CommONEnergy

DELIVERABLE 6.4

Energy savings result

European Commission DG Research and Innovation SP1 - Cooperation

Collaborative project

Large-scale integrating project

FP7-2013-NMP-ENV-EeB

GRANT AGREEMENT No. 608678

CommONEnergy

Re-conceptualize shopping malls from consumerism to energy conservation

FP7 European Union Funding
for Research & Innovation

Technical References

Project Acronym	CommON*Energy*
Project Title	Re-conceptualize shopping malls from consumerism to energy conservation
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Project Duration	1 October 2013 – 30 September 2017 (48 Months)

Deliverable No.	Deliverable 6.4
Dissemination Level	PU
Work Package	WP6
Lead beneficiary	CARTIF
Contributing beneficiary(ies)	EURAC, SINTEF, ACCIONA, BLL, EPTA, DURLUM, AMS, UNIUD, SCHNEIDER, DAPP
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Date	Draft document: M42; Final document: M48
File Name	WP6_D6.4_20170930_P04_Energy savings results

This document has been produced in the context of the CommONEnergy Project.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 608678. The content of this document does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the document lies entirely with the authors.

Contents

Executive Summary

The systemic retrofitting approach developed within the project in terms of solution-sets to reduce energy needs and to enhance energy efficiency was applied, at different retrofit levels, to three selected demo-cases:

- Mercado del Val (Valladolid, Spain): complete reconstruction of the entire building;
- Coop Canaletto (Modena, Italy): deep retrofitting of the entire building;
- City Syd (Trondheim, Norway): retrofitting solutions implemented and tested in four demonstration areas.

The overall energy performance of the retrofitted demo-cases and the solutions applied was evaluated through a tailored Measurement & Verification (M&V) plan for each demo-case depending on the retrofit intervention features. We referred to the four options defined in the International Performance Measure and Verification Protocol (IPMVP):

- Option A: Retrofit Isolation - Key Parameter Measurement. Savings are determined by measuring the performance parameters that will have the higher influence on the savings calculation and by combining measured values with estimates.
- Option B: Retrofit Isolation - All Parameters Measurement. Savings are determined by measuring energy use and all variables affecting energy use within the measurement boundary.
- Option C: Whole Facility: continuous measurements of entire facility's energy use. Savings are determined by measuring energy use at the whole facility or sub-facility level.
- Option D: Calibrated Simulation: savings are determined through simulations of the energy use at the whole facility or sub-facility level.

The most suitable M&V Option to evaluate the whole solution set and each Energy Conservation Measure (ECM) depend on existing data about the baseline, the expected energy savings, the metering of isolated key parameters and the measured data available.

In all the three demo cases, Option D was selected as the most suitable to assess the energy savings of the whole solution set, while the energy savings due to each ECM are evaluated using Option A, B or D depending on the factors above mentioned.

Building energy simulation models, if properly calibrated, allow for the evaluation of the energy savings over the whole year and for a fair comparison between the building before and after retrofit. Measured data during the reporting period were used to assess the input data set of the simulation model of the building after retrofit intervention and to perform model calibration following an agreed procedure.

When Option D is applied, the energy performance is assessed according to the following procedure:

1. Development of a simulation model of the reference building (demo-case as it was before the retrofitting process);
2. Evaluation of each ECM, implementing them individually in the reference building model;
3. Comparison of the results with the baseline case;
4. Evaluation of the effects of an ECM on the whole building energy behaviour;
5. Evaluation of individual ECMs based on real monitoring data compared with a suitable baseline.

In general, the implemented ECM influenced directly the total energy efficiency of a building. Single ECM influence might also produce negative effects, even though in combination with other measures produces positive effects. Therefore, an evaluation of measures should always be made in the context of total energy efficiency.

All the renovation projects are divided into three timing periods: i) baseline, i.e. the period before the intervention, ii) Energy Conservation Measures (ECMs) implementation, i.e. the retrofit intervention, and iii) the reporting period, that represents the post-retrofit period. In the reporting period, the improvements provided by the ECMs are evaluated.

Figure 1 to Figure 3 report the timing periods for each of the demo cases. Reporting period lasts 7 months in Coop Canaletto and CitySyd demo cases and 9 months in Mercado del Val. Therefore, calibrated simulation models were the only way to assess energy savings over the whole year.

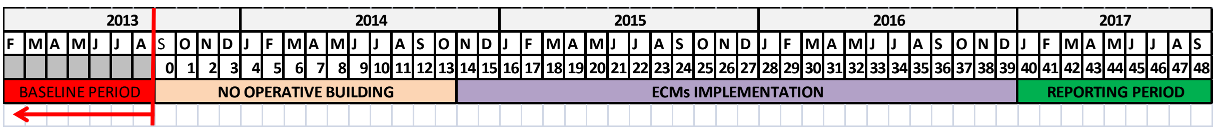


Figure 1. Mercado del Val demo: baseline and reporting periods.

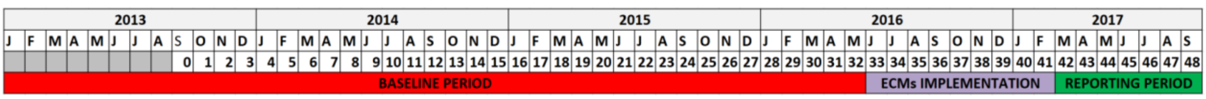


Figure 2. Coop Canaletto demo: baseline and reporting periods.

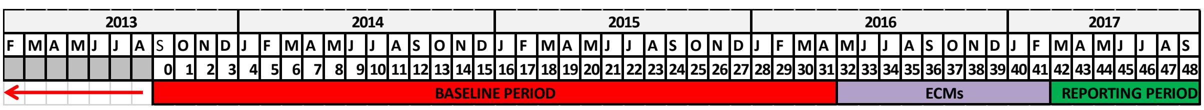


Figure 3. CitySyd demo: baseline and reporting periods.

The retrofitting solutions chosen and developed to satisfy the above targets are described in D6.1 and D6.2. They are a blend of passive and active solutions, as developed in WP3 and WP4. The performed analysis are based on the monitoring data gathered through the iBEMS installed in the buildings.

The performances of the applied solutions at the three demo-cases were compared with a baseline (before retrofitting):

- Mercado del Val demo case: whole building performance was analyzed by comparing the building before retrofit and the building after retrofit. Each ECM including CommONEnergy solutions was evaluated by comparing the retrofit project as defined by the local design team with the retrofit project including CommONEnergy solutions.
- CitySyd: performance of selected demonstration areas (where we installed renovation measures) were compared before and after the implementation of the CommONEnergy solutions. The individual CommONEnergy solutions are evaluated by comparing them with the conventional systems installed before the retrofitting.
- Coop Canaletto: whole building performance is analyzed by comparing the building before and after the deep retrofitting following the CommONEnergy approach. For the individual CommONEnergy solutions the comparison is with the conventional systems installed before the retrofitting.

More specifically the assessment included:

- assessment of overall energy performance of the demo-cases (thermal and electrical);
- assessment of overall energy savings in each retrofitting measure and the avoided CO_2 emissions as well as simple payback time;
- evaluation of the renewable energy facilities performance, calculation of energy contribution and system yield and match with load profile.

Table 1 and Table 2 summarize the results per demo and per each retrofitting measure.

Thanks to the retrofit intervention, in the **Mercado del Val we achieved electrical savings of around 75%,** if we compared the building before and after the renovation. Primary energy and avoided CO_2 emissions were proportional to the electrical energy savings. For the renewable energy production, in the new building all the heating, cooling and DHW demand was fully covered by renewable energy sources (geothermal heat pump system).

For the individual ECMs implemented in the new building we assumed only savings in terms of energy consumption for heating and cooling, keeping as unchanged the energy consumption for lighting, appliances and refrigeration (where the local players decided to not use the CommONEnergy technologies). Compared to the building standard retrofit (without CommONEnergy solutions), the electricity consumption for heating and cooling after the renovation with the multifunctional façade and the iBEMS control (ECM1+ECM2) was predicted to be reduced by 26%. Additional 28% less energy consumption was obtained with the use of geothermal heat pumps (ECM3). Totally, the renovation applied solution-set including CommONEnergy solutions reduced the electricity consumption for heating, cooling and ventilation by 43% compared to the the retrofit project as defined by the local team.

The demo-case of **Modena Canaletto** included a supermarket and a gallery connecting some shops to the supermarket, producing as a matter of fact a small shopping centre. In the gallery, the replacement of the existing lamps with dimmerable lighting brought improvement on the visual comfort and on the energy consumption. The light intensity was regulated according to natural light; the lighting concept implemented reduced the electrical consumption of 15% with respect to the existing case.

The intervention on the supermarket also included: an envelope insulation reducing the thermal losses with savings in the order of 7%; the replacement of open cabinets with closed ones reducing the refrigeration loads of 50%; improvements on the HVAC system and the coupling of this system with the waste heat of the refrigeration circuit saved 35% of energy used for space heating, cooling, hot water preparation and refrigeration.

The implementation of a control system able to communicate with all the parts of the supermarket as high level supervisor, together with other retrofit measures reduced the total **primary energy consumption of 46%**.

The retrofit intervention in **CitySyd** involved four demonstration areas where different lighting concepts were tested. An efficient lighting concept was tested on a tenant' shop and the common area in front of the shop itself. A modular roof skylight, combining different elements with the aim to enhance the daylight impression in the atria, was prototyped and installed over part of the common area. Due to several issues occurred in the prototyping phase and consequent delay in installation, it was not possible to perform measurements on the modular roof skylight performance (even if there is commitment and a formal agreement for going on with commissioning and performance assessment) . A natural ventilation strategy was developed and implemented in the whole common area.

The potential energy savings have been assessed by assuming the lighting solutions were applied to the whole building, resulting in **31% of primary energy reduction**. Even though the overall primary energy savings were positive, the lighting solutions cause an increase of heating demand as a result of reduction of internal loads. This was specific for the different zones and it remained difficult to generalize, with related challenge to distribute energy savings in specific (interconnected) zones of the shopping centre according to functional and/or organizational pattern.

Table 1. Energy and cost savings and CO_2 emissions avoided due to the retrofit intervention in each demo case over a reference year.

Demo	Thermal savings [kWh/m²/y]	Electrical savings [kWh/m²/y]	Renewable energy production [kWh/m²/y]	Primary energy savings [kWh/m²/y]	CO_2 emissions avoided [kg/m²/y]	Cost avoided [€/m²/y]
Mercado del Val	394	405	100%*	973	145	54.3
Modena Canaletto	84	326	N/A	589	144	40
City Syd	-70	104	N/A	232	30	7.4

N/A: Not Applied

* of the Heating and Cooling needs + DHW

Table 2. Summary of the results per each retrofitting measure.

Demo	Retrofitting measure	Thermal savings [kWh/m²/y]	Electrical savings [kWh/m²/y]	CO_2 emissions avoided [kg/m²/y]	Cost avoidance [€/m²/y]
Mercado del Val	ECM1: Multifunctional façade controlled by ECM2: iBEMS	N/A	14.7	5.3	1.9
	ECM3: Geothermal heat pump	N/A	16.1	5.8	2.2
	ECM1 + ECM2 + ECM3	N/A	31.7	11.4	4.3
Modena Canaletto	ECM1: Envelope retrofitting	2.1	7.3	4.2	0.9
	ECM2: Advanced lighting concept in the supermarket	0.0	106.2	54.1	12.7
	ECM3: Replacement of refrigeration cabinets	10.3	110.5	58.7	13.5
	ECM4: Linear air diffusers	No measured data available			
	ECM5: HVAC efficiency	78.2	-15.5	11.0	-0.2
	ECM6: HVAC-R coupling	0.0	11.4	5.8	1.4

	ECM7: General Retail Lighting in the galleries	0.0	10.6	5.4	1.3
	ECM8: iBEMS	0.0	12.7	6.5	1.5
	ECM9: Smart coatings	0.0	7	3.5	0.8
CitySyd	ECM1: Artificial lighting concept in Jens Hoff shop	-10.7	86	26.3	6.40
	ECM2: Light tubes in Jens Hoff Shop	No measured data available[1]			
	ECM3: General Retail Lighting (GRL) in common areas	-8	18	3.5	0.85
	ECM4: Natural ventilation	N/A	1.44	0.51	0.12
	ECM5: Modular roof skylight	No measured data available[2]			
	ECM6: iBEMS	-8	27	7.0	1.70

N/A: Not Applied

An additional demo, namely Maremá in Grosseto (Italy) was also considered. The aim was to design, develop and install a system able to increase the share of renewable energy (i.e. photovoltaic) with the combination of battery energy storage system (BESS) to cover the energy demand of the eV-charging system. The PV-BESS-eV charger system was the first prototype in a shopping mall in Italy able to fully cover the e-cars energy demand by the combination of PV and BESS. This make shopping centers a possible driver for the diffusion of the sustainable mobility not only in Italy but in all Europe.

[1] During the spot measurement campaign it was not possible to open the sun shading screens integrated in the skylight dome and thus only little daylight could enter the demonstration area.

[2] The modular roof skylight installation was just finished in M48. Thus there was not enough time to measure and analyze the data.

1. Introduction

Measurement and Verification (M&V) is the process to reliably quantify actual savings (energy, demand, cost and greenhouse gas emissions) delivered by an Energy Conservation Measure (ECM) within an area by using measurement. Energy savings cannot be directly measured, since savings represent the absence of energy use or demand. Instead, savings are determined by comparing measured use or demand before and after implementation of an ECM, making suitable adjustments for changes in conditions.

The verification of the impact of ECMs in the areas of energy and demand savings, as well as cost, can be addressed by adopting suitable M&V protocols. Formal M&V protocols are adopted to provide confidence in the accuracy of reported savings.

In order to assess the results, a first study about the state of the art in existing methodologies for M&V was carried out [1]. As a result, the International Performance Measure and Verification Protocol (IPMVP) [1] was selected as reference and adapted to the shopping malls requirements.

Specific objectives are to evaluate energy performance and efficiency improvement and furthermore, to obtain the data required for simulation tasks such as simulation model calibration and validation.

The main goal is to obtain energy saving measurements. To evaluate the energy consumption it is necessary to gather information about the isolated retrofit measure performance and the whole building energy performance.

This document presents the measurement of the energy performance improvements provided by the CommONEnergy approach compared with a reference building (demo-case as it was before the retrofitting). Although the objective is to show the improvements in terms of energy savings, the retrofit intervention should also ensure certain comfort levels for the occupants.

A specific M&V plan was selected for each demo case addressing the unique characteristics of the retrofit intervention. Thus, IPMVP defines four options for the evaluation of the specific project [1]: (A) individual ECM with measured and estimated parameters, (B) single ECM, but all the values are metered, (C) whole facilities through measurements, and (D) entire or partial installation by means of simulation. In any case, the energy savings are calculated by means of a key-condition for long-term success.

Assuming to evaluate the three demonstration buildings according to the IPMVP III method, option D “Whole building calibrated simulation”, the development of a reference building for each demonstrator becomes a crucial key task. In this case, we defined reference buildings as the buildings before retrofit intervention. Reference buildings are needed to evaluate the influence of realized ECMs on the energy demand of the demonstration buildings. ECMs performance is evaluated mainly by means of building energy simulations. In addition to building energy simulations, some of the individual solutions implemented in the demo-cases, are also evaluated referring to real monitoring data (also used for the calibration process of the model in simulations) and compared with a suitable baseline through Option A of the IPMVP.

2. Methodology to assess performance and energy saving

This section describes the methodology applied to assess the performance and energy savings due to retrofitting in the demo-cases. The performance and energy savings can be obtained by comparison of measured data after the retrofitting with measured data before the retrofitting or calculated values coming from simulation programs, standards, etc.

The methodology follows the process shown in Figure 4. First, the whole building performance is evaluated in terms of thermal and electrical energy need and second, specific components efficiencies (CommONEnergy solutions) are evaluated. The evaluation of Indoor Environmental Quality (IEQ) is reported in Deliverable 6.5 [2].

The performance evaluation methodology includes measuring techniques and thermal simulation models with diverse boundary conditions. The main objective is to provide comparable data, either measured or calculated, and to develop indicators in order to quantify the efficiency and allow comparison between building systems.

The comparison will be first applied to the whole building in order to evaluate the building with the CommONEnergy approach applied and the building as it was before the retrofitting.

At components level, the analysis will focus on the efficiencies of the innovative CommONenergy solutions individually compared to conventional systems with the support of building energy simulations if needed. Conventional systems are defined as state of the art techniques complying with the actual national energy standards.

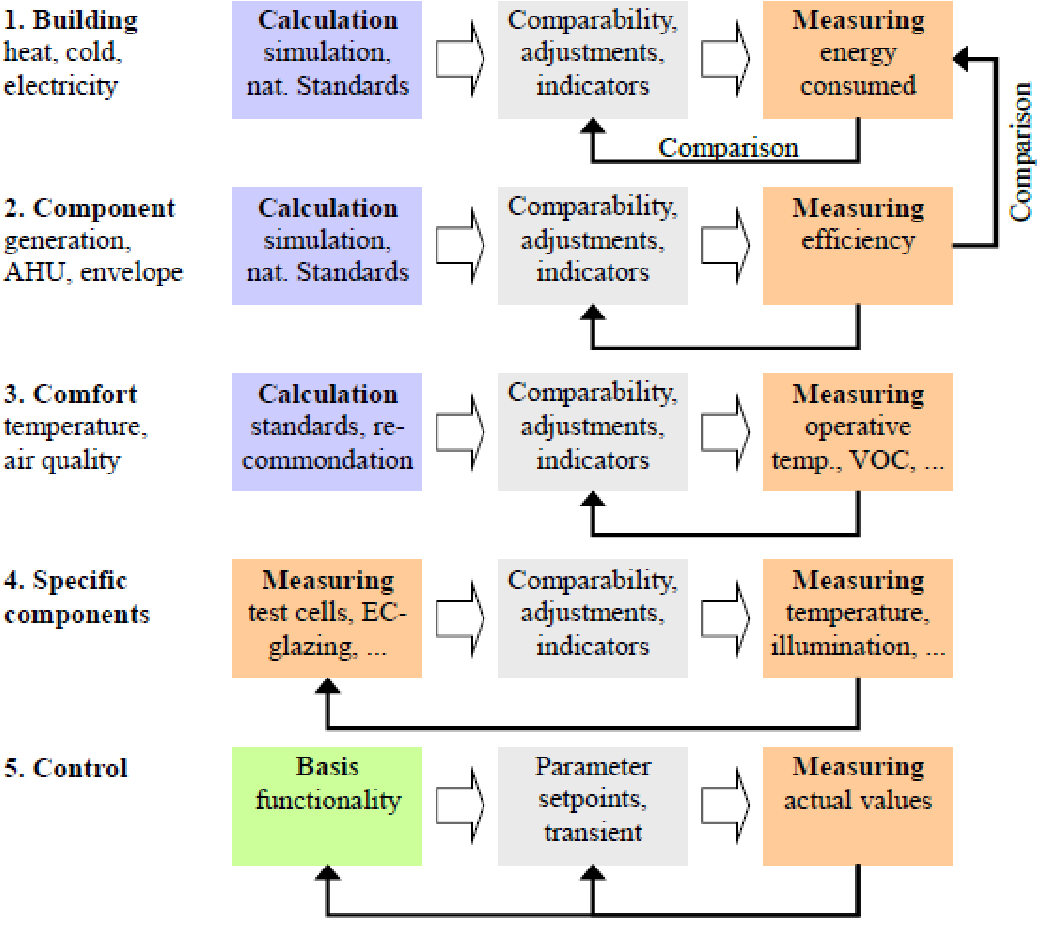


Figure 4. Evaluation methodology.

The evaluation methodology uses long-term measurements, simultaneous operation of identical zones to obtain information about the improvements and how to raise the efficiency, numerical simulation, combination of measurements and simulations and calculations to obtain information about the efficiency of the innovative systems compared against the standard systems and to gather information about the energy savings.

The different steps to develop the evaluation of energy performance through comparison are the follows:

- Evaluation of the thermal and electrical energy needs.
- Collection of information about the component efficiencies and comparison of the efficient subsystems from CommONEnergy project with conventional systems at component level and at whole building level, by means of energy simulations.
- Evaluation of the components that cannot be simulated or where is not possible to compare simulation results and measuring data.

One of the most important steps of the methodology is the definition of the monitoring layout for each of the demo-cases. The monitoring layout describes the number and position of sensors and meters. The monitoring layout defined allows the performance measurement of the whole building and its subsystems to facilitate the assessment of energy savings.

The main objective of the monitoring is to provide information about the energy performance of the building, the efficiency of several energy conservation measures, the efficiency of conventional systems, such as HVAC, and indoor environment quality, although this last one is out of the purpose of this document and it is included in another project report [2]. For this purpose, several monitoring devices have been placed in each of the demo-cases in order to collect the data needed to develop the analysis and evaluate the energy savings such as thermal meters to measure the energy consumption of heating and cooling, electrical meters for building services such as lighting, pumps, HVAC systems, etc.

The intelligent Building Energy Management System (iBEMS), developed within the framework of this project, allows to monitor, control, evaluate and detect fault of different building components, as well as collect the monitoring data.

In order to perform building energy simulations, weather data is required in order to have similar boundary conditions for measured and simulated data. In each demo-case a weather station is installed collecting data about: air temperature, relative humidity, precipitation level, solar radiation and wind speed and direction.

Data collected by the weather station and other operational data (hours of operation, occupancy, equipment loads, system set-points, etc.) derived from the monitoring system are used to set the inputs of the simulation model.

A first study about the state of the art in existing methodologies for M&V was carried out [1]. As a result, the International Performance Measure and Verification Protocol (IPMVP) was selected as reference and adapted to the shopping malls requirements.

The IPMVP [1] is a guidance document describing common practice in measuring, computing and reporting savings achieved by energy or water efficiency projects at end user facilities. The IPMVP Volume I presents a framework and four measurements and verification (M&V) options for transparently, reliably and consistently reporting a project’s saving. M&V activities include site surveys [3], metering of energy or water flows, monitoring of the independent variables (e.g. from the weather station), calculation and reporting. When adhering to IPMVP recommendations, these M&V activities can produce verifiable savings reports.

Energy, water or demand savings cannot be directly measured, since savings represent the absence of energy/water use or demand. Savings are determined by comparing measured or calculated use or demand with and without the implementation of a measure, making suitable adjustments for changes in conditions.

The IPMVP Volume III focuses on energy savings in new constructions where Volume I mainly refers to retrofit constructions. The fundamental difference between M&V in new and retrofit construction is related to the baseline. The baseline in a retrofit project is usually the performance of the building or system prior to modification. This baseline physically exists and can therefore be measured and monitored before the changes are implemented. In new construction the baseline is usually strictly hypothetical; it does not physically exists, and therefore cannot be measured or monitored. A new construction baseline can be defined or characterized by code or regulations, common practice, or even collecting documented performance of similar constructed buildings. This could be the case of Mercado del Val, where the new market is a completely new construction and it was needed to create a model of the old building based on the information documented in the energy audit [3].

Energy codes and standards can provide a convenient, clearly defined, and consistent baseline in order to ensure appropriateness. Whole building energy simulation tools in particular require high level of design detail for proper analytical rigor, requiring a fairly well-developed design of the building. M&V requires baselines that are consistent and repeatable, or that can at least be readily adjusted to allow performance comparisons on a broader scale.

An accurate determination of energy savings is a key condition for long term success of energy management projects. Energy savings are determined by comparing measured energy use before and after implementation of an energy saving measurements.

Energy savings = Base year energy use – Post retrofit energy use +- Adjustments

In this general equation, the adjustments term brings energy use or demand of the baseline and reporting periods to the same set of conditions. Conditions commonly affecting energy use are weather, occupancy, plant output, and equipment operations required by these conditions.

The baseline in an existing energy project is usually the performance of the facility or system prior to modification. In the case of CommONEnergy the baseline it is considered the shopping centres before the retrofitting approach. These baselines can be measured before changes are implemented or defined based on code, regulation, common practice or documented performance of similar facilities. In either case, the baseline model must be capable of accommodating changes in operating parameters and conditions so adjustments can be made.

2.1. Applicability of M&V options in CommONEnergy

The three demo-buildings integrated in the CommONEnergy project will be analyzed using the methodology defined previously.

For performing the measurements and verification of the energy savings under the IPMVP, there are four available M&V options. The most appropriate Option should be chosen by reviewing the proposed ECMs to determine the feasibility and expected level of effort to perform M&V.

IPMVP provides four options for determining savings (A, B, C and D). The choice among the options involves many considerations. The selection of an IPMVP option is responsibility of the designer of the M&V program for each project. These options are summarized in the following points:

Option A. Retrofit Isolation: Key Parameter Measurement

Savings determination

- Savings are determined by measuring the performance parameters that will have the higher influence on the savings calculation.
- Savings are calculated by combining measured values with estimates.

Measurement

- Measurement frequency ranges from short-term to continuous depending on the expected variations in the measured parameter and the length of the reporting period.
- Measurements of the same parameter must occur in the baseline and post-retrofit periods.

Considerations

Any remaining parameters are estimated, using historical data, manufacturer's specifications or engineering judgment.

Option B. Retrofit Isolation: All Parameter Measurement

Savings determination

Savings are determined by measuring energy use and all variables affecting energy use within the measurement boundary.

Measurement

Measurement frequency ranges from short-term to continuous depending on the expected variations in the savings and the length of the reporting period.

Considerations

Option B provides greater certainty of savings versus Option A.

Option C. Whole Facility: continuous measurements of entire facility's energy use

Savings determination

- Savings are determined by measuring energy use at the whole facility or sub-facility level.
- Actual cost savings can also be determined.
- Option C is for ECMs where expected savings are high compared to site energy use, and where measurement periods are long.

Measurement

- Continuous measurements of the entire facility's energy use are taken throughout the reporting period.
- This Option typically makes use of existing utility meters and/or energy invoices and the combined effect of all ECMs is determined.
- An energy model using techniques such as regression is developed spanning the baseline period, which is adjusted for the post-retrofit period.

Considerations

The primary challenges of Option C are to identify and incorporate all routine and non-routine adjustments, as well as ensuring that the savings are large enough (10% or more) when compared to the site's energy use.

Option D. Calibrated Simulation: savings are determined through simulations

Savings determination

Savings are determined through simulation of the energy use at the whole facility or sub-facility level.

Measurement

- Simulation routines are demonstrated to accurately model actual energy performance measured at the facility.
- Computer simulation software is used to predict energy use once detailed information is entered covering building facade, installed equipment, operating patterns and external variables such as weather.
- ECMs can be evaluated as a group, or individually, where multiple simulations are run.
- The simulation needs to be calibrated against actual monthly energy use and demand. Matching annual totals is insufficient.

Considerations

- Option D is useful where baseline data does not exist or is unavailable.
- The primary challenges are to develop an accurate simulation and to calibrate it against measured energy data.
- Specific software modelling skills and careful documentation is required.

Each option could be different in each building and will be determinate following a selection process described in IPMVP and showed in Figure 5. Figure 5 provides a guide to select an appropriate M&V option.

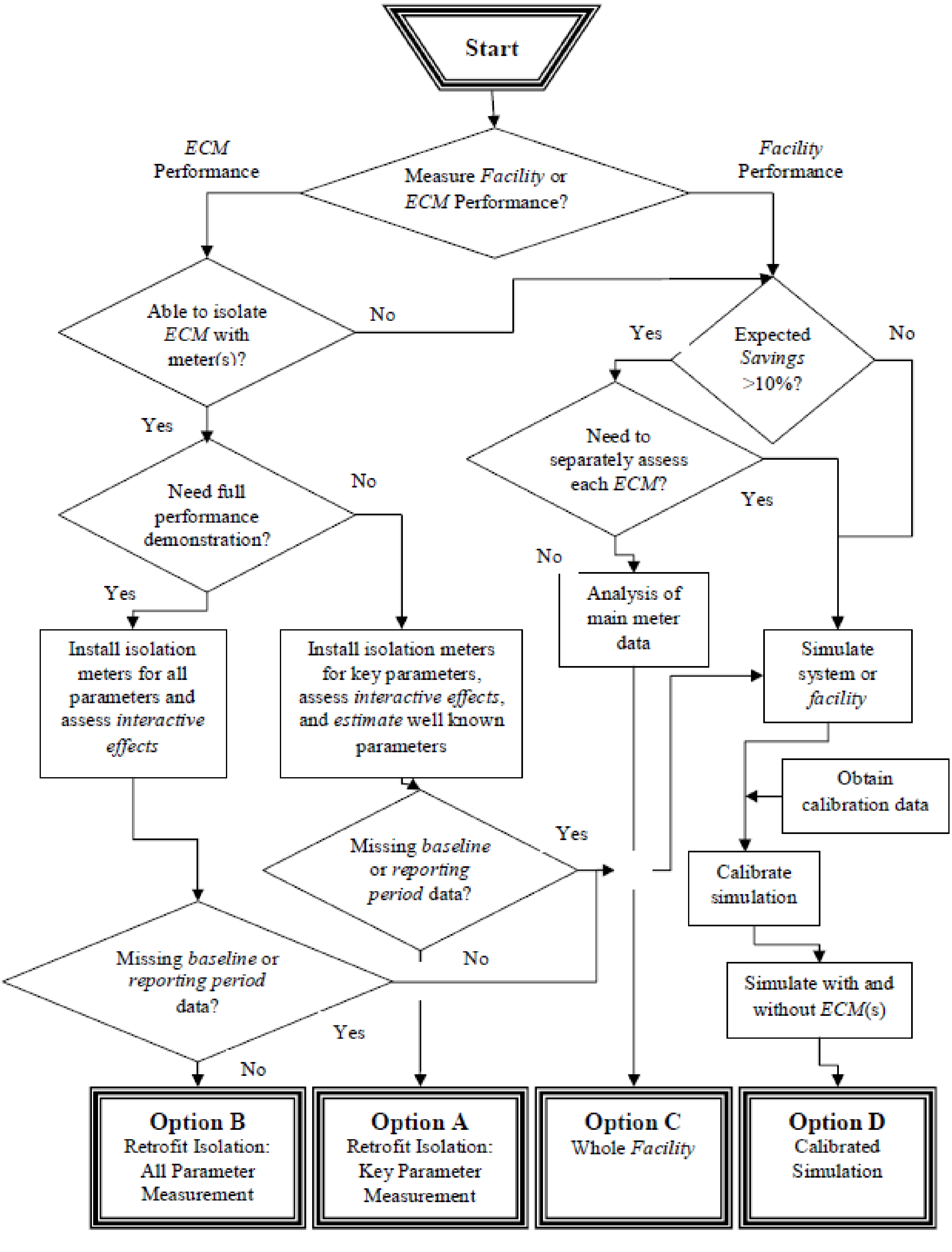


Figure 5. Selection process for the M&V option. Source: IPMVP January 2012 [1]

Options A and B focus on the performance of specific ECMs and involve measuring the energy use of systems affected by each ECM, separately from that of the rest of the facility. Before and after measurements should be compared to determine savings. Options C and D assess the energy savings at the facility level, when the ECM cannot be easily measured in isolation from the rest of the building. Option C assesses savings by analyzing measurement and utility bills before and after the implementation of the ECM. Option D uses simulations of equipment of facilities, when base year or post-retrofit data are unreliable or unavailable.

