MORE—CONNECT

# Tasks 2.7 and 3.6

# Advanced controls / Performance Monitoring and Control of Integrated Systems

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# Advanced controls / Performance Monitoring and Control of Integrated Systems

– D2.5 - Advanced controls for the modular elements
– D3.7 - Sets of embedded integrated control systems

Development and advanced prefabrication of innovative, multifunctional building envelope elements for **MO**dular **RE**trofitting and **CONNECT**ions (MORE-CONNECT)

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# Task 2.7 Advanced controls and Task 3.6 Performance Monitoring and Control of Integrated Systems

Presented tasks regarding the advanced controls and its integration (features and modular elements) to the panel are evolving continuously. In the terms of working progress, the More Connect (M-C) experimental panel will be located soon in our main testing area at UCEEB and development *starts to take a real shape*.

What's more, *work* at a high-tech development of More Connect experimental house is in early stage and progressing *well*.
Implementation of renewable energy sources (RES) into the More connect project was previously introduced and discussed at Concept Development workshop at H2020 MORE-CONNECT WS2 in Prague. Now we are in the process of implementing some new components into a High-tech version of More Connect experimental house and experimental panel.

## M-C experimental house

General description of main components, including the implementation of the hybrid photovoltaic system with energy storage system
The concept of M-C experimental house project falls perfectly under the Horizon 2020 program and the EU Strategic Energy Technology Plan (EU SET-plan). The European energy system (and its transformation) is facing new challenges. The rapid implementation of intermittent renewable energy sources connecting to the power grids is creating disruptions to the EU energy market because of RES inherent volatility.

The key issue is to maintain a stable and safe electricity supply all the time. The grid stability and energy security have major economic implications as well. This situation requires innovative solutions related to these issues. It is well discussed that the consumption of electricity has to be perfectly matched with its generation at any moment in time. This system is called the Demand and Response (DR).

EU SET-plan with the aim of a single, smart European electricity grid is considering energy storage technologies as one of the key elements. Energy storage system (ESS) could help deal with fluctuations in demand and generation. The ESS allows the excess electricity to be stored and consequently released when there is a higher electricity demand.

Energy storage has other benefits as a grid stabilization, quality of power (in terms of voltage and frequency) sent back to the grid, improving the grid´s operating capabilities and peak-load shifting. Controlled energy storage at the time of surpluses and controlled supply of electricity in case of shortages or disruptions also have a great economic potential for both the large utilities as well as for domestic use.

Furthermore, the implications of energy concept of Demand and Response together with the energy storage automatically leads to efforts to accurately predict the weather fluctuations as well. There is a direct correlation between weather patterns and the energy output from RES. For example, the accurate prediction of short-term performance of the photovoltaic power plants together with the prediction of solar radiation plays a key role in addressing both the technical and economic impacts of the use of RES mentioned previously.
The M-C experimental house project would try to implement and thoroughly test the key innovative components in response to actual challenges and issues described above related to EU SET-plan.

The main components proposed for the M-C experimental house:

A. Façade/roof hybrid photovoltaic system
B. Energy storage system
C. UCEEB PV Forecast service
D. Microgrid
E. Advanced controls, monitoring, optimization, application of multi-sensors

# Control strategies

## What we can control in an intelligent building

Objective

In the control problematics in buildings, we need to consider the four main factors that affect life quality inside of them:

- Thermal comfort
- Indoor air quality
- Visual comfort
- Aural comfort

The goal is to improve those factors with the least building's operating cost possible, ideally, even reducing it. Therefore, in summary, control objective is:

- To provide a good comfort level: Learn the comfort zone from the user's preference if possible; ensure satisfactory comfort level (thermal, air quality and illuminance) with good dynamic performance.
- To increase energy savings: Combine the comfort conditions control with an energy saving strategy.
- To improve air quality control: Provide enough ventilation to keep CO2 levels low – possible use of controlled ventilation (DCV) systems.

*"A good control system ought to have many benefits such as minimize the energy consumption, reduce the pollution caused by energy usage, improve the comfort, prevent out of hours operation of the equipment, reduce the maintenance cost and limit the excessive wear and tear associated with the building systems." D.W.U. Perera*

How to evaluate

- Thermal comfort can be measured by the Predictive Mean Vote (PMV) and PPD (predicted percentage of dissatisfied), presented in ISO 7730:2005.
- Visual comfort is about having enough luminance level either by solar radiation or by lighting - "The Lighting Handbook" by Zumtobel Lighting GmbH based on EN 12464-1 and EN 12464-2 standards serves as a good reference.
- Aural comfort is related to the acoustical environment inside a building, which means speech intelligibility and privacy.
- CO2 concentration inside a building characterizes the level of indoor air quality (IAQ).

→Relevant Standards

- EN15251 specifies indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.
- ANSI/ASHRAE Standard 55 defines the range of indoor thermal environmental conditions acceptable to a majority of occupants, but accommodates an ever-increasing variety of design

solutions intended both to provide comfort and to respect today's imperative for sustainable buildings.
- ISO 7730

→ PMV sensor cost has to be taken into account.

Finding optimal control solution
Main topics and issues of the problematics:

- Exists a compromise between the air quality and thermal comfort inside a building when it comes to energy savings. I.e., in general, a stronger ventilation requires higher energy consumption for heating the environment, while reduced ventilation means more difficulty in keeping satisfactory level of $CO_2$ concentration.
- Solar irradiation and lighting help to increase the indoor air temperature.
- Energy consumed to raise the temperature to a different level may be lower compared to preserving current conditions. Therefore, during low outside temperatures, low occupancy levels or at nights, temperature can be lowered either by lowering the heater power or by switching it off depending on which is more efficient. Subsequently, the temperature can be brought back to the desired level.
- All control systems should aim at reducing external heating requirements.

Furthermore:

- Maintaining IAQ is a major problem in a building with small openings as there is not much natural ventilation.
- When heating systems are operated continuously throughout the day, thermal comfort can be easily satisfied, but it may lead to energy overconsumption, regarding that the occupancy is intermittent.

Hence, it is important to manage these three factors simultaneously to obtain a better quality of life while saving energy:

- Ventilation
- Temperature
- Lighting

And other factors regarding energy consumption (age, size, envelope, weather conditions, equipment efficiency, hot water production, etc.).

Optimal solution:
Integrate the effects → precisely select a building control system.

What to control?
Actuators/Effectors:

- Shading systems, to control incoming solar radiation and natural light, as well as to reduce glare.
- Windows opening for natural ventilation or mechanical ventilation systems, to regulate natural airflow and indoor air exchange, thus affecting thermal comfort and indoor air quality.

- Electric lighting systems.
- Auxiliary heating/cooling systems.
- Demand-controlled ventilation (DCV) systems offer an efficient solution for the optimization of energy consumption and indoor-air quality.
- Load control switches - Demand-response technologies for home appliances.

## Most commonly used control strategies

| Control strategy | Advantages | Limitations |
|---|---|---|
| On/Off control (Thermostat) | ▪ Feedback type<br>▪ Availability<br>▪ Generic<br>▪ Well understood<br>▪ Low initial cost<br>▪ Simple structure<br>▪ Fast response | ▪ Accepts only binary inputs<br>▪ Often incapable of tracking the setpoint accurately and hence could be inefficient<br>▪ Not versatile and effective in the long run |
| Feed forward control (Weather-compensated) | ▪ Availability<br>▪ Increased energy savings<br>▪ Very fast reaction to changes | ▪ Open-loop type<br>▪ Negligence of all effects related to unmeasured signals/disturbances<br>▪ Unpredictable changes of the system behavior<br>▪ Parameter storage requirements to accommodate many operating conditions<br>▪ System performance not measured<br>▪ Possibility of system failure if the relationship between the environmental measurements and system model parameters change |
| PID control (Feedback) | ▪ Feedback type<br>▪ Robustness to disturbances<br>▪ Derivative term combat with sudden load changes in the system | ▪ Little measurement and process noise can cause large variations in the output due to derivative term<br>▪ Energy inefficient<br>▪ Tuning is time consuming |

| | | |
|---|---|---|
| MPC | ▪ Increased energy savings<br>▪ Cost effective<br>▪ Robustness to disturbances<br>▪ Can involve bounds<br>▪ Control of multiple variables<br>▪ Steady state response improvement<br>▪ Future disturbance prediction<br>▪ Prediction of future control actions<br>▪ Better transient response<br>▪ Handle slow moving processes with time delays | ▪ Need to identify a suitable model of the system<br>▪ Installation could be expensive<br>▪ Set-up can be time consuming |

*Table 1 - Typical control techniques used in buildings*

ON/OFF technique examples: thermostat, humidistat and pressure switch. Commonly found in home heating systems and domestic refrigerators.

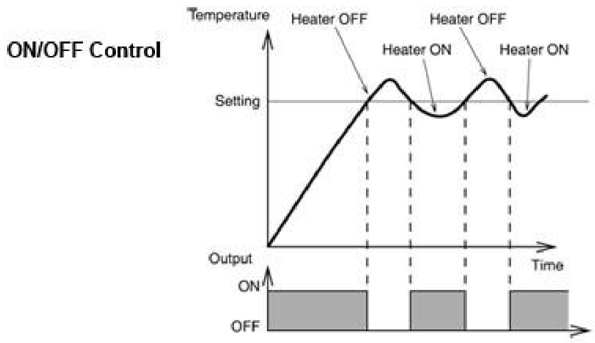



*Figure 1 - ON/OFF heater*

Example: Thermostat

— Simple and inexpensive control of heating or/and cooling method. Main disadvantage: often incapable of tracking the setpoint accurately which might turn into energy inefficiency.
— Work in a "hysteresis" mode or with a "dead-zone" in case there is cooling and heating systems.

Advantages:

- Simplicity
- Low initial cost

Disadvantages:

- High maintenance cost
- Low energy efficiency


*Figure 2 - Thermostat*

Most used in HVAC systems due to the advantages it offers. However, intensive oscillations during operation and low energy efficiency reflect high cost of both maintenance on actuators and energy.

Weather-compensated (Equithermal) control

A feed-forward type of control, known in the market as Equithermal controller for HVAC systems. The disturbances are measured and accounted for before they have time to affect the system. This strategy responds to its control signal in a pre-defined way without a feedback technique (not-error based), which means it is based on the knowledge of the process or measurements of its disturbances.

In heating systems, weather compensation is a communication between the source of hot water (boiler, for example) and an outside temperature sensor. Since the weather is the main influence on the heat demand of a building, the controller adjust the heat supplied according to the weather conditions and inside temperature set point, via pre-defined heating curves, ensuring a more constant temperature in the rooms and better energy savings (15 % according to some system manufacturers).

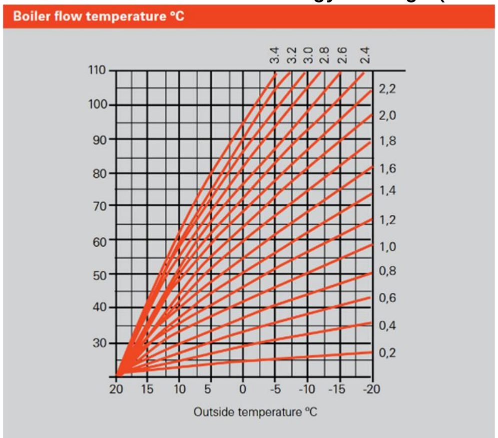



Figure 3 - Heating curves


Figure 4 - Equiterm regulator

Available equithermal regulators have the heating curves implemented in its memory, measure the temperature, and contain control circuitry and relays for pumps and valves.

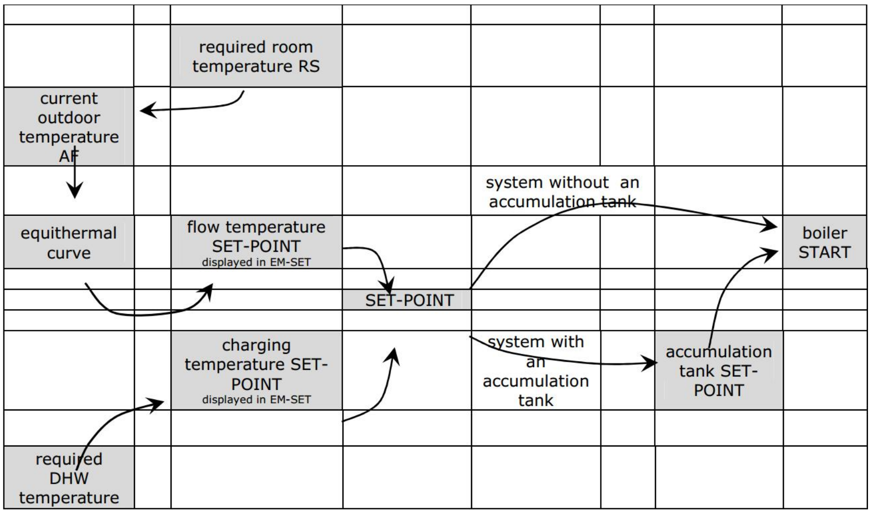



*Figure 5 - Typical residential equithermal control diagram*

PID controller: Continuously calculates the error between desired setpoint and a measured process variable, and adjusts the control signal accordingly. Also known as Feedback control for HVAC systems.

