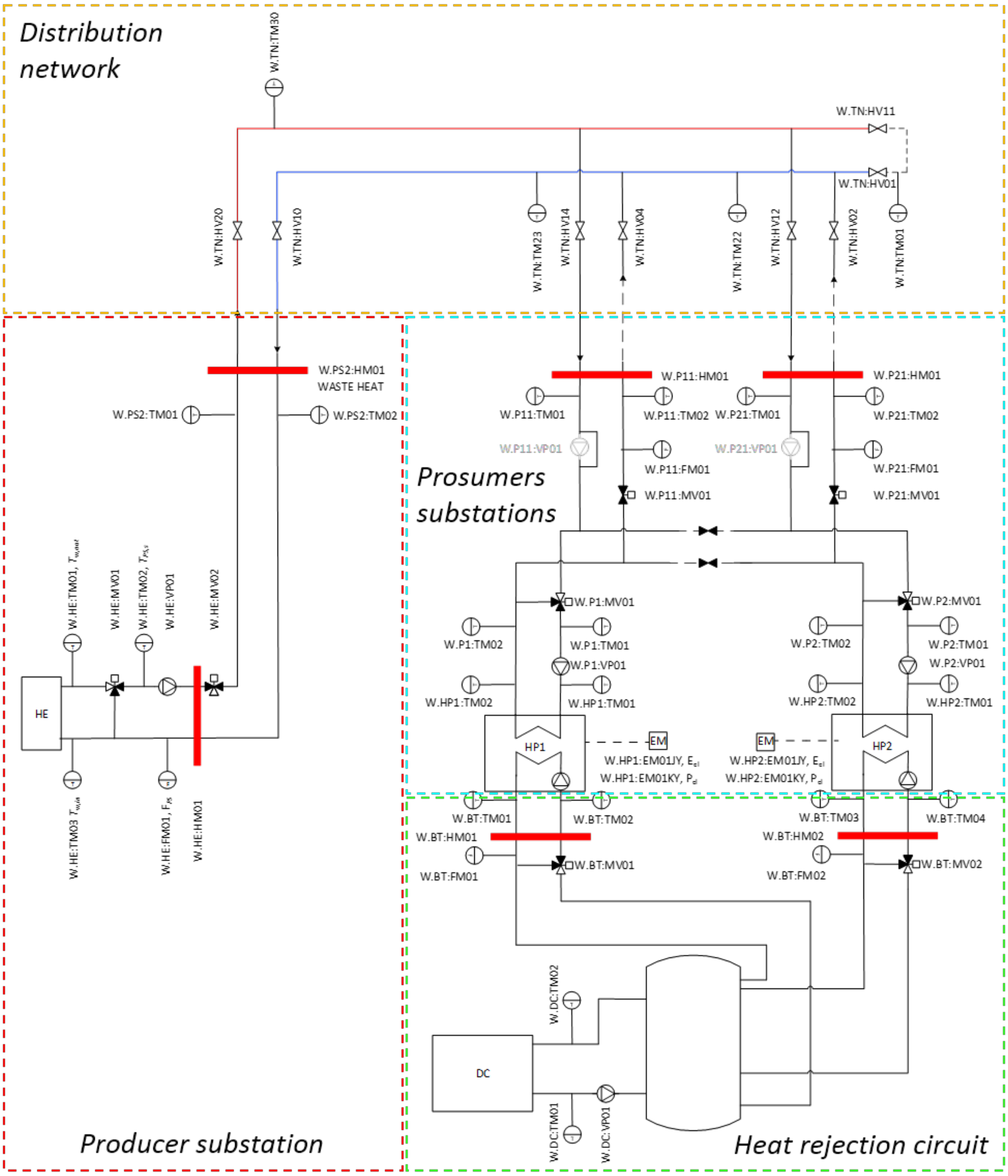


Figure 3. Configuration of the Energy Exchange Laboratory water circuit of Eurac Research

4.1.2 Domestic hot water (DHW) and space heating (SH) tanks emulation

The Energy Exchange Lab was not designed to include separate tanks for space heating (SH) and domestic hot water (DHW) for each substation. As it is shown in Figure 1, only a single buffer tank of 2000 litres is available in the heat rejection circuit for both the heat pumps. This buffer is properly conditioned by means of a dry cooler so that it was possible to tune the return temperature to the HPs with proper recirculation solutions. For example, concerning the HP1 the mixing valve W.BT.MV01 shown in both Figure 1 and Figure 2 allows achieving a close to reality return temperature if the substation is operated in space heating or domestic hot water production mode, respectively.

It was hence decided to implement virtual models of the DHW tank and of the SH buffer present in a 5GDHC substation.

Figure 2 aims at clarifying the emulation process of the two tanks and domestic hot water and space heating loads for the prosumer that exploit the substation HP1. In particular:

- The boundary highlighted in light red in Figure 2 includes the physical components installed at the test facility for the substation. These are the HP coupled with the hydraulic pumps and the mixing valves on both evaporator and condenser side. The electrical energy consumption of the substation, the thermal energy flows extracted from the network by the HP and supplied to the tanks are measured by means of electrical and heat meters.