As stated before, choosing the most suitable M&V Option will depend on a range of factors. Considerations include the following:

- Baseline data exists or can be made available.
- Expected savings are greater than 10% of total energy use within the measurement boundary.
- Continuous energy use measurements are available through utility metering and/or energy invoices.
- The ECM(s) can be isolated within the measurement boundary using appropriate measurement equipment.
- Energy use within the measurement boundary and all variables affecting energy use can be measured.
- There is a single or multiple key parameters that will have the most influence on the savings calculation.
- Parameters not measured directly can be estimated with an acceptable level of uncertainty.

In summary, and considering the measurement and verification of the energy performance and savings at CommONEnergy level, Option A and D seems to be the most suitable. Option A for the analysis of some isolated ECMs and Option D to take into account the whole shopping centre and individual ECMs using the Integrative Modelling Environment [4] developed within the project.

Figure 6 and Figure 7 show the selection process for Option A and D, respectively.

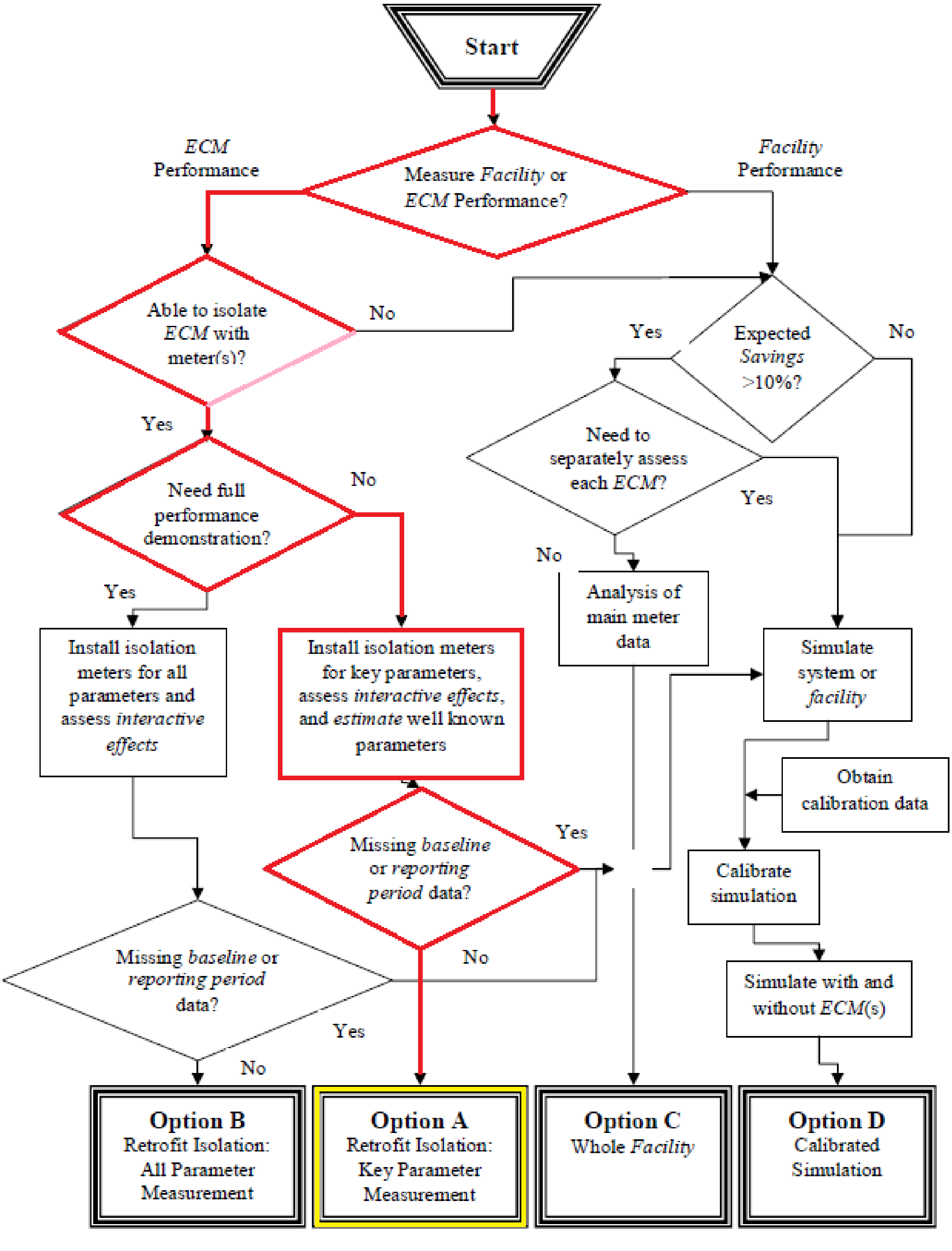


Figure 6. Isolated ECMs with Option A. Source: IPMVP January 2012 [1]

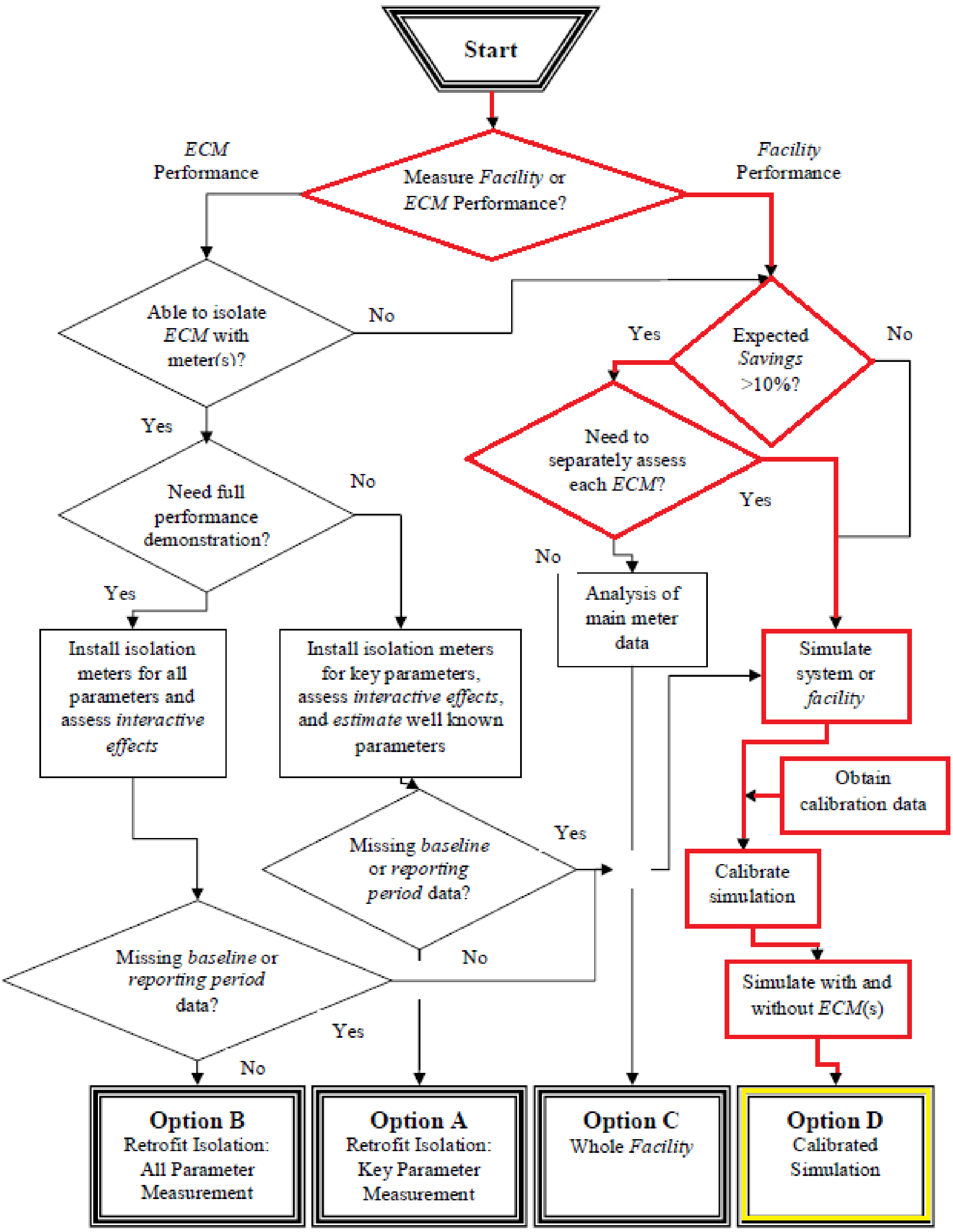


Figure 7. Whole building and isolated ECMs with Option D. Source: IPMVP January 2012 [1]

2.1.1. Model calibration

Calibrated simulation (Option D) regards the development of a calibrated building energy simulation model of the whole building. The Post-Construction Energy Use is determined by utility metering and/or sub-metering or by using an energy simulation model of the as-built building calibrated to meter energy use data. The Projected Baseline Energy Use is determined by energy simulation of the Baseline under the same climatic and operating conditions of the M&V period.

The use of numerical thermal simulation models/tools to obtain performance data either for the whole building or for subsystems is always applicable and mandatory, if there is no measured data available or other data is incomplete. The development and the validation of numerical models is time consuming, includes many sources of errors and contains the need to normalize the boundary conditions such as climate data or occupant schedules to allow the comparison of different cases. The advantages of numerical models primary refer to the subsystems due to the ability to obtain intermediate data for every step of the process, where installation of measuring equipment is not possible.

Whole Building Calibrated Simulations require a very accurate energy simulation model of the as-built building as well as similarly detailed simulation model of the Baseline (In practice the initial Baseline model is often developed from the as-built simulation model). The as-built energy use projections are compared to the measured Post-Construction Energy Use. Significant deviation are investigated and addressed, and corrections and adjustments are applied to the as-built model in order to achieve calibration. These same corrections and adjustments, to the greatest extent possible, are also applied to the Baseline simulation. The objective of the calibration process is not only to calibrate the as-built simulation, but also develop a calibrated and defensible Baseline simulation, thereby minimizing the error in the Projected Baseline Energy Use. System sub-metering facilities the calibration process and substantially enhances calibration accuracy and is strongly recommended for more intensive M&V programs.

The key task for energy prediction of the baseline and the post-construction is the development of the simulation model, the calibration process and the definition of adjustments.

From the detailed building models, reference models can be developed by replacing the implemented energy efficiency measures with standard measures. This will obtain a calculation of the demonstrators with the same boundary conditions as the as-built simulation, but taking into account a standard construction technology and standard systems engineering. The other boundary conditions such as building geometry, local climate and the use of the building (zoning, user profiles) remain constant.

Depending on the task, it is possible to quantify the influence of various efficiency measures in different levels of details by comparing the post-construction energy use with the reference-building energy use.

The following steps are necessary:

- Implementation of the measured climatic conditions in the building model
- Adjustment to the real discovered occupancy, including occupancy schedules
- Implementation of the actual measured efficiency of the components
- Consideration of maturities of components
- Consideration of actual measured set points for temperatures (including supply air)
- Correction of any modified boundary conditions during the period of construction, which are not included in the as-built model

These procedures provide the highest demands on the development of building models and the monitoring concept. After calibrating the building model, the calculated energy use should correspond to the measured energy consumption.

For a meaningful comparison of measured and simulated data, it is important to define accurate boundary conditions, typically residing in a weather file, around a given building. While outside weather data are obvious boundary conditions, simulation input can also consist of other additional measurements. These other measurements include occupancy, plug loads, electric lighting, and others. In addition, input for the simulation may include space temperature set points, particularly if those are user-adjustable.

Under ideal conditions the calculated energy use and the measured energy use should correspond by adjusting the as-built simulation. In practice, a significant deviation between calculation and measurement can be expected with high probability, which occurs despite high calculation accuracy.

The model validation procedure [4] follows 5 steps:

1. Define data resolution and target tolerances

To represent how well the building simulation model describes the variability in measured data we can refer to the two indices defined in ASHRAE guideline 14 [5]: the coefficient of variation of the Root Mean Square Error (CVRMSE) and the Normalized Mean Bias Error (NMBE).

$$CVRMSE = 100 \cdot \frac{\left[\frac{\sum(y_i-\hat{y}_i)^2}{n-p}\right]^{1/2}}{\bar{y}} \qquad NMBE = \frac{\sum^n (y_i - \hat{y}_i)}{(n-p)\cdot\bar{y}} \cdot 100$$

where

y	= utility data used for validation
ŷ	= simulation-predicted data
i	= hour or month
n	= total amount of hours or months of the validation period
p	= 1

The target output depends on the utility data available. According to the ASHRAE guideline 14 [5], the target tolerances for whole building simulation are defined according to the utility data resolution as follows:

- If monthly data are used to validate the model, $NMBE$ shall be 5% or less and $CVRMSE$ shall be 15% or less.
- If hourly data are used $NMBE$ shall be 10% or less and $CVRMSE$ shall be 30% or less.

2. Data collection

Data collection aims at minimizing default values in the simulation model and gather utility data to be compared with the simulation results at same weather conditions.

For the model validation, utility bills (electricity, gas or district heating) or monitoring data spanning at least one year composed of at least 12 meter readings are needed at a minimum. Ideal would be to have hourly meter readings available.

If utility data are available for more than one year, select the one referred to the most recent one as it is the most easily remembered by the operating staff.

3. Input data into the simulation model and run the model

The input data into the simulation model is made easier by the Integrative Modelling Environment developed within the project. Therefore, the input data should be easily controlled through the control cards.

4. Compare simulation model output to utility data

Simulation outputs should be coherent to the utility data available. If utility data are available for common areas only, simulation results should be aggregated for the common areas only.

The comparison of simulation outputs and utility data daily profile of power on typical summer day, winter day and mid seasons day monthly consumption.

5. Refine the model until an acceptable calibration is achieved.

Critical parameters for model calibration can be effectively identified by observing simulated and measured results comparison or by performing sensitivity analysis on the simulation model.

Main sources of uncertainties can be:

- Lighting power density and schedule
- Electric power density and schedule
- Infiltration rate
- Ventilation rate
- System efficiencies
- Heating and cooling setpoints
- Thermal capacitance

Once the critical parameters are identified the model can be refined through an iterative process or more systematically by setting an optimization process with the CVRMSE as cost function.

The model can be considered validated if the tolerances defined at point 1) are met.

This simulation model is validated in order to guarantee that it is a proper starting point and represents as close as possible the real building energy behaviour. Models have been calibrated with monitored data with hourly or monthly resolution.

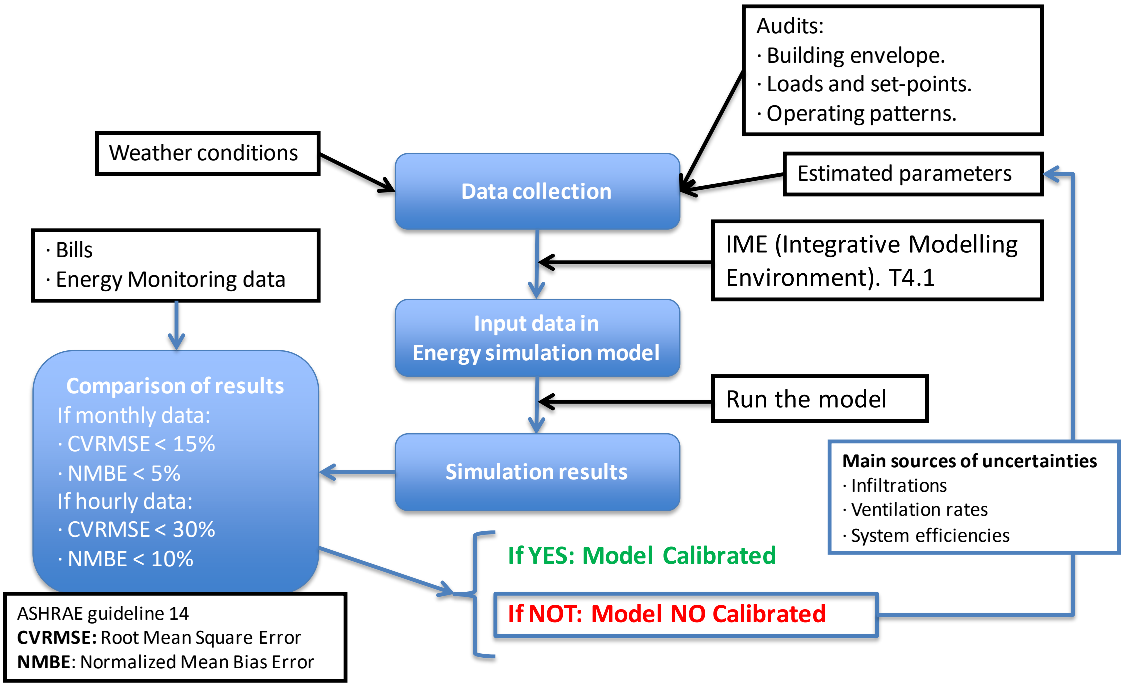


Figure 8. Models calibration methodology in CommONEnergy project

2.2. Cost avoidance

In the majority of the cases, the evaluation of the success of an ECM is based not only on the energy that has been saved, but rather on its financial returns. A successful ECM will result in a financial benefit due to reduced energy use, and this benefit is referred to cost avoidance. Often a project will realize other financial benefits which also help with improving the ECMs payback. Total project savings can be expressed as follows:

Project savings (€) = Cost avoidance (€) + Other financial benefits (€)

where

Cost avoidance (€) = Avoided energy cost due to ECM
Other financial benefits (€) = e.g. reduced maintenance costs, avoided future equipment, replacement, etc.

The cost avoidance associated with an ECM is derived from the measured energy savings by applying an agreed pricing schedule. The standard equation for cost avoidance is:

$$\text{Cost avoidance (€)} = \text{Pricing structure} \times (\text{energy use}_{\text{adjusted baseline}} - \text{energy use}_{\text{actual}})$$

It is important to note that a baseline energy model has to be adjusted for post-retrofit conditions, and the same energy pricing structure has to be applied to the adjusted baseline as well as the actual usage.

Basically, the previous equation determines the amount of money saved through the implementation of the ECM against the business as usual forecast had the ECM not been implemented, by applying an energy pricing structure to the measured energy savings.

“Cost savings” should not be confused with “cost avoidance”. The term “cost savings” infers that energy cost post-retrofit will be lower than those within the baseline period. This approach does not take into account changes in factors that determine energy use (e.g. changes in site activities, effects of independent variables such as production or weather, etc.), or price risks such as changes to energy contracts or tariff rates.

The effects of these factors may result in a situation in which energy cost rises despite a reduction in energy use. Although there would not be “cost savings”, “cost avoidance” could be claimed.

2.3. Greenhouse gas emissions reduction

Another key driver for determining the success of an ECM is the achievement of greenhouse gas emissions reductions. As in the previous case, the objective is to determine the reduction in greenhouse gas emissions through direct measurement of greenhouse gas emissions, or more typically through indirect means involving emissions factors.

3. Mercado del Val (Spanish demo case)

3.1. Retrofitting project description

Mercado del Val is an iron market whose construction was completed in 1882. Being an historic market within the city centre, it represents a very interesting case from a building and social points of view.

Originally, it had stones for foundations and plinth, and iron for the other elements, while ventilation was achieved using inclined blinds of iron sheets. A stained glass lantern was installed but later eliminated. It was first renovated in 1981 focusing mainly on the maintenance and sanitation of the structure with restoration of limestone blocks, the wall bricks, slats and the cover. The water, electricity and heating facilities were also modernized. End of 1983 the market reopened with 114 stalls and 2,220 m^2 in perfect condition.

The market was composed by two floors. In the ground floor there were the stalls for different activities and the first floor was only intended to house technical rooms and offices.

Heating and cooling needs were covered by two air/water heat pumps connected to the radiant floor on the ground level and to the air curtains located in each entrance.

The refrigeration system was composed by several individual compressor units located in the specific stalls. Heat produced by the condensers was released inside the building.

There was no mechanical ventilation system. Natural ventilation was performed through doors and skylight windows.

There were two lighting systems: one for the general lighting of the market composed by lighting balloons suspended from metal arches along the corridors and in the entrances; the individual lighting, corresponding to each individual stall, was mainly composed by fluorescent tubes. The artificial lighting system was supported by natural light coming from the windows and skylights.

Detailed information about the status of the old building can be found in Deliverable 6.3 “Energy audits” [3].

Since the last intervention until year 2013, year in which the building was closed, there was just maintenance works without restructuring the commercial format; which at the end resulted having functional and structural problems. Due to the age of the technical installations and overall deterioration of the building components, the market presented a decadent aspect, without any attraction. It could be said that the market was in much need of a complete redesign to increase its attractiveness for customers and vendors.

From 2013, Mercado del Val is fully renovated and is one of the three demo cases of the CommONEnergy project. The planned intervention aimed to recover a late nineteenth century building representative of an architecture and commercial activity from that period, being respectful with its essence, but transforming it into an innovative building that meets the potentialities and commercial needs of the XXI century.

The new building was reopened in November 2016 after nearly two years of works and is divided into 3 floors along 4,800 m^2 (Figure 9):

- Basement: Commercial use (Supermarket and technical rooms).
- Ground floor: Fresh Market.
- Mezzanine: Restaurant, offices and other different uses.

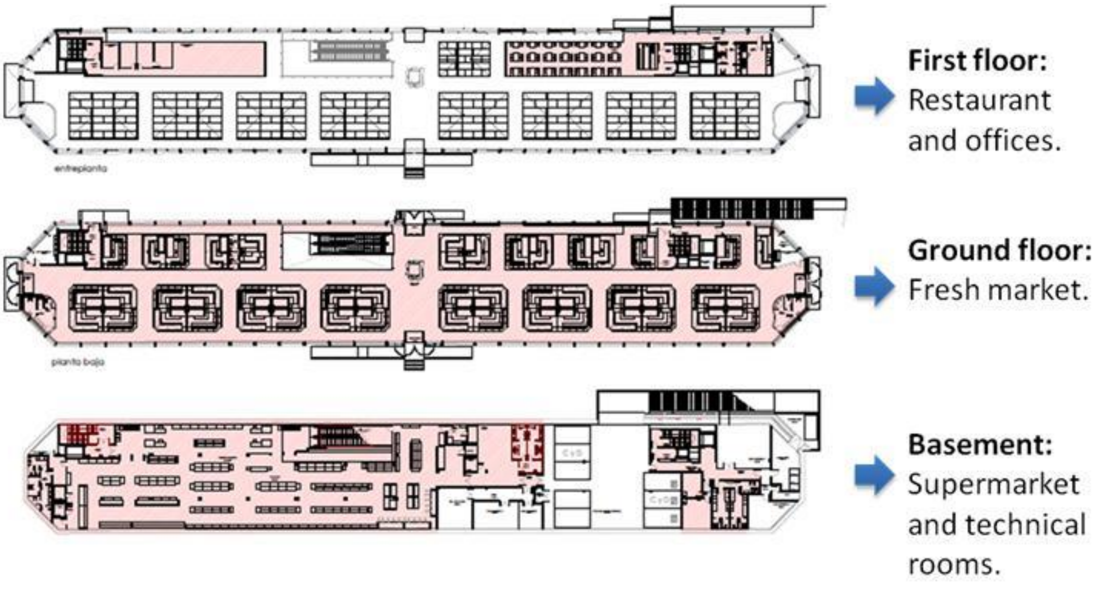


Figure 9. Mercado del Val floor distribution

After simulations and discussions with the city architects, the chosen technologies and solutions are now installed and comfort is improved for shop-owners and visitors.

The new indoor layout configuration and the glazed façade contribute to a better understanding of the global iron structure, to increase daylighting and to make the commercial activities visible from outside. The glazed façade is made by modular façade elements that aim at integrating thermal, daylighting and ventilation functions, being responsive when internal and external loads change.

To supply both cold and heat there are three reversible ground to water geothermal heat pumps, getting temperature from vertical boreholes done on the ground.

To cover the energy needs it has been selected a low temperature heating and cooling system, with radiant floor on the ground floor and mezzanine and fan coils in the basement.

For the DHW (Domestic Hot Water) supply the geothermal pumps are supported by storage tanks with electric immersion heaters for legionella prevention. The geothermal pumps can produce at the same time DHW and cooling in summer.

Regarding the fridge system, it has been designed a centralized installation to cover all the needs of the whole centre. This installation generates a very important amount of hot air on the condensers. This amount of heat is used to heat the water of the circuit for the radiant floor and for the AHU in winter, while in summer this heat is dissipated to the ground.

The overall system is managed by the iBEMS (intelligent Building Management System) that manage the switching (on and off) of the diverse equipment depending on the inlet and outlet conditions.

Figure 10. Mercado del Val democase, before refurbishment (left) after refurbishment (right)

3.2. ECMs implemented

The objective of the Energy Conservation Measures (ECMs) is to improve the energy performance of the building. However, individual and isolated measures are not as efficient as the combination of some of them in order to achieve better results in terms of energy efficiency. These ECMs can be classified into passive (Multifunctional façade) and active solutions (iBEMS, HVAC system).

The aim of passive solutions is to reduce the energy consumption, while active solutions focus on generating energy in a more efficient way, thereby increasing the system´s performance.

The expected benefits originated by the ECMs implementation on the demo site fall under three main categories:

- Energy savings and/or self-production of energy: it is the amount of energy saved (i.e.: not consumed) if compared to the previous scenario and/or the amount of energy produced by means of the innovative/renewable systems installed within the project.
- Costs savings: it is the quantification of the economic benefits directly related to the energy savings/self-production.
- CO2 savings: it is the environmental benefit originated by the energy saving/self-production; each kWh of energy, litre of fuel, or whatever the energy carrier considered corresponds through an emission factor to greenhouse gas emissions.

ECM 1: Multifunctional façade

The glazed façade contribute to a better understanding of the global iron structure, to increase daylighting and to make the commercial activities visible from outside. The glazed façade is made by modular façade elements that aim at integrating thermal, daylighting and ventilation functions, being responsive when internal and external loads change.

Main advantages of the glazed façade are:

- Improved glass wall envelope (Figure 11);
- Natural ventilation system to reduce the cooling needs during summer and reduce energy consumption for ventilation (Figure 12);
- Daylight exploitation and control: Shading elements in the south façade (lamellas) (Figure 13).

The connection of shading elements and natural ventilation system to the iBEMS allow introducing a sophisticated control strategy (e.g.: to switch off the mechanical ventilation in the market when natural ventilation is activated).

Thanks to this solution is possible:

- To reduce the heating and cooling demand of the building.
- To reduce energy consumption for ventilation.
- To reduce the amount of direct solar radiation entering in the building.

Figure 11. Multifunctional façade installed at the Mercado del Val

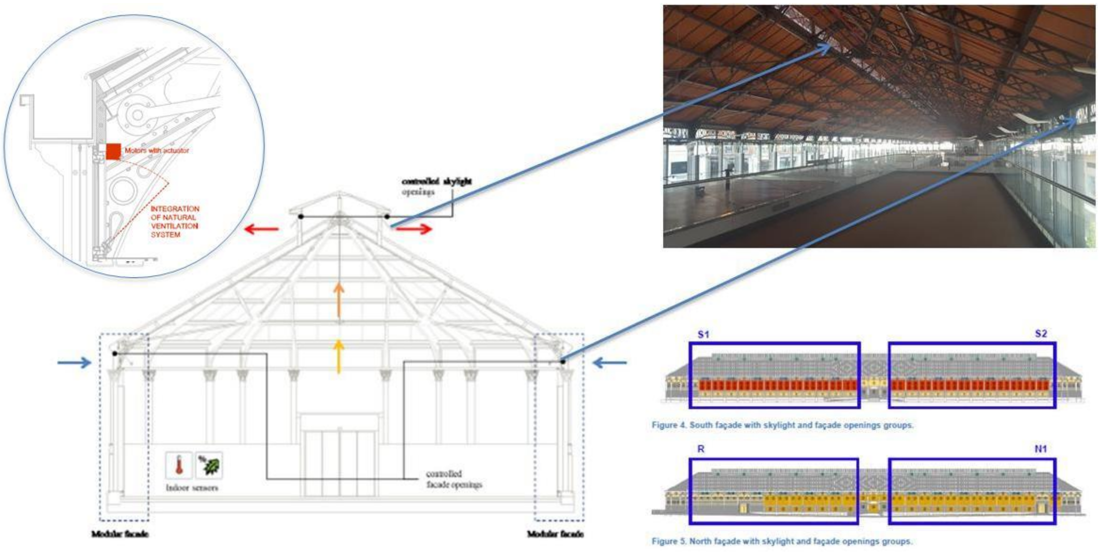


Figure 12. Natural ventilation system of the Mercado del Val

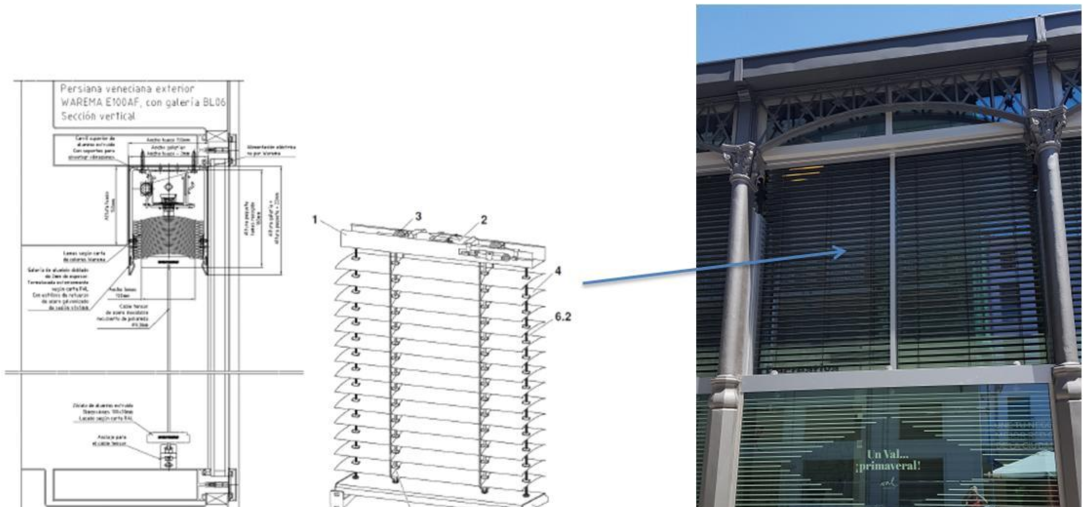


Figure 13. Shading system integrated into the multifunctional façade at the Mercado del Val

ECM2: iBEMS

The overall system is managed by the iBEMS (intelligent Building Management System) that switches on and off the diverse equipment depending on the inlet and outlet conditions.

The iBEMS is used for monitoring, controlling, evaluating and detecting fault of different building components and occupied zones.

Thanks to this solution is possible:

- To implement advanced control strategies;
- To control the shadings and windows for natural ventilation;
- To control the AHU;
- To monitor energy and comfort;;
- To optimize the operation of all the systems;
- To quantify and verify the energy savings achieved with the implementation of CommONEnergy solutions.

Figure 14. iBEMS components in Mercado del Val

ECM3: HVAC system
In order to supply both heating and cooling three reversible ground to water geothermal heat pumps are installed, getting temperature from vertical boreholes done on the ground (42 boreholes of 120 m). In order to cover the energy needs it has been selected a low temperature heating and cooling system, with radiant floor on the ground floor and first floor and fan coils in the basement. For the DHW supply, the geothermal pumps will be supported by storage tanks with electric immersion heaters for legionella prevention. The geothermal pumps can produce at the same time DHW and cooling in summer. Regarding the fridge system, it has been designed a centralized installation to cover all the needs of the whole centre. This installation generates a very important amount of hot air on the condensers. This amount of heat is used to heat the water of the circuit for the radiant floor and for the AHU in winter, while in summer this heat is dissipated to the ground. It is estimated an increase in the performance of the new heat pumps: • Estimated COP and ERR of the old air to water heat pumps are 3 and 2.5, respectively; • Average values for actual COP and ERR of the new geothermal heat pumps are 4.8 and 5.6, respectively, based on data monitoring. Thanks to this solution is possible: • To cover the heating and cooling demand of the building. • To cover the DHW demand of the building. • To reduce the amount of electricity.