Proportional accounts for present values of the error. For a large and positive error, for example, the control signal will be proportionally large and positive.
Integral accounts for past values of the error. For example, if the current control signal is not strong enough, error will accumulate over time and the controller will respond by applying a stronger action.
Derivative term predicts the future offsets based on the actual rate of change of the process and suppresses oscillations.

A control signal is delivered based on a weighted sum of these three “P”, “I” and “D” actions.

Main features:

- Commonly used in industrial control systems
- Widely applicable
- Robustness
- May require using only one or two terms (P or PI controllers, for example) to provide the appropriate system control
- Simplicity of implementation (Standard PLCs already have blocks for it)

*Figure 6 - PID controller*

Main disadvantages:

- Often unable to handle random disturbances
- Wind-up effect
- Incapability of dealing with multi-input multi-output systems
- Possibility of large deviations from setpoint
- Requires tuning
- Optimal control and stability are not guaranteed
- Operates at low energy efficiency (which may not be suitable in the long run)

A PID controller is very versatile and can be widely applied because it does not use knowledge/model of the interested system. When correctly tuned, the controller can adjust its output to match the power that is required to keep the process stable at the setpoint, however, it requires the tuning for this purpose, creating some limitations and inconveniences.
Thermal dynamics in a building is usually a slow responding process. Therefore, proportional control can be engaged in building temperature control with certain good stability and reasonable small offset, the same being valid for relative humidity control. Including the derivative term in the controller for such applications also contributes to combat the sudden load changes encountered in the system. However, not enough amounts of measurement and the noise of the process can cause large variations in the output due to the presence of this term.
PID control is one of the best control strategies, yet it might not be the most suitable for building control. In a building, thermal interaction between all its zones leads to multi-variable behavior and a standard PID controller assumes a single-input single-output (SISO) system. Additionally, it is true that it is easy to tune it for SISO systems but it might be even impossible to tune them for multiple-input, multiple-output (MIMO) systems. It cannot reflect outside temperature effects either and the three parameters tuning for each building zone after installation consumes time and re-tuning after the commissioning may be necessary.

| | PI | TWO-POSITION |
|---|---|---|
| Output | 0% to 100% of power | On or Off |
| Thermal Comfort | Much better | x |
| Equipment Life | Longer | x |
| Energy Consumption | Not much better | x |
| Simplicity | x | Much simpler |

*Table 2 -Comparison between PID x ON/OFF *based on M.R. Kulkarni, F. Hong / Building and Environment 39(2004) 31–38 comparison of these two control methods for a residential building*

Model predictive control (MPC)

Main characteristics:
Predictive control applied to building automation systems provides increased energy savings, being often more cost-effective than non-predictive control applications and some other benefits too. They can be applied to both single-zone and multi-zone buildings, whether residential, commercial or public buildings. However, the decision of implementing the predictive control for a particular building depends on the payback period. This multivariable control technique is based on a prediction model, using past information and future inputs to predict what the future output should be. While controlling the process accordingly to the model, MPC generates a cost function control vector to minimize it over the prediction horizon, disturbances and constraints that might be present. Model identification is the bottleneck of the whole MPC application procedure and there are not any stringent requirements on the model structure, it is possible to use any black box, grey box or white box model.

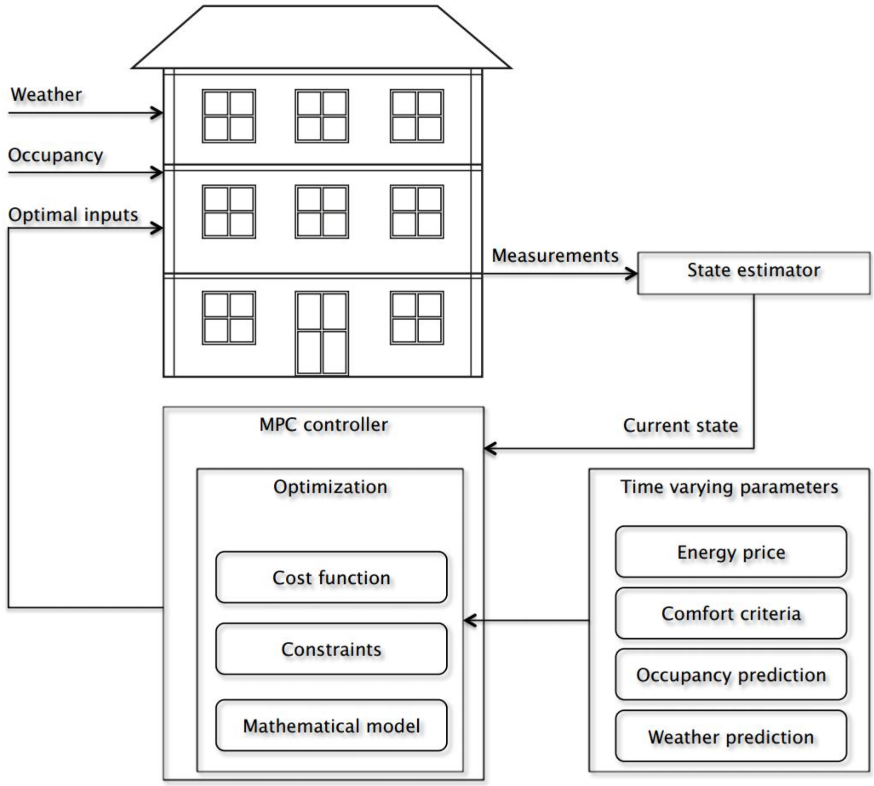



*Figure 7 - Basic principle of MPC for buildings*

Main benefits:

- Energy and maintenance cost savings
- Multivariable
- Peak load shifting capability
- Transient response improvement (decrease in rise time, settling time, and peak time)

- Steady-state response improvement (decrease in offset error)
- Predictions of future disturbances
- Future control actions prediction
- Control of variables within bounds
- Reduction in fluctuations from a set-point (better regulation)
- Efficiency and coefficient of performance (COP) improvements
- Robustness to disturbances and changes in operating conditions
- Indoor air quality and thermal comfort improvement

Main disadvantages:

- Relies on model accuracy
- Strong dependence of the model
- Need to identify a suitable model of the system
- Installation could be expensive (use of remote server for calculation, for example)
- Not possible a direct implementation to PLC
- Needs computational time
- Does not account for user controllability and subjective level of comfort is not adaptive

Modeling approaches:

- Physical based (white box)
- Data driven (black box and grey box)
  - Artificial neural networks
  - Fuzzy logic
  - Support vector machine
  - First and second order time delay models
  - Statistical models
    - → AR (Autoregressive),
    - → ARX (Autoregressive exogenous)
    - → ARMA (Autoregressive moving average)
    - → ARMAX (Autoregressive moving average exogenous)
    - → BJ (Box Jenkins)
    - → OE (Output Error)
    - → Subspace identification methods (4SID)
    - → Prediction error methods (PEM)
    - → MPC relevant identification (MRI)
    - → Deterministic semi-physical modeling (DSPM)
    - → Probabilistic semi physical modeling (PSPM)
  - Combinations of them

Software for comprehensive modeling:

- Energy Plus
- Fluent
- TRNSYS
- MATLAB/Simulink
- Modellica
- ANSYS
- HYSYS
- JModellica

It is important to highlight that the accuracy of data driven models depend on the measured data quality (measurements must have good accuracy, low noise and sampling frequency appropriate). Nevertheless, precision of data driven models is quite satisfactory in general (compared to physical models), being the problem the low generalization capabilities. High quality models are very accurate, but complex, not too tractable computationally and with loss of physical insight. On the other hand, low quality models offer less energy saving potential. There is always a trade-off between the accuracy and the computational tractability of the model, being the preferable solution in general the use of a model with the least complexity possible, developed on simple physics or simple mathematical formulations, to achieve reasonable accuracy and computational simplicity.

MPC offer the highest percentage of energy savings between the commonly used control strategies, up to 25%, some authors claim.

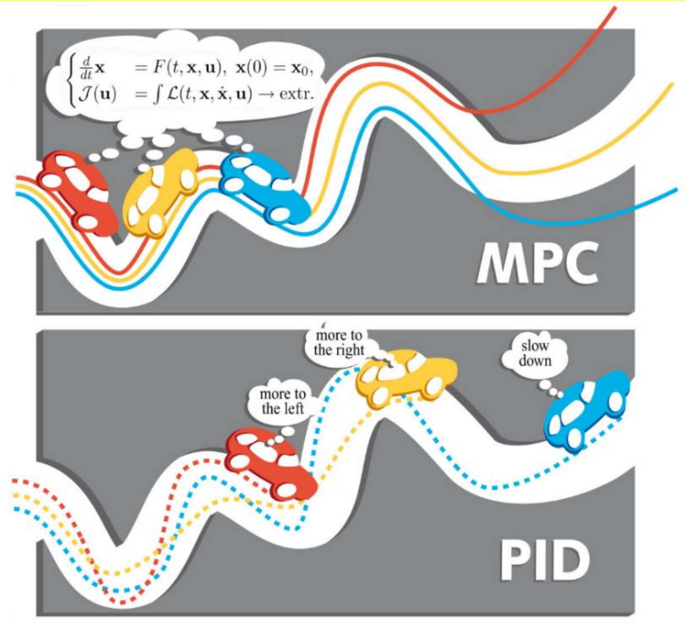



*Figure 8 - Illustrative comparison between MPC and PID*

## Forecasting - use and benefits for home application control strategies

### Smart-grids and forecast

Forecasting in energy consumption proves to be a powerful tool in the integration and expansion of renewables sources and the energy savings that come with it, whether in a micro-grid (residential building – MORE-CONNECT's focus) or a bigger scale one as more and more renewables sources plants have been installed lately. Predictive control itself allows smart operation of a system – reducing costs and increasing energy savings.

With the advent of smart-grids technology and Energy Demand Management - control of demand through different methods, such as flexible tariffs, education or dedicated control systems aiming at shaving the peaks - forecasting services regarding current demand on the grid, available energy sources or consumers' behavior play an increased percentage of cost savings.

Current demand response schemes can be executed with controllable relays and reducing the load during peak hours (e.g. by turning off high consumption appliances such as boiler, HVAC systems, washing machines.) or using alternate energy sources (solar systems, for example). Peak demand management does not necessarily decreases total energy consumption, but help the utilities with attending the requirements of energy infrastructure offering.
Another big concern of utilities with the increasing of PV power plants implementation is the intrinsic uncertainty of that source of energy and issues with overvoltage that might occur on the grid. To deal with such, that are four main actions that could be taken:

1. Reducing the voltage of the secondary on the distribution transformer
2. Allow PV systems to absorb the reactive power
3. Shave the PV peak by limiting the grid feed-in
4. Active power curtailment

Therefore, a local control scheme of optimal battery flow and grid feed-in with peak load demand shaved is also a great solution to meet the requirements of electric grids standards (not violating any constraints nor affecting the design or generating overvoltage), to provide better grid stability, and to ease and increase the integration of PV battery systems to existing grids infrastructure. Moreover, it can much benefit from the use of forecasting services (irradiance forecast, e.g.). Additionally, energy storage requires the scheduling of operation depending upon weather and load forecast in order to achieve the goals of peak PV and peak load shave. Heating systems can provide more comfort and less energy consumption by predicting and supplying the heat needs in advance, and so forth.