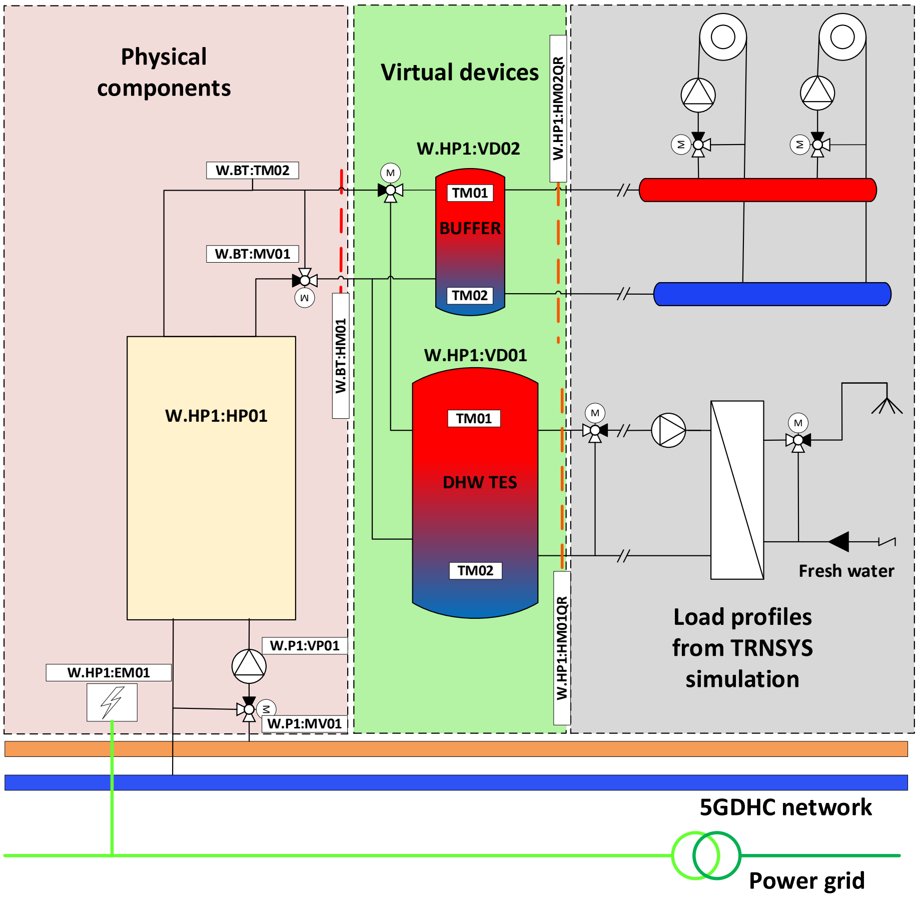


Figure 4. Buffer and DHW TES (virtual devices) emulated at the Energy Exchange lab.

- The boundary highlighted in light green in Figure 2 includes the virtual components that have been emulated by means of reduced order models (ROM) based on artificial neural networks (ANN). These components are the DHW and SH tanks. The flow deviation obtained through the diverting valve is emulated by virtually suppling the thermal energy to the DHW or the SH tank according to the operation in DHW or SH production mode, respectively.
- The boundary highlighted in light grey represents the load profile that has been adopted as boundary condition of the laboratory tests. These profiles are the thermal energy supplied to the space heating and DHW distribution systems obtained from numerical simulation in TRNSYS. The DHW distribution consists of the exploitation of decentralised heat exchangers for instantaneous hot water production in small multi-family houses.

4.1.3 Description of the control strategies tested

This chapter describes the implementation of the control strategies tested at the Energy Exchange lab. The aim of these tests is to compare the assessment of the impact in the substation performance and end user's total bill for DHW production under three different control strategies.

Three kinds of decentralised control of the substation have been considered and in particular:

- Rule based control strategy that has been assumed as baseline;
- Rule base control plus deterministic demand response strategy;
- Advanced control strategy: rule-based control plus model predictive demand response strategy.

In the following a description of the control strategies.

Rule based control strategies

The baseline scenario considered takes into account the operation of the substation by means of a deterministic rule-based controller (RBC). This control strategy has been implemented for the two prosumer substations presented above. In particular, it consists of two mutually exclusive hysteresis that control the temperature at the top of DHW TES and at the top of the space heating TES in winter time (thermostatic control in Figure 3. The control of the DHW TES has priority over the control of the buffer TES.

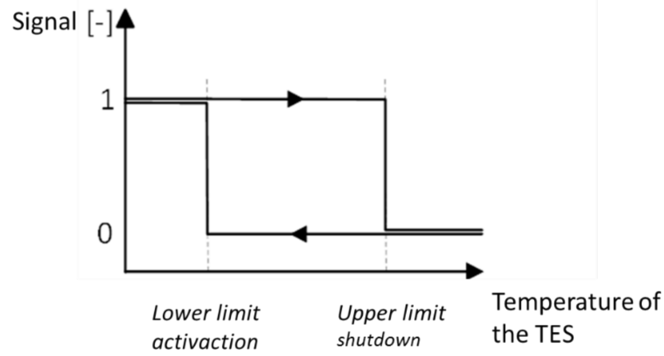


Figure 5: Thermostatic control for heating a TES.

The limit for the activation and shutdown of the two different hysteresis are listed in Table 1.

Table 3: Parameters of the thermostatic control hysteresis.

Hysteresis name	Acquisition signal	Lower limit activation	Upper limit shutdown
Signal A	Top temperature of the DHW TES (TM1) to assess if the energy content is sufficiently high to cover the DHW request.	45 °C	50 °C
Signal B	Top temperature of the buffer TES (TM3)	32°C	38°C

The resulting rule-based control algorithm that activates the prosumer substation in space heating or DHW production mode is a combination of the output of the two hysteresis. In particular, the HP is turned on according with the following rule

$$HP\ ON = (DHW\ scheme) OR\ (SH\ scheme)\ ,$$

where the two operating schemes are activating according with the following rules

$$DHW\ scheme = signal\ A\ ,$$

$$SH\ scheme = NOT(signal\ A) \times signal\ B\ .$$

The negation of the $signal\ A$ in the SH scheme equation guarantees the mutual exclusion of the DHW and SH operation modes.

Since at the test bench the buffer and the DHW TES for each substation are not physically present, there was the need to reproduce their behaviour during the charging and discharging processes as above. The LabVIEW code implemented at the test bench operates so that the TES ANN models are updated every three minutes, taking into account the thermal energy supplied by the HP to the TES and the thermal energy extracted from the TES to cover the loads. The duration of this time step has been fixed in order to allow the PID controller of the motorised mixing valve W.BT:MV01 and W.BT:MV02 to reach the return temperature set point provided by the ANN model. The result of the TES emulation are temperature signals that are used to activate the rule-based control described above.

Rule base control plus deterministic demand response strategy

The second control strategy investigated is based on the rule base control of the substation (as described above) coupled with the time-of-use (TOU) demand response strategy. The demand response (DR) is one of the demand side management (DSM) strategies those includes a portfolio of practices aiming to modifying the demand side of an energy system [1]. The time-of-use (TOU) demand response strategy is based on a predefined variation of electricity prices generally within the day and the week and on the exploitation of the DHW TES capacity of a single substation that is charged to a higher temperature before the increase of the electric energy price. The aim of the developed control strategies is to shift the DHW production from high-cost (peak) to low-cost (off-peak) hours exploiting the capacity of the DHW TES.