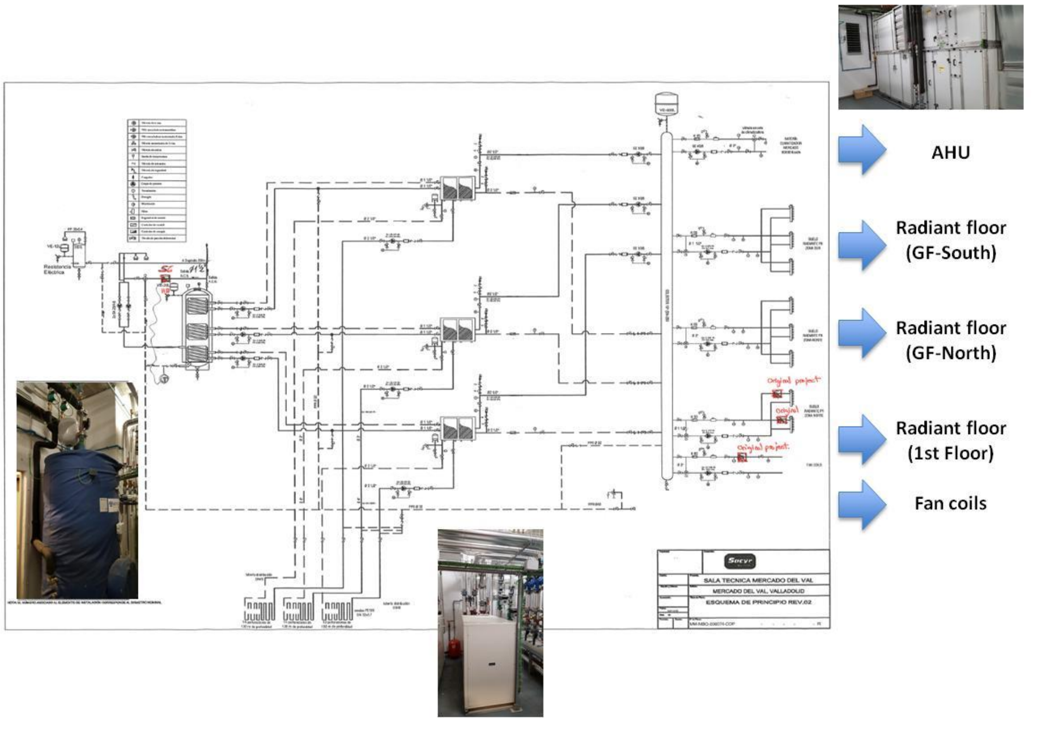


Figure 15. HVAC scheme in Mercado del Val

3.3. Assessment of overall energy performance in Mercado del Val

This paragraph presents an evaluation of the ECMs effect at whole building level.

3.3.1. Baseline period

All the renovation projects are divided into two timing periods: baseline period, the period before the intervention, and reporting period, that represents the post-retrofit period. During baseline, the analysis, diagnosis and proposed ECMs for retrofitting are the main tasks. In fact, ECMs implementation is the element that splits both periods. In the reporting period, the improvements provided by the ECMs are evaluated.

In the case of Mercado del Val, the baseline period, is the period before the closure of the building at the end of 2013 and starting of the construction works. This means that the reference building is the old building for which detailed information was collected during the energy audit [3]. Table 3 summarizes the input data used for the baseline simulation described in detail in D6.3 [3].

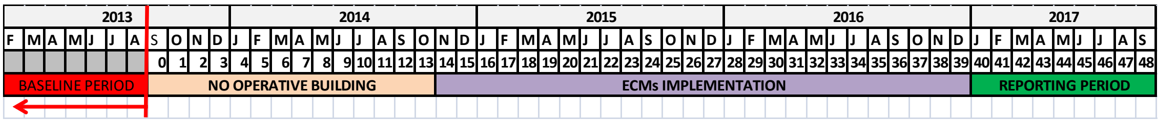
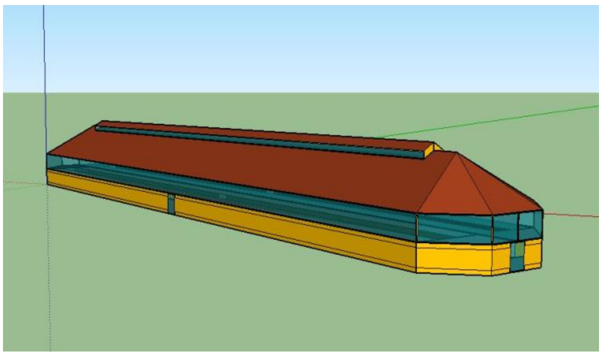


Figure 16. Baseline period schedule

Table 3. Input data for the baseline model.

General Data	
Floor area (m^2)	2,220
Opening hours per day (h/d)	From Monday to Saturday 7 am – 4 pm
Opening days per week (d/w)	6 (Sunday closed)
Thermal zone model	
	Number of thermal zones: 9 Shops: 2,220 m^2
Building envelope	
Wall (U-value [W/m^2K])	A: 1.642; B:0.738; C:1.897
Roof (U-value [W/m^2K])	Interior: 2.191; Exterior: 1.066
Floor (U-value [W/m^2K])	Without radiant floor: 1.243 With radiant floor: 0.507
Windows (U-value [W/m^2K]; g-value)	5.8; 0.8
Doors (U-value [W/m^2K]; g-value)	3.25; 0.76
Building loads and set points	
Lighting (W/m^2)	Common areas: 23.7 Shops: 36.2
Appliances (W/m^2)	Shops: 10
Heating set point temperature (ºC)	20
Cooling set point temperature (ºC)	25
Ventilation [$kg/hr \cdot m^2$]	7.35
Infiltration [ach]	4
Active systems	

Heating and cooling demands were covered by two air/water heat pumps connected to the radiant floor on the ground level and to the air curtains located in each entrance.

The refrigeration system was composed by several individual compressor units located in the specific stalls. Heat produced by the condensers was released inside the building.

There was no mechanical ventilation system. Natural ventilation was performed through doors and windows.

There were two lighting systems: one for the general lighting of the market composed by lighting balloons suspended from metal arches along the corridors and in the entrances; the individual lighting, corresponding to each individual stall, was mainly composed by fluorescent tubes. The artificial lighting system was supported by natural light coming from the windows and skylights.

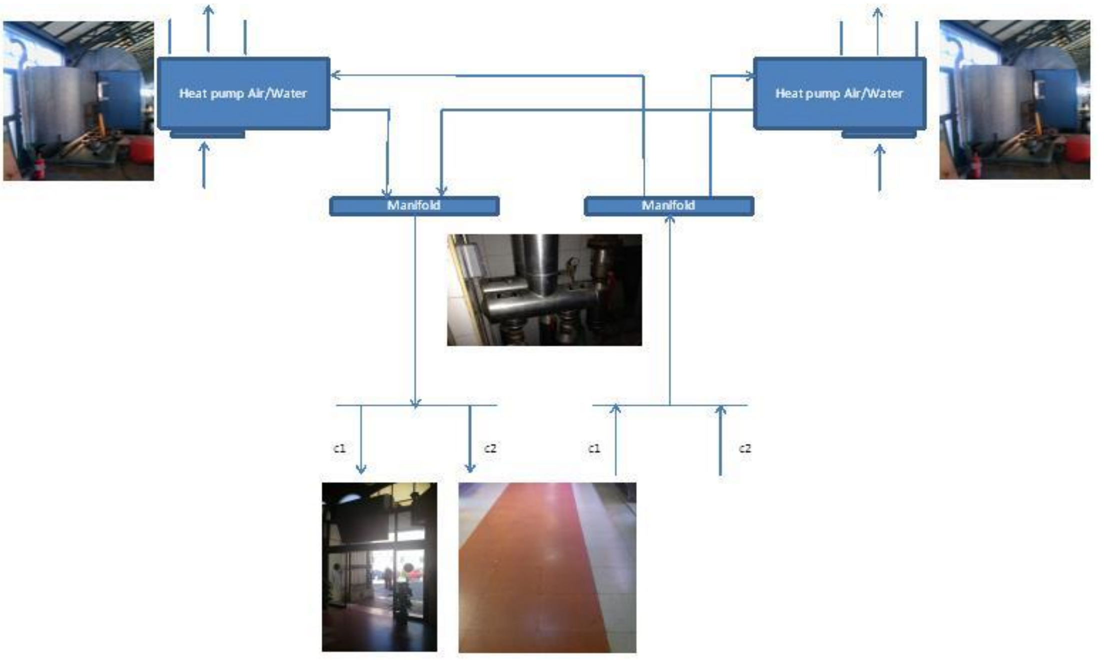


Figure 17. HVAC scheme in the old building

It was difficult to collect reliable energy consumption data for the market due to the fact that almost each stall had its own individual energy meter. Additionally electrical bills collected were not very clear regarding the type of use to which they were related to. Since the building was not operative since 2013, it was not possible to perform direct measurements. Therefore, the building energy demand was estimated by energy simulations within the Integrative Modelling Environment.

Simulations are performed with unlimited power, able to guarantee the indoor temperature within heating and cooling set-point all the time. The time step is set to 15 min and a preconditioning period of a month is considered.

For the base case the same schedules of the existing market were used as well as a similar percentage of occupancy of the building.

The inlet air temperature is assumed to be equal to the outdoor air temperature. No heat recovery is taken into account.

The infiltration rates are set to a constant value of 4 ach in each zone of the model due to the low airtightness of the building.

The weather file used for the analysis derives from historical data series (2000-2009) of a weather station located in the city of Valladolid, which is part of the Meteonorm database (Weather station ID 81410) [7].

It is necessary to calculate the energy demand for heating and cooling of the market, always assuming that a minimum comfort condition is reached (even though actually it was not reached in the old building).

3.3.2. Meter specifications and monitoring

A large number of sensors were installed in the building with control and evaluation purposes. The innovative integration of the multifunctional façade together with the ventilation and shading system, in addition to the geothermal heat pump and other devices, made necessary the integration of a high number of sensors in order to draw the energetic print of the building. Figure 18 represents the energy monitoring layout for Mercado del Val.

The signals collected in the building are being saved in the iBEMS.

The monitoring layout includes 8 thermal energy counters.

- H1: Waste heat from refrigeration unit.
- H2: DHW production.
- H3,4,5: Geothermal heating and cooling production.
- H6: Restaurant heating and cooling radiant floor.
- H7: Offices heating and cooling radiant floor.
- H8: Supermarket heating and cooling fancoils.

and 5 electrical counters:

- E1,2,3: Geothermal heat pumps electricity consumption.
- E4,5: AHU ventilators electricity consumption.

Thermal meters H6, H7 and H8, are not collecting data. These thermal meters were foreseen in the original project and are also useful for the performance assessment in the CommONEnergy project. According to the facility manager, H6 is not collecting data because the restaurant is not operative yet, but no reasonable answers were given for H7 and H8 disfunctioning.

The identified meters and sensors would allow to have a calibrated model of Mercado del Val (post-retrofit), but also to measure directly the energy consumption of some of the isolated solutions.

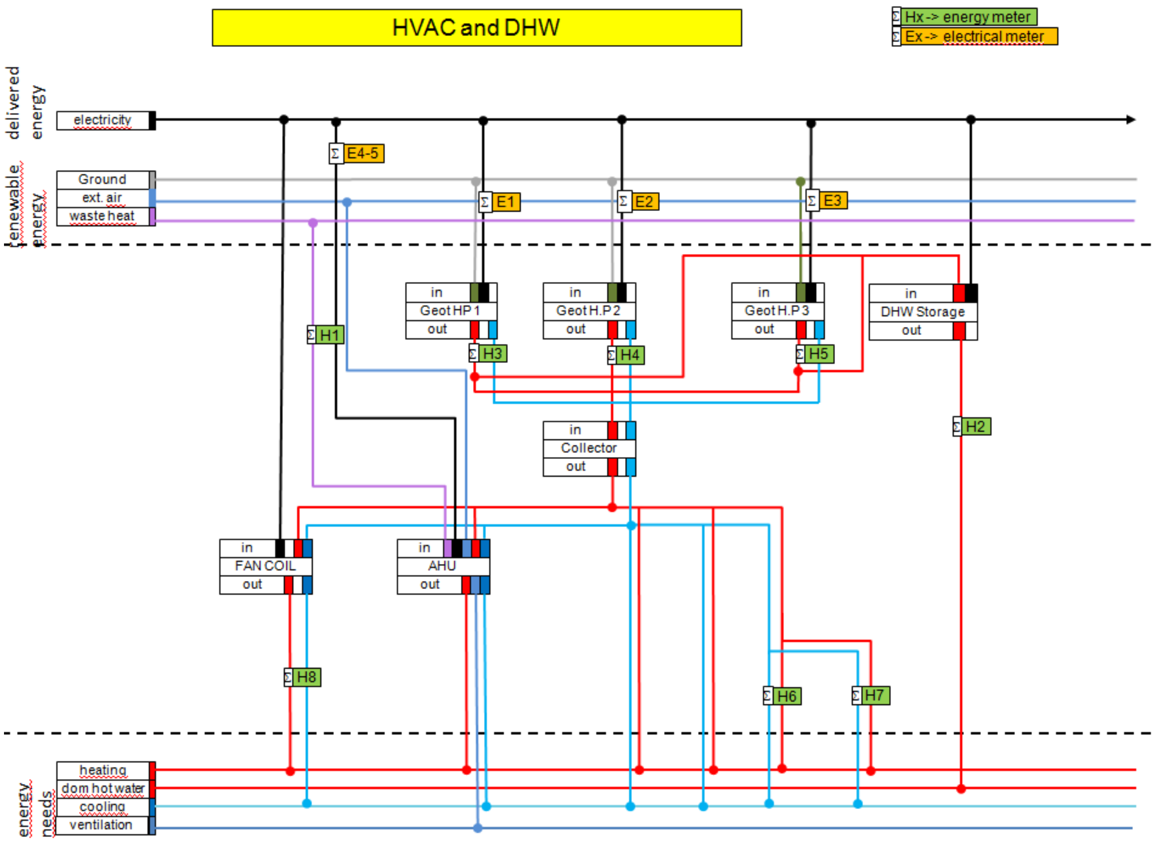


Figure 18. Scheme showing the thermal and electrical meters location

A Weather Station is located on the roof of the building collecting data about the following outdoor climate variables:

- Outside temperature and humidity.
- Wind sensor.
- Wind direction.
- Precipitation sensor.
- Global radiation sensor. Reading in a vertical plan of the south façade for controlling the shading system.

Table 4. Weather station sensors.

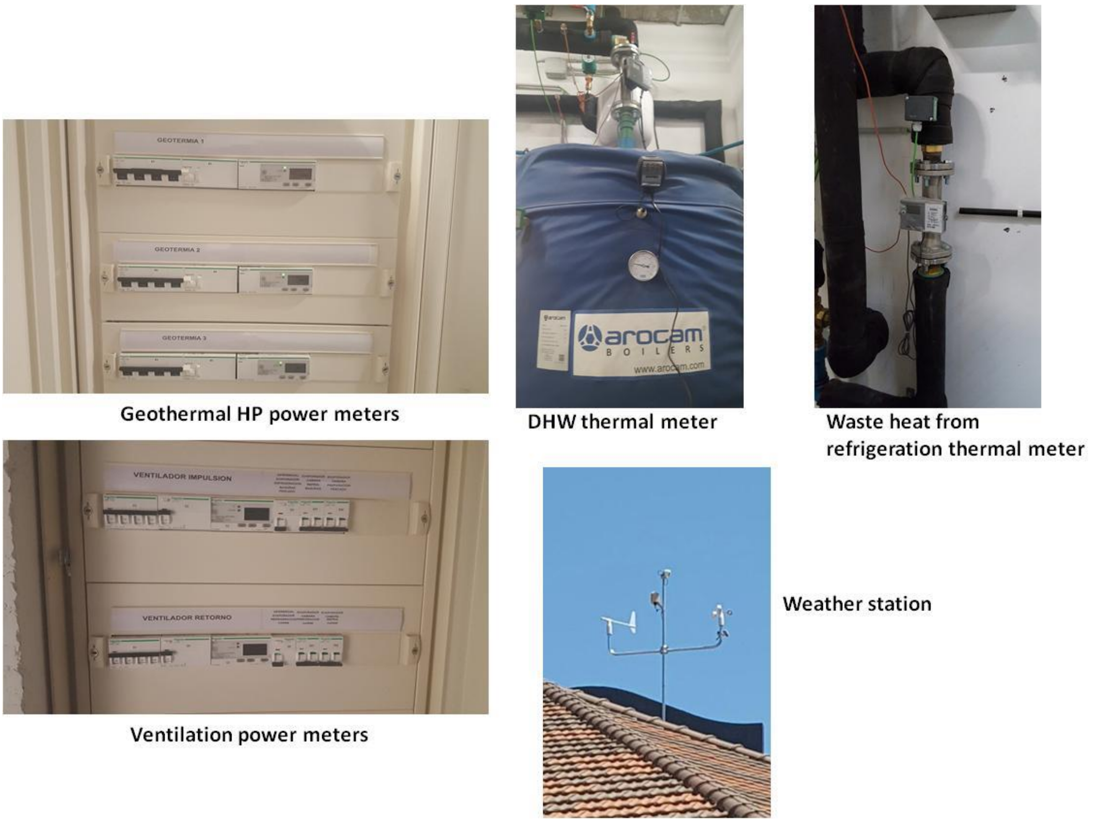


Figure 19. Real pictures of the meters inside the building and the weather stations on the roof

3.3.3. Reporting period

The reporting period must begin once the interventions have already finished and the commissioning and test of different ECMs have finished too. According to the implementation plan the reporting period in the Valladolid demo site starting date should be January 2017.

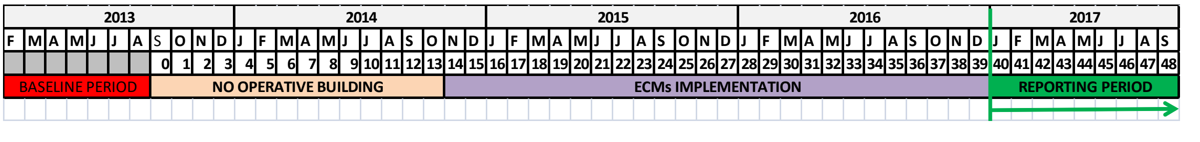
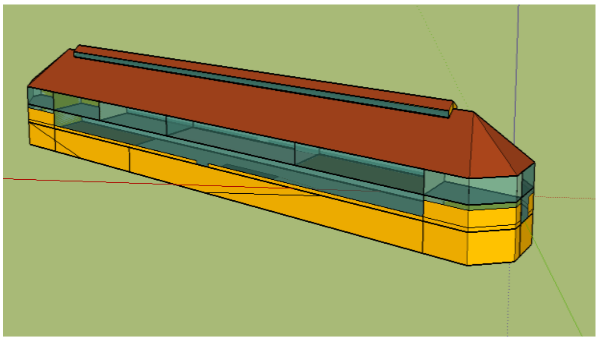


Figure 20. Reporting period schedule

Table 5 summarizes the input data set in the simulation model for the building post-retrofit.

Table 5. Input data for the reporting model

General Data	
Floor area (m^2)	4,800

Opening hours per day (h/d)	Monday: 9:00 – 23:00 Tuesday: 9:00 – 23:00 Wednesday: 9:00 – 23:00 Thursday: 8:30 – 0:30 Friday: 8:30 – 0:30 Saturday: 8:30 – 0:30 Sunday: 10:00 – 16:00
Opening days per week (d/w)	7
Thermal zone model	
	Number of thermal zones: 22
	Shops: 3,030 m^2
	Technical rooms: 555 m^2
	Common areas: 479 m^2
	Restaurant: 119 m^2
	Parking: 466 m^2
	Services: 286 m^2
Building envelope	
Wall (U-value [W/m²K])	A: 0.641; B:1.350
Roof (U-value [W/m²K])	0.377
Floor (U-value [W/m²K])	0.358
Windows (U-value [W/m²K]; g-value)	North windows: 1.29; 0.631 South windows: 1.29; 0.333 East and west windows: 1.29; 0.333
Building loads and set points	
Lighting (W/m²)	Common areas: 4.5 Shops: 9 Restaurant: 8.5 Parking: 2
Appliances (W/m²)	Shops: 5 Restaurant: 5 Technical rooms: 5 Parking: 5 Services: 5
Heating set point temperature (ºC)	20
Cooling set point temperature (ºC)	Shops: 24

	Common areas: 24 Restaurant: 25
Ventilation [kg/hr·m^2]	7.35 (Common areas, shops, restaurant) 3.02 (Technical rooms, services, parking).
Infiltration [ach]	1.2
Active systems	
To supply both heating and cooling there are three reversible ground to water geothermal heat pumps, getting temperature from vertical boreholes done on the ground. To cover the energy needs it has been selected a low temperature heating and cooling system, with radiant floor on the ground floor and first floor and fan coils in the basement. The AHU can work also in free-cooling mode and has heat recovery efficiency of more than 65%. Regarding the refrigeration system, it has been designed a centralized installation to cover all the needs of the whole centre through a central condenser and one evaporator per each zone with refrigeration needs. This installation generates a very important amount of hot air on the condensers. This waste heat could be used to heat the water of the circuit for the radiant floor and for the AHU in winter, while in summer this heat could be dissipated to the ground.	
ECMs parameters in the simulation model	
Multifunctional façade	Glazing: (see table below) Shadings: adaptation based on control rules (see below). Windows for natural ventilation: adaptation based on control rules (see below)
iBEMS	Adaptation of control rules for shading and windows for natural ventilation (see below)
HVAC system	Real performance of the geothermal heat pumps.
Summary of control rules for windows	

Glazing:

	U (W/m2K)	g (%)
North	1.1	56
South	1	27
East	1	27
West	1	27

During the market opening time:

- If the outdoor climate is not suitable for natural ventilation, air handling unit works on recirculation mode with minimum airflow;
- If the outdoor climate is suitable for natural ventilation to provide fresh air, the level of CO_2 is over the maximum concentration level allowed but there is no cooling need, windows are opened with opening factor set to 0.2 (opening angle = 18°) and the airflow from air handling unit is reduced proportionally;
- If the outdoor climate is suitable and there is cooling need, windows are opened with opening factor set to 0.4 (opening angle = 35°), the airflow from air handling unit is reduced proportionally;
- If the outdoor climate is not suitable and there is cooling need, windows are closed and the air handling unit provides the hygienic airflow rates.

During the market closing time, if the day was hot, night cooling is activated by opening all windows with opening factor is set to 0.4 (opening angle = 35°).

Summary of control rules for shadings

During the market opening time the Warema system can be controlled as followings:

- If T_{out_24} > 12°C the shading control switches on summer mode:
  - If I_{south} > 120 W/m² close lamella in cut-off position
- Otherwise (i.e. if $T_{out\_24} \leq$ 12°C), winter mode:
  - If $T_{in} \leq T_{set,h}$ shadings are open
  - $T_{set,h} < T_{in} \leq T_{set,c}$-1°C and I_{south} > 120 W/m² close lamella in the next open position before the cut-off position (e.g. from 40° to 30° tilt angle)
    - If $E_v \leq$ 2670 lux keep the current position
    - If E_v > 2670 lux close the shadings in cut-off position
  - If $T_{in} > T_{set,c}$-1°C and I_{south} > 120 W/m² close lamella in cut-off position

In order to reduce the heat losses during the winter time and increase the heat rejection during the summer time, overnight the shading system is controlled as followings:

- If $T_{out\_24} \leq$ 12°C close the shadings at 80° tilt angle.
- Otherwise (T_{out_24} > 12°C), shadings are open.

Table 6 reports the electricity consumption of the geothermal heat pump.

Table 6. Geothermal Heat Pump power meters. Electricity consumption [MWh] (E1, E2 and E3)

	E1 (G1)	E2 (G2)	E3 (G3)
01/01/2017-15/01/2017	-	0.442	1.943
15/01/2017-31/01/2017	-	2.855	5.067

01/02/2017-15/02/2017	-	3.222	5.249
15/02/2017-28/02/2017	0.087	1.349	3.540
01/03/2017-15/03/2017	0.093	2.243	2.112
15/03/2017–31/03/2017	0.095	1.264	2.791
01/04/2017-15/04/2017	0.090	1.028	0.948
15/04/2017-30/04/2017	0.096	0.334	0.987
01/05/2017-15/05/2017	0.082	0.689	0.656
15/05/2017-31/05/2017	0.110	0.725	2.192
01/06/2017-15/06/2017	0.089	0.487	2.687
15/06/2017-30/06/2017	0.097	1.422	2.753
01/07/2017-15/07/2017	0.265	1.536	1.851
15/07/2017-31/07/2017	0.840	2.508	1.377

Values from 01/01/2017 to 15/02/2017 were estimated based on an average COP and the thermal production for the same period (H3, H4 and H5). During that period the values were not collecting for these meters because the building was under commissioning. Values for E1 during that period, were finally not estimated, because as can be seen from the real values and from the comments of the facility manager, the geothermal heat pump 1 was working badly and was necessary a readjustment. Heat pump 1 started performing well again in July 2017.

Table 7. AHU power meters. Electricity consumption [MWh] (E4 and E4)

	E4 (AHU1)	E5 (AHU2)
01/01/2017-15/01/2017	UC	UC
15/01/2017-31/01/2017	UC	UC
01/02/2017-15/02/2017	UC	UC
15/02/2017-28/02/2017	UC	UC
01/03/2017-15/03/2017	UC	UC
15/03/2017–31/03/2017	0.9587	1.2657
01/04/2017-15/04/2017	1.0239	1.3372
15/04/2017-30/04/2017	1.0945	1.4304
01/05/2017-15/05/2017	0.9544	1.2475
15/05/2017-31/05/2017	1.1336	1.6387
01/06/2017-15/06/2017	1.0053	1.5043
15/06/2017-30/06/2017	0.8023	1.1801
01/07/2017-15/07/2017	0.3520	0.4702
15/07/2017-31/07/2017	0.4780	0.6251

UC: Under commissioning

Table 8. Refrigeration heat recovery and DHW thermal meters. Thermal energy consumption [MWh] (H1 and H2)

	H1 (HR)	H2 (DHW)
01/01/2017-15/01/2017	UC	UC
15/01/2017-31/01/2017	UC	UC
01/02/2017-15/02/2017	UC	UC
15/02/2017-28/02/2017	NA	2.2
01/03/2017-15/03/2017	NA	2.11
15/03/2017–31/03/2017	NA	NA
01/04/2017-15/04/2017	0.47	NA
15/04/2017-30/04/2017	0.45	NA
01/05/2017-15/05/2017	0.85	NA
15/05/2017-31/05/2017	0.27	NA
01/06/2017-15/06/2017	0	NA
15/06/2017-30/06/2017	0	NA
01/07/2017-15/07/2017	0	NA
15/07/2017-31/07/2017	0	NA

UC: Under commissioning; NA: Not Available

DHW thermal meter was again replaced in September 2017 because it was not performing well. For the simulations it was used an average value of the data already collected, as it is supposed to be an almost constant value during the whole year.

Table 9. Geothermal Heat Pump thermal meters. Thermal energy produced [MWh] (H3, H4 and H5)

	H3 (G1)		H4 (G2)		H5 (G3)	
	Heat	Cold	Heat	Cold	Heat	Cold
01/01/2017-15/01/2017	1.52	0.05	2.43	0.03	7.9	0
15/01/2017-31/01/2017	0.99	0.09	15.75	0.13	20.58	0.02
01/02/2017-15/02/2017	0	0.03	17.88	0.04	21.34	0
15/02/2017-28/02/2017	0.01	0	7.50	0	14.39	0
01/03/2017-15/03/2017	0.01	0	12.47	0	8.59	0
15/03/2017–31/03/2017	0	0.02	6.32	0.03	12.05	0
01/04/2017-15/04/2017	0	0	5.81	0.16	3.77	0
15/04/2017-30/04/2017	0.01	0.01	1.77	0.05	3.56	0.02

01/05/2017-15/05/2017	0	0	3.97	0.14	2.85	0
15/05/2017-31/05/2017	0	0	2.47	1.78	3.33	7.84
01/06/2017-15/06/2017	0	0	0	3.04	0.02	13.88
15/06/2017-30/06/2017	0.01	0.03	0.01	11.11	0.04	13.47
01/07/2017-15/07/2017	0.01	0.96	0.04	11.34	0.09	8.98
15/07/2017-31/07/2017	0.13	3.96	0.06	14.40	0	7.25

Values from 15/02/2017 to 15/03/2017 for H3, H4 and H5 were estimated based on an average COP and the electrical consumption for this period (E1, E2 and E3) (Table 10). During this period the values were not collecting for these meters due to technical problems.

The change from heating season to cooling season occurred on May 24th 2017.

Table 10. Calculated COP/EER (H3/E1; H4/E2; H5/E3). COP (Heating mode); EER (Cooling mode)

	COP/EER G1	COP/EER G2	COP/EER G3
15/03/2017–31/03/2017	COP: 0.210	COP: 5.022	COP: 4.318
01/04/2017-15/04/2017	COP: 0.000	COP: 5.807	COP: 3.975
15/04/2017-30/04/2017	COP: 0.209	COP: 5.454	COP: 3.625
01/05/2017-15/05/2017	COP: 0.000	COP: 5.963	COP: 4.344
15/05/2017-31/05/2017	COP: 0.000	COP: 5.865	COP: 5.097
01/06/2017-15/06/2017	EER: 0.000	EER: 6.239	EER: 5.173
15/06/2017-30/06/2017	EER: 0.411	EER: 7.818	EER: 4.907
01/07/2017-15/07/2017	EER: 3.655	EER: 7.408	EER: 4.499
15/07/2017-31/07/2017	EER: 4.868	EER: 5.766	EER: 5.267
AVERAGE COP	-	5.562	4.066
AVERAGE EER	4.851	6.015	5.089

Figure 21 reports the measured solar radiation in Valladolid available online. While Figure 22 shows the outdoor temperature and wind speed measured by the weather station.