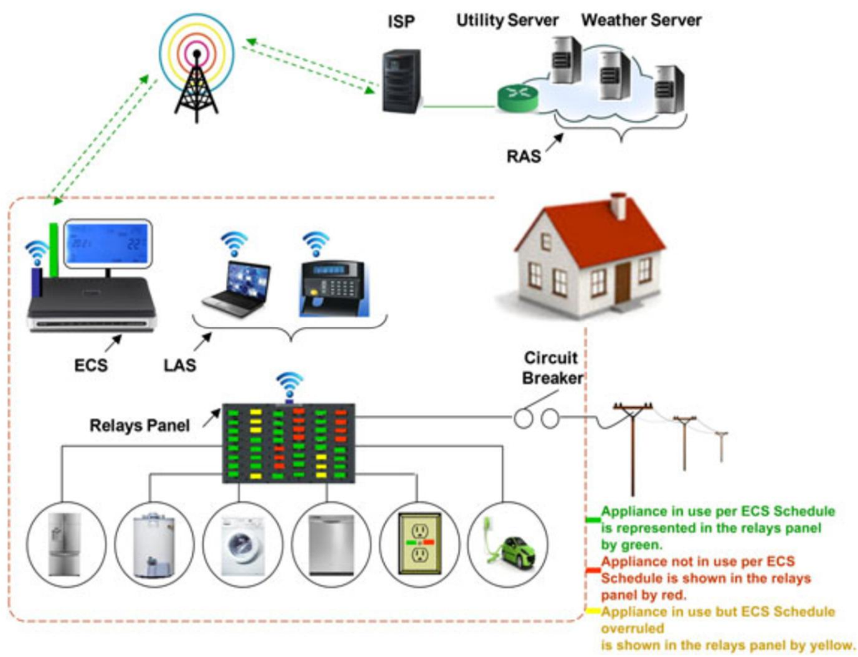



*Figure 9 - Intelligent home with appliances schedule*

Energy pricing and control
In a real-time electricity, pricing context where consumers are sensitive to varying prices, having the ability to anticipate their response to a price change a forecast system is very valuable. Price-responsive devices that allow an economic operation of system as whole are possible to control:

-Directly, when there is a bi-directional communication interface and knowledge about the end-user's environment.
- Indirectly, which decentralizes the consumption control task by sending out a generic control signal interpreted by each consumer's energy management system. Each consumer can then react to it by its own devices specially optimized for his/her environment.

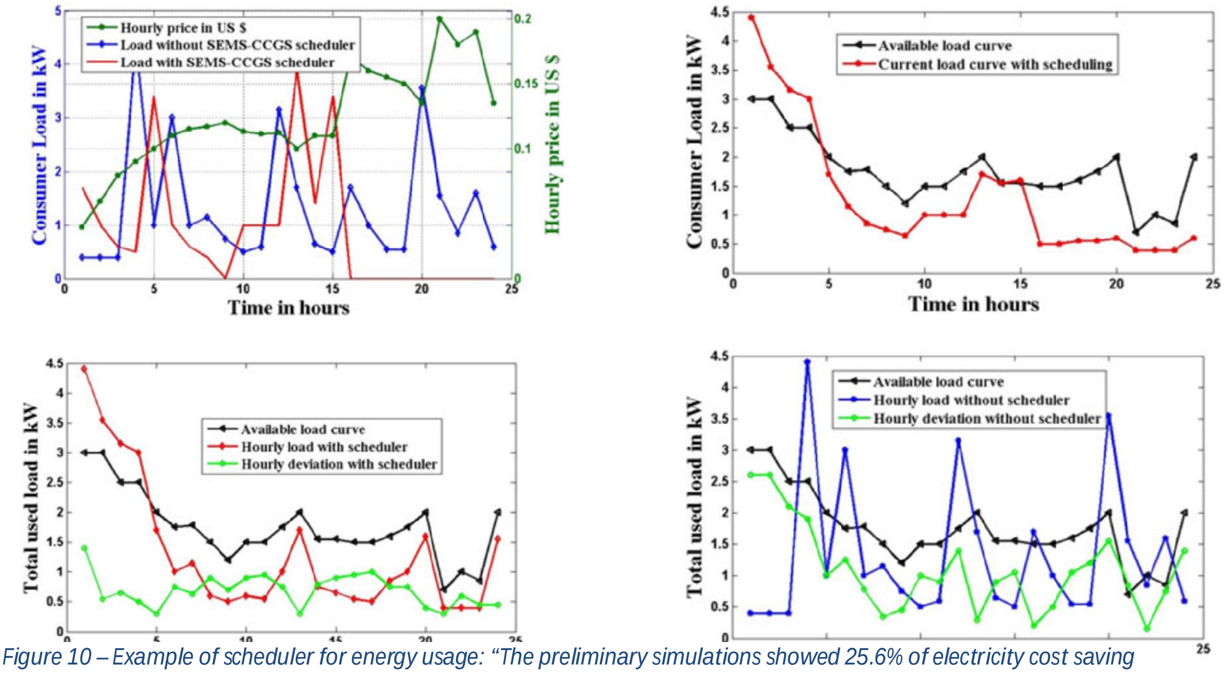



*Figure 10 – Example of scheduler for energy usage: "The preliminary simulations showed 25.6% of electricity cost saving using SEMSCCGS" - Raziq Yaqub1, Sadiq Ahmad, Ayaz Ahmad and Muhammad Amin*

Development of NWP and PV Forecast
Numerical weather predictions (NWP) tools have helped in the advance of new power forecasting models for electric plants based on renewable resources, providing valuable inputs for operation. NWP aim at the supply of information concerning the state of the atmosphere for a given time horizon.

UCEEB's PV Forecast
The forecast of solar irradiance is mainly designed for the prediction of power produced in the following day. Forecast horizon is from 24 to 48 hours in advance in hourly increments. The service is based on a number of independent sources, thus ensuring its reliability. For a better accuracy, it is possible to install a solar radiation sensor in the place for which the weather forecast is calculated and thus provide feedback to our algorithm. It will then take care of the future more accurate predictions for a given site.

PV FORECAST

For the calculation of photovoltaic power plants' performance according to prediction, one can use an adaptive algorithm, which is running in the local PLC and communicates with the service PV Forecast. This algorithm takes into account production conditions in forecasting weather in local PV installations to balance production and consumption, ensuring they can meet customer demands while avoiding costly energy purchases on the local market. It helps the efficient production and distribution of solar power resources by advanced PV technology, achieving cost parity in more markets where systems are tied to electrical distribution networks.
Utility and distributed solar customers can use this feature to predict and manage energy output and to minimize energy costs. Solar managers can plan solar generation even during rapidly change of weather patterns. This technology takes full advantage of the performance modeling capabilities of our software platform, including compatibility with PVsyst models and multiple inverter modules, as well as other system variables you may have designated in the software (panel tilt and azimuth, shading modules, etc.). Results are further fine-tuned using virtual weather data for atmospheric and module temperature.

Heating demand and scheduling from utility's varying price and user's behavior
Various modern heating systems in the market can be connected through communication systems and controllers (energy manager), offering possibilities such as:

- Self-adaption to heat requirements of the individual rooms
- Optimization of the inlet temperatures
- Self-learning in accordance with the physics of the building and the habits of the residents
- Demand-based hot water heating
- Display and documentation of the yield of an installed photovoltaic system
- Optimum mix between local consumption and generation of the energy, and how much is fed into the grid
- Automatic optimization own power consumption

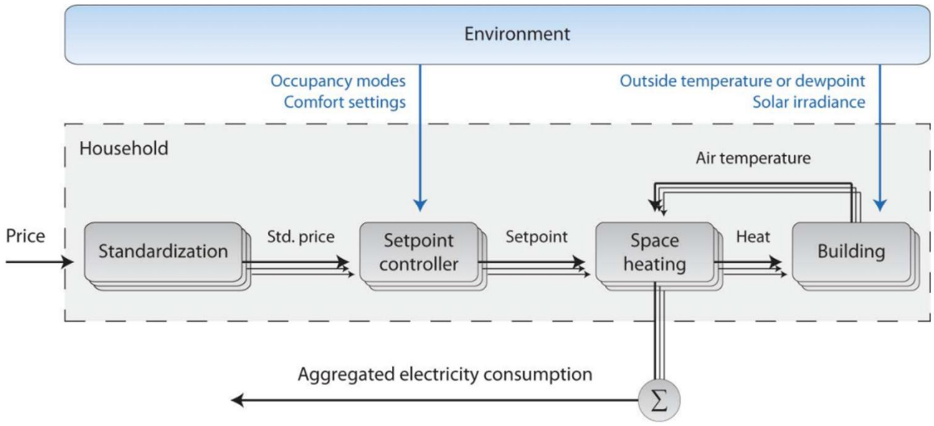



*Figure 11 - Scheduling for heating systems*

## Control from the users' perspective

User interactivity:
User interactions always have a direct effect on the system under consideration in order to give the user the feeling that he or she controls his or her own environment. A combined control process for the actuator/effectors listed before requires optimal performance of almost each of them. It is indispensable that the operation is safely ensured in respect to users' preferences and the simultaneous normal operations of these control subsystems, in order to avoid conflicts arising between.
User's subjectivity of comfort:
Satisfaction within the environment is important and has great impact on health and productivity. Since environmental comfort is different for every person, physiologically and psychologically, it is hard to find an optimal point for everyone in a given space. The methodologies here cited are based on laboratory and field data to define conditions that satisfy a specific percentage of occupants.

Personal factors involved:
- metabolic rate
- clothing level

Environmental factors involved:
- Air temperature
- Mean radiant temperature
- Air speed
- Humidity

Thermal Comfort Tools:
- CBE Thermal Comfort Tool, available at: http://comfort.cbe.berkeley.edu/
- ASHRAE's Thermal Comfort Tool software, available at: https://www.ashrae.org/resources--publications/bookstore/thermal-comfort-tool

## Some of the main relevant companies in the Czech market

The following companies offer solutions and products regarding control systems, control strategies, control devices and connections, integration of system, heating systems and controls.
- Teco a.s.
- Siemens
- Honeywell
- Regulus
- Buderus
- Viessmann
- Crestron
- Energocentrum
- Jablotron
- Feramat
- ABB
- SPEL
- Schneider
- B&R

# Control system for modular components

## Data and electrical connections in M-C panels

Figure 12 shows the schematic of the planned connections to be demonstrated in the prototype panel and later in Czech M-C pilot project. The control and home automation systems will be based on the Czech company Teco a.s., which provides solutions that suit the projects goals and have a relevant market in the field.

As can be seen, there will be installed junction boxes in each panel that will have any electrical connections. In the shown scheme, a set of circuit breakers is provided to connect a possible 230 VAC socket, motor for blinds, electric heating control and RFox network router, besides RCD protection device. There will be an individual energy meter that can be located in the box as well in the case of each flat in a M-C retrofitted building will need to separately provide energy consumption to the utility. All the standard procedures of electrical installations and protection measures for them stand.

An additional visualization of part of the electrical installations to be located in the M-C engine is shown in Figure 12. In it, the central unit for control and communication of all the indoor environments, electrical protection devices, and the communication buses and networks can be seen.