The TOU DR program investigated here, based on the Italian tariff D1 taken as a reference, distinguishes peak hours (from 8:00 until 19:00) from the remaining off-peak hours. During weekend days, only the off-peak tariff is applied. The DR signal is activated only once a day for one hour preceding the increment of tariff as it is shown in Figure 4**.** During this period the DHW TES hysteresis upper dead band (Tdhw,h) is shifted from 50°C to 55°C so that as much as thermal energy is stored.

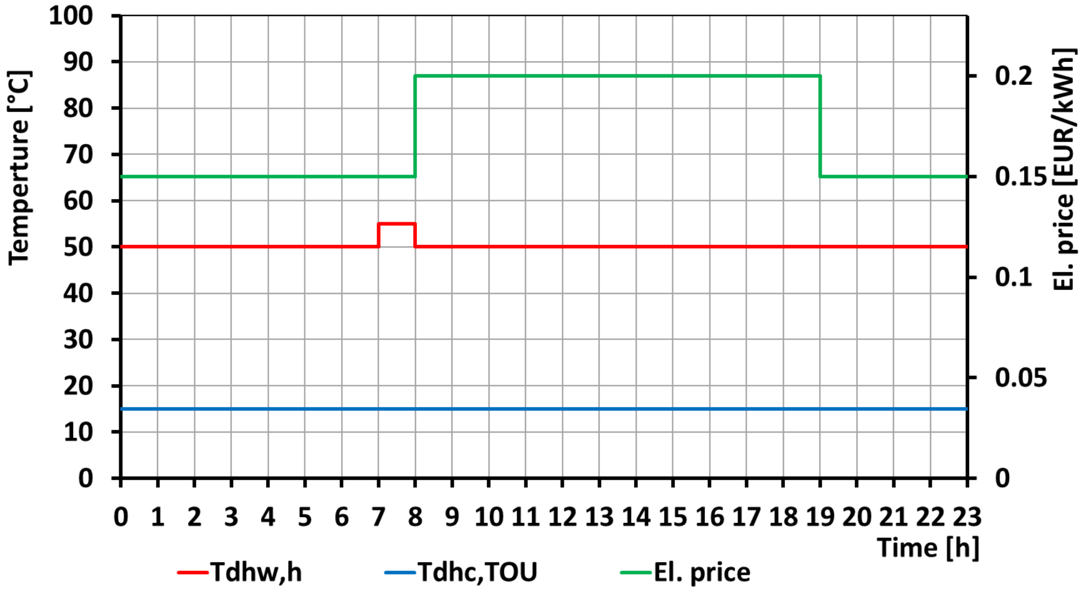


Figure 6. Description of the TOU DR program considered

Advanced control strategy: rule-based control plus model predictive demand response strategy.

The aim of the test is to assess the MPC performance to minimise the operating cost of a single substation for the DHW production.

The objective function to be minimised is the operating cost for the DHW production of the substation under variable boundary conditions that evolve along the prediction horizon. The operating costs of a 5GDHC substation include the cost for the electrical energy taken from the grid and the cost for the thermal energy taken from the DHC network. The variable boundary conditions include the variable price of the electricity $c_{el}(t_j)$ [€/kWh] hour by hour according to a Time-of-Use tariff variation. The price of thermal energy taken from the DHC network $c_{th}(t_j)$ [€/kWh] and the temperature of the thermal network have been fixed constants.

In general, MPC employs a model of the process. This identification phase is usually high demanding in terms of effort, depending on the complexity of the process or on the grade of detail to achieve. Once the model of the process has been identified, it is used to make prediction of the future output of the process according to a sequence of future inputs that one would like to apply. Taking into consideration the different evolutions of the process that are a consequence of the different future inputs sequences, the MPC is able to choose the sequence of control actions that minimises (or maximises) a given performance indicator over a time window. The vector representing the “best” control action sequence $\bar{u}^*(t)$ is a result of a constrained optimization problem that it is needed to be solved in real-time at each control time step. Only the first element u_0^* is applied to the process at the current time-step t throwing away the rest of the “best” control action sequence. At the next time step $t+1$, once the new measurements have been got, the optimization problem is solved again considering a *prediction horizon* shifted of one-time step as it is shown in Figure 15. In this study a control time step of 30 minutes has been adopted.

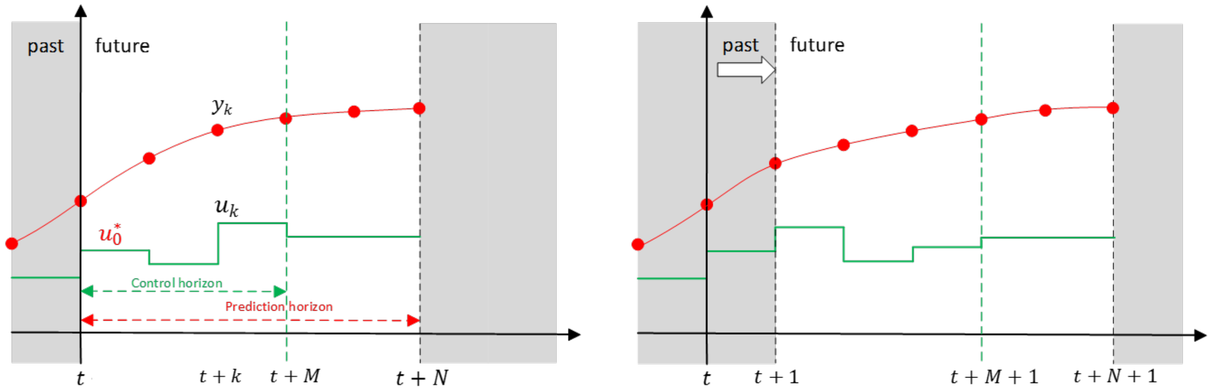


Figure 7: Receding horizon control approach.