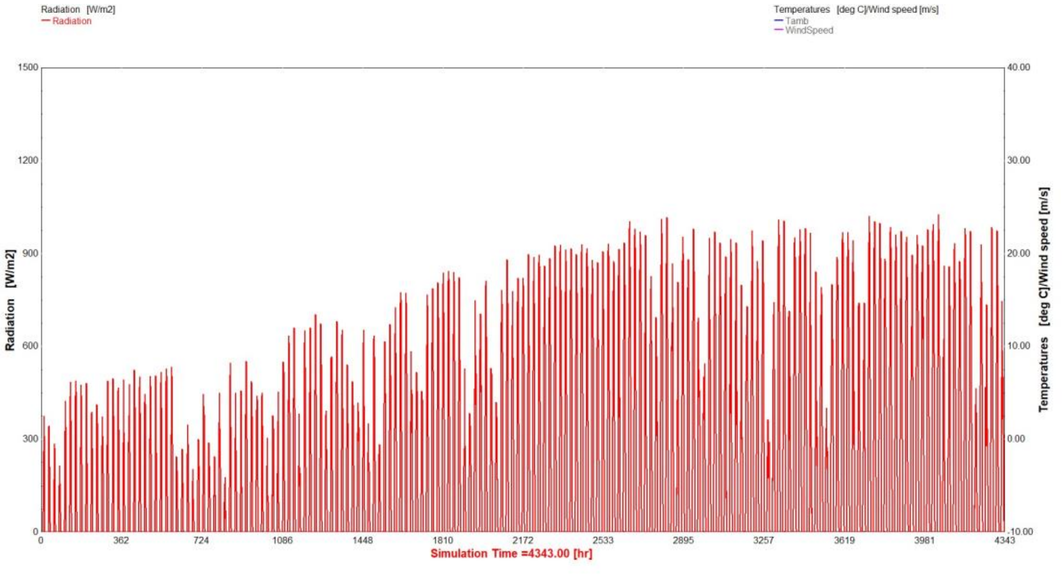


*Figure 21. Radiation in Valladolid from January to June 2017. Source: CAM Radiation Service **Error! Reference source not found.***

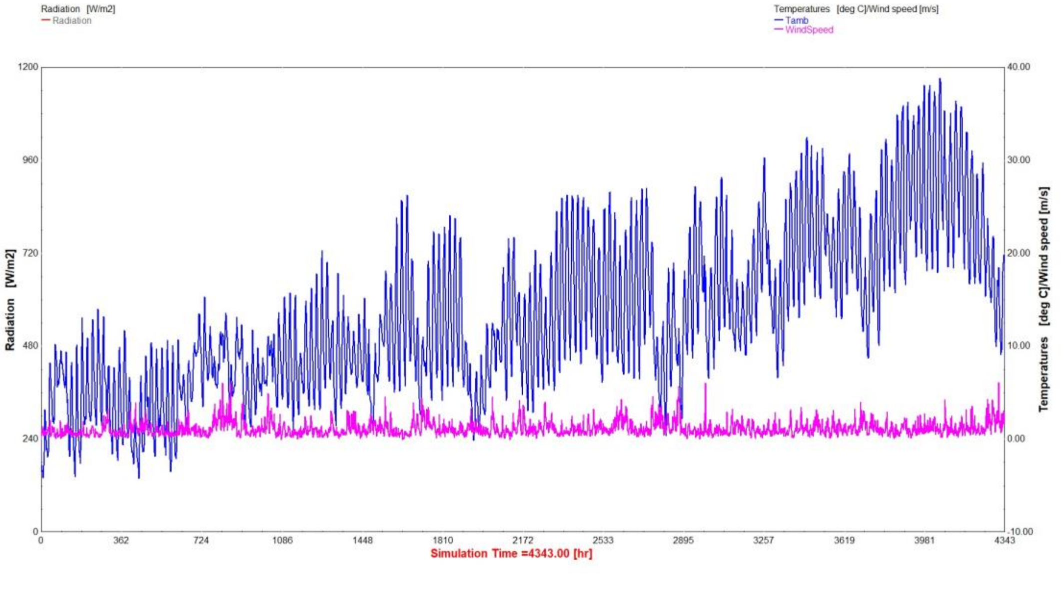


Figure 22. Temperature and wind speed in Valladolid from January to June 2017 measured by the weather station installed at Mercado del Val.

3.3.4. Analysis procedure for calculating results

In the case of Mercado del Val, in order to evaluate the energy savings for the whole building we compare the new building with the CommONEnergy solutions included (reporting period) with the old building (baseline period). Parameters and information about the baseline model is described in section 3.3.1 and more detailed information in D6.3 [3]. Parameters and information about the new building and the ECMs implemented can be found in section 3.3.3.

Option D (simulations) of the IPMVP is applied to evaluate the energy savings of the whole building. The model of the new building with the CommONEnergy solutions implemented is calibrated with the real data coming from the monitoring system from January 2017 until July 2017. The building post-retrofit is calibrated with the data coming from the weather station installed on the roof of the building, only the radiation has been taken from CAM Radiation Service **Error! Reference source not found.** due to the position of the radiation sensor in the weather station which receive the radiation in a vertical plane for the control of the shadings. Then for the comparison of both buildings new and old, we used the same weather file to set the same boundary conditions for both models. The weather data derives from the historical data series (2000-2009) of a weather station located in the city of Valladolid, which is part of the Meteonorm database [7].

Table 11 reports simulated and monitored heating and cooling demand on monthly basis from January to July 2017.

Table 11. Real data monitoring vs simulations results.

Month	Real data monitoring (MWh)			Simulations (MWh)		
	Heating (*)	Cooling (**)	Total	Heating	Cooling	Total
January 2017	45.88	0	45.88	89.78	0	89.78
February 2017	57.84	0	57.84	50.70	0	50.70
March 2017	36.15	0	36.15	36.95	0	36.95
April 2017	11.63	0	11.63	12.47	0	12.47
May 2017	9.33	9.76	19.09	3.81	11.64	15.45
June 2017	0	41.53	41.53	0	46.36	46.36
July 2017	0	46.89	46.89	0	46.55	46.55

*Heating season monitoring data: H3 + H4 + H5 + H1 – H2 (DHW average value)

**Cooling season monitoring data: H3 + H4 + H5

Measured heating demand in January 2017 is circa 50% lower than the predicted one. That is because the geothermal system was not performing well and comfort conditions were not reached inside the market. Information coming from the maintenance people and the owners of the different stalls support this statement as they were passing cold inside the building, also internal temperature sensors measured an average temperature of around 16 ºC in January (Figure 23) which is a very low value (not comfort inside the building).

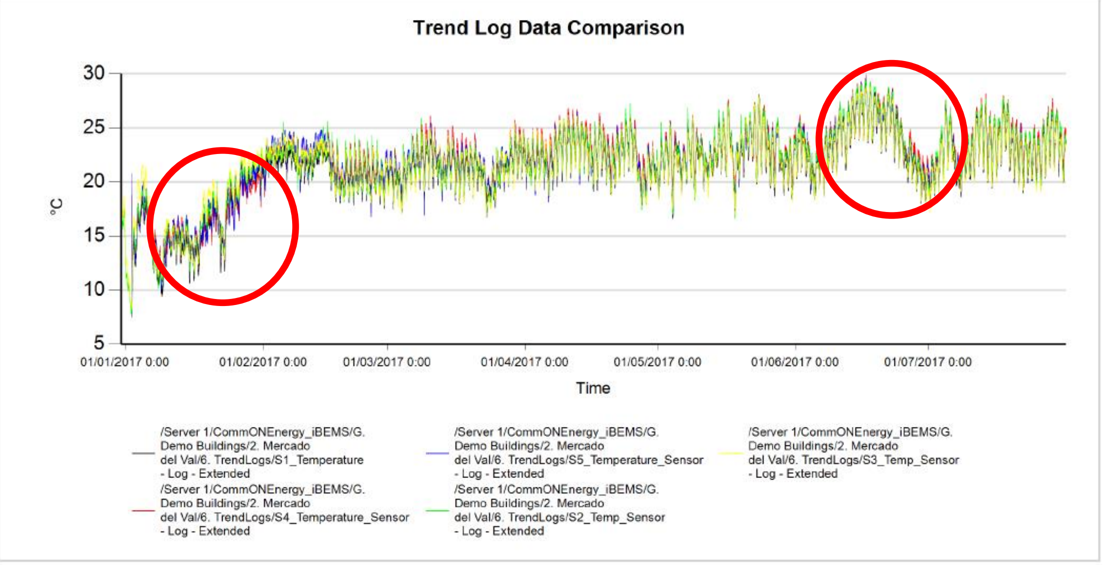


Figure 23. Indoor temperatures trend from January 2017 to July 2017.

Therefore, the period from February 2017 to July 2017 was selected for model calibration.

The model calibration process is described in detail in section 2.1.1 using monthly data to validate the model so we can consider the model calibrated (Table 12) since $NMBE$ is 2.6% (less than 5%) and $CVRMSE$ is 11.9% (less than 15%).

Table 12. CVRMSE and NMBE indicators.

Indicator	Tolerance (%)	Target tolerance (%)
CVRMSE	11.88	<15
NMBE	2.61	<5

It is worth to mention that one of the three heat pumps was not performing properly during January and May/June because of settings adjustments. For example in the period May - June, when the system changed from winter to summer mode, there were some complains from the tenants due to the high temperatures inside the market, as shown in Figure 23. This explains some of the deviations between measured and simulated performance (Figure 24).

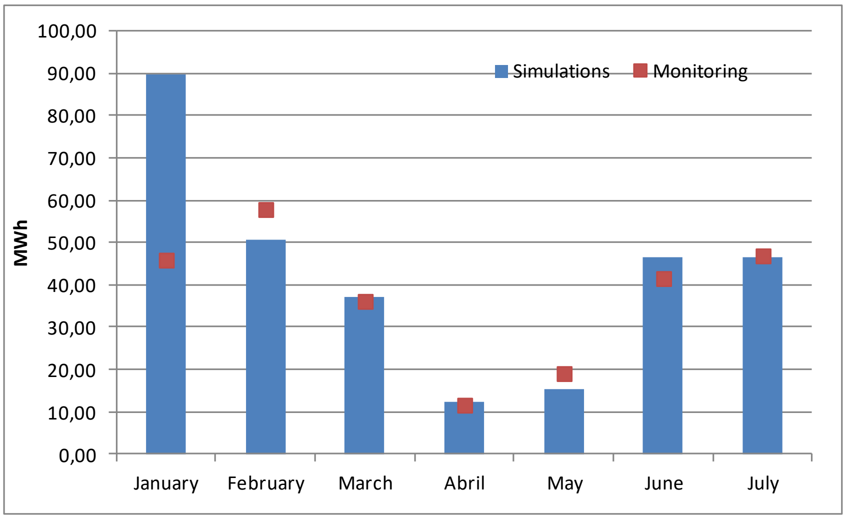


Figure 24. Comparison between real data from the monitoring and the simulations in the period January – July 2017

Once the model can be considered as calibrated, we can simulate the energy demand of the building for a complete year referring to a Typical Meteorological Year for weather conditions.

Table 13,

Table 14 and

Table 15 report the factors that will be used to convert energy consumption into primary energy, CO_2 emissions and operation costs.

Table 13. Electricity price for the Spanish demo-case

Energy source	Price
Electricity	0.134016 €/kWh[3]

Table 14. CO_2 emissions factor for the Spanish demo-case

Energy source	CO2 emissions factor
Electricity	0.357 kg CO_2/kWhfe[4]

Table 15. Primary energy factor for the Spanish demo-case

Energy source	Primary energy factor

[3] data source: https://www.endesaclientes.com/

[4] http://www.minetad.gob.es/energia/desarrollo/EficienciaEnergetica/RITE/Reconocidos/Reconocidos/Otros%20documentos/Factores_emision_CO2.pdf

Electricity	2.403 kWhpe/kWhfe[5]

3.3.5. Energy savings results

In this section we report the overall predicted energy performance of the Mercado del Val before and after the retrofit intervention, comparing the reporting period (New market with the ECMs implemented) with the baseline period (Old market as it was before the retrofitting) by means of building energy simulations. The scheme in Figure 25 recalls the methodology applied for the whole building performance assessment.

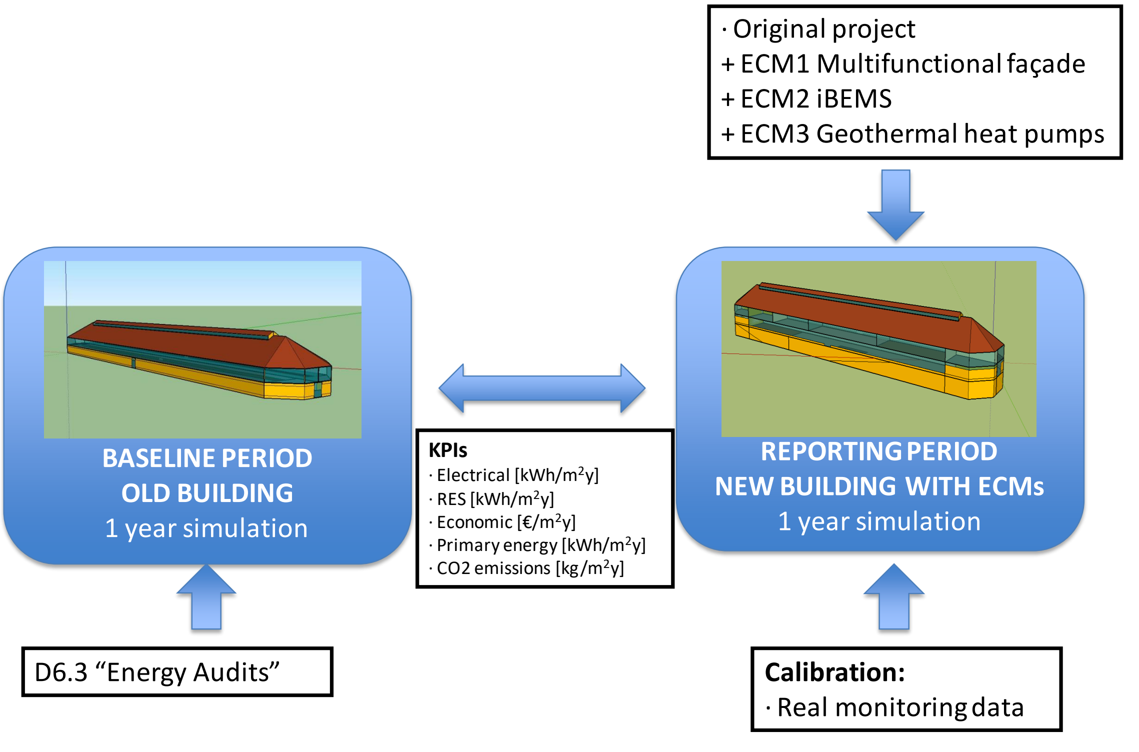


Figure 25. Methodology for the whole building performance assessment

Thermal energy demand

Table 16 and Table 17 report the thermal energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Table 16. Predicted heating and cooling demand of the Mercado del Val before the retrofit (building area = 2,220 m^2).

5 http://www.minetad.gob.es/energia/desarrollo/EficienciaEnergetica/RITE/Reconocidos/Reconocidos/Otros%20documentos/Factores_emision_CO2.pdf

Month	Heating demand		Cooling demand	
	kWh	kWh/m2	kWh	kWh/m2
January	88,178	39.7	0	0.0
February	66,221	29.8	0	0.0
March	48,273	21.7	351	0.2
April	29,193	13.2	1,906	0.9
May	11,953	5.4	14,406	6.5
June	1,396	0.6	46,577	21.0
July	252	0.1	58,629	26,.4
August	358	0.2	55,988	25.2
September	3,781	1.7	26,826	12.1
October	18,981	8.6	6,197	2,.8
November	58,919	26.5	16	0.0
December	83,194	37.5	0	0.0
TOTAL	410,699	185.0	210,896	95.0

Table 17. Predicted heating and cooling demand of the Mercado del Val after the retrofit (building area = 4,800 m^2).

Month	Heating demand		Cooling demand	
	kWh	kWh/m2	kWh	kWh/m2
January	100,244	20.9	0	0.0
February	74,539	15.5	0	0.0
March	51,794	10.8	0	0.0
April	32,732	6.8	0	0.0
May	13,698	2.9	1,933	0.4
June	2,181	0.5	21,422	4.5
July	275	0.1	31,536	6.6
August	308	0.1	28,351	5.9
September	3,888	0.8	6,964	1.5
October	18,326	3.8	122	0.0
November	66,482	13.9	0,0	0.0
December	96,266	20.1	0,0	0.0
TOTAL	460,732	96.0	90,328	18.8

Before the retrofit, no RES systems were installed while after the retrofit all the heating, cooling and DHW demand i is covered at 100% by the three geothermal heat pumps.

Useful energy

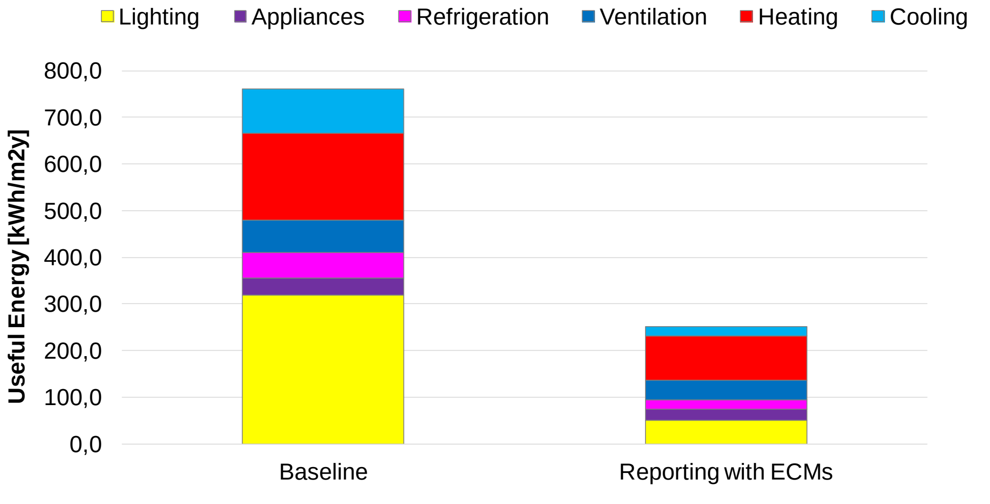


Figure 26. Useful energy demand of the Mercado del Val before (left) and after (right) retrofit

Table 18. Useful energy demand of the Mercado del Val before and after retrofit

	Before retrofit [kWh/m²y	After retrofit [kWh/m²y]	Savings [%]
Lighting	318.2	49.5	84
Appliances	36.5	25.2	31
Refrigeration	55.0	19.0	65
Ventilation	70.5	42.3	40
Heating	185.0	96.0	48
Cooling	95.0	18.8	81
Total	760.2	250.8	67

In terms of useful energy, the total savings are 67% comparing the new building with the CommONEnergy solutions with the old building. Lighting and cooling is where the savings are higher above 80%, following refrigeration with 65% and ventilation and heating above 40%.

Final energy

Figure 27 and Table 20 report the final energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Final energy demand is calculated using the energy conversion efficiencies reported in Table 19.

Table 19. Energy conversion efficiency of the building systems in the Mercado del Val before and after the retrofit.

Conversion factors	Before retrofit	After retrofit
Ventilation [Wh/m³]	0.45	0.45
COP	3	4.8
EER	2.5	5.6

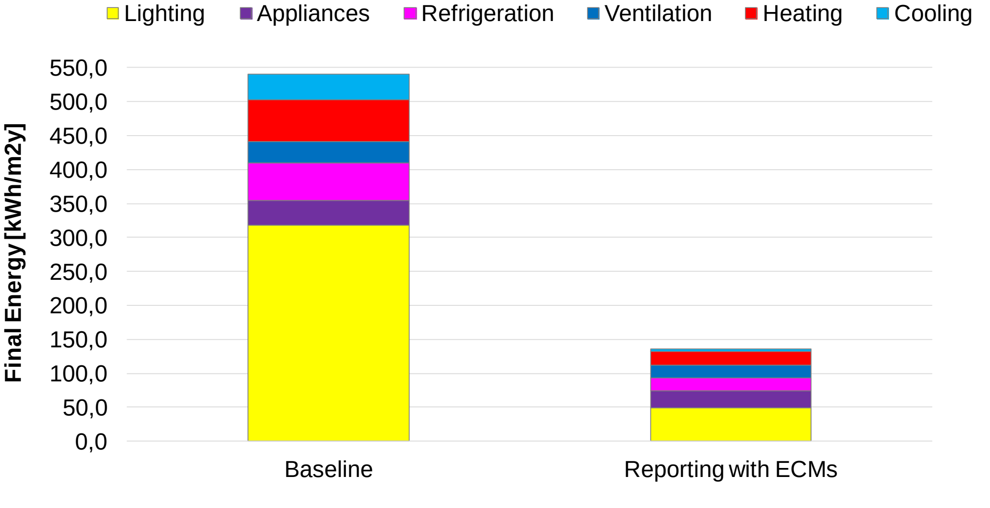


Figure 27 Final energy demand before (left) and after (right) the retrofit intervention in the Mercado del Val.

Table 20. Final energy demand before and after the retrofit intervention in the Mercado del Val

	Before retrofit [kWh/m²y]	After retrofit [kWh/m²y]	Savings [%]
Lighting	318.2	49.5	84
Appliances	36.5	25.2	31
Refrigeration	55.0	19.0	65
Ventilation	31.7	19.0	40
Heating	61.7	20.0	68
Cooling	38.0	3.4	91
Total	541.1	136.1	75

In terms of final energy, the total savings are 75% comparing the building before and after the retrofit. Lighting and cooling is where the savings are higher than 80%, following heating with 68%, refrigeration 65% and ventilation 40%. The performance of the new geothermal system is clearly higher (COP: 4.8 and EER: 5.6) in comparison with the old one based on air/water heat pumps (COP: 3 and EER: 2.5).

Primary energy

Figure 28 and Table 21 reports the final energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Primary energy demand is calculated using the conversion coefficients reported in par. 3.3.4.

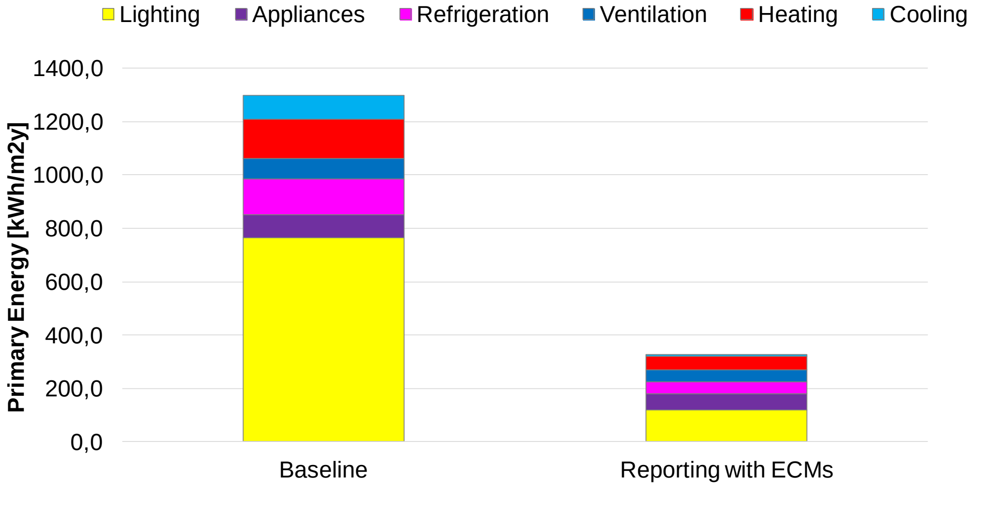


Figure 28 Primary energy demand before (left) and after (right) the retrofit intervention in the Mercado del Val.

Table 21. Primary energy demand before (left) and after (right) the retrofit intervention in the Mercado del Val.

	Before retrofit [kWh/m²y]	After retrofit [kWh/m²y]	Savings [%]
Lighting	764.6	118.8	84
Appliances	87.7	60.5	31
Refrigeration	132.2	45.6	65
Ventilation	76.2	45.8	40
Heating	148.2	48.1	68
Cooling	91.3	8.1	91

Total	1300.2	326.9	75

In terms of primary energy, the total savings are 75% comparing the building after retrofit and before retrofit. Lighting and cooling is where the savings are higher than 80%, following heating with 68%, refrigeration 65% and ventilation 40%.

For the calculation of the simple payback of the whole retrofit intervention we took into account the costs listed in Table 22.

Table 22. Original project and CommONEnergy budgets

Item	Budget (€)
Original project	
New lighting system	+329,072
New refrigeration system	+192,257
New HVAC system	+776,959
Glazing proposed originally	-151,052
Enclosures + isolations	+245,787
CommONEnergy	
Windows for natural ventilation Shadings iBEMS	+314,442
New glazing system	+224,846
TOTAL	1,932,320

Taking into account the final energy savings (405 kWh/m^{2}y) due to the retrofit intervention, the surface of the new building (4,800 m^2) and the price of the electricity described before in section 3.3.4, we finally obtain an estimated simple payback of 7,42 years.

For the calculation of the CO_2 emissions avoided we apply the CO_2 emission factor described in section 3.3.4 to the final energy savings (405 kWh/m^{2}y) and to the surface of the building after retrofit and we obtain a reduction of around 694 tons/year.

3.4. Assessment of energy savings, payback time and CO_2 emissions avoided in each ECM

Figure 29 below summarizes the methodological approach we applied to assess the energy savings of each energy conservation measure.

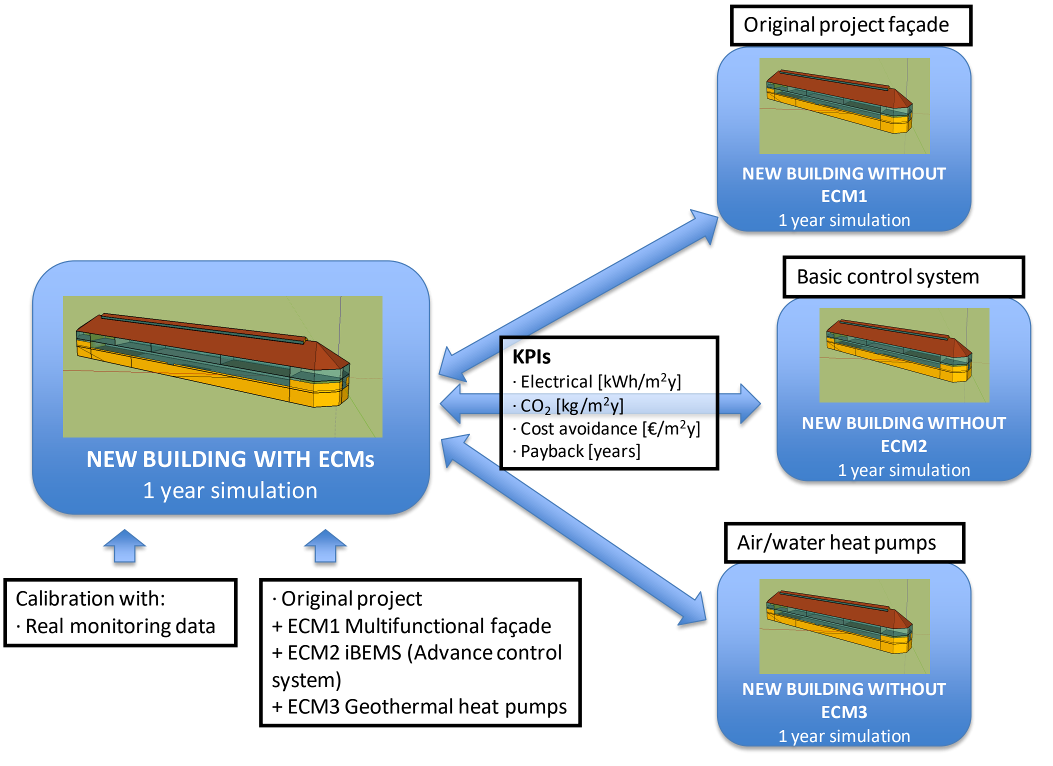


Figure 29. Methodology for the validation of the ECMs

ECM1: Multifunctional façade + ECM2: iBEMS
<u>Analysis procedure for calculating results</u> The performance of the multifunctional façade is closely connected to the iBEMS as the natural ventilation and shading system control strategies are implemented within the iBEMS. This means both solutions need to be validated together in order to evaluate the real performance of the system. The energy savings of this ECM are evaluated using OPTION D according to which we compared the energy performance resulting from building energy simulations over the whole reference year of the multifunctional façade system controlled by the iBEMS and the original project with a basic control system. Main differences between the original project and the CommONEnergy proposal are listed in Table 23.

Table 23. Comparison between original project and CommONEnergy proposal

<table>
<tr><th>Multifunctional façade + iBEMS</th><th>Before</th><th>After</th></tr>
<tr><td>Glazing characteristics</td><td><table><tr><th></th><th>U (W/m2K)</th><th>g (%)</th></tr><tr><td>North</td><td>1.9</td><td>-</td></tr><tr><td>South</td><td>3</td><td>48</td></tr><tr><td>East</td><td>2.3</td><td>33</td></tr><tr><td>West</td><td>2.3</td><td>33</td></tr></table></td><td><table><tr><th></th><th>U (W/m2K)</th><th>g (%)</th></tr><tr><td>North</td><td>1.1</td><td>56</td></tr><tr><td>South</td><td>1</td><td>27</td></tr><tr><td>East</td><td>1</td><td>27</td></tr><tr><td>West</td><td>1</td><td>27</td></tr></table></td></tr>
<tr><td>Natural ventilation</td><td>No</td><td>Yes</td></tr>
<tr><td>Shadings to control solar radiation</td><td>No</td><td>Yes</td></tr>
<tr><td>Control system</td><td>Basic control system:
ON-OFF Ventilation when open and close the building.</td><td>Advanced control system:
· Windows and shading strategies
· Regulation of ventilation (0-100%)</td></tr>
</table>

Table 24 reports the heating and cooling demand of the new building without the multifunctional façade controlled by the iBEMS.

Table 24. Simulation results of the new building without ECM1 + ECM2 (area: 4,800 m²).

Month	Heating demand		Cooling demand	
	kWh	kWh/m²	kWh	kWh/m²
January	103,345	21.5	0	0.0
February	78,774	16.4	0	0.0
March	56,249	11.7	0	0.0
April	35,802	7.5	0	0.0
May	13,937	2.9	2,386	0.5
June	619	0.1	23,394	4.9
July	22	0.0	34,880	7.3
August	32	0.0	32,024	6.7
September	1,724	0.4	8,254	1.7
October	19,517	4.1	-87	0.0
November	69,547	14.5	0,0	0.0
December	99,027	20.6	0,0	0.0
TOTAL	478,593	99.7	101,024	21.0

Useful energy

Figure 30 and Table 25 report the useful energy of the new building with and without the multifunctional façade controlled by the iBEMS.