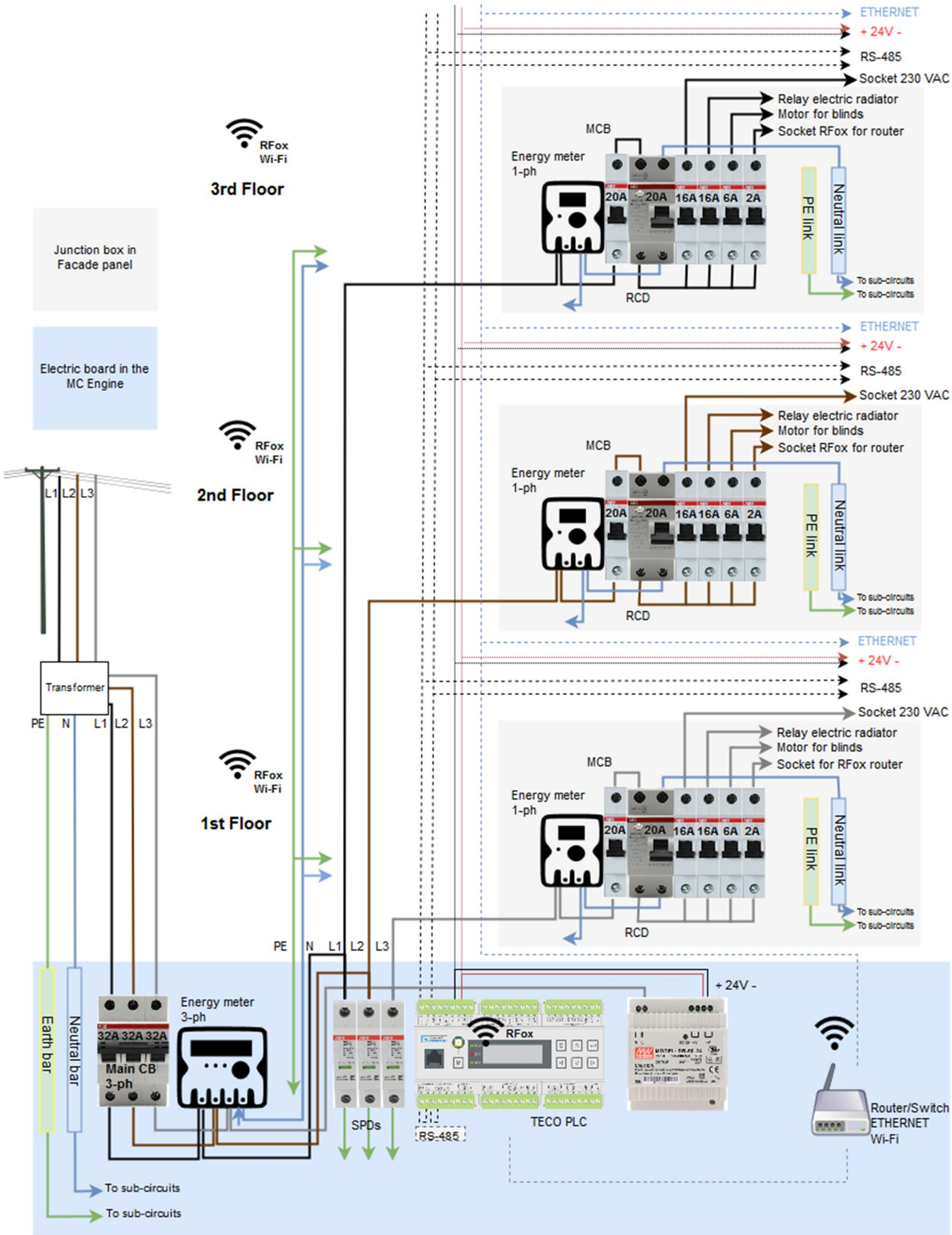



*Figure 12 - Schematic of connections in the panel*

List of devices present in the diagram

Junction boxes
Circuit breaker:

- Overcurrent: 1 x 20A as MCB; 2 x 16A for 230VAC socket and relay; 1 x 6A for motor; 1 x 2A for RFox router
- Residual current device: 1 x 20A;

Energy meter: 1 x single phase

M-C engine board

- Circuit breaker: 1 x overcurrent 3-phase 32A as MCB
- Energy meter: 1 x three-phase
- Surge arrester: 1 for each phase installed in accordance with standards' procedures
- TECO PLC: 1 x as central unit control for the devices present in the façade an in the indoor environment (blinds, heating, environmental sensors, operator panel, ventilation, moisture guard, etc. depending on what is offered)
- DC supply: 1x 24V as supply for PLC and as a possible supply bus present for connecting the operator panel on the façade panel (a device with LCD display and touch screen allowing the complete control of the whole environment)
- Router and ETHERNET Switch: Provides Wi-Fi and LAN connectivity.

Buses

- ETHERNET: For provision of internet, TV and communication of TECO operator panel
- RS-485: serial communication via MODBUS for MoistureGuard, Environmental Sensor and control of blinds; possibility of connecting any other devices that need serial communication (Ventilation control, e.g.)
- 24V: Power supply for TECO operator panel

Networks

- Wi-Fi: Wireless internet
- RFox: Wireless radio communication for TECO devices (see section Wireless sensor systems)

## Control system description: programmable controllers produced by Teco a.s. company

PLC
A programmable logic controller (thereinafter PLC) is a digital control electronic system designed for control of industrial machines and processes within industrial environment. Through digital or analog inputs and outputs, the PLC receives and sends information from/into the unit being controlled. Control algorithms are saved in the memory of the user program that is executed cyclically.
TECOMAT FOXTROT
The TECOMAT FOXTROT PLCs are small and compact automatic controllers with a number of modular enhancements designed for any application in industry, transport, measurement and energy control etc. They unify the advantages of compact automatic controllers in size and the advantages of modules in expandability and variability. You may find in it all functions of big programmable controllers with IEC EN

61131 standard compatibility, even combined with latest technologies known better from IT, telecommunication and internet.

External modules

TECOMAT FOXTROT offers with CFox and RFox protocol modules, which are a logical extension of Foxtrot system especially for the field of intelligent building control and building management systems.

Communication

FOXTROT systems support basic transmissions via the Ethernet network or the EPSNET industrial Network (besides wireless RFox protocol). Also fitted with various types of physical interfaces for serial communication according to customer's specifications (RS-232, RS-485, and RS-422), industrial protocols and buses can be supported, such as MODBUS, PROFIBUS DP, CAN, etc. Eventually, asynchronous communication. Through universal transmission channels controlled directly from the user program is possible, too. All central units are standardly equipped with a 10/100Mb Ethernet interface allowing operation of more logic connections at a time.

Connection with PC

A PC can be used as a programming device and as a direct monitoring of the system. The computer configuration must be selected according to the software features (Mosaic, Reliance, ...). The TECOMAT FOXTROT offers a number of useful system services that makes the programming more simple and user-friendly. An example can be a wide range of time data, current date and time displayed or system support of the states handling while switching on the PLC power supply.

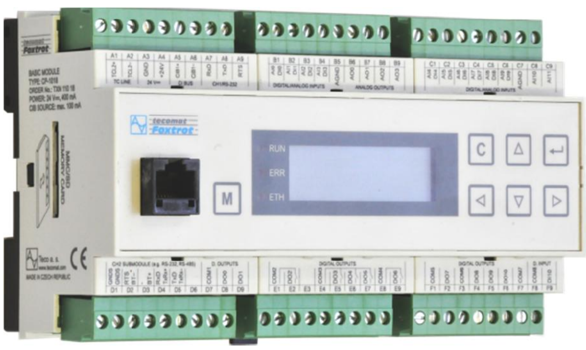
## CP-1018 as basic module into M-C pilot house

The CP-1018 was chosen to be the central unit in the Czech pilot project as it differs from other basic modules by the number and type of inputs and outputs and indication or operation elements. The device is equipped with great number of multipurpose, analog and binary inputs, and offer also a good set of different outputs (TRIAC, PWM, analog and relays). The basic operation and displaying elements have a and 6 user push buttons, between other features, such as the expansibility and others, this CP offers.

Teco a.s. control unit (Programmable controller) - PLC Tecomat Foxtrot – basic module

CP-1018 - Basic module with 28 I/O for use in HVAC

| | | |
|---|---|---|
| DI | 1 | 1x 230 V AC |
| DO | 11 | 7x Relay,<br>4x SSR |
| AI | 10<br><br><br>(4+6)<br><br>+2 | AI0 - AI9<br>(RTD, can be configured as DI<br>(24 V DC);<br>AI4-AI9<br>(4-20mA,);<br>AI10-AI11<br>(-20..+50mV, 0-2V) |
| AO | 2 | |
| COM | | 1x Eth 100, 2-3x Serial, 1x CIB,<br>1x TCL2, LCD 4x20 char., 6 keys |
| DESIGN | | 9 modules for DIN rail |
| CONNECTION | | Removable screw type<br>connectors |



MORE—CONNECT

## User’s interactive device

ID-28 / ID-32: Operator graphic touch display & Microbrowser

| | |
|---|---|
| Display | ID-28 640x480 pixels / ID-32 480x272 pixels |
| Keyboard | touch screen |
| I/O | |
| Power supply | 24 V DC, screw terminal |
| COM | 100Mbit Ethernet, RJ-45 |
| DESIGN | Assembly into cover or door of control cabinet |
| SW | Built-in microbrowser for fast access to internal web pages of central modules Foxtrot and TC700 |

Operator panels ID-28 or ID-32 are meant to be used in co-operation with Foxtrot systems. Designed for built-in installation, the screen interface with the use can be created using Teco’s WebMaker tool (in Teco’s Mosaic development environment) and accessed via web server. They can interpret built-in web - displaying www pages in the central module and thus allowing the user complete control of its environment. Via this web feature, it is possible to access and monitor the states of system via any browser whether in a laptop or a smartphone.

Panels have a backlit LCD with a resolution of 640×480 pixels in ID-28, and 480×272 pixels in the case of ID-32. They are supplied from an external power supply of 24 V DC and communicates with a control system via Ethernet 100Base-TX with EPSNET protocol.

Such panels are intended to be demonstrated as a high-tech concept with the interaction between the user, sensor, and systems into what the controls will be a key feature to the consumer. An illustrative diagram of such idea is shown in the next section.

## User control and data presentation

Tecomat control systems come with a built-in web server implemented. The web server is a standard part of the last series of processor modules developed by Teco and it can be used for two purposes. The first one is the control system with diagnostics, its basic settings and monitoring of basic states via common web browsers, without necessity of installing any special software. Further, the web server can be used for running of user’s web pages. Customer can create for his device, machine, technology or building a web site with his own graphical interface. Web pages are stored in a memory card in XML format.

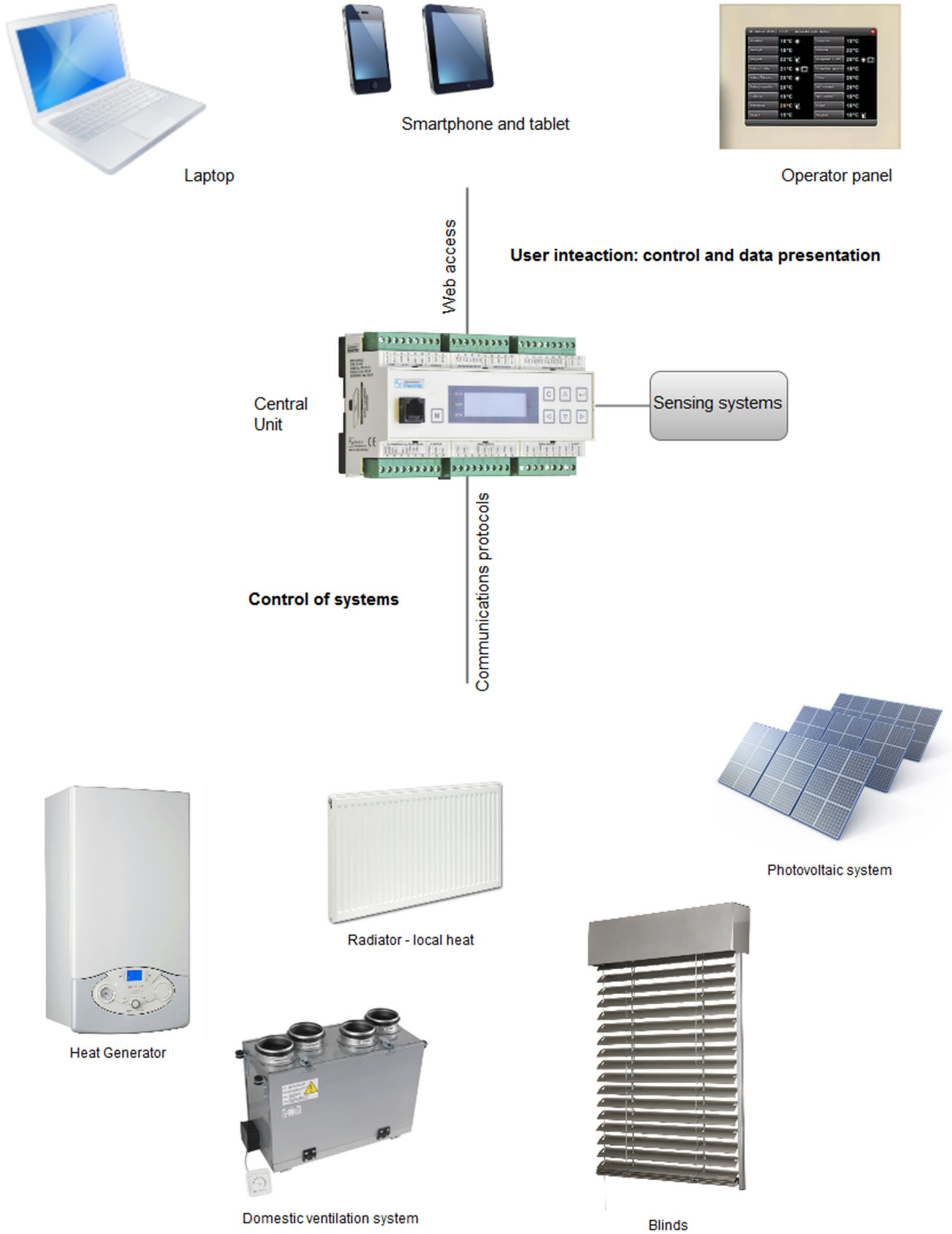



*Figure 13 - Web access illustrative diagram for user control of diverse systems*

# Wireless sensor systems

## RFox network

RFox network is a Teco a. s. wireless radio network operated in accordance with the Czech Telecommunication Office's General Authorization No. VO-R/10/05.2014-3 on the use of radio frequencies and the operation of short-range equipment. It operates in the unlicensed 868 MHz radio band; no other permission is required to operate it in the country.