This methodology is the so-called *receding horizon* control approach. It consists of a time window that moves forward at each iteration with a step of one control time step. On one hand, the length N of this time window is constant and equal to the *prediction horizon* (future time interval in which the outputs of the model are computed). On the other hand, the *control horizon* has a length M is equal to the “best” control action sequence resulted from the optimization problem. It is a common rule to adopt a control horizon shorter than the prediction horizon ($M < N$). The larger the control horizon, the harder is the optimization problem to solve. This could compromise the speed of the MPC. Thus, in this study a “move blocking scheme” has been applied so that the last input of the control horizon is keep constant and used in the prediction horizon. For the test described above the prediction horizon has been limited to 4 control time steps (2 hours) whereas the control horizon has been limited to 2 control time steps. The first element of the optimal trajectory provided by the algorithm is sent as control input to the plant whereas the second element of the optimal trajectory is used as a reference value for the rest of the prediction horizon.

In this case study the control input of the MPC u_0^* consists of the thermal energy that should be provided by the HP to the DHW TES at every control time step (30 minutes). The output of the MPC controller y_0^* is a temperature set point that should be maintained in the DHW TES. This reference is sent to the plant that turn on the HP in the DHW mode if the measured DHW TES temperature is lower than the MPC temperature set point. Once the value measured DHW TES temperature is equivalent to the temperature set point y_0^*, the DHW scheme is deactivated. To avoid very high return temperature to the HP in case of mismatch between actual and predicted DHW load, an additional hysteresis has been used so that the MPC signal is ignored once the temperature of the DHW TES reach 55°C. The lower limit for the activation of this hysteresis has been fixed to 53°C so that the output of the MPC controller is enabled once the DHW TES has been discharged up to this value. Moreover, the MPC has been implemented so that the rule-based control described in the previous section can operate in parallel as a back-up controller according with the scheme of Figure 6. This could occur in case of underestimation of the DHW load by the MPC.

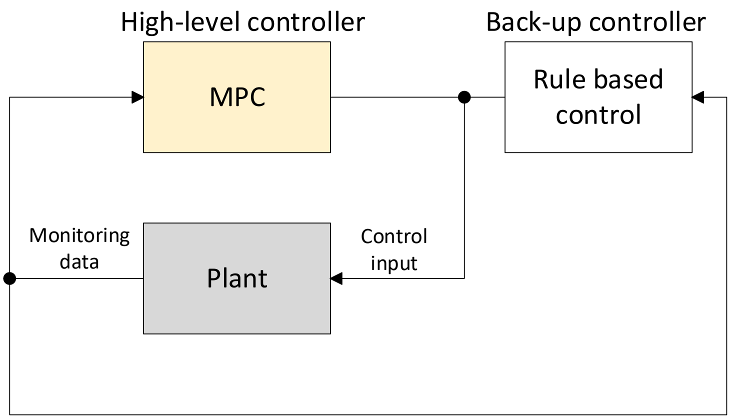


Figure 8: Integration of the MPC with the back-up controller.

Concerning the model adopted by the MPC, it consists of a data driven model based on an Artificial Neural Network (ANN). This model is first initialized and then called several times until the optimization algorithm reaches convergence at each control step of 30 minutes. In the LabVIEW code the MPC components described above have been integrated according to the scheme of Figure 7. In particular, the vector of 4 external variables $w(t)$ including the perfect prediction of the DHW load, the prediction of the 5GDHC network temperature (set constant at 15°C), whereas the electricity price and DHC thermal energy price profiles are computed externally at each control step. They are evaluated for the entire length of the prediction horizon. The optimal control trajectory provided by the optimization algorithm $v(t)$ together with the vector of external variables $w(t)$ represent the input vector $u(t)$ that is applied to the model. During the online MPC simulation the estimation of the substation performance along the prediction horizon are sent to the cost function evaluation module.

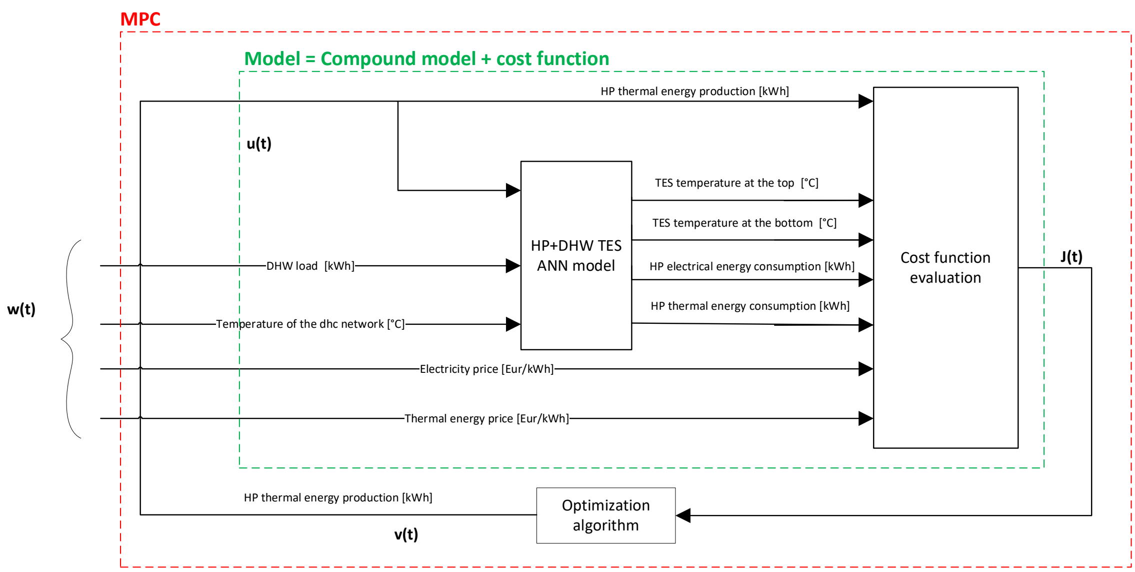
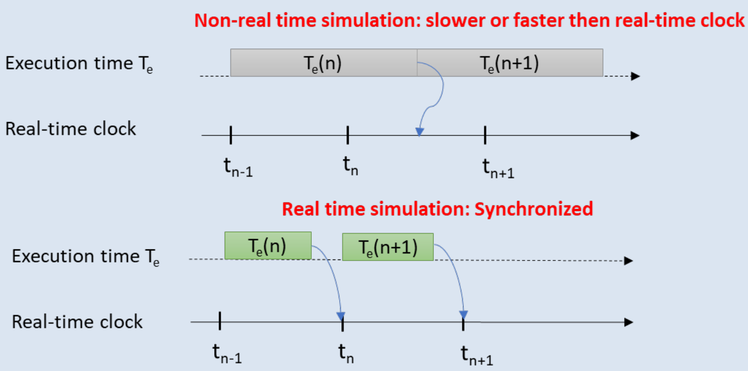


Figure 9: Flow chart of the MPC component integration in the LabVIEW code.