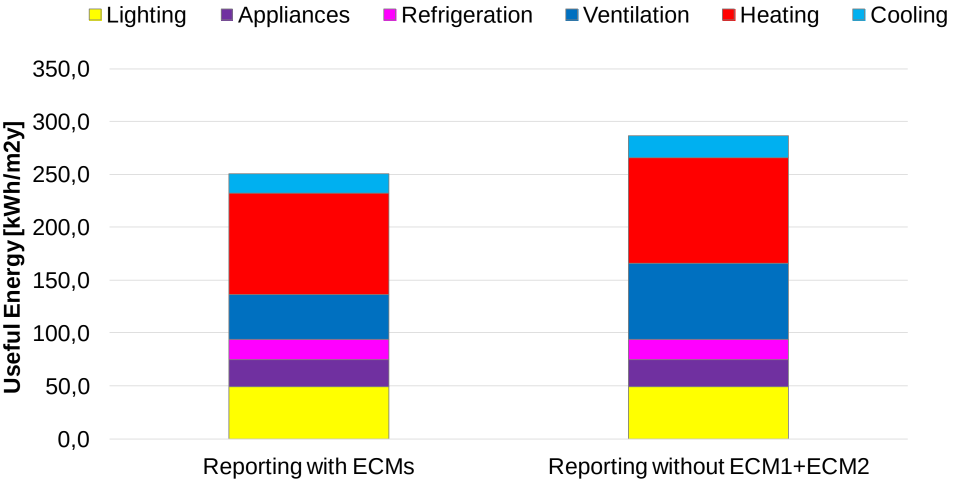


Figure 30. Useful energy new market with ECMs vs new market without ECM1 + ECM2

Table 25. Useful energy new market with ECMs vs new market without ECM1 + ECM2

	New market with ECMs [kWh/m²y]	New market without ECM1+ECM2 [kWh/m²y]	Savings [%]
Lighting	49.5	49.5	0
Appliances	25.2	25.2	0
Refrigeration	19.0	19.0	0
Ventilation	42.3	72.3	41
Heating	96.0	99.7	4
Cooling	18.8	21.0	10
Total	250.8	286.7	13
HVAC	157.1	193	19

In terms of useful energy, the total savings are 13% comparing the new building with the CommONEnergy solutions with the new building without the multifunctional façade (ECM1) + iBEMS (ECM2), instead of ECM1 and ECM2 the original project façade and a basic control system has been included in the model. If we only look at the HVAC, which is the system in which CommONEnergy is mainly affecting with the solutions, the savings are around 19%. In terms of ventilation the savings are above 40% because the mechanical ventilation system is working at lower load when the natural ventilation system is active. Also the heating and cooling demand is reduced in 4% and 10% respectively due to the improvement of the glazing, the natural ventilation and shading system. The rest energy uses (lighting, appliances and refrigeration) remains the same, as the CommONEnergy has no effect on those fields.

Final energy

Figure 31 and

Table 27 report the final energy demand of the retrofitted building building with and without the multifunctional façade controlled by the iBEMS.

Final energy demand is calculated using the energy conversion efficiencies reported in Table 26.

Table 26. Energy conversion efficiency of the building systems in the Mercado del Val with and without ECM1 and ECM2.

Conversion factors	New market with ECMs	New market without ECM1+ECM2
Ventilation [Wh/m³]	0.45	0.45
COP	4.8	4.8
EER	5.6	5.6

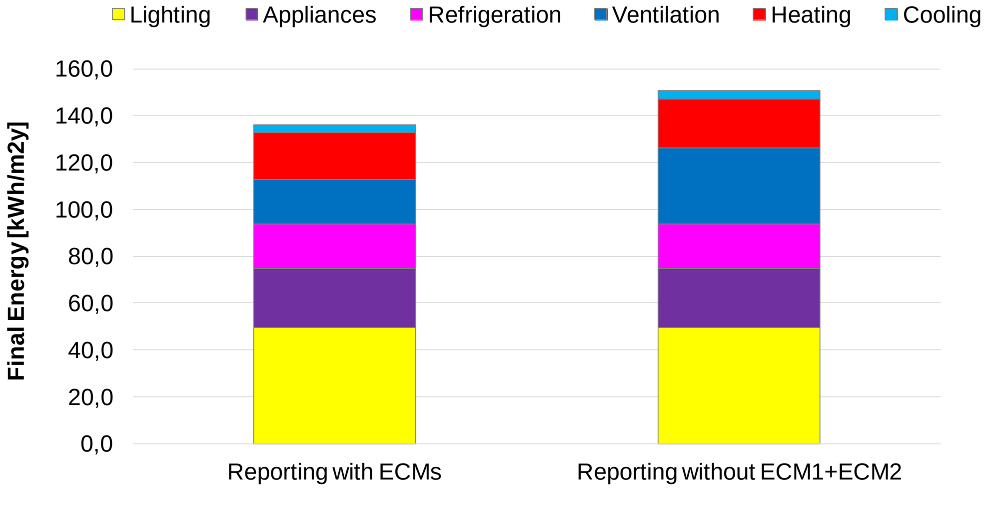


Figure 31 Final energy of Mercado del Val vs final energy of the building with standard solutions (without ECM1 + ECM2).

Table 27. Final energy of Mercado del Val vs final energy of the building with standard solutions (without ECM1 + ECM2).

	New market with ECMs [kWh/m²y]	New market without ECM1+ECM2 [kWh/m²y]	Savings [%]
Lighting	49.5	49.5	0
Appliances	25.2	25.2	0
Refrigeration	19.0	19.0	0
Ventilation	19.0	32.5	41
Heating	20.0	20.8	4
Cooling	3.4	3.8	11
Total	136.1	150.8	10
HVAC	42.4	57.1	26

In terms of final energy, the total savings are 10% comparing the new building with the CommONEnergy solutions with the new building without the multifunctional façade (ECM1) + iBEMS (ECM2), instead of ECM1 and ECM2 the original project façade and a basic control system has been included in the model. If we only look at the HVAC, which is the system in which CommONEnergy is mainly affecting with the solutions, the savings are around 26%. In terms of ventilation the savings are above 40% because the mechanical ventilation system is working at lower load when the natural ventilation system is active. Also the heating and cooling demand is reduced in 4% and 11% respectively due to the improvement of the glazing, the natural ventilation and shading system. The rest energy uses (lighting, appliances and refrigeration) remains the same, as the CommONEnergy has no effect on those fields.

Primary energy

Figure 32 and Table 28 report the primary energy demand of the retrofitted building with and without the multifunctional façade controlled by the iBEMS.

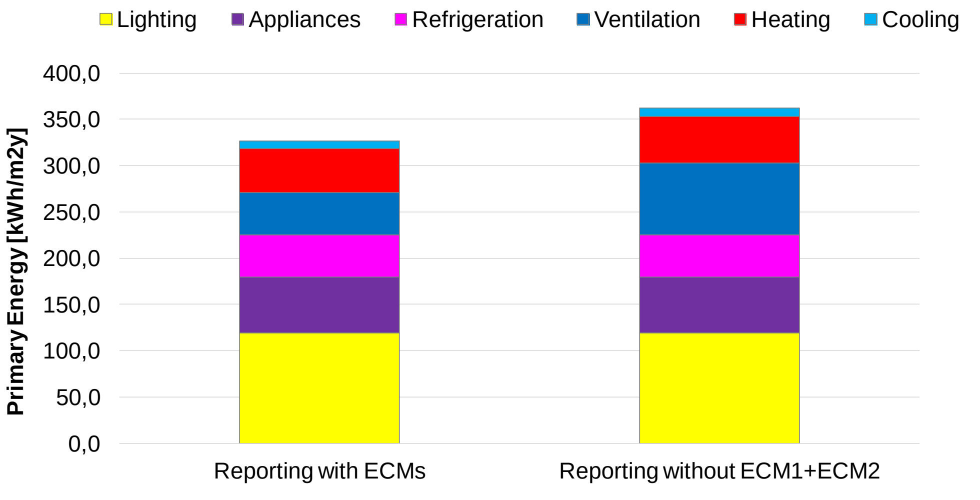


Figure 32. Primary energy of Mercado del Val vs final energy of the building with standard solutions (without ECM1 + ECM2).

Table 28. Primary energy of Mercado del Val vs final energy of the building with standard solutions (without ECM1 + ECM2).

	New market with ECMs [kWh/m²y]	New market without ECM1+ECM2 [kWh/m²y]	Savings [%]
Lighting	118.8	118.8	0
Appliances	60.5	60.5	0
Refrigeration	45.6	45.6	0
Ventilation	45.8	78.1	41
Heating	48.1	49.9	4
Cooling	8.1	9.0	10
Total	326.9	361.9	10
HVAC	102	137	26

In terms of primary energy, the total savings are 10% comparing the new building with the CommONEnergy solutions with the new building without the multifunctional façade (ECM1) + iBEMS (ECM2), instead of ECM1 and ECM2 the original project façade and a basic control system has been included in the model. If we only look at the HVAC, which is the system in which CommONEnergy is mainly affecting with the solutions, the savings are around 26%. In terms of ventilation the savings are above 40% because the mechanical ventilation system is working at lower load when the natural ventilation system is active. Also the heating and cooling demand is reduced in 4% and 10% respectively due to the improvement of the glazing, the natural ventilation and shading system. The rest energy uses (lighting, appliances and refrigeration) remains the same, as the CommONEnergy has no effect on those fields.

ECM3: HVAC system
Analysis procedure for calculating results In order to assess the energy savings of the CommONEnergy solutions, we compared the thermal energy demand of the solutions defined in ECM3 for the HVAC system, with the original project based on two air to water heat pumps only.

Table 29. Comparison between HVAC system with and without the CommONEnergy solutions.

HVAC system	Before	After
Heat pumps	Air/water	Geothermal
COP	COP: 3 ERR: 2.5	COP: 4.8 ERR: 5.6
Distribution system	Radiant floor Air curtains	Radiant floor AHU Fan-Coils

Table 30. Heating and cooling demand of the Mercado del Val with ECM1 and ECM2 but without ECM3 (area: 4,800 m²).

Month	Heating demand		Cooling demand	
	kWh	kWh/m²	kWh	kWh/m²
January	100,244	20.9	0	0.0
February	74,539	15.5	0	0.0
March	51,794	10.8	0	0.0
April	32,732	6.8	0	0.0
May	13,698	2.9	1,933	0.4
June	2,181	0.5	21,422	4.5
July	275	0.1	31,536	6.6
August	308	0.1	28,351	5.9
September	3,888	0.8	6,964	1.5
October	18,326	3.8	122	0.0
November	66,482	13.9	0,0	0.0
December	96,266	20.1	0,0	0.0
TOTAL	460,732	96.0	90,328	18.8

Useful energy

In terms of useful energy, there are no savings as the energy demand of the building remains the same.

Final energy

Figure 33 and

Table 32 report the final energy demand of the retrofitted building with the multifunctional façade controlled by the iBEMS and the HVAC system with geothermal heat pumps and the final energy demand of the retrofitted building with the multifunctional façade but without the geothermal heat pump.

Final energy demand is calculated using the energy conversion efficiencies reported in Table 31.

Table 31. Final energy conversion factors

Conversion factors	New market with ECM1+ECM2+ECM3	New market with ECM1+ECM2
Ventilation [Wh/m^3]	0.45	0.45
COP	4.8	3
EER	5.6	2.5

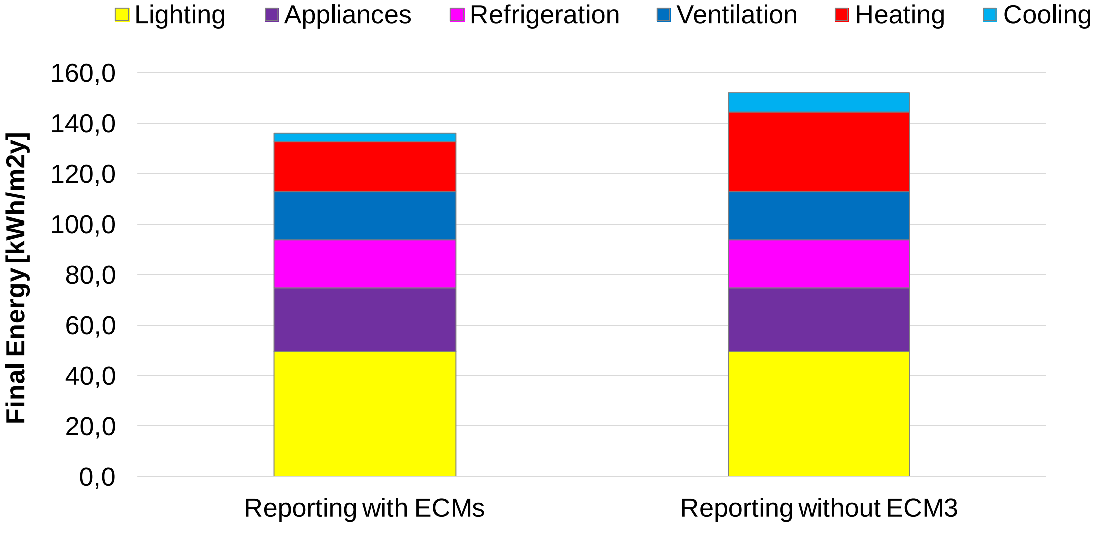


Figure 33. Final energy new market with ECMs vs new market without ECM3

Table 32. Final energy new market with ECMs vs new market without ECM3

	New market with ECM1+ECM2+ECM3 [kWh/m²y]	New market with ECM1+ECM2 [kWh/m²y]	Savings [%]
Lighting	49.5	49.5	0
Appliances	25.2	25.2	0
Refrigeration	19.0	19.0	0
Ventilation	19.0	19.0	0
Heating	20.0	32.0	38
Cooling	3.4	7.5	55
Total	136.1	152.2	11
HVAC	42.4	58.5	28

In terms of final energy, the total savings are 11% comparing the new building with the CommONEnergy solutions with the new building with an air/water heat pump system instead of the new geothermal system. If we only look at the HVAC, which is the system affected by the CommONEnergy solution, the savings are around 28%. Due to the improvement in the performance of the generation system from COP=3 and EER=2.5 of the old system to COP=4.8 and EER=5.6 of the new geothermal system the savings in heating are 38% and the savings in cooling are 55%.

Primary energy

Figure 34 and Table 33 report the final energy demand of the retrofitted building with the multifunctional façade controlled by the iBEMS and the HVAC system with geothermal heat pumps and the final energy demand of the retrofitted building with the multifunctional façade but without the geothermal heat pump.

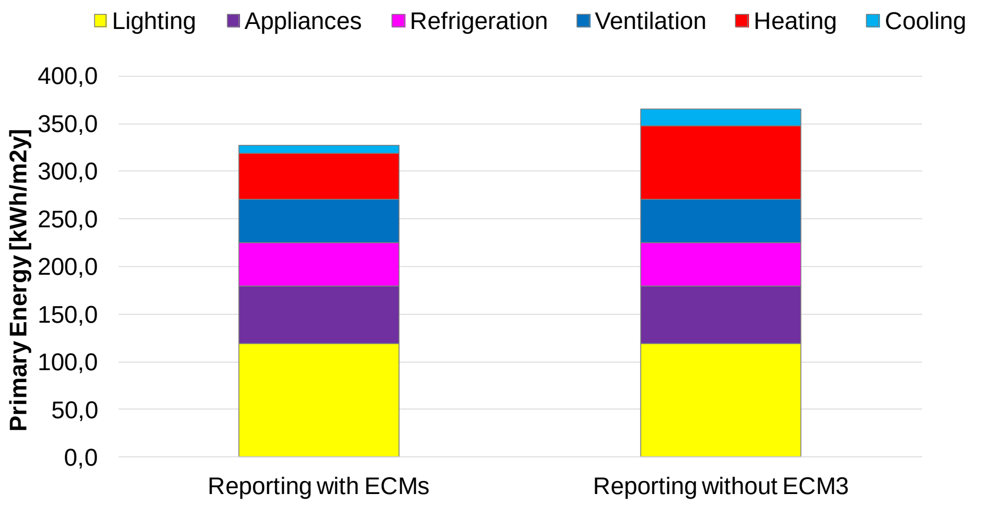


Figure 34. Primary energy new market with ECMs vs new market without ECM3

Table 33. Primary energy new market with ECMs vs new market without ECM3

	New market with ECM1+ECM2+ECM3 [kWh/m²y]	New market with ECM1+ECM2 [kWh/m²y]	Savings [%]
Lighting	118.8	118.8	0
Appliances	60.5	60.5	0
Refrigeration	45.6	45.6	0
Ventilation	45.8	45.8	0
Heating	48.1	76.9	37
Cooling	8.1	18.1	55
Total	326.9	365.7	11
HVAC	102	140.8	28

In terms of primary energy, the total savings are 11% comparing the new building with the CommONEnergy solutions with the new building with an air/water heat pump system instead of the new geothermal system. If we only look at the HVAC, which is the system affected by the CommONEnergy solution, the savings are around 28%. Due to the improvement in the performance of the generator system from COP=3 and EER=2.5 of the old system to COP=4.8 and EER=5.6 of the new geothermal system the savings in heating are 37% and the savings in cooling are 55%.

3.5. Summary of results in Mercado del Val

The building has only one energy carrier which is electricity. Therefore, there are only savings in terms of electricity.

For the whole building comparison (old market with new market with ECMs), the electrical savings are due to HVAC system, lighting, appliances and refrigeration.

The savings are assessed according to different approaches. Here below, we summarize the simulation model and the methods used for energy savings estimation:

- HVAC savings estimated by means of simulations of the old building based on the energy audit and the estimated COP/EER for the old system (manufacturer technical sheets) and calibrated simulations of the new building (including CommONEnergy solutions) and the real values of COP/EER of the new geothermal heat pump system (monitoring system).
- Lighting savings: Lighting consumption in the old building is estimated based on energy audit whereas lighting consumption in the new building is estimated based on real information from the project.
- Appliances savings: Appliances consumption in the old building is estimated based on energy audit, whereas appliances consumption in the new building is estimated based on real information from the project.
- Refrigeration savings: Refrigeration consumption in the old building is estimated based on energy audit, whereas refrigeration consumption in the new building is estimated based on real information from the project.

The renewable energy production is the one provided by the geothermal heat pump systems installed in the new building to cover all the heating and cooling needs, DHW included. The old building did not have any renewable system installed.

Table 34. Mercado del Val results summary: energy savings of the whole building retrofit.

	Electrical savings [kWh/m²/y]	Renewable energy production [kWh/m²/y]	Primary energy savings [kWh/m²/y]	CO2 emissions avoided [kg/m²/y]	Cost avoidance [€/ m² / year]
Before retrofit	541.1	0	1,300.2	193	72.51
After retrofit	136.1	114.8	327.1	48	18.24
Savings	405	114.8	973.1	145	54.27 /7.42

As can be seen in Table 34, if we compare the building after retrofit with the CommONEnergy solutions with the building before retrofit, we reach an electrical savings of around 75% in terms of final and primary energy. The cost avoidance and the CO_2 emissions avoided are proportional to the energy savings so 75% of savings in both are achieved. For the renewable energy production, in the building after retrofit all the heating, cooling and DHW demand is covered by RES (New geothermal heat pump system). So this means that the potential of improvement of the old market was very high due to their decadent status.

For the individual ECMs implemented in the new building, the approach to calculate the electrical savings is different. In this case we need to compare the new building with and without each ECM individually. In this case we can assume only savings in terms of HVAC, as the lighting, appliances and refrigeration could be assumed remains unchanged. For these evaluations, individual simulations taking into account each ECM has been developed.

Table 35. Summary results of ECMs

Energy Conservation Measure (ECM)		**Electrical savings HVAC [kWh/m²/y]**	**CO_2 emissions avoided HVAC [kg/m²/y]**	**Cost avoidance HVAC [€/m²/y] / Simple payback [y]**
ECM1 + ECM2	New building without ECM1 + ECM2	57.1	20.4	7.65
	New building with ECM1 + ECM2	42.4	15.1	5.68
	Savings	14.7	5.3	1.97
ECM3	New building without ECM3	58.5	20.9	7.83
	New building with ECM1+ECM2+ECM3	42.4	15.1	5.68
	Savings	16.1	5.8	2.16
All ECMs	New building without ECM1+ECM2+ECM3	74.1	26.5	9.93
	New building with ECM1+ECM2+ECM3	42.4	15.1	5.68
	Savings	31.7	11.4	4.25

As summary of the evaluation of the individual ECMs we can say that it is difficult to obtain big savings if we take as base case a new building, as the potential of improvement it is much reduced (good insulation, high efficiencies of the systems, good characteristics of the enclosures, etc.) compared to the old one. Anyway with the inclusion of the CommONEnergy solutions (multifunctional façade + iBEMS) instead of the ones proposed in the original project, is possible to achieve energy savings in HVAC around 26%.

4. Coop Canaletto (Italian demo case)

4.1. Retrofitting project description

Coop Canaletto (Figure 35) is a small supermarket of ca. 1200 m^2 selling area, located in a residential area close to Modena's centre, underwent renovation during the summer 2016, before reopening on September 15th 2016.

Figure 35. Coop Canaletto democase before (left) and after (right) the retrofit intervention.

The supermarket is managed by COOP Alleanza 3.0, while the retrofitting process was supported by INRES (for study, design and implementation) together with the CommON*Energy* partners, who suggested and implemented solutions and technologies. In the past couple of years, this neighbourhood experienced a social degradation, which encouraged the city of Modena to define a project requalifying this area, both from a social and functional point of view. The supermarket's retrofitting was therefore included in the overall neighbourhood requalification. The supermarket is completed with a para-pharmacy of 76 m^2 and a bar with an ice-cream shop of 67 m^2, participating to reviving the R-Nord area.

The innovative solutions developed within CommONEnergy and applied to this democase include:

- Integrated solutions for HVAC and refrigeration;
- General Retail Lighting (GRL) in galleries;
- Integrated building energy management system (IBEMS);
- Smart coatings;
- Linear air diffusers to prevent mist formation over refrigeration cabinets' doors.

Other solutions, integrated in the original project thanks to the CommONEnergy partners' support, are:

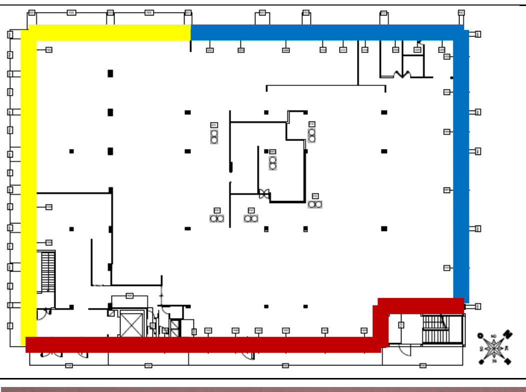
- Solar tubes over the food preparation area in the supermarket;
- Envelope insulation and air tightness improvement;
- Replacement of refrigeration cabinets;
- Improvement of the AHU efficiency by adding heat recovery and free cooling options;
- Replacement of the existing generation system (boiler+heat pump) with heat pumps.

4.2. Energy Conservation Measures (ECMs) implemented

Coop Canaletto is an old small size supermarket that needs an overall restyling. Therefore, it is cost-effective to apply energy conservation measures also at building envelope level. Due to the small size of the supermarket, refrigeration in Coop Canaletto is responsible for over 50% of the overall energy consumption [8]. Therefore, the solution set is focused on HVAC and refrigeration plant integration. Because of the small size of the supermarket, recovered waste heat can significantly contribute to reduce the supermarket energy use for heating if combined to other energy conservation measures (i.e. closed refrigeration cabinets, envelope insulation).

ECM1: Envelope retrofitting

External walls are insulated partly on inner side with 7 cm of PIR insulation (Uwall = 0.29 W/m^2 K), partly on outside with 10cm of PIR insulation (Uwall = 0.275). The old glazed facade facing the outside parking area and the wall facing the gallery are replaced with a better performing glazed façade. The new façade has an aluminium frame with thermal break (Uf= 0.9 W/m^{2}K), Ug = 1 W/m^{2}K , g-value= 0.6.



external insulation with 10 cm PIR (3cm PIR over columns)
internal insulation with 7 cm PIR
glazed façade (Uw = 1.8 W/m^{2}K)

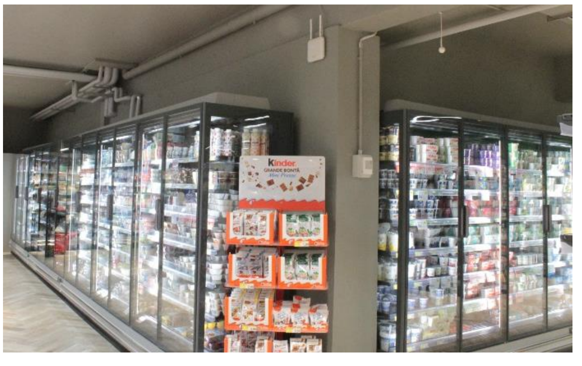
Figure 36. Glazed façade towards gallery after retrofit.

Figure 37. North-east facade after retrofit.

ECM2: Advanced lighting concept in the supermarket

12 light tubes are installed over the food preparation area providing the daylight level required by local building regulation. Advanced artificial lighting controls dimmerize the lamps depending on daylighting level.

ECM3: Replacement of refrigeration cabinets	
 *Figure 38. New refrigeration cabinets in the food store.*	Refrigeration cabinets (76 m of cabinets) are replaced by new ones with closed doors and higher energy efficiency. The temperature distribution between cabinets' corridors and the rest of the supermarket is more uniform, improving thermal comfort.

ECM4: Air diffusers on cabinets	
 *Figure 39. Air diffusers installed on the ceiling.*	Air is distributed through linear air diffusers to prevent mist formation on cabinets' doors and reduce electricity consumption of resistances.

ECM5: HVAC efficiency

The overall efficiency of the existing HVAC systems is improved by:

- replacing the existing generation system (boiler + heat pump) with the heat pump only for the heating and cooling production and an additional heat pump for the DHW preparation;
- installing a heat recovery section in the already existing AHU (heat exchanger plus supply and exhaust fan) to pre-treat the supply air;
- using mechanical free-cooling during daytime and night-time to reduce cooling consumption.

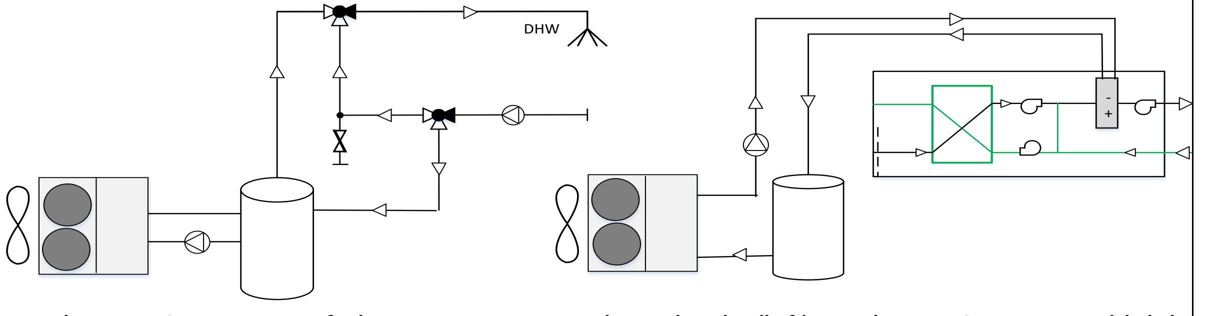


Figure 40. Layout of the DHW preparation circuit (left) and HVAC system (right) composed by a heat pump that serves an AHU with heat recovery, recirculation and fan for the free cooling mode.

ECM6: HVAC + R coupling

The central refrigeration unit is replaced with a new one using CO_2 as refrigerated fluid.

Waste heat from the refrigeration circuit is firstly used for the hot water preparation (higher temperatures) and then for post-heating (lower temperatures) during summer-time or space heating during winter time. In case of exceeded heat, a gas cooler is activated.

To improve the refrigeration system performance, part of the cooling load of the HVAC system can be used for the sub-cooling. Refrigeration could be used as cooling back-up during summer-time.

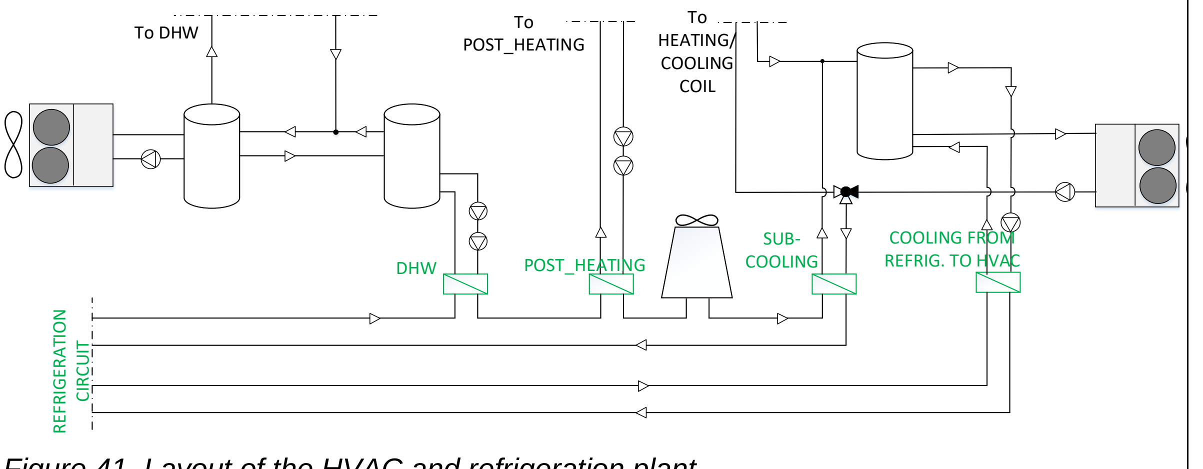


Figure 41. Layout of the HVAC and refrigeration plant.

ECM7: General Retail Lighting (GRL) in galleries

Figure 42. Gallery at Coop Canaletto.

Figure 43. Ground floor plan with gallery lighting zones.

General Retail Lighting (GRL) is installed in the galleries reducing the installed power density to 6 W/m². Zonal lighting concept reduces ambient lighting, accentuates zones with higher intensity and maintains the perceived brightness impression. Visual comfort and perception are managed to bring indoor lighting condition closer to outside natural situation.

ECM8: iBEMS

The overall system is managed by the iBEMS (intelligent Building Energy Management System) that manage the switching (on and off) of the diverse equipment depending on the inlet and outlet conditions.

The iBEMS enables:

- to implement advanced control strategies (i.e. free-cooling, night purge ventilation strategies);
- to monitor energy and comfort;
- to optimize the integration between HVAC and refrigeration system;
- to quantify and verify the energy savings achieved with the implementation of CommONEnergy solutions.

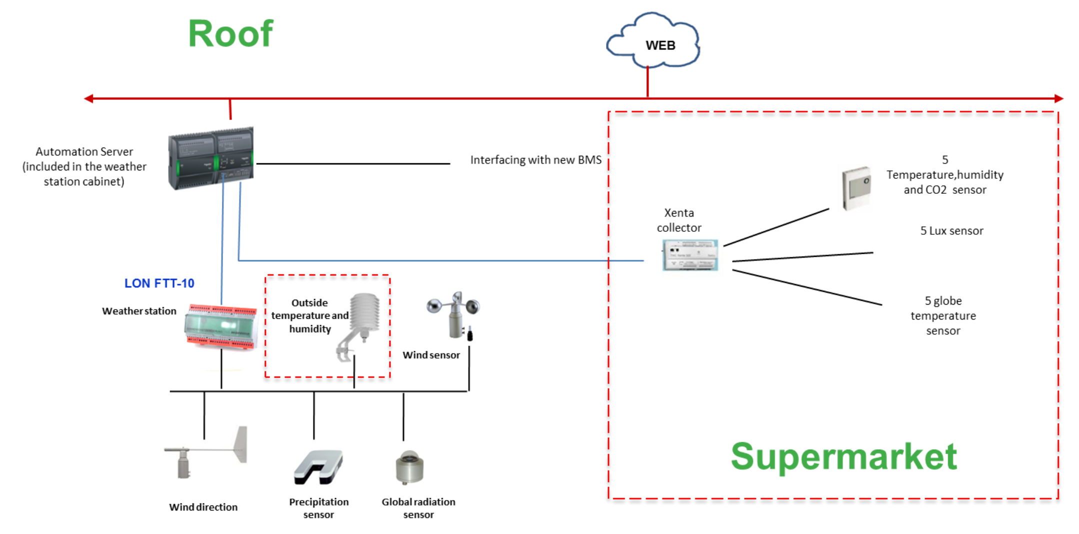


Figure 44. iBEMS architecture.