RFox Parameters

| | |
|---|---|
| Communication model | Master-slave (up to 64 slaves per bus (master)) |
| Transmission power | 3.5mW (standard); 25mW (max.) |
| Duty cycle | 1% max. (standard configuration) |
| Frequency band | 868.35 MHz (license free ISM band)<br>CEPT ERC/REC 70-03 General License |
| Channels (Frequency range) | 8 (from 868.05 to 868.75 MHz) |
| RF modulation | FSK (frequency-shift-keyed) |
| Type of communication | Two-way (with confirmation packet) |
| Baud rate | 19.2 kb/s |
| Topology | Star or Mesh |
| Mode of operation | Permanent or intermittent (sleep mode) |
| Routing | Max. 4 routers per bus (master) |
| Range | 100m outside – 30m inside |

The communication between the RF master and RF peripheral module is supported for star (direct communication) and mesh topologies (direct and routing communication), see figures 14 and 15. The router (repeater) is a device that receives incoming RF packet, amplifies it and sends it further. By using routers, it is possible to increase the master's basic communication range. A maximum of four routers can be used in one RFox mesh network. The transmitted RF packet must reach its recipient after making no more than five hops.
It is important to highlight that each hop represents an increase in the time lag between sending and delivering of the packet and that either a dedicated RF router or any RF module in continuous operation can be selected for the function of the router (this function is assigned to the module during its configuration to the RFox network).
In terms of operation, the modules with continuous operation are always able to respond to commands from the master (they are mostly permanently powered modules), while the ones with intermittent operation go into the "sleep mode", during which they do not respond to master's commands (they are usually battery-powered modules).

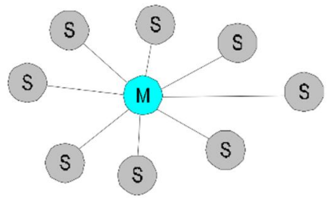



Figure 14 - Example of star topology

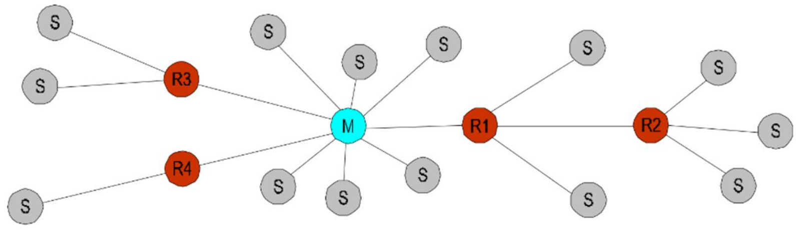



Figure 15 - Example of mesh topology

## RFox connected devices

The following Teco a. s. devices will provide wireless solutions to the controlling problematics inside the building retrofitted with MORE-CONNECT panels.

R-HC-0101F - proportional head of radiator valve

| | | |
|---|---|---|
| DI | | |
| DO | | |
| AI | 2 | 1x internal temperature sensor<br>1x external temperature sensor or window contact |
| AO | 1 | Valve position 0-100% |
| COM | | RFox slave |
| DESIGN | | For assembly to radiator valve, M30x 1,5 mm |
| CONNECTION | | Integrated antenna,<br>Power supply from battery |

Basic features
- Motor control of head of radiator valve.
- Contains internal sensor of room temperature.

Connection
- Head mount on radiator valve only.
- It has no wire connections.
- Module is connected to RFox network by bonding process.

Use
- Regulation of hot water heating in rooms – radiator or floor heating.
- Direct fixing on radiator valve M30 × 1.5 or via reduction.

R-RT-2305W: RFox router

| | | |
|---|---|---|
| DI | | |
| DO | | |
| AI | | |
| AO | | |
| COM | | 1x RFox- wireless 869MHz |
| DESIGN | | Socket adapter |
| CONNECTION | | Into socket 230V AC |

Description
The R-RT-2305W dedicated router is a network component of the R-Fox platform intended for delivering packets to devices out of range, especially where there is no other RFox module in range that could be used as a non-dedicated router.

RF-1131: RFox master

| | | |
|---|---|---|
| DI | | |
| DO | | |
| AI | | |
| AO | | |
| COM | | 1x RFox- wireless, 1x TCL2 |
| DESIGN | | 1 module for DIN rail |
| CONNECTION | | Fixed screw type terminals |

Basic features
• The module is the gateway of Foxtrot system into the wireless data network RFox. It is the master of bidirectional communication (with confirmation of each data transmission) with slaves, and operates in the license free frequency band of 868 MHz.
• As coordinator/master of data network, this RFox module enables to connect up to 64 wireless modules with inputs and outputs to Foxtrot system.
• Module RF-1131 is not included in the limit of max. 10 modules on TCL2 bus.
• Module is operated on low power up to 10mW.
• Master module continuously monitors the network to keep the actual status of all slaves. This status image is available for central module anytime. Vice-versa the master module sends commands from the central module and writes new statuses to slave modules.
Connection
• Module is designed as a standard communication module at TCL2 bus.
• Mechanical design is suitable for installation on DIN rail.
• Antenna or cable can be connected on module directly with SMA connector.
Use
• Creation of wireless control system with centralized processing of signals and commands.
• Creation of wireless and wire system combination.
• Suitable for reconstruction of buildings in places, where we cannot install the electrical installation bus.
• For any application, where digital or analog values needs to be wireless transferred.

RC-RC-OO1R - Room Control Manager


| | | |
|---|---|---|
| DI | | Rotation + press button |
| DO | | |
| AI | 2 | internal temperature measurement NTC, external NTC |
| AO | | |
| COM | | RFox slave, internal antenna; LCD display |
| DESIGN | | Plastic box on the wall with rotation button and feedback |
| CONNECTION | | screw terminals for power supply |

Basic features

• Wireless module for interior design in offices or residential facilities. Module is designed for visualization of status and setting required values (Room Control Manager).
• LCD displays the values (temperature, time, humidity, speed, heating, cooling) and many other graphic icons often used in HVAC field.
• Rotational element with pushbutton for confirmation is available to program individual needs over the menu.
• Built-in temperature sensor. Also possibility to connect external NTC sensor to choose suitable place of measuring, independent of device position.
• Module is freely programmable by user. Any icon or number can be controlled as a digital output. The operations of rotational element and its pushbutton are accessible to the programmer.
Connection
• Module is designed as standard device of radio network RFox. Power supply comes from battery.
Use
• Use as Room Control Manager in each room or space, where we require individual control of temperature and ventilation.

R-OR-001B - Output module for wireless network RFox

| | | |
|---|---|---|
| DI | | rotation + press button |
| DO | 1 | Relay, switching contact 16A |
| AI | | internal temperature measurement NTC, external NTC |
| AO | | |
| COM | | RFox slave, internal antenna; |
| DESIGN | | Built-in module into installation box |
| CONNECTION | | Integrated antenna<br>Outputs embarrassed with CY 3x 1,5 mm2<br>Power supply 230 V AC |


Basic features
• Module with one switching relay contact for power loads at 230 V AC.
• Power supply from 230 V AC. Wireless communication.
• Modules are designed for switching independent loads/devices by relay output.
• Relay is independently addressed and wirelessly controlled by central module via sending commands with confirmation.
Connection
• Module is designed as standard device of radio network RFox.
• Mechanical design suitable into standard installation box.
• Recommended installation position vertical, according to sign on the cover.
Use
• Used for switching the loads at 230 V AC, where we need to replace wire bus communication by wireless connection.
• During the project, contact load and its protection type should be taken into account.

# BIPV façade, roof system key elements and options for both M-C experimental panel and M-C experimental house

## M-C experimental house BIPV Facade

1) PV cladding technology
- Thin-film
- Monocrystalline
- Polycrystalline

2) Façade system
- Ventilated
- Non-ventilated

3) Fitting Anchor methods
- Mullion –transform
- Point-fixing such as clamp or undercut system
- Structural sealant glazing (SSG)

Each of these options has some advantages and disadvantages. Our pre-selected criteria for PV façade which would fit our needs are based on some specific aspects:

- Due to an issue with façade space restrictions our solution requires the use of monocrystalline/polycrystalline PV panels. They produce a greater amount of electricity than thin-film solar panels for the same amount of space (figure 16).
- We would consider PV modules specifically developed for the façade applications has considerably darker glass, black frame with the black backing lamination (in the case of frame modules) , or almost black panels with frameless construction. They have also small distance gaps with visually pleasant and clean uniform look.


*Figure 16 – Solar technologies. Source: http://www.homepower.com/articles/solar-electricity/equipment-products/solar-electric-options-crystaline-vs-thin-film*

- Ventilated façade system was pre-selected due to the better aesthetic possibilities, elimination of the thermal bridges and condensation problems. Very important aspect of pre-selection criteria was the impact of so-called "chimney effect action" on thermal properties of BIPV panels.
  The ventilated façade system is creating the specific thermal conditions well suited for BIPV system.
  Firstly it is breaking the direct contact between the externally irradiated surface of PV panels and the thermal insulation thus greatly reduce direct heat transfer.
  Secondly, the airflow created by chimney effect in ventilation cavity would subtract the irradiation heat from the back of the PV panels (figure 17).
  There will be temperature sensors placed on the back of the PV module in predefined positions

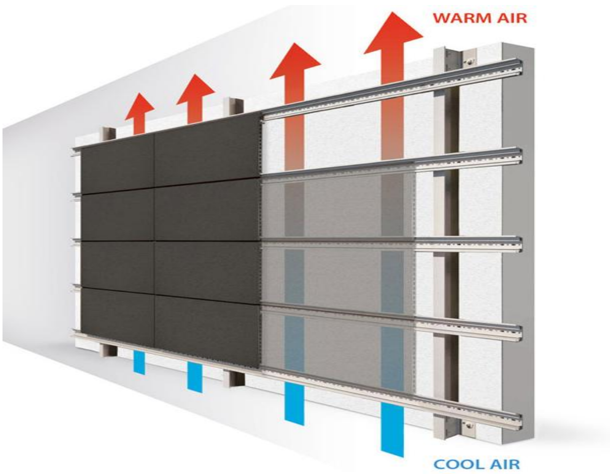



*Figure 17 – Ventilated facades. Source: http://www.tempio.es/en/ventilated-facades.php*

- Each of the fitting anchor methods has a different aesthetic impact on BIPV façade. In our case, we would try to achieve the highest possible level of aesthetics of BIPV M-C façade.

Thus the clamp fixing or SSG anchor system would be more suitable for our project (figure 18).