4.2 PV integration lab

Title	Evaluation of outdoor and in-field PV modules
Lab involved	PV integration
Objective	Evaluate the PV module electric performance, degradation and production in real-field installation
Description	The performance and electric characteristics of a PV module are usually defined through rigorous procedures to assure the repeatability and traceability of the measured quantities. However, on-field performance characterization based on the real position and inclination of the PV module in a roof or facade, as well as real weather condition exposition can significantly affect the behavior, production, and durability of the module under test. For this reason, the PV integration laboratory is composed of different architectonic infrastructure where PV modules, from different manufacturers and also from different materials, can be tested and compared for a long time. D5.1 describes the three different infrastructure where it is possible to install the PV modules. They are the rotating roof, the facade infrastructure, the container for stand-alone system and earth installation. Specific sensors (i.e., thermocouple, pyranometers, energy meter) are installed to acquire all interested measurements (such as the irradiance, the ambient temperature, and the PV temperature, the voltage and current) which could characterize the production of thePV module.
Expected results	Characterize the PV module electrical performances in a real installation outdoor environment.

Title	Evaluation of grid connected inverters/power optimiser/fire protection
Lab involved	PV integration
Objective	Measure the efficiency of PV inverters in DC/AC conversion and in MPPT tracking. Evaluate the use of power optimisers and devices for fire protection and rapid shotdown at single module level.
Description	A PV simulator or real PV system can be used to check the efficiency of a PV inverter. Rooftop PV system can present microinverters or power optimisers solutions which can also be used for rapid shotdown in case of safety issues.
Expected results	Characterisation of the DC/AC power conversion and safety aspects.

Title	Real-time and non-real time simulation of electricity grid in presence of PV generation and EV loads
Lab involved	PV integration
Objective	Evaluate the impact of PV production or/and EV loads in a distribution grid
Description	"A system is said to be real-time if the total correctness of an operation depends not only upon its logical correctness but also upon the time in which it is performed" [2]. Real-time simulation refers to a computer model of a physical system that can execute at the same rate as actual clock time. Type of these simulations have: • Discrete-time simulation of dynamics/transients • Constant step size • Make sense in combination with interfaces to the real world → Hardware in the loop (described in the next table) Generally, as reported in the literature, a real-time task responds to the following requirements:  *Figure 10 - Non-real time and real-time simulations time schedule* RT simulations applied to the power system can be divided into two categories: 1) fully digital real-time simulation (e.g., model-in-the-loop, software-in-the-loop or processor-in-the-loop) and 2) hardware in the loop (HIL) described in the next table. The first category wants that all system (including control, protection, and other parts) is modelled inside the simulator and do not requires external interfacing or input/output. This is the type of simulation in which we are interested here. Several different model can be developed in order to evaluate the impact of PV generation (or EV load) in a distribution grid. In general, the necessary steps are the following: 1) Model the distribution electricity grid in software environment 2) Test the correctness of model through non-real time simulation 3) Adapt the model to be simulated with the real-time target OPAL-RT 4510 [3].

<table>
<tr>
<td></td>
<td>

4) Use the measured data (e.g. PV production) collected in INTEGRIDS database

The OPAL-RT simulator thanks to the software can perform load flow and phasor analysis of large distribution grid which correspond for example to a whole city. However, in this kind of simulations more than real-time characteristics is used the computational power of the device, because the phasors regime requires an almost static.

The real-time simulation become very meaningful in presence of electric transient (due to electro-magnetic or electromechanical components in power systems) and when there is interest to include and study the behaviour of power electronic devices. Indeed, power electronics operates at high switching time (order or microsec) which can affect the operation of the rest of the grid.

This type of models and simulations are fundamental to really understand and estimate the impact of PV, but also electric vehicle, storages in the grid due to the fact they are all connected through a power converter.

An example of a micro-grid demo that presents operation of a PV unit and lead-acid battery feeding an AC load is reported below.

In this demo-example the DC bus voltage is regulated with a PI controller. If PV's current is below a set-point (10A) and the battery's state of charge is enough (initially set as 90%), then the battery provides the power. If PV's current is bigger than the set-point and the battery's state of charge is below of its limit, then the battery is charged by PV. The solar radiation and temperature can be controlled from the console subsystem. The capacitor of the boost converter is used in a Stubline to decouple the system.

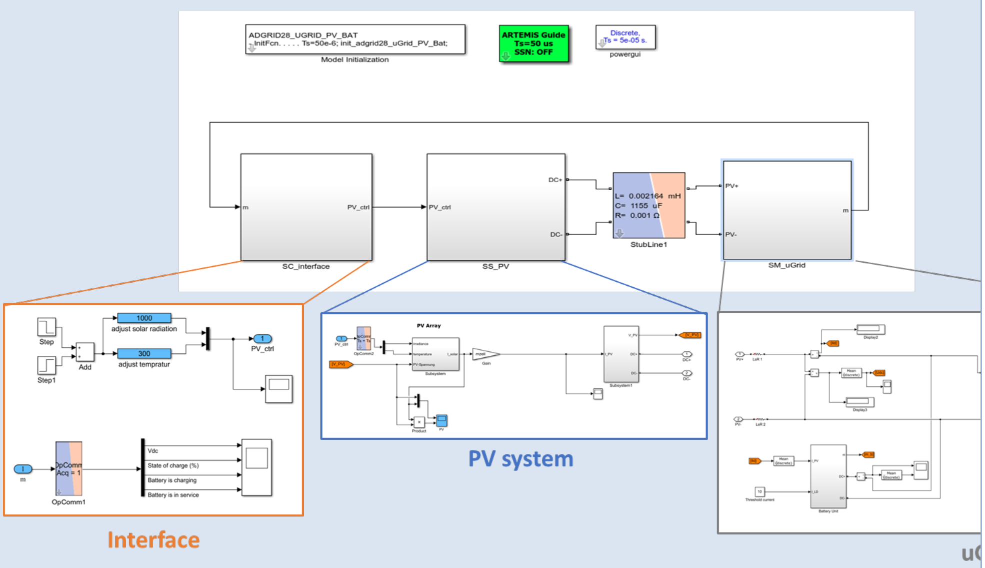
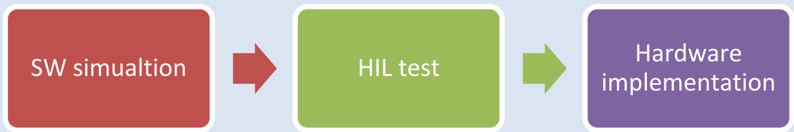