ECM9: Smart coatings	
 *Figure 45. Roof painted using smart coatings.*	The roof is painted using smart coatings with new multi-functional formulation that combines the following features: • Thermal behaviour enhancement • Anti-bacterial/anti-molding • Self-cleaning/VOC elimination • hydrophilicity

4.3. Assessment of overall energy performance in Coop Canaletto

The overall energy performance of the retrofitted supermarket in Coop Canaletto and the CommONEnergy solutions applied was evaluated through monitoring. All the renovation projects are divided into three timing periods: baseline, the period before the intervention, ECMs implementation, the retrofit intervention, and the reporting period, that represents the post-retrofit period. In the reporting period, the improvements provided by the ECMs are evaluated.

4.3.1. Baseline period

The baseline period is the period before June 2016 and the starting of the refurbishment works. Baseline period data represents the building before the retrofit intervention. Detailed information about the status of the building before retrofit was collected during energy audit reported in Deliverable 6.3. The renovated supermarket and gallery opened in September 2016. The installation of the iBEMS and the commissioning phase were first completed in February 2017 and the monitoring data acquisition started on March 2017. Figure 46 shows the timeline of intervention over the project duration.

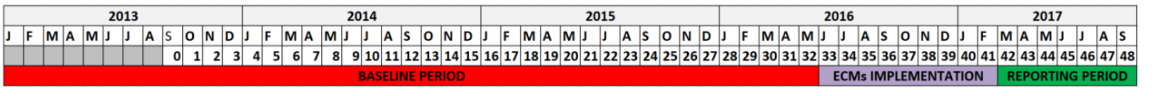


Figure 46. Timeline of the retrofit intervention

The graph in Figure 47 reports the statistics about the electricity consumption of the whole supermarket between 2007 and 2014, reported also in Table 36. The simulation model was calibrated using the monthly electricity consumption measured in 2013 since weather data were also available for this year. Table 37 reports measured data about gas consumption in 2009-2014. After the retrofit, all heating and DHW demand is provided by the two heat pumps and there is no gas consumption.

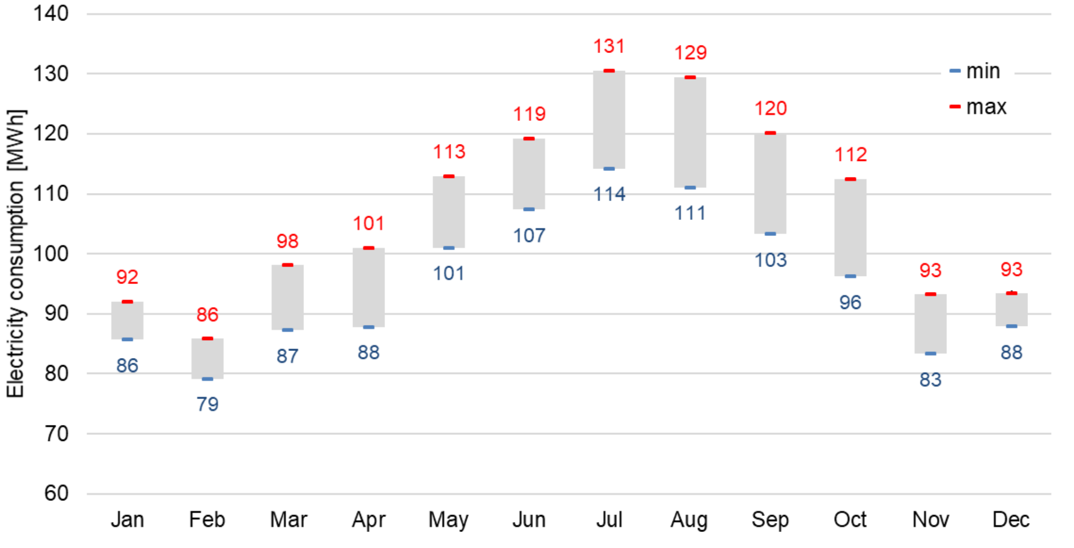


Figure 47. Statistics about measured monthly electricity consumption of the whole supermarket between 2007 and 2014.

Table 36. Monthly electricity consumption [MWh] in 2007-2014.

	2007	2008	2009	2010	2011	2012	2013	2014
Jan	86	87	90	88	92	90	91	90
Feb	79	82	84	84	83	86	85	81
Mar	91	87	93	95	94	98	97	96
Apr	90	88	94	95	101	92	94	93
May	105	101	111	108	113	107	105	102

Jun	111	112	112	116	117	119	107	108
Jul	115	131	123	130	122	125	123	114
Aug	114	129	129	122	126	124	119	111
Sep	103	112	117	109	120	116	109	105
Oct	96	107	104	99	101	112	107	102
Nov	83	88	88	90	91	93	89	91
Dec	88	93	93	93	93	92	90	93
Tot	1162	1217	1238	1230	1254	1254	1216	1187

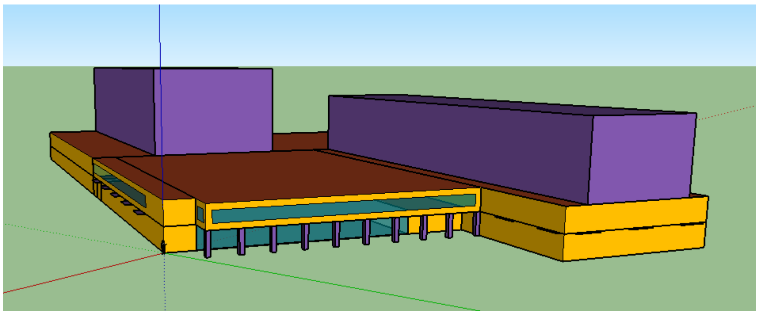
Table 37. Monthly gas consumption [m³] in 2009-2014

	2009	2010	2011	2012	2013	2014
Jan	5542	3213	3998	2911	1769	1480
Feb	3319	3084	2164	2904	1628	1221
Mar	1335	1995	2000	253	1497	1010
Apr	0	0	182	0	291	12
May	0	0	0	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	0	0	0	1	0	0
Oct	0	2	170	0	0	0
Nov	0	362	1310	467	176	0
Dic	1808	3071	2125	1493	1320	861
Tot	12004	11727	11949	8029	6681	4584

Since only aggregated data about electricity consumption before retrofit were available, we developed a building energy simulation model of the supermarket within the Integrative Modelling Environment (Deliverable 4.1) in order to analyse the energy performance of the building system (lighting, HVAC system, refrigeration system, envelope) before the retrofit. The model was validated against the measured data available for 2013, since weather data were available for 2013 only (Deliverable 5.1). Table 38 reports the input data set in the baseline model.

Table 38. Input data summary for the baseline simulation model

General data	
Gross floor area [m²]	1224

Gross Leasable Area [m^2]		1102
Food store vending area [m^2]		1224
Tenants vending area external to supermarket area [m^2]		1900[6]
Common areas and galleries [m^2]		521[7]
Number of opening hours per day [h/d]		12
Number of opening days per week [d/w]		7
Number of closing days per year [d/y]		6
Thermal zone model		
	Number of thermal zones	2
	First floor height [m]	3.16
	Second floor height [m]	3.16
	Zone typology	Zone group area [m^2]
	Food selling	1102
	Food preparation	122
Building envelope		
Opaque envelope components	U-value [W/m^2K]	Solar absorptance [-]
Exterior walls	1.84	0.6
Adjacent walls	2.47	0.6
Exterior roof	1.64	0.6
Ceiling/interior floors	1.51	0.6
Ground floor	1.73	0.6
Glazed envelope components	Ug [W/m^2K]	g-value [-]
Exterior window	1.4	0.622
Building loads and setpoints		
Lighting [W/m^2]		36
Appliances [W/m^2]		10
Heating set point temperature [ºC]		20

[6] these zones are not included in the model

[7] these zones are not included in the model

Heating setback temperature [°C]	15
Cooling set point temperature [ºC]	24
Ventilation rates [1/hr]	1.3 - 2
Infiltration rates [1/hr]	0.5
Active systems	
The supermarket area, both selling area and preparation area, is fully-air conditioned. The air-handling unit (AHU) before the renovation was equipped with a mixed-use battery connected to a heat pump and with a heating battery connected to a methane boiler used as back-up system during winter period. The heat pump covers both heating and cooling demand; final energy is calculated by assuming a COP of 2.36, which takes into account control, distribution and emission losses. The methane boiler is assumed to have a global efficiency (generation, distribution and emission) of 0.8. The two generation devices (heat pump and boiler) work alternatively during winter-time depending on a control based on the outside temperature (if Tout < 4 °C then heat pump is switched-off and boiler covers the entire heating demand; otherwise, the heat pump is switched-on). In summer, the heat pump provides the required cooling power. The AHU works in a constant air-flow rate mode during opening hours; no heat recovery is considered, while 80% of the exhaust air is recirculated. A specific fan power of 0.7 Wh/m³ is considered to estimate the electricity consumption for ventilation. The refrigeration system consists in the refrigeration circuit and terminal units (cabinets/cold rooms). There are two separated plants for refrigeration, one for low temperature (LT) and one for medium temperature (MT) cabinets. Both plants use R404a as refrigerant and air condensers.	

4.3.2. Meter specifications and monitoring

A large number of sensors were installed in the building with control and evaluation purposes, as well as a weather station to record outdoor temperature, relative humidity, solar radiation, wind speed and direction.

Figure 48 represents the energy monitoring layout for Coop Canaletto democase. The signals collected in the building are being saved in the iBEMS.

The monitoring system includes:

- Thermal energy counters.
  - H1: Thermal meter heat pump for DHW.
  - H2: Thermal meter for heat recovery from refrigeration.
  - H3: Thermal/Cooling meter for UTA/Fancoils.
  - H4: Cooling meter for sub-cooling in refrigeration.
- Electrical counters metering.
  - E1: Power meter supermarket – total.
  - E2: Light energy consumption galleries.
  - E3: Electrical meter for the Heat Pump (HVAC).
  - E4: Electrical meter for the Heat Pump (DHW).
  - E5: Electrical meters for the refrigeration system.
  - E6: Light energy consumption Supermarket (selling area).
  - E7: Electrical meter for the AHU.

The monitored data were used to calibrate the building simulation model of Coop Canaletto post retrofit intervention and to measure directly the energy consumption of some of the retrofit solutions applied as well as of the overall retrofit intervention.

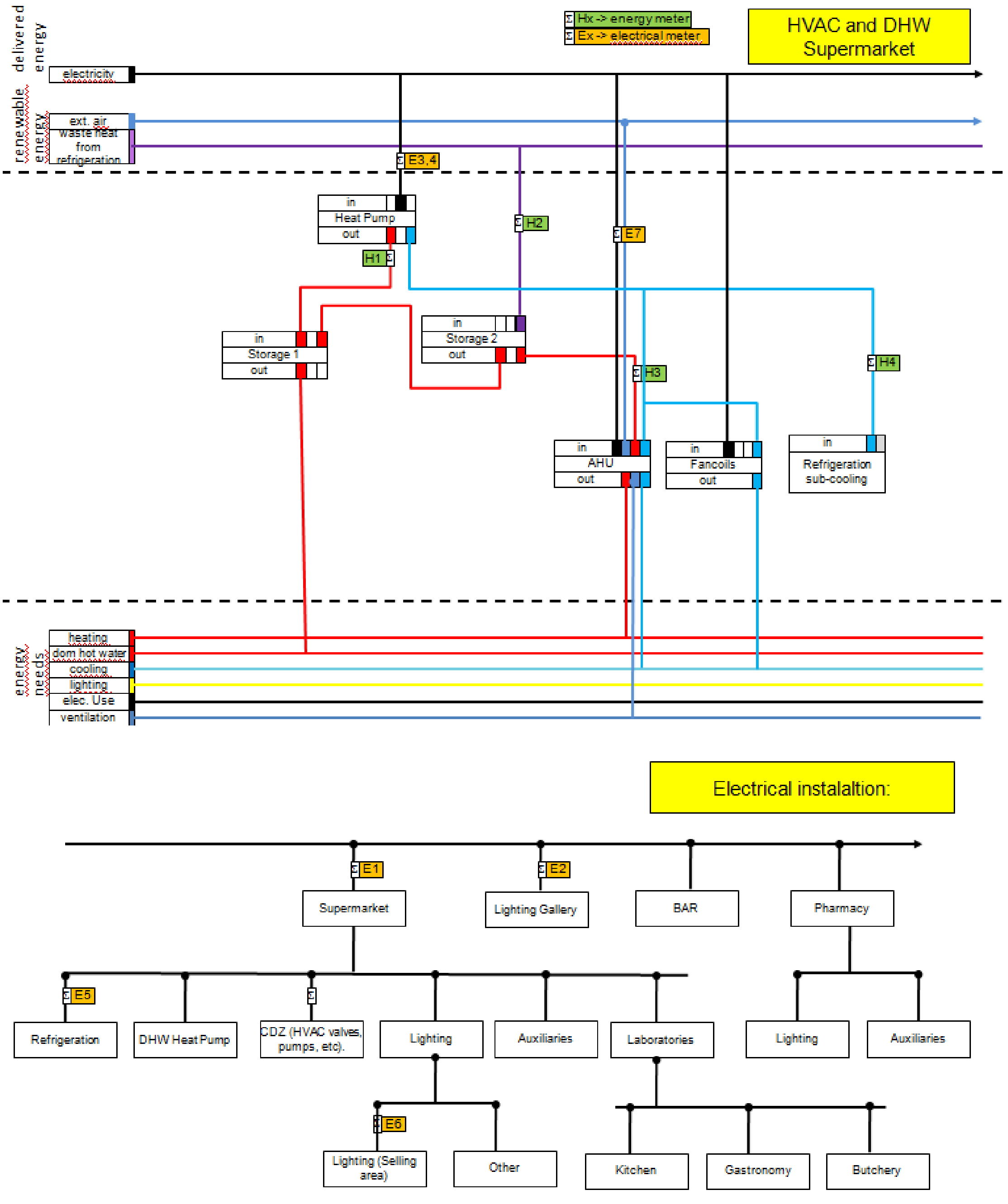


Figure 48. Monitoring layout of Coop Canaletto democase.

4.3.3. Reporting period

Data acquisition about the Coop Canaletto demo site started on March 2017.

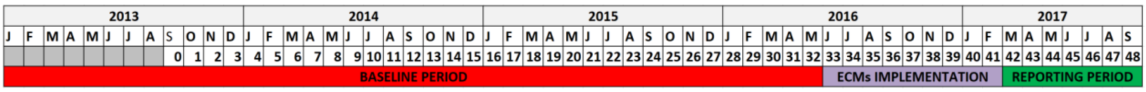


Figure 49. Timeline of the retrofit intervention

Table 39 and Figure 50 report the monthly measured electricity consumption from March to September 2017. Circa 40% of the overall electricity consumption of the supermarket is now due to laboratories and auxiliaries, another 40% due to refrigeration, 7% due to lighting, 10% due to the AHU and the rest 3% for the heat pumps.

Table 39. Measured electricity consumption [MWh] of the Coop Canaletto supermarket in 2017.

	Total (E1)	Heat Pump for HVAC (E3)	Heat Pump for DHW (E4)	Refrigeration (E5)	Lighting (E6)	AHU (E7)	Others
March	58	2.3	0.3	20	-	5.2	26.9
April	54	2.1	0.4	20	4.8	5.7	21.0
May	59	2.1	0.3	23	5.1	6.3	22.7
June	70	2.3	0.2	27	5.6	6.5	28.5
July	73	2.0	0.2	28	5.1	6.7	31.3
August	74	2.2	0.1	27	5.1	6.8	32.3
September	61	2.0	0.3	23	5.1	5.9	24.6

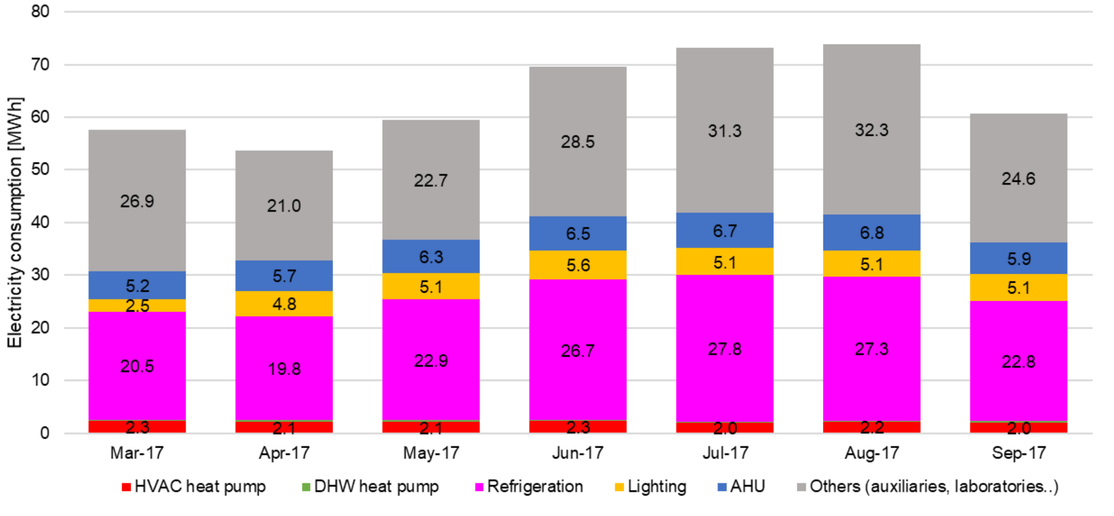


Figure 50. Measured electricity consumption of the Coop Canaletto supermarket in 2017.

If compared to the monthly electricity consumption statistics before the retrofit (Figure 51), the electricity consumption after retrofit is 40% less over the period March-September 2017. Since electricity consumption data also depends on weather conditions over the year, data should be normalized depending on weather conditions. No weather data are available before the retrofit intervention, therefore data normalization could not be performed.

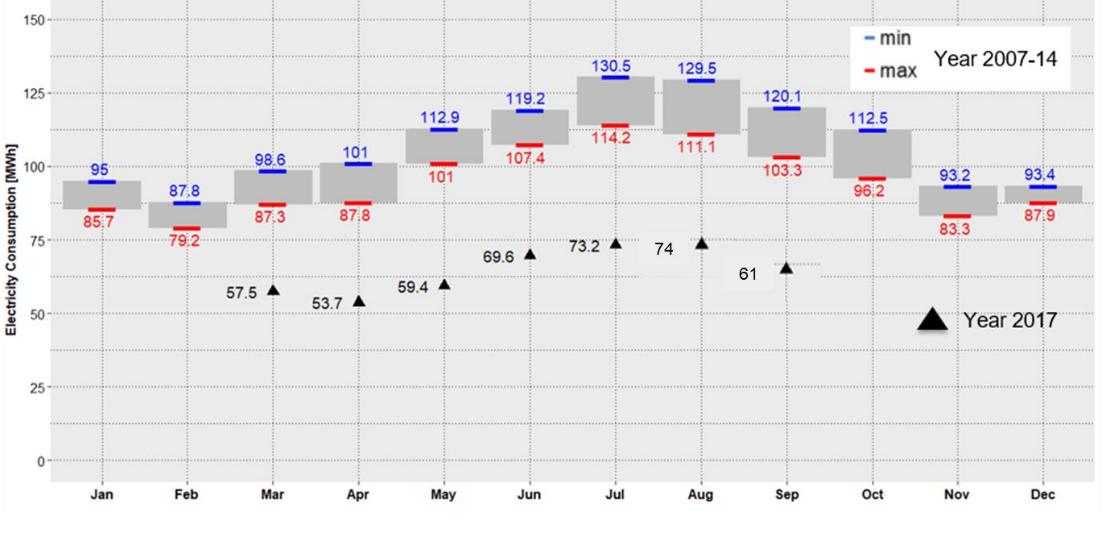


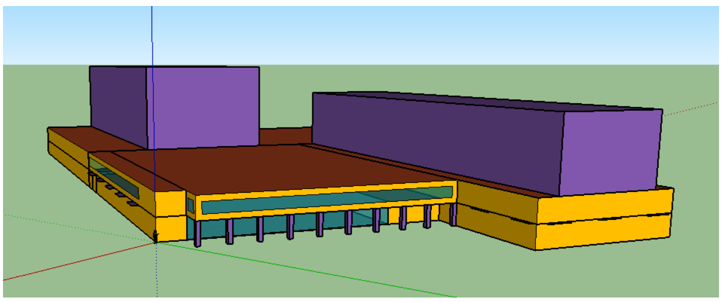
Figure 51. Measured electricity consumption before (2007-14) and after retrofit (2017).

4.3.4. Analysis procedure to assess the overall energy savings

Building energy simulation models, if properly calibrated, allow for the evaluation of the energy savings over the whole year and for a fair comparison between the building post and after retrofit.

Measured data during the reporting period were used to assess the input data set of the simulation model of the building after retrofit intervention and to perform model calibration. Table 40 reports the input data set in the simulation model after retrofit intervention.

Table 40. Input data summary for the simulation model of the building after retrofit intervention.

General data		
Gross floor area [m²]		1224
Gross Leasable Area [m²]		1102
Food store vending area [m²]		1224
Tenants vending area external to supermarket area [m²]		1900[8]
Common areas and galleries [m²]		521[9]
Number of opening hours per day [h/d]		12
Number of opening days per week [d/w]		7
Number of closing days per year [d/y]		6
Thermal zone model		
	Number of thermal zones	2
	First floor height [m]	3.16
	Second floor height [m]	3.16
	Zone typology	Zone group area [m²]
	Food selling	1102
	Food preparation	122
Building envelope		
Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]
Exterior walls with exterior insulation	0.275	0.6
Exterior walls with interior insulation	0.29	0.6
Ceiling/interior floors	0.93	
Ground floor	1.73	
Glazed envelope components	Ug [W/m²K]	g-value [-]
Exterior facade	1.8	0.6

[8] these zones are not included in the model

[9] these zones are not included in the model

Building loads and setpoints	
Lighting [W/m²]	9.6
Appliances [W/m²]	10
Heating set point temperature [ºC]	22
Cooling set point temperature [ºC]	26
Ventilation rates [1/hr]	
Infiltration rates [1/hr]	
Active systems	
Space heating and cooling is covered by an existing heat pump; during winter period, waste heat from the refrigeration system is used for covering part of the heating demand. Energy needs are covered by an AHU fed by the heat pump. During winter, a heat recovery pre-heats external air with exhaust air coming from the supermarket; during swing seasons and summer, the free-cooling mode allows using external air for naturally cooling the zone. A new heat pump is dedicated for the hot water preparation. Also for this use, waste heat from the refrigeration system is recovered for pre-heating tap water. The refrigeration system is a CO2 booster system used for the cold rooms and closed cabinets. The heat rejection of the system is partially done through the heat recovery with the HVAC system and the rest with a gas cooler. In case of availability from the heat pump used for the conditioning and high external temperatures, the surplus cooling can be used for sub-cooling the refrigeration circuit.	

Option D (simulations) of the IPMVP [1] is used to evaluate the energy savings of the whole building. The model of the building after retrofit is calibrated with the real data coming from the monitoring system from March 2017 to July 2017.

Data from onsite weather station are available from April 2017. Missing data about outdoor temperature, relative humidity and wind are replaced with data recorded by Arpa Emilia Romagna weather station in Modena city centre [9]. Missing radiation data has been downloaded from CAM Radiation Service **Error! Reference source not found.**.

In order to compare the energy performance of the building before and after the retrofit intervention, we set the same weather file in both models. The weather file used for the analysis is the Typical Meteorological Year (TMY), which derives from Meteonorm database [7] and is representative of the standard weather conditions in Modena.

The factors used to calculate primary energy, equivalent CO_2 emissions and cost are the followings:

Energy source	Price
Electricity	0.12 €/kWh
Gas	0.23 €/m³

Energy source	CO_2 emissions factor
Electricity	0.509 kg CO_2/kWh
Gas	0.241 kg CO_2/kWh

Energy source	Primary energy factor
Electricity	2.046 kWh_{pe}/kWh_{fe}
Gas	1.114 kWh_{pe}/Smc

4.3.5. Energy savings results (thermal and electrical)

In this section we report the overall predicted energy performance of the Coop Canaletto supermarket before and after the retrofit intervention. The gallery was included only with the lighting consumption as they are part of the CommONEnergy solutions.

Thermal energy demand

Table 41 and Table 42 report the thermal energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Table 41. Predicted heating and cooling demand of the supermarket before the retrofit.

Month	Heating demand		Cooling demand	
	kWh	kWh/m²	kWh	kWh/m²
January	13450	11	0	0
February	15648	13	0	0
March	6987	6	0	0
April	477	0	303	0
May	0	0	4384	4
June	0	0	11054	9
July	0	0	14554	12
August	0	0	13909	11
September	0	0	6011	5
October	461	0	1625	1
November	7592	6	0	0
December	19561	16	0	0
TOTAL	51667	53	51839	43

Table 42. Predicted heating and cooling demand of the supermarket after the retrofit.

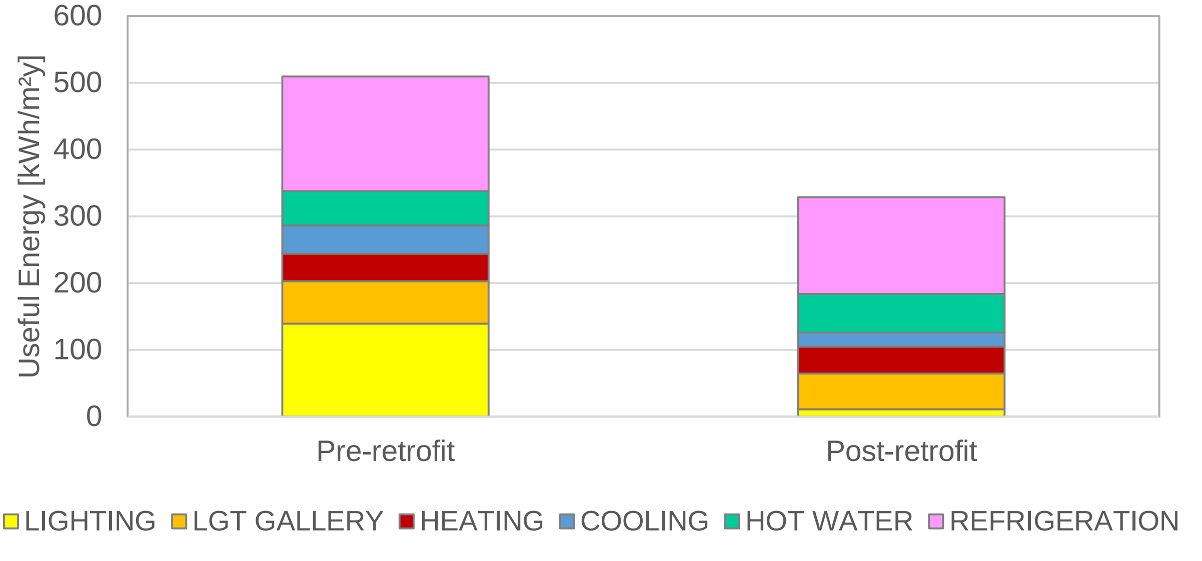
Month	Heating demand		Cooling demand	
	kWh	kWh/m²	kWh	kWh/m²
January	14408	12	0	0
February	11356	9	0	0

March	7018	6	0	0
April	732	1	65	0
May	128	0	796	1
June	0	0	5300	4
July	0	0	7651	6
August	0	0	7616	6
September	381	0	2078	2
October	1348	1	374	0
November	7188	6	0	0
December	13107	11	0	0
TOTAL	55665	46	23878	20

Before the retrofit, part of the heating demand was covered by a gas boiler. After the retrofit, all the heating/cooling/DHW demand is covered by two heat pumps.

Useful energy

Figure 52 reports the useful energy of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.



	Before retrofit [kWh/m²y]	After retrofit [kWh/m²y]	Savings [%]
Lighting	139.2	10.6	92.4%
Lighting Gallery	63.4	53.7	15.2%
Heating	41.4	40.0	3.5%

Cooling	42.4	21.1	50.1%
Hot Water preparation	51.3	58.1	-13.4%
Refrigeration	171.7	144.8	15.7%
Total	509.3	328.4	35.5%

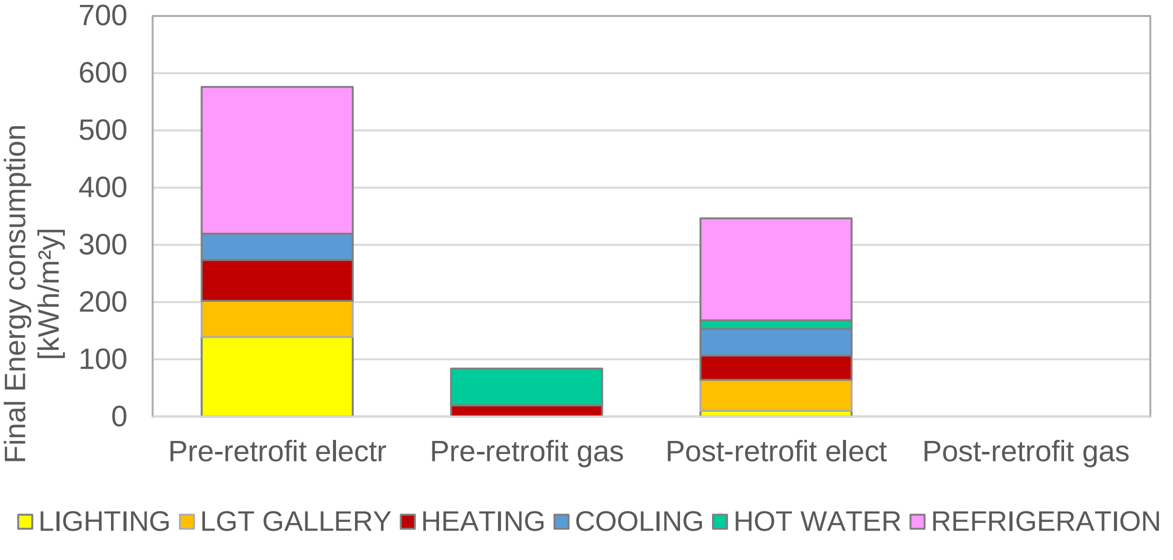
Figure 52. Useful energy before and after the retrofit intervention in Coop Canaletto supermarket

In terms of useful energy, the savings amount at 35.5% for the building after retrofit compared to the building before retrofit.

Final energy

Figure 53 reports the final energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Final energy demand is calculated modelling and simulating the existing heat pump for air conditioning and using a conversion factor of 0.8 for the boiler used during extreme conditions for air condition and for the hot water preparation.