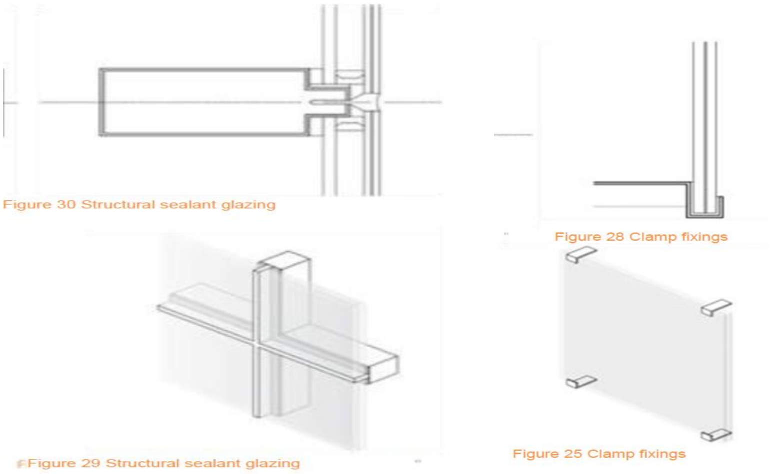



*Figure 18 – Fitting methods. Source: http://www.polysolar.co.uk/_literature_138380/2015_Guide_to_BIPV*

M-C experimental house BIPV Roof:

- Pitched roof east-west orientation with slope of 20°
- The PV system with east-west orientation
- PV modules based on monocrystalline or polycrystalline technology with high efficiency
- Solar insolation sensors and PV module temperature sensors

| Position | Number of PV modules | Size of the PV system [kW] | Output 1 kW/Year (PVGIS estimate*) [kWh] | Total system output / Year [kWh] |
|---|---|---|---|---|
| Roof slope 20°/ Azimuth-90° east | 8 | 2,16 | 794 | 1715 |
| Roof slope 20° /Azimuth 90° west | 8 | 2,16 | 790 | 1706 |
| South façade 90° slope/ Azimut 0°south | 6 | 1,62 | 633 | 1025 |
| All surface areas- Total | 22 | 5,94 | 2 217 | 4 446 |

*Table 3 - Specifications of façade/roof PV system on M-C experimental house. Based on PV modules 270Wp. Different PV modules could be chosen during the design process*

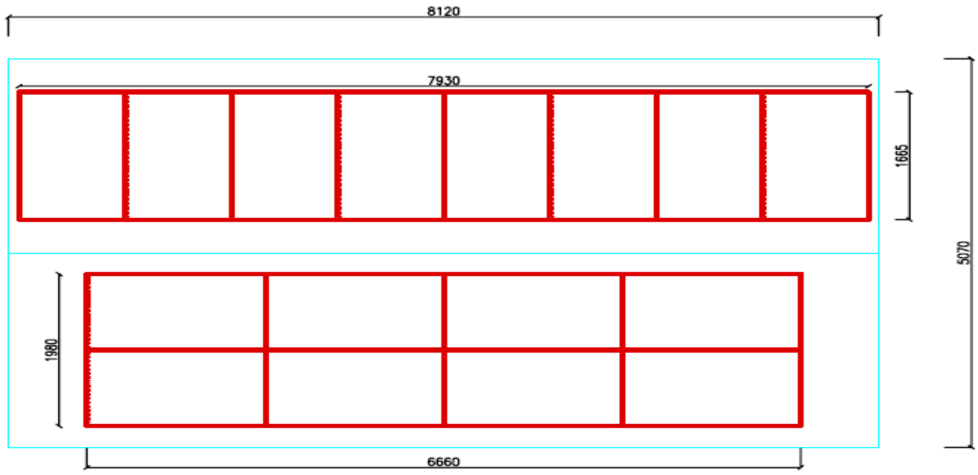



*Figure 19 - M-C experimental house PV roof configuration (landscape or portrait orientation of the PV modules)*

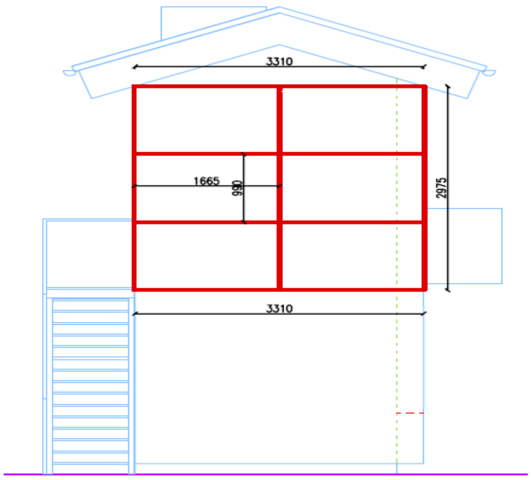



*Figure 20 - M-C experimental house PV south facade configuration (landscape orientation of the PV modules)*

There are two types of connection topology related to a solar hybrid system that would be investigated in M-C experimental house. The connection is usually called AC coupling and DC coupling (Figure 21).

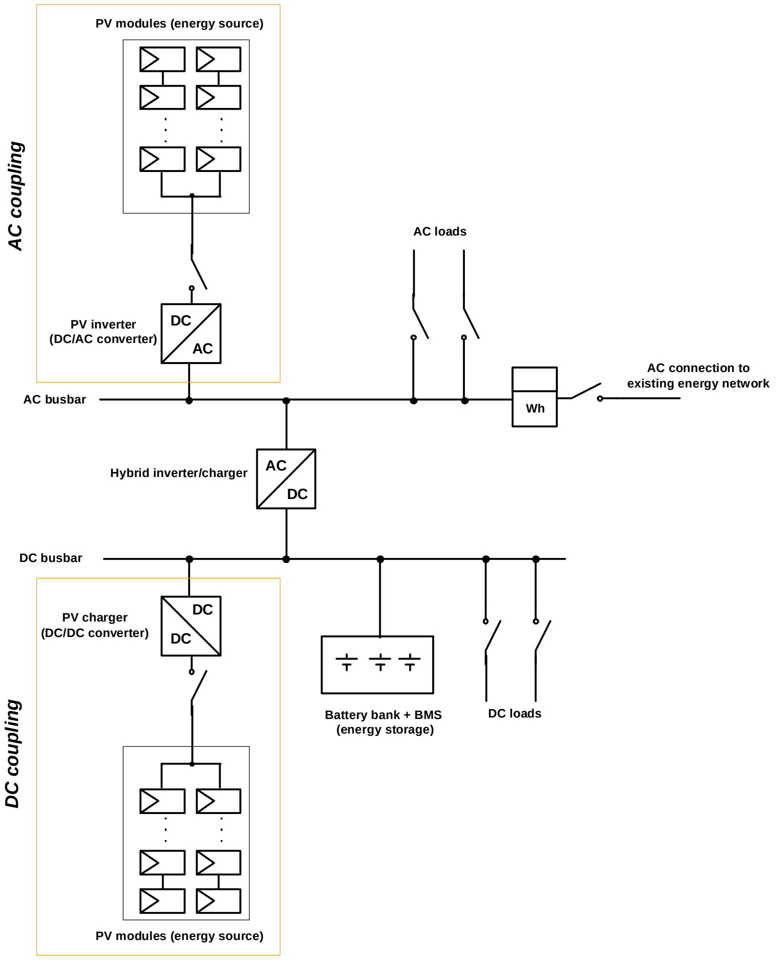



*Figure 21 - Block diagram of the DC and AC coupling*

The Hybrid roof and façade PV system would supply energy for the loads – directly using AC coupling and indirectly using DC coupling (Figure 6). Both principles have their pros and cons, a mixed concept is in some cases recommended as well [1].

The system will be precisely monitored and data will be evaluated. This will enable to specify and present the pros and cons of both principles (AC and DC coupling), to find optimal control procedure and methodology for optimal system design and control.

Also, several types of operation will be tested – hybrid operation with a distribution network, stand- alone system, micro-grid system cooperating with main UCEEB building and technology which is installed nearby (e.g. CHP unit). The control will be based on innovative approaches to PV forecasting, demand response techniques, model predictive control, and intraday tariff.

Brief description of electrical concept (Figure 21):
A mixed concept of AC and DC coupling would be implemented. This will enable for testing purposes to run the system in all three states (AC, DC, AC+DC coupling). AC coupling shows usually better performance if energy is directly consumed when generated (during the day), on the other hand, DC coupling is suitable for loads running most time when there is no PV source present (during the night). Hybrid inverter/charger will be the main unit to transfer the energy between the DC and AC bus bar; it will enable an autonomous operation as well (switching off the grid and running the local grid in autonomous mode).

The whole system will be electrically connected to existing energy network of UCEEB research center, the energy control system will enable both – fully autonomous control and operating the UCEEB building and technology together to support each other.

*[1] New Trends in Hybrid Systems with Battery Inverter. Pierre-Olivier MOIX. Proceedings of Small PV-Application 2009. Ulm, Germany.*

## Energy Storage System

M-C experimental house would have PV system with battery storage implemented. The battery storage system will consist of a series of characteristic components. For each of these components, there are several basic types according to the materials used, production technologies, technical design or topology. Yet the most important component of all is the battery technology itself.
Battery storage system combined with the photovoltaic system allows storing the excess power produced by the PV system. It can be then used to offset peak load or nighttime use. Another possible use of the battery storage system is to buy the energy at the time of its low cost (low tariff, off-peak) and use it at a time when the electricity from the grid has a high price typically during the peak load time (figure 22)

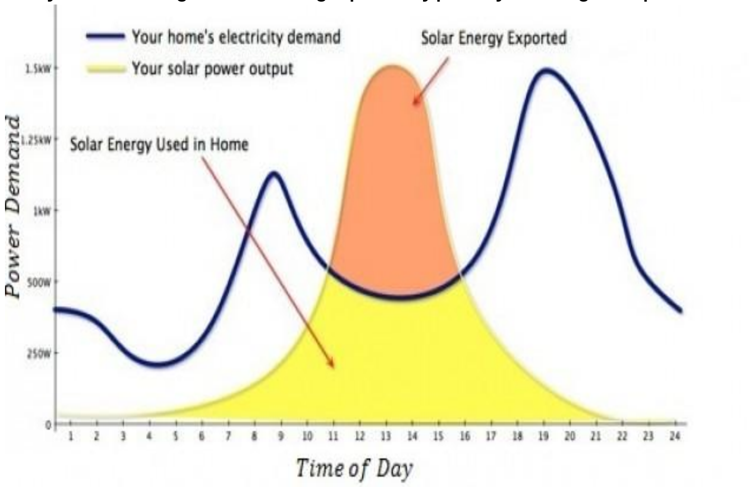



*Figure 22 – Power demand. Source: http: //www.goingsolar.com.au/what-we-do/solar-electricity-hybrid*

Batteries
The market with battery technology is evolving dramatically. Focus is on improving main battery characteristics like the high number of cycles (life), the possibility of charging / discharging with high currents, the possibility of cycling with deep discharge, low self-discharge rate, and low maintenance.
The newest types of the batteries on the energy market are Lithium Iron Phosphate ($LiFePO_4$) and Lithium Titanium Oxide (LTO), which are characterized by a very high number of cycles, high safety, charge / discharge rate and resistance to temperature fluctuations. Their main disadvantage is the high purchase price.
The new types are also so-called „flow batteries“. Vanadium Redox (VRB) and Zinc Bromide (ZNRB) are the most common. The flow technology is based on the electrochemical reaction of reduction-oxidation, which is used for energy storage and subsequent retrieval of electricity. There is an electrolyte divided into two separate containers and the special membrane that allows the passage of ions (figure 8).

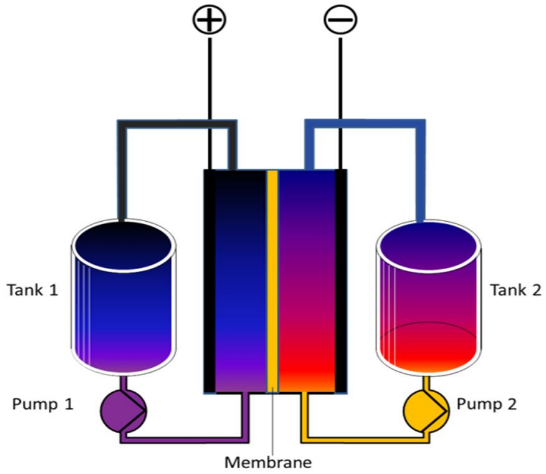



*Figure 23 Flow battery. Source: https://en.wikipedia.org/wiki/Flow_battery#/media/File:Redox_Flow_Battery_English.png*

The main advantages of the flow technology are theoretically an unlimited number of cycles, in practice, approximately 15,000 (membrane as one of the few elements of the system that must be changed over the time), no degradation of the electrolyte.
The main disadvantage of this technology is the low energy density (about 20 kWh/m3 or 25Wh/kg). This means that it is quite a large and heavy battery more suitable for industrial applications. Some companies start to introduce smaller units for residential market applications as well.