Figure 11 - Example of Simulink model to run in Opal-RT that presents a PV system and lead-acid battery feeding into the AC grid. Present in RT-LAB example [3].

</td>
</tr>
<tr>
<td>**Expected results**</td>
<td>Quantitative evaluation of the impact of photovoltaic generator in a distribution grid considering a real-time behaviour of the operations.</td>
</tr>
</table>

Title	**Hardware in the loop (HIL) for control and protection in smart grid**

<table>
<tr><td>Lab involved</td><td>PV integration</td></tr>
<tr><td>Objective</td><td>Test and evaluate the performance of a device for control and/or protection in the smart grid context</td></tr>
<tr><td>Description</td><td>A dedicated platform for HIL test acquired thanks to INTEGRIDS project is the RTS Opal-RT 4510 [3]. A Hardware in the loop simulation refers to a simulation in which parts of the system are replaced with actual physical components. This type of simulation can be used for a different purpose:
i) To understand the behavior of a new device
ii) To evaluate the performance of a device out of standard working behavior
iii) Help in the definition of the model and validate the model with the device itself.
If there is power transfer from/to the power the test is called power in the loop simulation, and this requires a specific power amplifier connected to the RTS. In the most common case, the HIL is used for controller simulation, and in this case, the power system part is simulated on the computer while the signal of control is given by the external Hardware.
The HIL is particularly useful in the design procedure for a controller under test (CUT)


Possible CUT in power system context are:
• Protection equipment
• Motor controllers
• PWM controllers
• Inverter controllers
It is remarkable that this process is particularly useful to save money in a new device or before to place a certain device in the field and force it to work in extreme conditions.</td></tr>
<tr><td>Expected results</td><td>Evaluation of performance of new products or behaviour in non-conventional working or support the model definition and check with the real hardware.</td></tr>
</table>

Title	**Test of PV inverter**
Lab involved	PV integration
Objective	Evaluate PV inverter performances
Description	In order to minimize the losses of a system, it is essential to use suitably-sized inverters. These must be able to convert the electricity generated from DC to AC with a high-efficiency level and to push photovoltaic modules to work at their maximum power point. By using a string PV emulator, it is

	possible to measure the performances of a solar inverter according to IEC 50530 standard. To perform this type of test, the PV integration lab is provided by a PV simulator, which taking as input irradiance data and I-V curve, can provide a suitable electrical range for standard compliances up to 5kW [4].
Expected results	Characterize the PV inverter quantities according to IEC 50530 standard.

<table>
<tr><th>Title</th><th>Test and development of control logics for PV combined with BESS and EV</th></tr>
<tr><td>Lab involved</td><td>PV integration</td></tr>
<tr><td>Objective</td><td>Evaluate the energy storage performances or the behaviour of the battery combined with PV in buildings</td></tr>
<tr><td>Description</td><td>

A standard photovoltaic system connected to a system of electric accumulations and electronic loads allows innovative storage systems to be tested. Accumulation systems are the key to optimising the ratio between energy produced locally and energy consumed, especially in buildings.

Example of possible experiment which can be performed have been published by Eurac researcher in [5]. A small-scale prototype of PV-BESS-EV for a commercial building have been developed and installed in the PV integration area with the collaboration with building energy management and a battery producer within a European project. Ad hoc control strategy has been developed to maximize the renewable energy consumption for EV. The strategy reported in [5] is shown below.

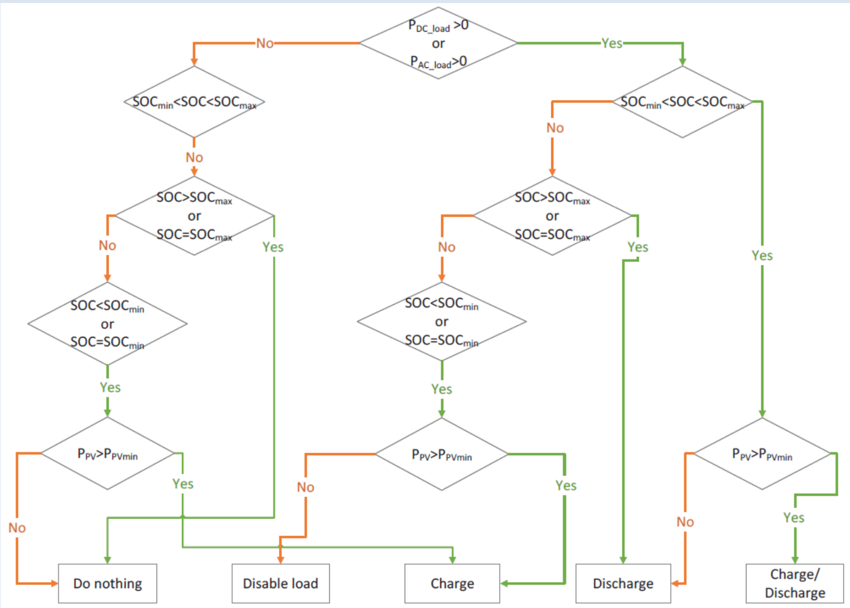


Figure 12 - Flowchart of the control algorithm implemented into the BEMS to maximize PV generation for BES charging. Source [5].