	Before retrofit [kWh/m²y]	After retrofit [kWh/m²y]	Savings [%]
Lighting	139.2	10.6	92.4%
Lighting Gallery	63.4	53.7	15.2%
Heating (electricity)	71.1	42.8	39.8%
Heating (gas)	19.8	-	100%
Cooling	45.7	46.0	-0.7%

Hot Water preparation (elect)	-	15.2	-
Hot Water preparation (gas)	64.1	-	100%
Refrigeration	256.4	177.9	30.6%
Total Electricity	575.8	346.2	39.9
Total gas	83.9	-	100%

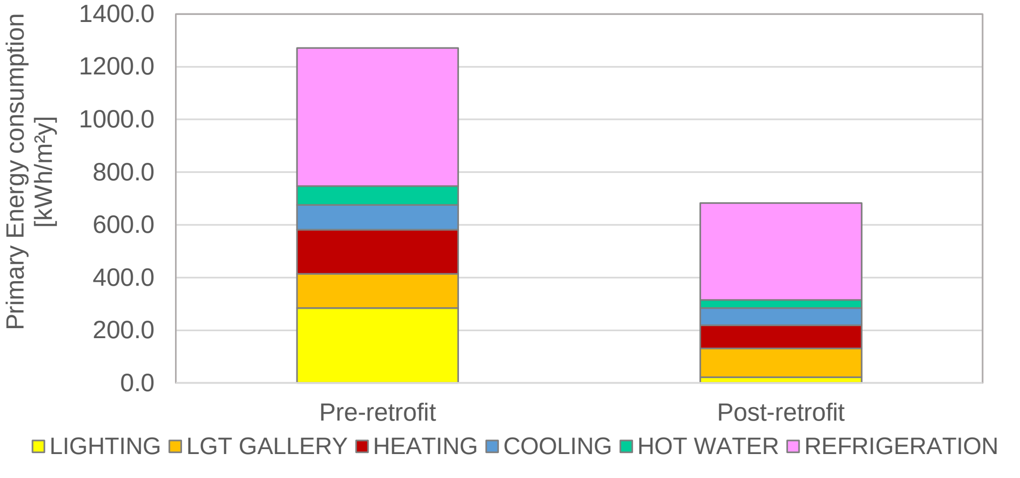
Figure 53. Final energy demand before and after the retrofit intervention in Coop Canaletto supermarket

In terms of final energy, the savings amount at 40% for the electricity only while the use of gas is completely eliminated for the building after retrofit compared to the building before retrofit.

Primary energy

Figure 54 reports the final energy demand of the building before and after the retrofit predicted by the calibrated building energy simulation models under the same standard weather conditions.

Primary energy demand is calculated using the conversion coefficients reported in par. 4.3.4.



	Before retrofit [kWh/m²y]	After retrofit [kWh/m²y]	Savings [%]
Lighting	284.7	21.6	92.4%
Appliances	129.7	110.0	15.2%
Refrigeration	167.6	87.6	47.8%
Ventilation	93.4	65.4	30.0%
Heating	71.4	31.0	56.6%
Cooling	524.6	366.8	30.1%
Total	1271.5	682.3	46.3%

Figure 54. Primary energy demand before and after the retrofit intervention in Coop Canaletto supermarket.

In terms of primary energy, the savings amount at 46% for the building after retrofit compared to the building before retrofit.

4.4. Assessment of energy savings, payback time and CO_2 emissions avoided in each ECM

Table 43 below summarizes all the procedures and performance indicators we applied to assess the energy savings of each energy conservation measure. The analysis procedures refer to the IPMVP (see ch. 2).

Table 43. Procedure used to assess the energy savings of each ECM in Coop Canaletto democase.

ECM ID	Description	IPMVP Option	Area	Performance indicator	Note	Interactive effects
1	Envelope retrofitting	D	whole supermarket	Heating and cooling need		
2	Advanced lighting concept in the supermarket	A	Selling area	Lighting electricity consumption	Baseline power uncertain, operating hours known	Heating and cooling need, refrigeration
3	Replacement of refrigeration cabinets	B	whole supermarket	Refrigeration electricity consumption		Heating and cooling need
4	Linear air diffusers	A	Cabinets' performance	Refrigeration electricity consumption	Linear air diffusers are installed over few refrigeration cabinets	
5	HVAC efficiency	D	whole supermarket	AHU electricity consumption	Consumption of 2 additional fans	
6	HVAC-R coupling	D	whole supermarket	Final energy for space heating, cooling and hot water; SCOP/SEER		Influenced by lighting and envelope measures
7	GRL in the galleries	A	Galleries	Lighting electricity consumption	Baseline power uncertain, operating hours known	
8	iBEMS	D	supermarket+gallery	Tot electricity consumption	Savings are accounted for the interaction of the systems	Interaction between HVAC & R, AHU & natural ventilation
9	Smart coatings	A	Gym roof	Internal surface temperature	Comparison between roof area with and w/o coatings	No significant effects on supermarket energy consumption

ECM1: Envelope retrofitting

Analysis procedure for calculating results

Savings due to envelope retrofitting cannot be directly measured. Therefore, we assessed the overall heating and cooling need of the supermarket with and without envelope insulation by means of building energy simulations. Simulations are performed over a whole reference year (Meteonorm weather file) and internal gains (lighting, refrigeration, appliances) are set equal to the status after retrofit in both cases.

The average Uvalue of the external walls and windows before the retrofit was estimated to be around 1.6 W/m²K and after the retrofit 0.6 W/m²K.

Energy savings, CO2 emissions avoided and simple payback

According to the above described procedure, the envelope retrofitting would allow to reduce by 6% the heating primary energy consumption and almost 3% for cooling.

ECM	Gas savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avo [€/m
ECM1	2.1	7.3	4.2	0.9

ECM2: Advanced lighting concept in the supermarket

Analysis procedure for calculating results

Savings due to the advanced lighting concept in the supermarket are determined by measuring the electricity consumption due to lighting in the selling area (power meter E6).

Hourly power values measured from April to September 2017 are post-processed to get the maximum lighting power intensity and to define the schedule over an average weekday (Mon-Sat) and on Sundays.

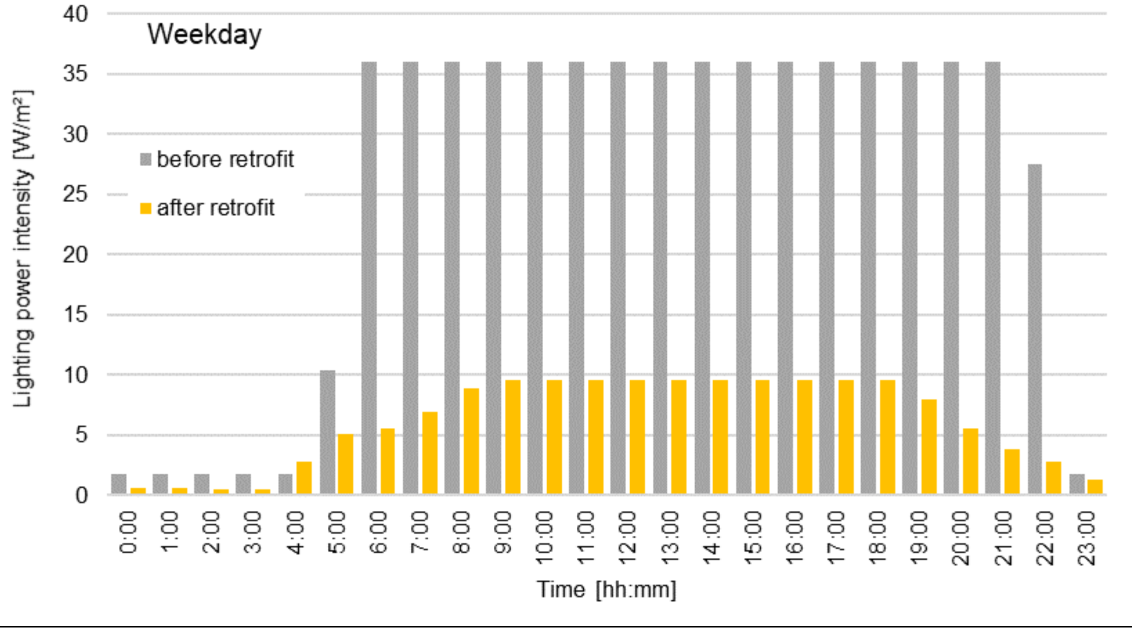


Figure 55. Average supermarket lighting power intensity after the retrofit over weekdays.

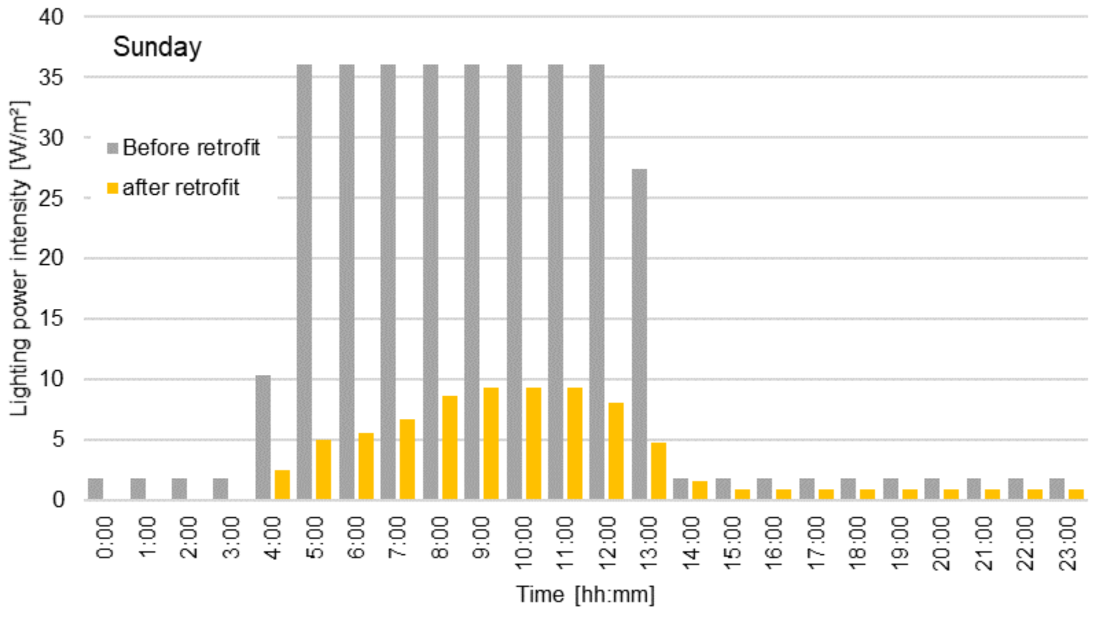


Figure 56. Average supermarket lighting power intensity after the retrofit over Sundays.

The overall energy consumption for supermarket lighting during the whole year is calculated by combining the measured values with estimates derived by the average lighting power intensity schedules.

Lighting power intensity before retrofit was estimated during the energy audit according to lamps number and typology. Lighting schedule before retrofit is derived through the model calibration process. The annual energy consumption for supermarket lighting before the retrofit is estimated by combining lighting power intensity and lighting schedule.

The energy savings evaluation ignores the effect on the thermal energy demand for building heating and cooling, which is affected by the lower internal gains due to lighting. The interactions between this solution and the building energy balance will be analysed by the building energy simulation model with all solutions integrated.

Table 44. Electricity consumption before (estimated) and after (measured) the retrofit over the period 01/04-30/09/2017

	Before retrofit	After retrofit
lighting power density [W/m²]	36	9.6
nr of working hours [hr]	4392	4392
Electricity consumption [kWh]	130534	30777

<u>Energy savings, CO2 emissions avoided and simple payback</u>

According to the above described data analysis procedure, the advanced lighting concept would allow to reduce by 76% the electricity consumption for lighting the selling and food preparation are of the supermarket.

The lighting power intensity before retrofit was 36 W/m² and, thanks to the new lighting concepts and LED lighting, it is reduced to 9.6 W/m². The reduction of lighting power intensity causes also a reduction of internal heat gains with consequent additional savings due to the lower cooling demand, which cannot be directly measured through this procedure.

Table 45. Electricity consumption before (estimated) and after (measured and estimated) the retrofit over the whole year

Lighting	Before retrofit	After retrofit
Electricity consumption [kWh/y]	258168	61153
Electricity consumption [kWh/m²-y]	211	50
Primary energy consumption [kWh_{pe}/m²-y]	432	102
Equivalent CO_2 emissions [tonCO_2]	131	31

ECM	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avoidance [€/m²/y]
ECM2	106.2	54.1	12.7

ECM3: Replacement of the refrigeration cabinets

Analysis procedure for calculating results

Savings due to the replacement of the refrigerated display cabinets with more efficient ones are determined by simulations as no monitoring data are available before retrofit. Neither the direct energy consumption (i.e. lighting, fans, defrost and anti-mist heaters) nor other useful data used to infer the indirect energy consumption related to the cooling load on the commercial refrigeration units are available from the monitoring data.

The developed mathematical model allows to adjust the performance of the refrigerated display cabinets at rated conditions taking into account the realistic and time-dependent working conditions in the supermarket (off-rated conditions). In particular, the influence of indoor air temperature and humidity on the sensible and latent fractions of the cooling load are considered as well as the different air infiltration in the refrigerated volume between open-fronted display cabinets or closed ones.

Energy savings, CO2 emissions avoided and simple payback

All the refrigeration display cabinets have been replaced by new generation ones with closed doors and higher energy efficiency.

A comparison of the cooling load of the two refrigeration supermarket layouts, that is the one of the refrigeration cabinets and cold rooms, has been carried out between the old supermarket and the new one installed with the retrofitting. The following figure shows the annual cooling load profiles of the old and new systems.

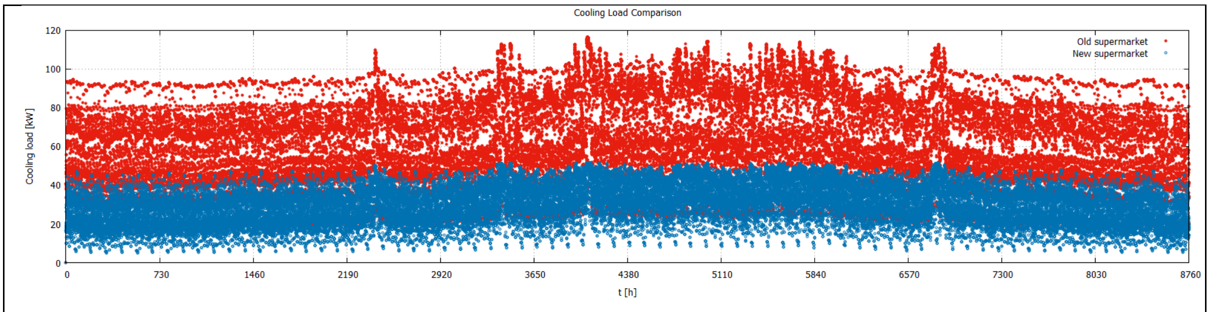


Figure 57. Year cooling load comparison between new and old refrigeration system.

It results that with the new installation the cooling load has considerably decreased, as well as the power consumption. This means that the refrigeration system with the new generation cabinets permits to save strong amounts of energy, around 50%.

The following table shows the total cooling energy of a whole year.

	Cooling Load [MJ]		Difference (Old – New)	Savings
	Old System	New System	[MJ]	[%]
Year	1974690	935770	1038920	-52.6

Considering the solution in the whole system, energy savings, CO2 emissions and Cost avoidance obtained with this solutions are reported in the following table.

ECM	Gas savings [kWh/m^2/year]	Electrical savings [kWh/m^2/year]	CO_2 emissions avoided [kg/m^2/year]	Cost avoidance [/ Simple payback
ECM3	10.3	110.5	58.7	13.5

ECM4: Linear air diffusers

<u>Analysis procedure for calculating results</u>

In the display zones of the food stores, usually located in open spaces, full-air HVAC or ducted fan-coil systems ensure the comfort conditions by means of forced air supplied through ceiling diffusers. The air flow is generally supplied from the ceiling. In order to prevent the mist formation on the doors of closed display cabinets reducing the use of electrical resistances, the air movement on the proximity of glass surfaces can be enhanced through the use and proper adjustment of specific air diffusers. The supply diffusers shape affects the air distribution and the surface temperature of the glazed doors of the display cabinets. The heat transfer coefficient on the external surfaces of the display cabinets may be enhanced with a suitable distribution of the air particularly with high mass flow rate. As a consequence of the analysis carried out it is on evidence that, for the LT display cabinet aisles, in absence of electric resistance heaters, HVAC or ducted fan-coils can prevent or significantly reduce the risk of mist formation on the cabinet doors only if equipped with linear ceiling diffusers. The velocity of the supplied airflow should be maintained relatively high to guarantee an adequate convective coefficient. The electric resistance heaters usually installed on the doors of vertical LT display cabinets have an electric power varying from 100W/m to 200W/m of display horizontal length and they can operate continuously during the opening time of the food store or their activation can be controlled according to the dew-point temperature of the ambient air. For example, in the simulated aisle the electric power installed for the prevention of mist formation can be higher than 2 kWel. If the air diffusion system completely removes the risk of mist formation the energy savings can be as reported in the following tables. The estimation is based on an efficiency of the national electric system equal to 0.45 and an efficiency of the dew-point control system equal to 2.0, meaning that the electric resistances controlled by the dew-point temperature operates half time. The daily open time is considered of 12 hours and 360 open days per year are assumed.

Table 46. Energy needs for demisting in LT cabinets per display unit length.

	Continuous operation		Dew-point temperature controlled	
power of electric resistances installed (W/m)	100	200	100	200
Daily (12h) electric energy needs (kWh/m)	1.20	2.40	0.60	1.20
Daily (12h) estimated primary energy needs (kWh/m)	2.67	5.34	1.33	2.67

Considering, as reference, an aisle like that simulated, with 2 arrays of cabinets, each 12 meter long the daily and yearly energy needs for the whole aisle are reported in Table 47.

Table 47. Daily and annual energy needs for demisting in a LT cabinets aisle.

	Continuous operation		Dew-point temperature controlled	
power of electric resistances installed (W/m)	100	200	100	200
Daily (12h) electric energy needs (kWh)	28.8	57.6	14.4	28.8
Daily (12h) estimated primary energy needs (kWh)	64.0	128.0	32.0	64,0
Yearly electric energy needs (kWh)	10368	20736	5184	10368
Yearly primary energy needs(kWh)	23040	46080	11520	23040

<u>Energy savings, CO2 emissions avoided and simple payback</u>

The electrical energy requirements for demisting resistances depends on ambient temperature and humidity conditions. In the case it is wanted to completely avoid mist formation, up to 50% energy saving on electricity demand for demisting can be achieved combining a suitable distribution of the supplied air with a control system of electrical resistances able to identify the beginning mist formation in an analogous way like in the operation control of radiant panels cooling rooms in summer period. The results presented in the previous sections show that all kind of air supply and HVAC systems, if adequately managed, allow the required comfort level (typically -0.5 < PMV < +0,5 and PPD < 10%) and thus no costs are considered related to the thermal comfort of customers.

The CO_2 emission avoided can be estimated simply multiplying the electrical energy saved (kWh_{el}) by the coefficient of conversion from electricity to CO_2. The only difficult that arises depends on the different coefficient to use for each EU Member and for each considered year of calculation, caused by different efficiencies in converting primary energy to electrical energy.

The use of properly designed air diffusers, to avoid the risk of mist formation, has very low additional cost if this decision is taken during the design phase, despite the additional effort needed at control level. The additional costs are strictly dependent on the refrigeration cabinets' layout which determines the choice of the air diffusers geometry, number and position. In an existing food store, the installation of new air diffusers can be convenient only if the HVAC system and/or on the internal part of the ceiling is subject to other refurbishment actions. Problems may arise during the life cycle of the system mainly because it needs an accurate maintenance of the diffusers to ensure that the supply air correctly flows over the cabinet doors and the control system operates correctly.

ECM5: HVAC efficiency

Analysis procedure for calculating results

The calibration process for the HVAC system involved only the summer period because of the monitoring data availability. In this period, the heat exchanger named “heating” in the above picture, did not working, consequently the calibrated circuit is the one within the red dashed line.

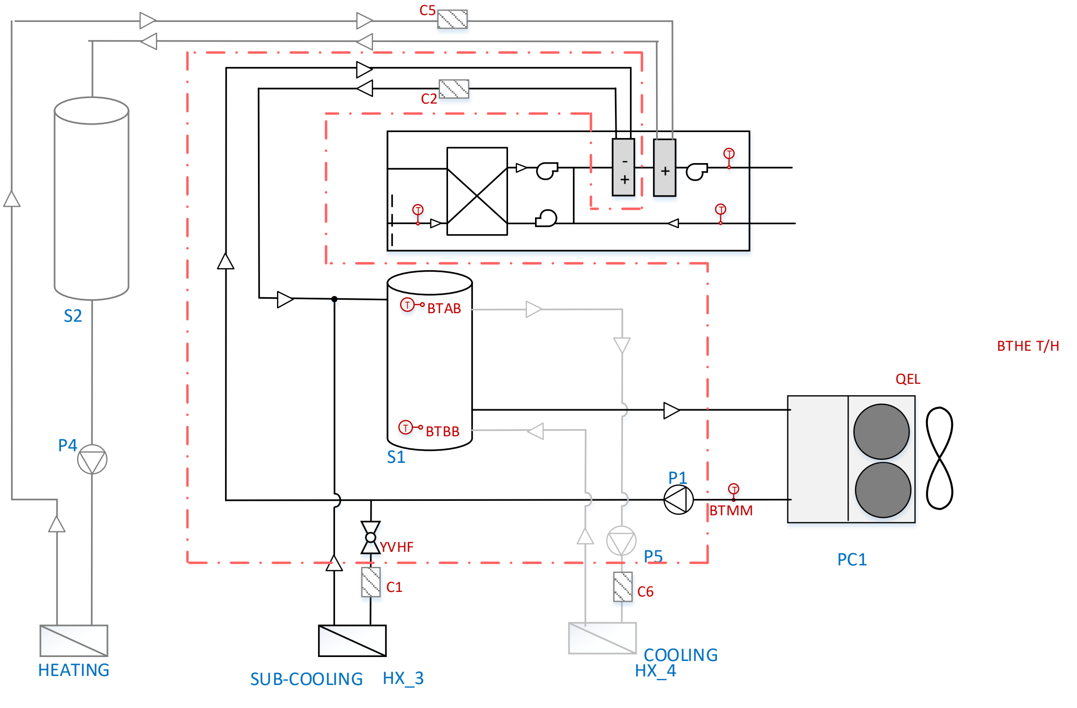


Figure 58. Layout of the HVAC system (right) composed by a heat pump that serves an AHU with heat recovery, recirculation and fan for the free cooling mode.

Due to the only-summer period data, the model is calibrated comparing the AHU consumption, supply air flows, supply air temperatures and exchanged heat to the air flow.

The calibration work showed a good agreement between the monitored and simulated supply air temperature (conditioned air through the cooling/heating coil of the AHU) ending with an error of 1% for the AHU electric consumption.

The analysis on the monitored data with simulation results showed an inconsistency in the heat pump electric consumption. Calculating the COP from monitoring, it results to be around 6.5 against 3.7 from simulations. Using a factor 2 for the measured electricity, the “new” COP is 3.24. This inconsistency will be verified with the energy manager of the supermarket.

Energy savings, CO2 emissions avoided and simple payback

The replacement of a boiler for the partial production of heating and the hot water preparation can bring relevant savings both in terms of energy and environmental indicators. Moreover, the new proposed HVAC system includes a heat recovery in the AHU for exploiting the internal exhaust air and the free cooling mode for blowing fresh external air directly into the supermarket.

While the first solution exploits the rejected heat of the internal air for pre-heating external air with any additional energy costs, the free cooling mode is based on the temperature difference between internal and external and works with higher fan speeds. As a consequence, the latter working mode has to be used only when the cooling potential is higher than the energy used for blowing air into the zone.

The coupling of heat pumps for space heating and cooling and for hot water preparation, together with a more efficient AHU reduces the primary energy used for heating of 20 % and for hot water preparation of 48%, while the exergy for space cooling increases of 9% due to the above mentioned effect of the free cooling

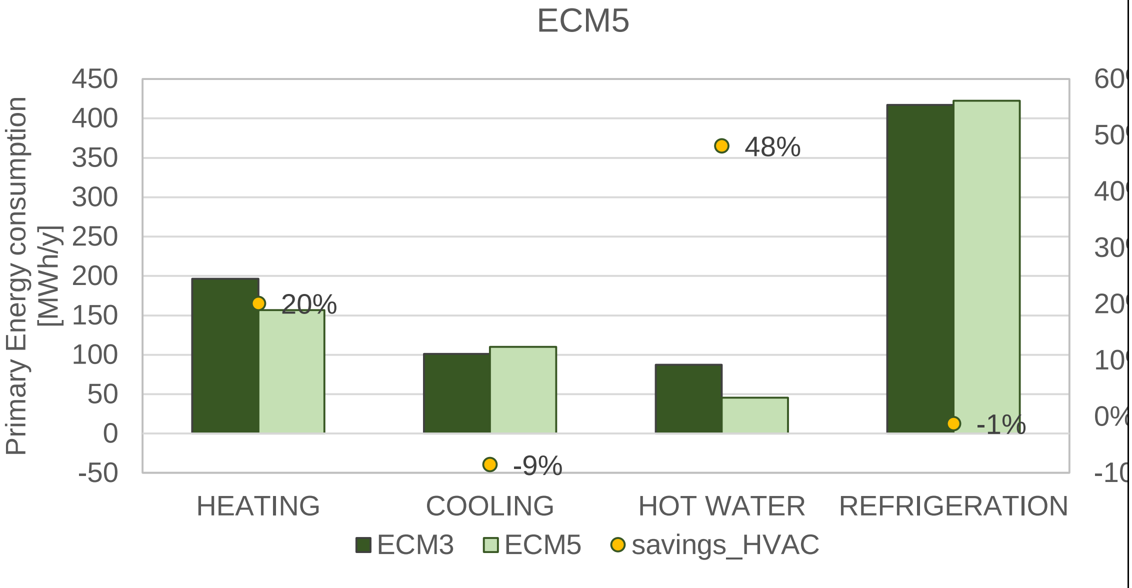


Figure 59. Primary energy consumption and energy savings of ECM3 compared to ECM5.

Despite this, the achieved savings with the ECM5 with respect to the case before retrofit are here reported.

ECM	Gas savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avoidance [€/m²/y]
ECM5	78.2	-15.5	11.0	-0.2

ECM6: HVAC + R coupling

Analysis procedure for calculating results

The HVAC system is composed by different circuits that interact each other: refrigeration system (compressor unit and cabinets/cold rooms), DHW preparation, space conditioning. For calculating the energy savings that each intervention brings to the overall system, initially each circuit has been modelled and calibrated separately. In a second step, all the parts of the HVAC+R system are gathered and the total savings calculated.

The analysed circuits with the implemented solution are:

- Replacement of traditional refrigeration circuit with a CO2 transcritical cycle; replacement of cold cabinets and cold rooms with new ones;
- Use of waste heat from the refrigeration to the hot water preparation circuit.

For the two cases, a numerical model for dynamic simulations is developed. That model is firstly calibrated with available monitored data and then used for estimating consumption and performance during the whole year. Finally, a comparison with consumption before retrofit is performed and savings calculated.

Depending on the data availability, consumption pre-retrofit is taken from bills, measurements or model simulation.

1. Refrigeration circuit

The mathematical model has been validated with the experimental data from the monitoring system. The data has been analysed in order to correctly calibrate the parameters in the model. The profiles of the computed values of the variables used to validate the model align quite well with the measured data, confirming that the correlations in the model are correct.

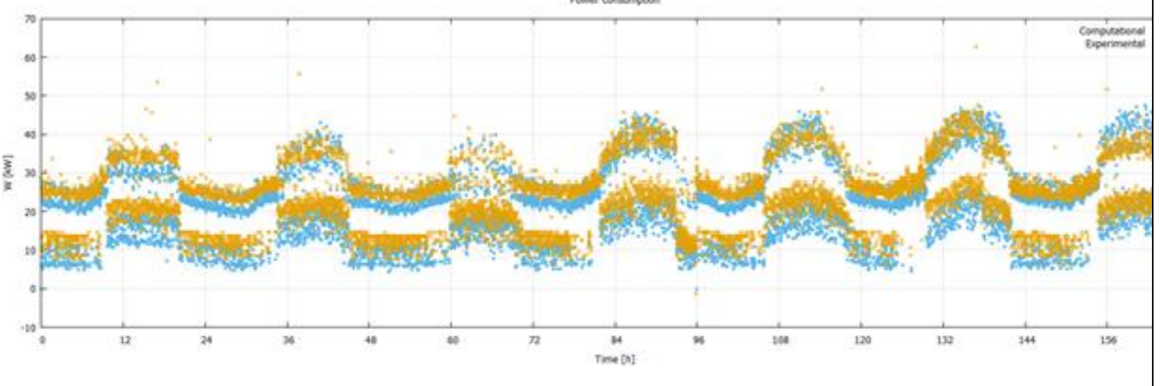


Figure 60. Power consumption of the CRU compressors [kW] vs. time [h], transcritical, week 8. Experimental data in yellow and computed values in blue.

The comparison of the compressor power consumption between experimental and computed data shows a good estimation of the electrical consumption. The averaged difference between the two measures over 9 weeks is 10%.

2. Hot water production

The estimation of the savings due to this kind of system is conducted through the model of the system with and without the heat exchange activation. The model is firstly calibrated through monitoring data for a time interval of 2 months; afterwards estimation of the whole year consumption with and without the contribution of heat recovery is calculated and compared each other.

The calibration aimed at minimizing the error on the estimated exchanged thermal power C3, C4 and heat pump electricity consumption (see figure below).

The missing measurement of the DHW demand caused a higher uncertainty on the model calibration. However, based on the available monitored variables (red indicated in Figure 61), a DHW profile was defined and monthly-based calibration was performed.

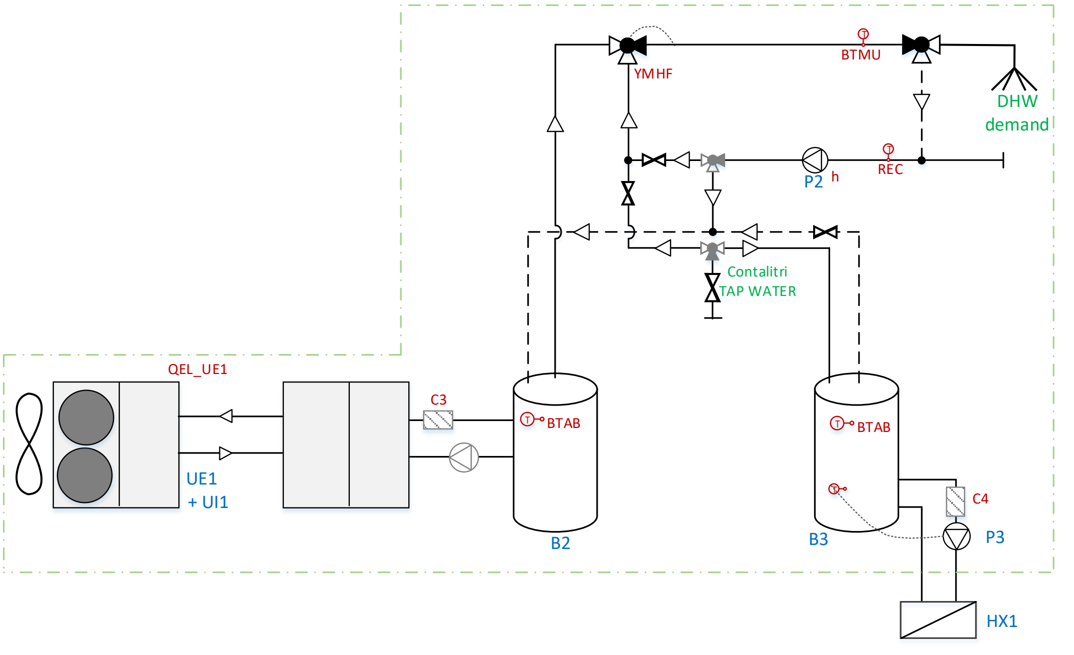


Figure 61. Energy plant for the hot water production – layout of the developed model

The error between the measured and the estimated values are reported in the following table.