The main parameters of the batteries:

- Voltage [V]-The batteries are composed of a number of cells. The batteries are usually assembled into a battery bank with a voltage of 12V, 24V or 48V.
- Battery capacity [Ah]- is the discharge current a battery that can be delivered within certain time.
- C-Rate [C] is a measure of the rate at which a battery is discharged / charged relative to its maximum capacity
- The Depth of Discharge ( DOD) [%] - is expressed as a percentage and determines the percentage of operational discharge of the battery providing the desired service life.

| Parameters | NiCd | Ni-MH | Li-ion | LiFePO4 | LTO | Pb |
|---|---|---|---|---|---|---|
| Specific energy density [Wh/kg] | 45-80 | 60-120 | 90-120 | 90-120 | 50-70 | 30-50 |
| Cycle life ( 80% discharge) | 1500 | 300-500 | >1500 | 2000+ | 10000+ | 400-500 |
| Lifespan [year] | 5 years | 3-4 years | 10 years | 10 +years | 25 years | 10 years |
| Self-discharge [%] | 20 % | 30 % | 5-10 % | 3-5% | 1,5-2,5% | 5 % |
| Cell nominal voltage [V] | 1,2 V | 1,2 V | 3,3 V | 3,2 V | 2,4 V | 2 V |
| Price [EUR/Wh] | 0,33 | 0,65 | 0,33 | 0,60 | 1,5 | 0,11 |

*Table 4 - Key battery parameters for different chemistry types*

| Producer | Chemistry | Parameters | Sale Price (CZK) | CZK/kWh |
|---|---|---|---|---|
| Fronius Solar Battery 12.0 Li-ion | Li-ion | 12 kWh, 8000 cycles 80% DoD | 292 240,- (2) | 24 353,- |
| Hoppecke, OPzV bloc solar power 180 Pb | Pb | 12V, 2,16 kWh, 2700 cycles 50% DoD | 17 010,- (1) | 7 875,- |
| Hoppecke sun powerpack classic Li-ion | Li-ion | 48V, 11,0 kWh, 2500 cycles 50% DoD | 65 715,- (6) | 5 974,- |
| Victron Energy, Lithium Battery-BMS Li-ion | Li-ion | 12,8V, 2,56 kWh, 5000 cycles 50% DoD | 60 166,- (4) | 23 502,- |
| Winston 12V90AH LiFeYPO4 | LiFEYPO4 | 12V, 1,08 kWh, 6000 cycles 50% DoD | 14 008,- (3) | 12 970,- |
| GWL/EV-Power LiFePO4 | LiFePO4 | 12V, 1,092 kWh 2000+cycles 80% DoD | 12 933,- (5) | 11 843,- |
| GWL/EV Power LTO | LTO | 2,4V 0,096 kWh 10000+cycles 80% DoD | 2 080,- (5) | 21 666,- |

*Table 5 - Examples of batteries and prices (the Czech Republic market)*

| Producer | Chemistry | Parametres | Sale Price [CZK] | CZK/kWh |
|---|---|---|---|---|
| Tesla PowerWall Li(NiMnCo)/Li(NiCoAlO2) | Li(NiMNCo) Li(NiCoAlO2) | 7 kWh/10 kWh 5000 cycles 100% DoD | 72 360,-/105 000,- (8) | 10 337,-/ 10 500,- |
| Sonnenbaterrie ECO4/PRO LiFePO4 | LiFePO4 | 4-16 kWh/24-96 kWh | Od 145 000,- (including inverter) (8) | 36 250,- |
| SafeBOX Home SBH 2,6-4,5-2,3/2,6-7,5-3,5 LiFePO4 | LiFePO4 | 4,5 kWh/7,5 kWh 4000 cycles 95% DoD | *149 000,-/*194 000,- (7) | 33 111,-/ 25 866,- |
| ElectroIQ Power All in One | Li-ion | 10kWh 8000+ cycles 80% DoD | 384 720,- (11) | 38 472,- |
| ABB React REACT-3.6/4.6-TL (jen baterie) | Li-ion | 2kWh 4500 cycles 94% DoD | 85 003,- (14) | 9 775,-/ 8 238 |
| Bosch BPT-S 5 Hybrid | Li-ion | 4,4-13,2kWh 6500 cycles 50% DoD | 590 012,-/ 1 111 930,-(13) | 134 093,- / 84 237,- |
| Varta Engion Family | LiFePO | 3,7-13,8 kWh. 6000 cycles 80% DoD | 351 842,-/ 541 296,- (12) | 95 092,-/ 39 224,- |

*Table 6 - Examples of residential battery storage systems so-called home batteries (*prices without VAT)*

| Technical Specifications | Total price [CZK] | Technical Specifications | Total price [CZK] | Technical Specifications | Total price [CZK] |
|---|---|---|---|---|---|
| 3 kWp Set ,10x Sharp 285W,1x3,0 kW hybrid měnič Solax, baterie Pro Solax LiFePO4 4,8 kWh (6) | 171,380,- | 5 kWp Set ,20x Omsun 250 W 1x5 kW hybrid měnič Solax,baterie Pro Solax LiFePO4 7,2 kWh (6) | 229 455,- | 8,67 kWp, 34xAmerisolar 255W, Kostal Piko BA 8, Wattrouter ECO+SSR relé,baterie Li-ion 12kWh (1) | 718 000,- |
| 3,18 kWp, 12xPolySol 265 W,1x 1 x Fronius Symo Hybrid 3.0-3-S, Fronius Solar Battery LiFeYPO 4,5 kWh (9) | *304,900,- | 5,22 kWp, 36xNexPower NT145AX,1x Studer Xtender XTM 4000-48,regulátor, Studer,16xWB-LYP300AHALiFeYPO4 15,36 kWh (9) | *425,800,- | 7,50 kWp, 30xWinaico WST-250P6, 3 x Studer Xtender XTM 2400-24, 2 x Studer VarioTrack VT-80´+MPP, Batterie 24 x MOLL OPzV solar 2 V / 710 Ah 34,00kWh (9) | *555 900,- |
| 3,18 kWp, 12xKyocera KT 265 6MCA, Fronius Symo Hybrid 3.0 - 3-S, Fronius Solar Battery LiFeYPO4 7,5 kWh | *352,865,- | 5,3 kW,20xKyocera KT 265 6MCA, Fronius Symo Hybrid 5.0 - 5-S, Fronius Solar Battery LiFeYPO4 9 kWh | *465 580,- | | |

*Table 7 - Examples of complete sets of PV and battery bank (price* without VAT)*

*Sources:*
*(1) Frankensolar Eastern Europe s.r.o., Kostelecká 59/879, 196 00 Praha 9, Česká republika*
*(2) Silektro s.r.o., Perunova 17, 130 00, Praha 3*
*(3) Ing. Martin Kolařík, ostrovni-elektrarny.cz, Náves 112, Vlkoš, 751 19*
*(4) Neosolar spol. s r.o., Stavbařů 4334/41, 586 01, Jihlava*
*(5) i4wifi a.s., GWL/EV-Power, Průmyslová 11, 102 19 Praha 10*
*(6) Nanosun s.r.o,, Křižíkova 36a, Praha 8*
*(7) Fotovoltaické systémy, Slunečná 342,751 11 Radslavice*
*(8) http://oenergetice.cz/technologie/elektroenergetika/souboj-domacich-baterii-sonnenbatterie-vs-tesla/*
*(9) SOLARENVI a.s., Dukelská 145, 379 82 Třeboň*
*(10) Sun Pi s.r.o. Sedláčkova 472/6, 397 01 Písek*
*(11) electriqpower.com*
*(12) Swonia Tržiště 372/1,Praha 1, 118 00*
*(13) http://www.enter-shop.com.au/catalogue/c3/c44/c261/p1254*
*(14) ABB s.r.o., BB Centrum budova Delta II, Vyskočilova 1561/4a ,140 00 Praha 4*

## PV-battery systems development in relation to EU SET-plan

Despite the fact that the market for hybrid systems combined with battery storage in the Czech Republic is influenced by many specific factors, in the long term is to assume an inevitable upward trend following the trend in the EU energy market as a whole. Here are some examples of trend prediction:
In figure 24 the market volume is displayed with the PV energy storage for the private sector in the size up to 10kWh net capacity. Here is clearly shown a rapid increase in the market volume of the storage for the whole European market.

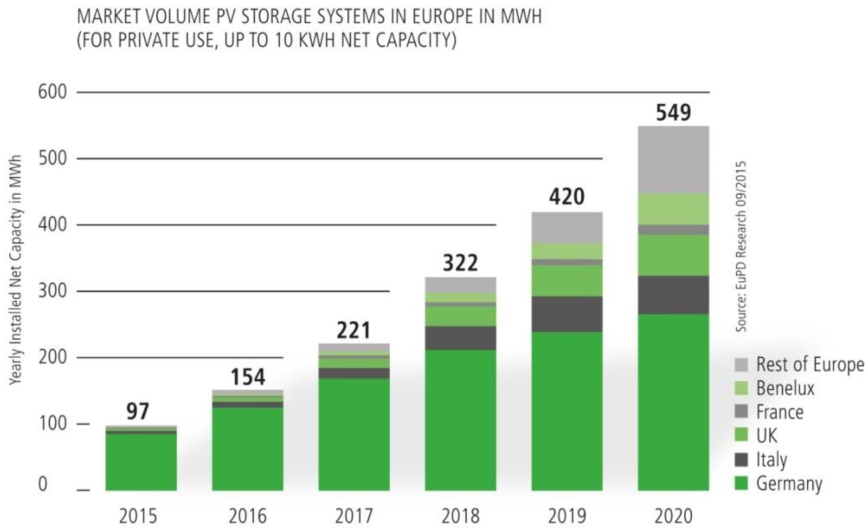



*Figure 24 - Expected development of the capacity of residential PV systems to store energy in Europe. Source: http://www.ees-europe.com/en/news-press/press-material/market-information.html*

The next figure 25 shows the price index development for battery storage system costs according to technology used in the previous years.

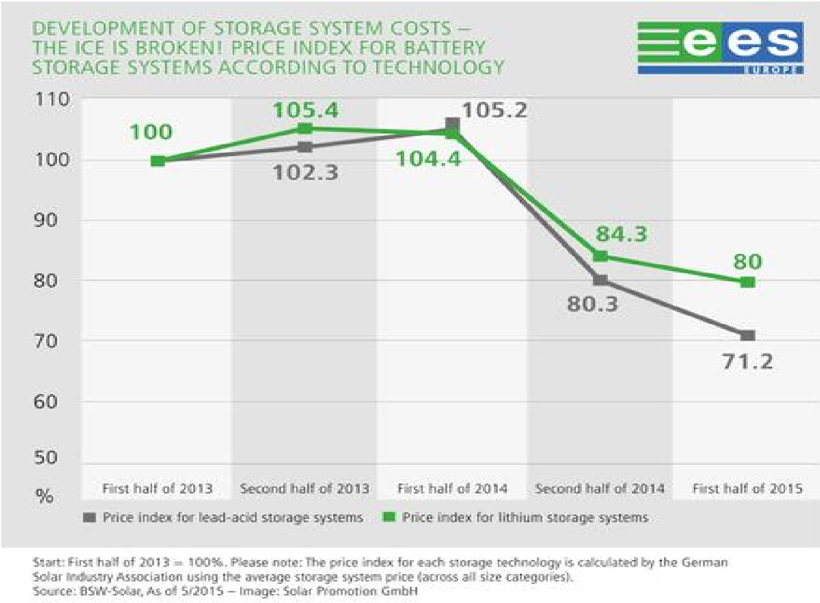



*Figure 25 - The expected price development of energy storage system. Source: http://www.ees-europe.com/en/news-press/press-material/market-information.html*

Below is the forecast information from another source with the clear uptrend displayed. There is an interesting detail about new storage systems installation projections outside German market (Figure 26).