Similar test and experiments for specific buildings (e.g. residential, commercial, industrial) considering PV and battery only or also the combination with EV charger can be performed for different chemistry of battery or EV charger. The consumption from building can be emulated using DC electronic load, assuming to cover part of the households, while the EV can be emulated by an AC electronic load available in the laboratory.

</td></tr>
</table>

Expected results	Evaluation and validation of battery, EV charger or control strategy for a renewable system PV-BESS-EV which combine production, storage and electric mobility.

4.3 Multi lab

“MultiLab”, called also “Facade systems interactions lab”, is an innovative experimental facility that has two main purposes: testing building envelop components such multifunctional façade systems, and conducting analysis on human thermal comfort and, more broadly, on indoor environmental quality. In the latter case, realistic indoor scenarios (residential and non-residential) are recreated inside the lab to evaluate specific aspects such as users’ preferences in controlled conditions. Hence, the lab offers the possibility to investigate users’ choices and their implications on energy usage.

In the MultiLab, there are two identical environmental chambers, and it has been designed to guarantee an accurate control of the environmental conditions in the two test chambers. Moreover, the whole laboratory can rotate to obtain the desired orientation.

The net internal floor dimensions of the two environmental chambers are approximately 4.00 m x 8.00 m, and their internal height (floor to ceiling) is 3.00m. The floor, ceiling, and non-replaceable walls (thus, three walls per chamber) of environmental chambers are equipped with radiant panels in order to be able to control their surface temperature. Each surface can have a different set-point temperature. Moreover, it is possible to hang additional radiant panels to the ceilings.

The ventilation system can deliver fresh air at a chosen set-point temperature to each test chamber. The set-point temperature can be different in the two cells, and the air flow can be supplied (and extracted) at ceiling and floor level, as required by each experimental design.

The following tables summarizes the tests that can be performed using “MultiLab”.

Title	**Thermal and energy tests**
Lab involved	MultiLab
Objective	Evaluation of the energy performances of façade components.
Description	Measurement of (i) the heat flux through façade elements and (ii) the energy balance of the environmental chambers
Results	Energy performance characterization at component level in semi controlled environmental conditions (inner side only; the chambers are not meant to be calorimeters)

Title	**Visual comfort tests**
Lab involved	MultiLab
Objective	Evaluation of visual comfort due to natural lighting
Description	Measurements of the visual comfort (daylight levels and glare) by means of illuminance sensors and dedicated cameras
Results	Calculation of lighting KPIs (e.g. lux level) and relative energy usage

Title	Thermal comfort tests
Lab involved	MultiLab
Objective	Evaluation of thermal comfort and preferences in (semi) controlled conditions
Description	Measurement of physical parameters (air temperature, mean radiant temperature, air speed and relative humidity) inside the chambers in combination with (i) the collection of subjective evaluations from human participants, or (ii) further measurements taken using thermal manikins
Results	Calculation of KPIs based on measurements and on subjective evaluation, and insights into related energy usage

Title	Performance tests of active components
Lab involved	MultiLab
Objective	Performance evaluation in realistic controlled environments
Description	Evaluation of the performances of active components integrated into the façade prototypes (e.g. PV models) or installed inside the chambers (e.g. radiant panels). In the former case, the focus is usually on the integrability issues, in the latter case on the level of comfort delivered.
Results	Estimates of likely integration issues (e.g. risk of overheating in cavities) in real conditions, and comfort and energy KPIs for the radiant systems.

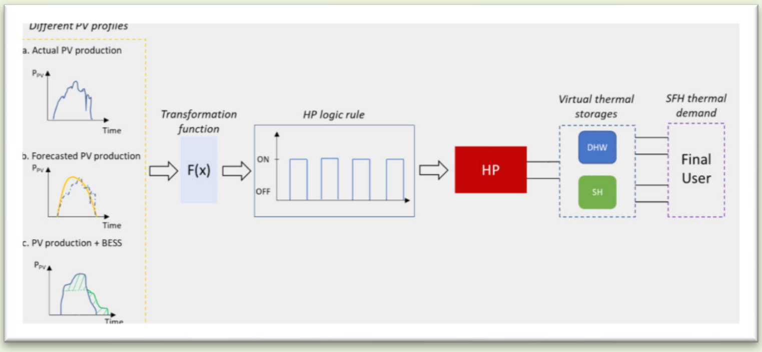
Title	Hygrothermal tests
Lab involved	MultiLab
Objective	Evaluation of the condensation risk
Description	Measurement of physical parameters (air temperature and relative humidity) inside and next to the façade prototypes to evaluate the condensation risks in semi-controlled environmental conditions: fully controlled on the inner side (temperature and humidity), while weather-dependant on the external side of the façade element.
Results	Calculation of the condensation risk in different points of the façade prototypes

Title	Mechanical ventilation, natural ventilation, and IAQ tests
Lab involved	MultiLab
Objectives	Evaluation of ventilation strategies and IAQ implications
Description	Definition of a set of possible combinations of mechanical ventilation and natural ventilations to evaluate the air change rates achieved and the resulting indoor air quality (IAQ)
Results	Calculation of the IAQ achieved by using different ventilation system and the relative energy implication

5 Integrate labs experiments

5.1 Energy Exchange – PV integration labs

Title	Use PV production to cover the HP consumption
Lab involved	Exchange – PV integration
Objective	The objective of the test is to maximize the use the PV production to cover the HP consumption.
Description	The HP of the Energy Exchange lab is used in heating mode coupled with two virtual tanks (space heating and domestic hot water, see 4.1.3) in order to satisfy the space heating and domestic hot water demand profiles of a single-family house(SFH). The profiles used are the results of simulations. The control strategy of the HP is mainly based on the rule-based control, as described in 4.1.4. In order to take into account, the PV production, the rule-based control is modified by including an extra charge of the two tanks. In practise, the DHW tank is charged until 55°C (instead of 50°C) and the SH tank until 43°C (instead of 38°C) if there is PV production. Based on the PV production profiles (collected on the field or generated with the PV simulator [4]) different scenarios can be emulated. As reported in the figure below the extra-charge of the DHW and SH tanks can be based on: • Actual PV production: is used the power produced by PV (properly scaled) stored in INTEGRIDS DB (for the same period of thermal demand) or directly measured by the sensors. • Forecasted PV production: the PV power is forecasted using simple or sophisticated method (i.e. persistence or neural network) in order to evaluate the impact of forecasting uncertainty in the HP rule-based control. • Modify PV production with battery (BESS): the forecasted or actual profile can be shaved or shifted using and electrical storage in order to maximize the use of the renewable source for the extra-charge of thermal tanks instead to inject into the grid when the demand is low. A simple conceptual schema is reported below:

	 *Figure 13 - Simplified conceptual scheme of integrated experiment PV integration and Exchange*
Expected results	Integrated test between thermal system and renewable production, maximizing the use of PV power for the extra-charge of DHW and SH thermal tanks.

Title	**Impact of HP electricity profile in LV distribution grid**
Lab involved	PV integration - Exchange
Objective	Evaluate the impact in a distribution grid of the HP electricity consumption using the real-data provided by Exchange.
Description	The increasing use of heat-pump to cover the thermal demand at building level is increasing the total electricity demand at low voltage distribution network. In order to quantify in a specific modelled network, the impact in terms of voltage deviation, lines overcurrent and power transformer of the HP penetration and integrated experiments can be performed using the real-time simulator OPAL-RT and the HP electricity profiles produced by Exchanged. This experiment can be performed using the actual or the database stored HP profiles generated by Exchange. In particular two different phases can be considered: 1) The LV grid under test is modelled in the software environment with its nominal values. After that in some specific buses are included the electricity consumption of the HP properly scaled according to the specific user (e.g. residential, commercial, single family house, multi-family house). The penetration of HP in the grid can be increased to find a critical level. 2) The model tested in the PC is sent to the real time simulation target with a defined simulation time The obtained results are compared in terms of specific KPIs. This starting experiment can be extended considering the inclusion of PV generation based on the production in PV integration lab.
Expected results	Integrated and sector-coupling simulation based on a LV distribution grid and HP profiles provided by Exchange, in order to quantify the impact in terms of power flow of thermal sector electrification.

5.2 Energy Exchange – Multilab

Title	
Lab involved	Energy Exchange and MultiLab
Objectives	Evaluate the effect of lower supply water temperature for space heating on thermal comfort
Description	The energy exchange lab can be used to provide hot water for domestic hot water (DHW) and space heating (SH). In case of simultaneous need of DHW and SH with the total demand that exceeds the capacity of the heat pump, the priority is given to the DHW, while the remaining power is used for SH. However, this means that, in this scenario, the temperature (Tsh) used to provide SH is lower than required, therefore the power delivered to the room (or rooms) via systems such as a radiant floor is lower, and hence the temperature in the room decreases. MultiLab can be used to evaluate this decrease in room temperature and its effect on occupants' thermal comfort. A typical domestic room configuration can be created inside the lab, and a radiant system can be used with Tsh as circulating water temperature (circuit supply temperature). The temperature in the room can then be monitored, and it is therefore possible to evaluate the effect of such a lower room temperature on thermal comfort.
Results	Range of acceptability of lower room temperatures due to simultaneous need of DHW and SH

5.3 PV integration - Multilab

Title	PV cover the electricity consumption of ventilation machine to maintain a certain comfort profile
Lab involved	PV Integration - Multilab
Objectives	
Description	In MultiLab, different scenarios can be created to replicated indoor spaces such as a room of a dwelling or an office. In tests with human participants, these can either (i) be exposed to certain fixed hygro-thermal conditions and they express their level of liking, or (ii) they may have the possibility to adapt to the environment to feel it comfortable (e.g. control on temperature set-point, use of fans, use of portable heaters, etc.). In both cases, there is a certain electricity consumption which depends on the chosen configuration. The aim of the integrated experiment is to maximize the match between the consumption and the PV production (measured or generated using the PV simulator up to 5kW) to achieve a "sustainable comfort". In order to do this, we can assume to use the actual PV production or a shaped PV profile

	using a battery storage. Self-consumption and self-production of the building will be evaluated and related to the comfort level and satisfaction.
Results	Maximize the use of PV generation to achieve internal comfort in Multilab

5.4 PV integration - Multilab – Energy Exchange

Title	**Electricity and thermal needs for health and comfort reequipment in a building**
Lab involved	
Objectives	
Description	The energy exchange lab can be used to provide domestic hot water (DHW) and space heating (SH). In case of simultaneous need of DHW and SH with the total demand that exceeds the capacity of the heat pump, the priority is given to the DHW, while the remaining power is used for SH. However, this means that, in this scenario, the temperature (Tsh) used to provide SH is lower than required, therefore the power delivered to the room (or rooms) via systems such as a radiant floor is lower, and hence the temperature in the room decreases. MultiLab can be used to evaluate this decrease in room temperature and its effect on occupants' thermal comfort. A typical domestic room configuration can be created inside the lab, and a radiant system can be used with Tsh as circulating water temperature (circuit supply temperature). The temperature in the room can then be monitored, and it is therefore possible to evaluate the effect of such a lower room temperature on thermal comfort. The PV integration lab can provide the renewable electricity to cover the HP demand of Exchange to produce the required DWH and SH, as well as if surplus is present to supply other machine to increase the comfort level in Multilab room when this is not achieved.
Results	

References

[1] S. Buffa, M. Cozzini, G. P. Henze, C. Dipasquale, M. Baratieri, and R. Fedrizzi, "Potential study on demand side management in district heating and cooling networks with decentralised heat pumps," presented at the International Sustainable Energy Conference - ISEC 2018, Graz (Austira), 2018.

[2] "Real-time computing," *Wikipedia*. 29-Apr-2019.

[3] "Real-Time simulation | Real-Time Solutions | OPAL-RT." [Online]. Available: https://www.opal-rt.com/. [Accessed: 20-Feb-2019].

[4] "Photovoltaic Simulator, Elgar, ETS 600X." .

[5] G. Barchi, G. Miori, D. Moser, and S. Papantoniou, "A Small-Scale Prototype for the Optimization of PV Generation and Battery Storage through the Use of a Building Energy Management System," in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I CPS Europe)*, 2018, pp. 1–5.