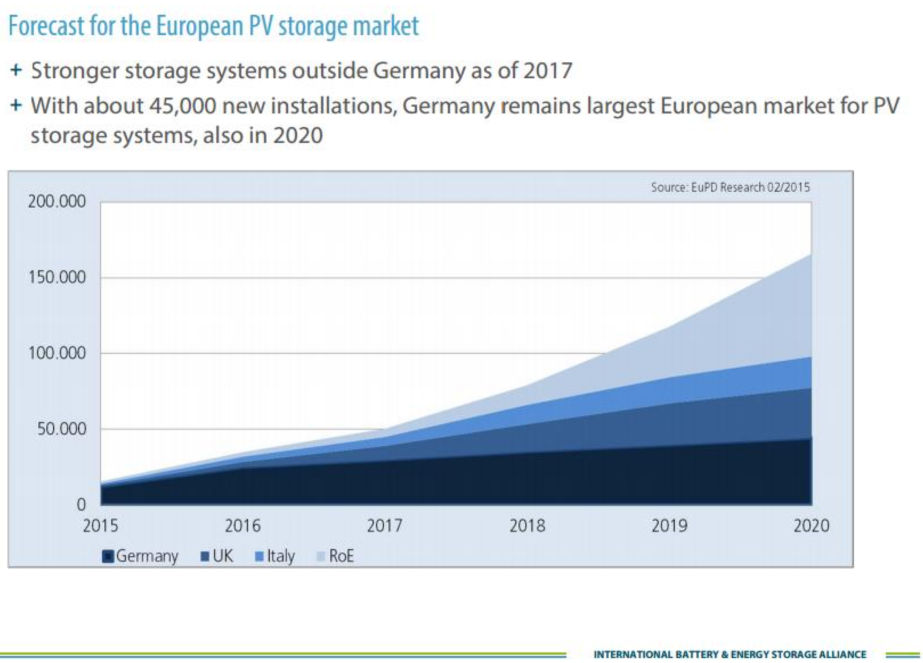



*Figure 26 - Estimated market with PV systems, energy storage Number of new systems. Source: http://ibesalliance.org/fileadmin/content/download/presentation/Markus_AW_Hoehner_Smart_Cities_Renewable_Energy_Storage.pdf*

Other factors that greatly speeds up the number and size of the installed battery storage on the European market are:
1. The EU's stabilization and balancing electricity system in connection with the need to integrate an increasing amount of RES
2. The pressure to reduce expenses on maintaining the balance of power in the EU distribution electricity network closely related to so-called the emergency disconnection of RES (such as solar or wind power).
3. Falling prices of hybrid PV systems and battery storage speeds up the number of installations for both the private sector and for industrial applications as well.
4. European energy reform in progress as an Energy Technology Plan (EU SET-plan)which would focus more on power generation, transmission, and smart grids.
5. The increasing demands on the energy security of transmission and distribution systems across the EU in the event of major and unexpected outages and disruptions.

## PV forecast service to control PV hybrid system

As shown in figure 22 the main energy demand peaks in residential segment happen in periods where the PV production is generally low. Hybrid system containing batteries is able to store the energy generated by PV and use it in later time when the demand exceeds actual PV power. The batteries enable building to switch to tariff supply only and to minimize the energy supplied from the grid. The batteries the charge only during night low tariff (Dual tariff structure Czech Republic) and discharge during the day in high tariff periods. Therefore, the supply from the grid is minimized and energy bills reduced.

The night tariff charging can be improved by knowledge of forecasted PV energy for the next day. When the advanced energy management system knows the predicted amount of energy generated in the coming day (or two, depending on the total battery capacity), it can set the charging level only to a desired point to cover the night and morning demand and to use fully the day PV energy for charging as well as for covering the actual day demand of the building. Such a control mechanism will eliminated situations where the PV energy during the day exceeds the day consumption and the batteries are fully charged (e.g. from night charging). Such situations are not efficient because the system cannot generate as much energy as is available.
More connect advanced energy management system will use the PV forecast service to get the information of the predicted PV power to eliminate situations mentioned in previous paragraph and to increase the energy efficiency of the whole system. The main parameters of the service are summarized in following points:

- Irradiance forecasting for next 24/48 hours with one hour step
- Uses multiple forecasting sources to improve reliability and accuracy
- Standardized requesting commands using http
- Selectable format of the responding forecast data
- Easy to implement in PLCs and automated control systems

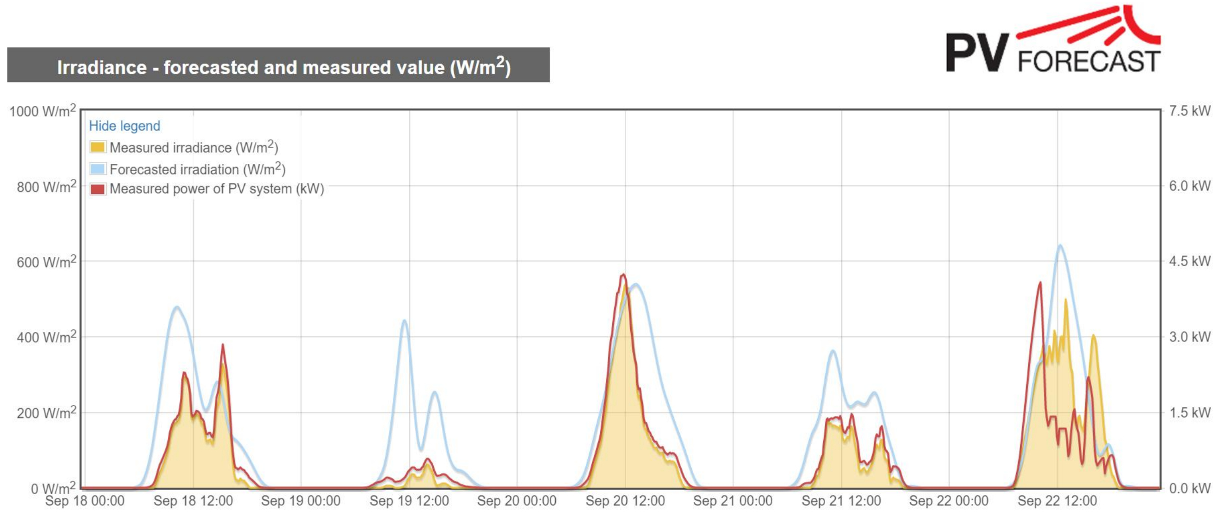



*Figure 27 – PV Forecast*

## Micro Grid

The M-C experimental house would be incorporated as an integral part of UCEEB Microgrid (figure 12). It will play an important role in energy demand management, storage and generation.

In the first step, we would like to demonstrate the advantages of micro grid on the inner grid of our research center where we already operate different energy sources (gas boilers, CHP unit, PV, Lithium battery, among others) and collect data on energy production, operating data (indoor and outdoor temperatures, solar irradiance, and possibly other data as well). The research center composes of administrative rooms and laboratories that can be separately measured and evaluated.

As part of the M-C experimental house, we would measure and analyze the new energy data. Based on the data collection process we will create an efficient control algorithm which will be based on model predictive control strategy (MPC).

Next step would be the utilization of the algorithm to fully control the M-C experimental house related to UCEEB microgrid as a whole and evaluate the results in order to see the benefits, issues, and areas of possible improvements.

The research would focus on optimization of M-C experimental house with a hybrid photovoltaic system connected to energy storage system within the concept of the smart grid.

Another important focus area would be the short term weather prediction so-called “nowcasting”. Within the M-C experimental house project, the research team would adapt our PV Forecast service to new requirements for the intraday energy trading platforms and use new equipment (RaZON+ ALL-IN-ONE Solar Monitoring System with pyranometer and PH1 pyrheliometer) to refine short-term PV-forecast service.

The main aim would be to precisely predict and control energy fluctuations, the microgrid balancing, peak-load shifting, improvement of electric power quality(voltage / frequency) and demand – response control. These elements are now critical for the concept of the smart grid in the whole EU electricity distribution network.

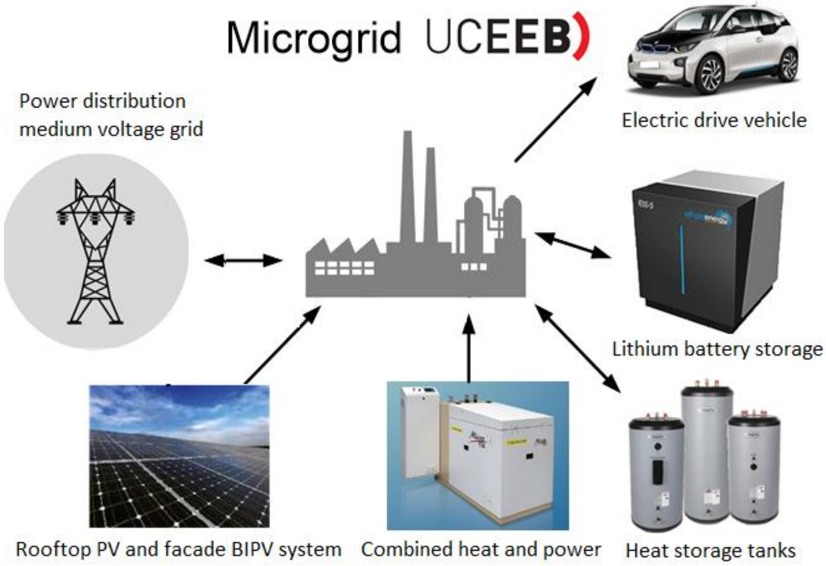



*Figure 28 – Micro grid UCEEB providing heat and electrical energy for laboratories and administrative rooms*

## Advanced controls, monitoring, optimization and application of multi-sensors

New sensor set for more-connect has been developed to be integrated directly in to the facade as well as in the interior of the building to monitor indoor environment. Some of these sensors allow being equipped with wired digital communication interface as well as with wireless communication interface. The examples of the sensors used for monitoring of the structure as well as for monitoring and control of the internal climate are given bellow. All the sensors are provided by RS485 communication interface and some of them can be equipped with RF communication interface as well as the IoT interfaces LoRa and Sigfox.

### Wood moisture monitoring – MoistureGuard

MoistureGuard is a unique system for continual monitoring of moisture content within the wood and was developed to be integrated directly in the MORE-CONNECT wooden façade structure. System is able to detect the health of the wooden parts continuously and to detect problem related to vapor condensing, leaks or high levels of moisture in the structure that are not easily discoverable in the interior. The sensors are integrated in the façade elements during the manufacturing process and are connected via RS-485 to the control and monitoring system. Except the pin wood moisture measurement, the system also detects the air humidity and temperature in façade elements cavities or insulation material.

Technical parameters

| | |
|---|---|
| Measurement: | Moisture content in building materials, air humidity, temperature |
| Power: | 5 to 16 V DC, < 3 mA at 5 V |
| Working environment: | −40 to +85 °C (−40 to +176 °F), 0 to 80 %RH noncondensing |
| Communication interface: | RS-485 & Modbus RTU (configurable) |
| Mounting: | 2 stainless screws (serves also as measuring electrodes) |
| Dimensions: | 42 x 28 x 18 mm |

| | |
|---|---|
| Wood resistance measurement: | range 0 to 50 GΩ<br>resolution 2 kΩ |
| Moisture measurement: | range approx. 7 to 30 % (depends on material)<br>resolution 0.01 %<br>accuracy ±2 % |
| Relative air humidity measurement: | range 0 to 100 %RH<br>resolution 0.04 %RH<br>accuracy ±2 %RH (typical)<br>repeatability ±0.1 %RH<br>hysteresis ±1 %RH<br>nonlinearity <0.1 %RH |

Absolute air humidity measurement conversion from relative humidity: resolution 0.01 g/m$^3$ (0.01·10$^{-4}$ lbs/ft$^3$)


HT01485 MHT02485

*Figure 29 – MoistureGuard sensors*

## Indoor air quality sensor

Combined indoor air quality sensor was developed within MORE-CONNECT project to control air ventilation system. The system is equipped with most important sensors covering temperature, air humidity, CO2 sensor and volatile organic compound sensor. These four variables were selected as the most important for healthy indoor environment and are used for direct control of the ventilation system and heating in the building.

Technical parameters
Measures: $CO_2$ concentration, VOC concentration, temperature, relative humidity
Power: 7 - 24 V DC, 140 mA
Working range: 400 – 3000 ppm $CO_2$, 0 – 30 ppm VOC
−40 to +85 °C (−40 to +176 °F), 0 to 80 %RH non-condensing
Communication interface: RS-485 & Modbus RTU (configurable), IQRF


*Figure 30 – Environmental sensor UCEEB*

## Irradiance sensor

Irradiance sensor will be also part of the control system to measure instant irradiance and thus enabling the energy management control of the building components. The irradiance sensors will be used to control and verify the PV production and all adjustable loads within the building.

Technical parameters

| | |
|---|---|
| Measurement: | Irradiance, temperature of sensing element, inside box and up to 4 additional temperatures |
| Power: | 6 to 35 V DC, < 3 mA at 5 V |
| Working environment: | −40 to +85 °C (−40 to +176 °F), 0 to 80 %RH noncondensing |
| Communication interface: | RS-485 & Modbus RTU (configurable) |
| Mounting: | 4 holes for screws (ø4 mm, 98 x 36 mm) |
| Dimensions: | 110 x 57 x 29 mm |
| Ingress protection: | IP54 |


*Figure 31 – Irradiance sensor UCEEB*

- Temperature sensors on back of the PV panels on M-C experimental house facade and roof
- Solar insolation sensors on M-C experimental house facade and roof
- RaZON+ ALL-IN-ONE Solar Monitoring System with pyranometer and PH1 pyrheliometer

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