Table 48. Measured vs estimated energy and error of the calibrated models

	Thermal Energy [kWh]		Error [%]
	Measured	Estimated	
C3 meter	2381	2315	2.8%
C4 meter	2156	2068	4.1%
	Energy consumption [kWh]		Error [%]
	Measured	Estimated	
Heat Pump	1058	1075	-1.6%

Energy savings, CO2 emissions avoided and simple payback

1. Refrigeration circuit

The model of the whole system, refrigeration cabinets, cold rooms and compressor, has been used for the estimation of the annual consumption and cooling load from the refrigeration system to the supermarket. The annual values of the new system after retrofit with the CO2 technologies has only the 4% of additional energy consumption with respect to the old system. This demonstrates as also in mild climates, systems working with the CO2 transcritical booster system have their applicability.

The analysis on the CO2 systems studied also two different working conditions of the systems: subcritical and transcritical. In the first case, the priority is given to the most favourable conditions for the refrigeration system; in the second case instead heat recovery from the refrigeration to the HVAC system is maximized with consequent worse working conditions for the CO2 system. This study showed as final energy consumption in the two cases is comparable. In both cases the difference in energy consumption with a traditional system is of 5%.

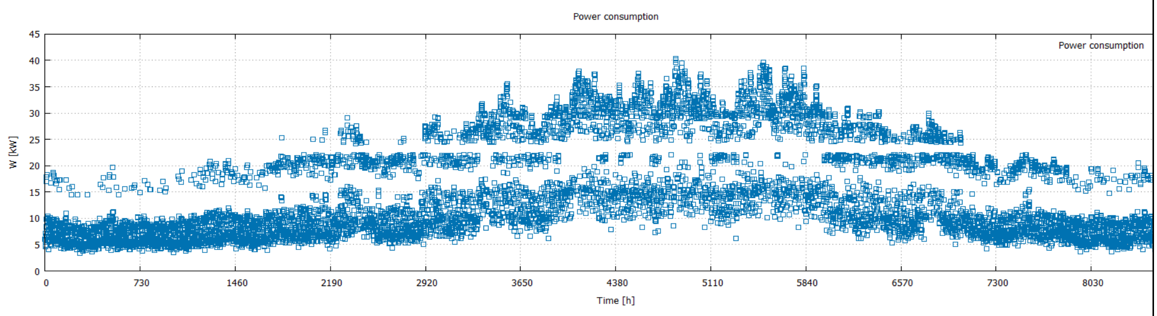


Figure 62. Energy consumption when the refrigeration system works in subcritical conditions

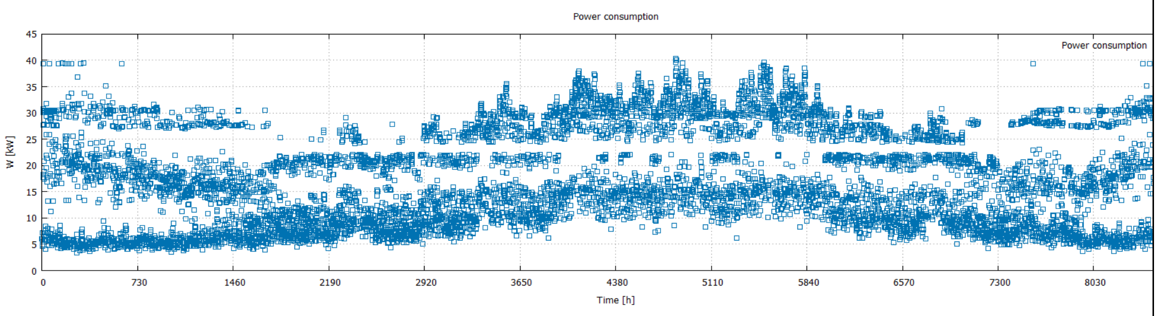


Figure 63. Energy consumption when the refrigeration system is forced to work in transcritical conditions.

The highest energy savings related to the refrigeration system result when the existing cabinets are replaced with new ones.

The following table shows the total cooling energy and the total electric energy consumption of a whole year.

Table 49. Cooling load and energy consumption with and without HVAC+R coupling.

	Cooling Load [MJ]		Difference (Old – New)	Saving % with new system
	Old System	New System	[MJ]	[%]
Year	1974690	935770	-1038920	-52.6
	Energy consumption [kWh]		Difference (Old – New)	Saving % with new system
	Old System	New System	[kWh]	[%]
Year	228300	135650	-92650	-40.36

The integration of the refrigeration system with the HVAC and hot water production systems allow higher savings on the overall electric consumption.

2. Hot water production

One of the solution proposed for the Modena Canaletto demo case proposes to recover waste heat from the refrigeration process and use it for the hot water production and space heating. To do so, after the compressor, CO2 of the refrigeration circuit crosses a heat exchanger and transfers heat with the hot water production circuit firstly and to the post-heating coil secondly. The calibration of the system model is developed in two phases: the hot water circuit first and the whole system later. As already mentioned for the ECM 3, the data availability for the AHU did not allowed the calibration of the second exchanger neither for the winter season.

Here after the calibration of the hot water circuit is described.

From monitored data, a DHW profile is retrieved and used for the definition of the yearly consumption. A comparison between electricity consumption and thermal energy used for hot water production is carried out between the systems with and without the exchange with the refrigeration circuit.

The following graph shows the calculated yearly hot water demand with and without the recovery from the refrigeration system. The study in this phase is conducted without taking into consideration the whole system and given a defined heat availability from the refrigeration. As we can see from the graph, almost more than the 70% of the total demand is covered by waste heat.

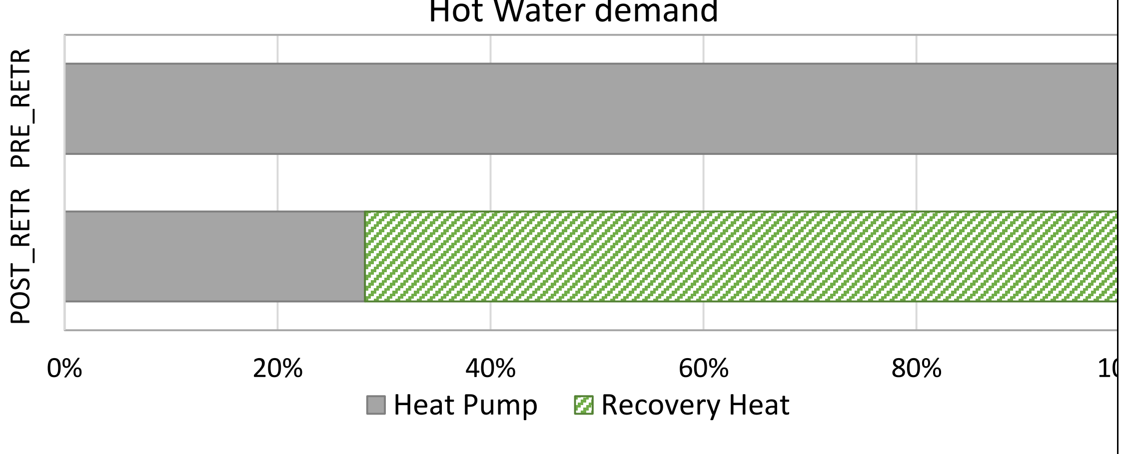


Figure 64. Hot water demand covering pre and post-retrofit

A reduced use of the heat pump means a reduction of electricity consumption. On the contrary, the solution post-retrofit accounts for an additional pump used for the heat exchange with the refrigeration circuit. The overall electricity consumption without and with heat recovery is reported in the figure below. Despite the additional consumption of the pump used for the recovery circuit, the solution post-retrofit brings almost 40% of energy savings

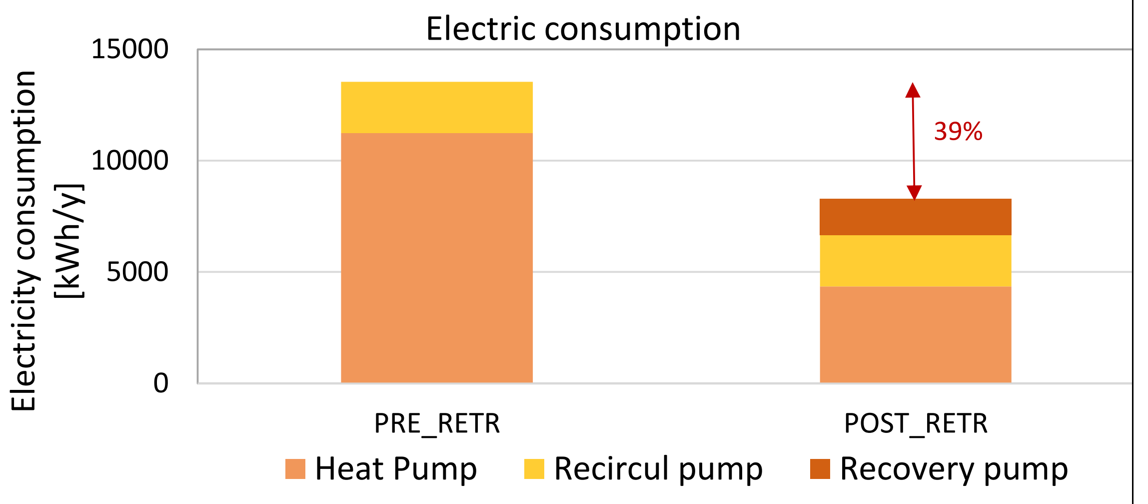


Figure 65. Electricity consumption pre and post-retrofit

3. Heat recovering from the refrigeration system to the HVAC system

For the sake of simplicity, each circuit is firstly studied separately, but as they are strictly connected, simulations are run with the whole system and building together.

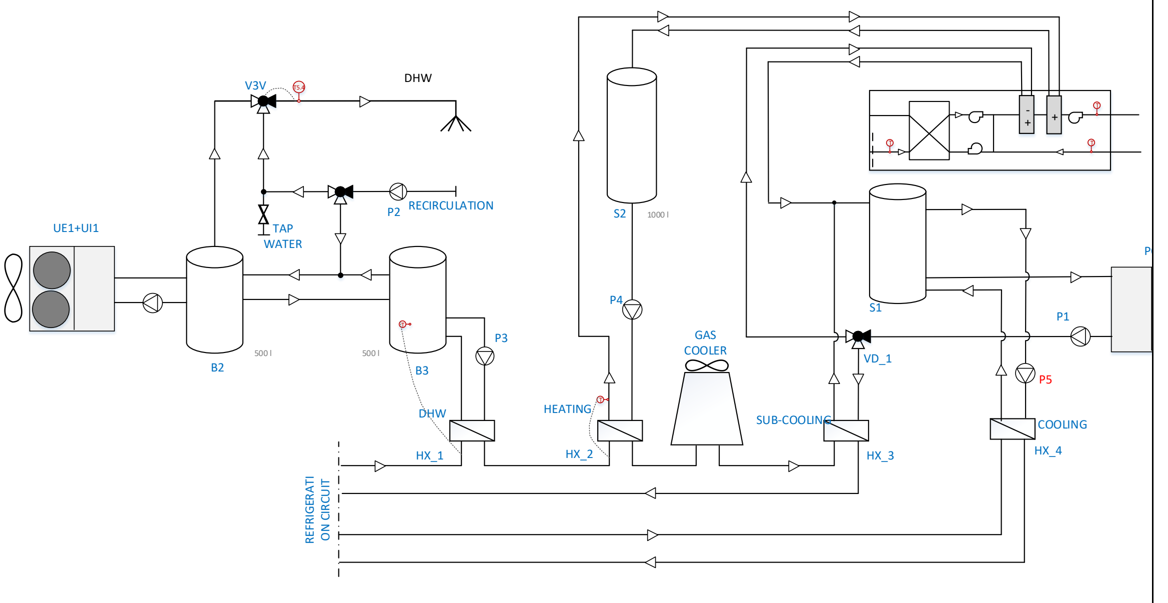


Figure 66. Schematic of the HVAC system layout and heat exchangers with the refrigeration system

In the following results all the before described ECMs are included in the same model together with ECM6. The savings that the coupling between the refrigeration system with the HVAC system amount to 43% of the primary energy consumed with respect the case before retrofit.

Looking into the details of each energy use, the higher savings are reached in the heating production with a reduction of around one third of consumed electricity. The savings in the hot water production amount to 16% although more than half of the demand is covered by the heat recovery. If from one side the exploitation of waste heat reduces the consumption on the HVAC side, the refrigeration circuit performance could decrease if it works at higher temperature. As a consequence, for the here studied case, the refrigeration circuit consumes 5% of electricity more (as also reported in the first part of this paragraph) than without the heat exchange. This percentage can be reduced or almost eliminated after an optimization of the set-points values.

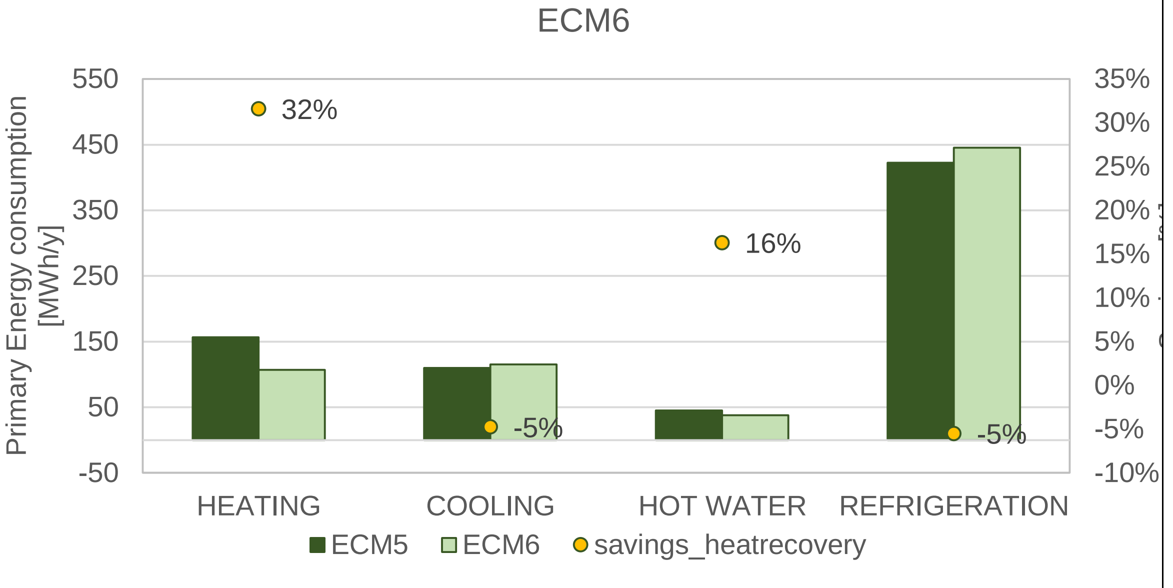


Figure 67. Primary energy consumption for heating, cooling, hot water preparation and refrigeration with and without ECM6.

The total electrical savings, CO2 emissions avoided and Cost avoidance of the described solution in comparison with the case before retrofit are reported here below.

ECM	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avoida [€/m²/y]
ECM6	11.4	5.8	1.4

ECM7: General Retail Lighting (GRL) in the galleries

Analysis procedure for calculating results

Savings due to GRL in the galleries are determined by measuring the electricity consumption due to lighting in the gallery (power meter E2).

Hourly power values measured from April to September 2017 are post-processed to get the maximum lighting power intensity and to define the schedule over an average weekday (Mon-Sat) and on Sundays.

The gallery lighting solution have been evaluated by comparing the lighting power density calculated from measured data after the measure implementation (6.2 W/m²) and the lighting power density before the intervention. The lighting consumption of the gallery was not measured before intervention. Lighting power intensity before retrofit was estimated during the energy audit according to lamps number and typology. We assumed the installed power density was 8W/m² and kept it constant for the same number of working hours, since there was no lighting control before.

The overall energy consumption for gallery lighting during the whole year is calculated by combining the measured values with estimates derived by the average lighting power intensity schedules.

The annual energy consumption for gallery lighting before the retrofit is estimated by combining lighting power intensity and lighting schedule.

The galleries are not conditioned and directly connected to the outdoor environment. Therefore, there are no interactions with the other building systems and the energy savings related to gallery lighting are considered aside from the overall building performance.

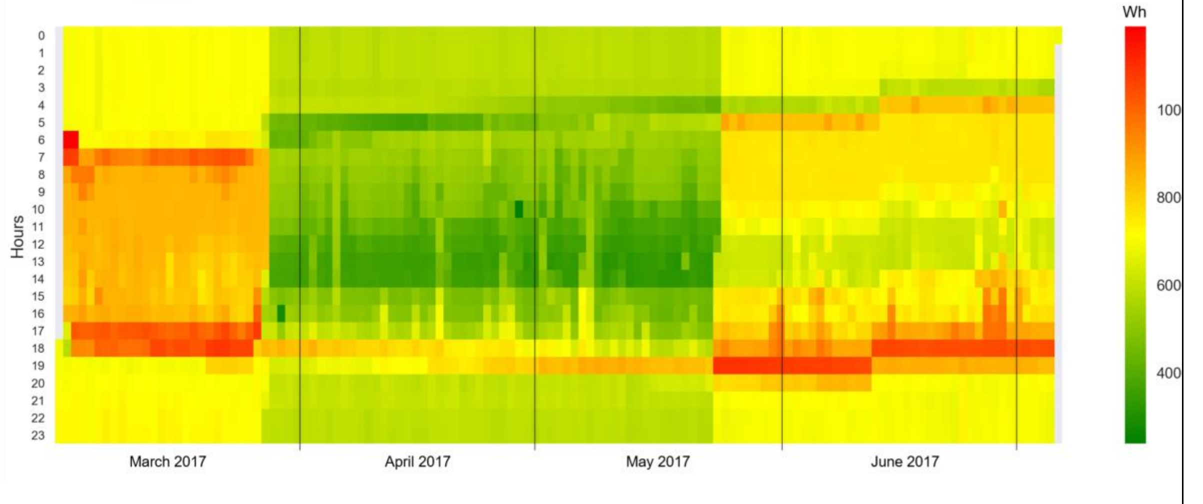


Figure 68. Hourly electricity consumption measured by meter E2 from March 2017 to June2017.

The carpet plot above shows the electricity consumption over the period March – June 2017. The commissioning of the system occurred at the end of March, during which lower lighting power intensities where set through the iBEMS. The lighting power intensity was increased again in May because of complains.

The plot shows how lighting are dimmerized over each day taking advantage of daylighting and how the energy consumption varies depending on the lighting dimmering.

Table 50. Electricity consumption before (estimated) and after (measured) the retrofit over the period 02/03-30/09/2017

	Before retrofit	After retrofit
lighting power density [W/m²]	8	6.3
nr of working hours [hr]	5110	5110

Electricity consumption [kWh]	45273	35714	

Energy savings, $CO2$ emissions avoided and simple payback

According to the above described data analysis procedure, the new gallery lighting concept would allow to reduce by % the electricity consumption for lighting the galleries.

The lighting power intensity before retrofit was estimated 8 W/m² and, thanks to the new lighting concepts and LED lighting, it is reduced to 6.3 W/m².

Table 51. Electricity consumption before (estimated) and after (measured and estimated) the retrofit over the whole year

Lighting	Before retrofit	After retrofit
Electricity consumption [kWh/y]	77611	65781
Electricity consumption [kWh/m²-y]	70	59
Primary energy consumption [kWh_{pe}/m²-y]	143	122
Equivalent CO_2 emissions [tonCO_2-y]	40	33

The total electrical savings, CO2 emissions avoided and Cost avoidance due to the replacement of the lighting in the gallery and referred therefore to the gallery area (1107 m²) are reported here below.

ECM	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avoidance [€/m²/y]
ECM7	10.6	5.4	1.3

ECM8: iBEMS

Analysis procedure for calculating results

The effect of this solution is not univocally identified as it acts for the integration of different solutions.

The validity of the iBEMS modelling lies in the conformity between the field and the simulation model of the implemented control rules and set points.

An example here reported considers the changing of the setpoint for the summer season and the estimation of energy savings. In the field, it is common use to *test* different set point temperatures and then compare the energy consumption. Through simulation, it is possible to assess energy consumption and performance with different set points and, at the same time, taking into consideration the interaction of the different systems.

Energy savings, CO2 emissions avoided and simple payback

The change of the set temperature from 23°C (temperature observed in the monitoring data) to 25°C can reduce of 30% the primary energy consumed for the cooling.

Here below, total electrical savings, CO2 emissions avoided and Cost avoidance of all the analysed ECMs with the case before retrofit are reported.

ECM	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]	Cost avoidance [€/m
ECM8	12.7	6.5	1.5

ECM9: Smart coatings

The smart coatings are applied over the gym roof and therefore they are not affecting directly the supermarket energy performance. We assessed the effect of reflective coatings on the gym heating and cooling need by means of simulations. Simulations were run using the weather data over the period July 2016 – June 2017 and solar radiation over the roof surface was calculated taking into account of the surrounding building shading.

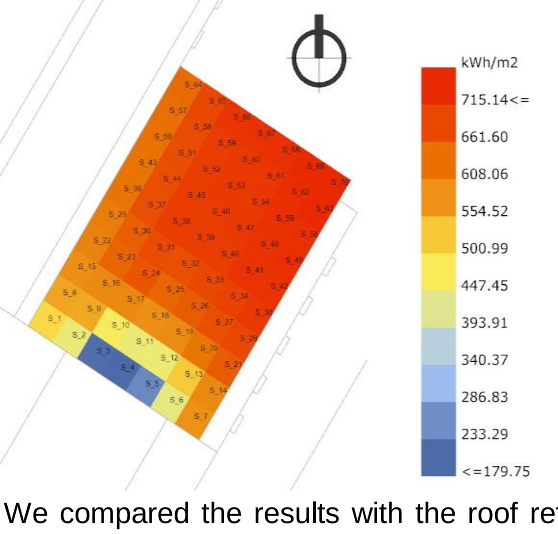


Figure 69. Amount of solar radiation over the whole year on the gym roof area.

We compared the results with the roof reflectivity of 0.87 (reference case without smart coatings) and 0.1 (case with coatings).

The roof was not completely covered by smart coatings. A small area of the roof was painted with standard coatings. We performed a short measurement campaign to demonstrate the effect of the coatings on roof surface temperature.

Surface temperature sensors E1 and E2 were placed over the roof surface treated with smart coatings, while sensors E3 and E4 were placed over the roof surface treated with conventional coatings.

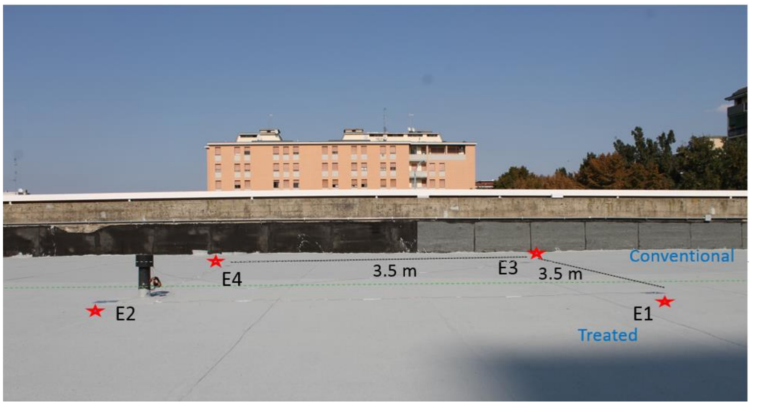


Figure 70. Surface temperature sensors installed on the roof.

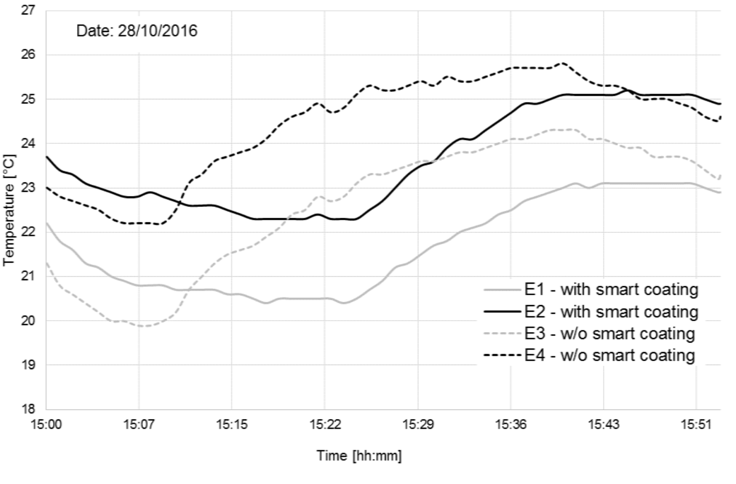


Figure 71. Measured surface temperatures.

Results show a surface temperature decrease of around 2K for the surface with smart coatings compared to the surface with conventional coatings at the same boundary conditions.

<u>Energy savings, CO2 emissions avoided and simple payback</u>

According to the building energy simulation performed, the smart coatings application would allow to reduce by 15% the total heating and cooling demand of the gym (gym area = 1304 m²).

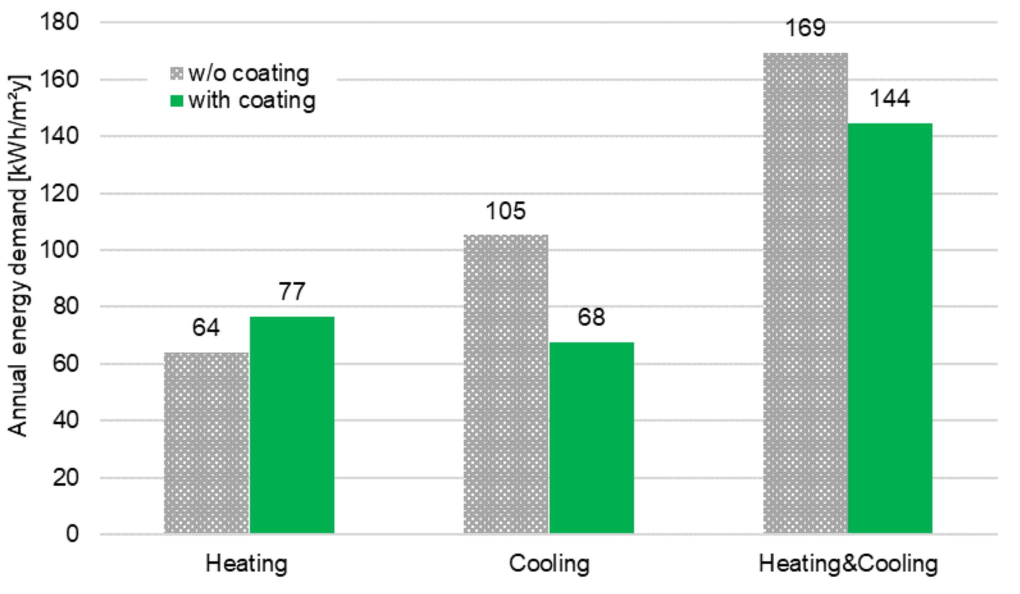


Figure 72. Annual energy demand of the building with and without coatings.

ECM	Electrical savings [kWh/m^2/year]	CO_2 emissions avoided [kg/m^2/year]	Cost avoidance [€/m^2/y]
ECM9	7	3.5	0.8

4.5. Summary of results in Coop Canaletto

In the Modena Canaletto demo case several solutions are implemented for reducing the energy consumption. From this experience, we can assert that a preliminary analysis on the main energy uses is the basis for defining the solutions to be implemented. In fact, in this specific case, the heating and cooling demands are not the highest energy needs; solutions that aim at reducing significantly these consumption, in absolute terms may be however not relevant.

In this sense, the effect on the total energy consumption of the increase of the envelope performance is lower than the replacement of the lighting or of the open with the closed cabinets.

Worth to mention for this demo case is the implementation of a CO2 refrigeration system and of a heat recovery from the refrigeration circuit to the HVAC system. The advantage of this is the exploitation of waste heat during the whole year from the compressor to the hot water production or space heating and post-heating. However, this kind of system needs to be previously studied in its complexity taking into account all the systems that interact together. In fact, when the heat recovery is fully used by the HVAC system, the refrigeration circuit could be penalized. As a consequence, the consumption of this latter system can increase.

As a first system configuration without an optimization of the working modes, the implemented solutions are able to significantly reduce the energy consumption of the demo case.

Thermal savings [kWh/m²/y]	Electrical savings [kWh /m²/y]	Renewable energy production [kWh/m²/y]	Primary energy savings [kWh/m²/y]	CO_2 emissions avoided [kg/m²/y]	Cost avoidance [€/ m²/y]
84	233	N/A	569	139	30

The graph in Figure 73 reports the primary energy consumption and the energy savings that each ECM add to the existing case.

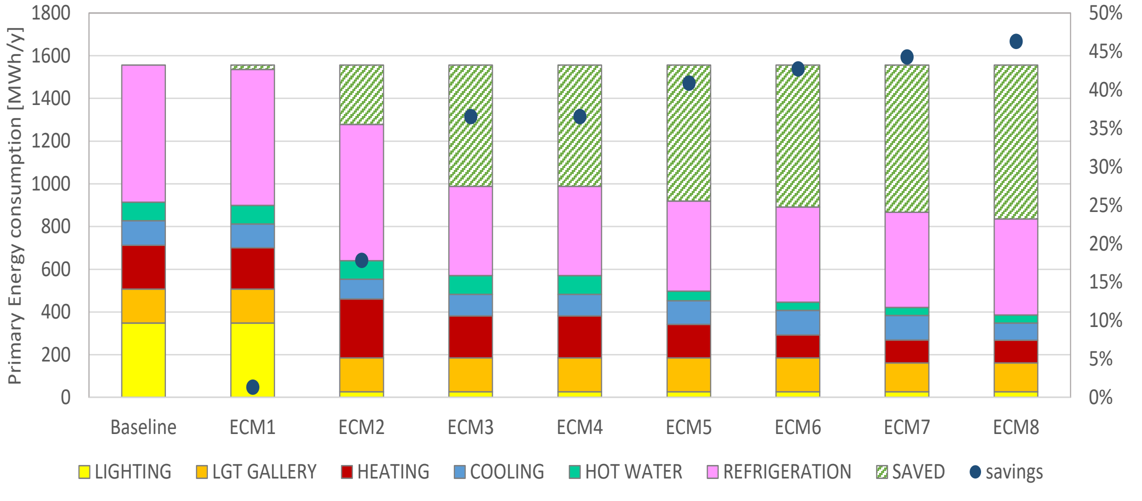


Figure 73. Primary energy consumption and savings of the Coop Canaletto demo by adding progressively each ECM.

Based on the gained experience, we can assert that:

- A preliminary analysis on the main energy needs is needed in order to individuate the most energy-needed uses; consequently, solutions that aim to reduce the consumption of these uses have higher impact on the final energy consumption savings;
- In cases as Modena Canaletto where the ratio of lighting consumption is higher on the overall consumption, the replacement of existing lighting brings the highest energy savings;
- The replacement of open cabinets can reduce the cooling load due to the cabinets up to 50%;
- The waste heat of the refrigeration circuit has a big potential to be exploited for other uses, but an optimization of the working modes – set temperatures, working conditions – is needed in order to penalize one or the other system;
- A control system able to interact with all the parts of the supermarket can bring relevant energy savings by means the optimization of the working modes of the different systems.

Energy Conservation Measure (ECM)		Thermal savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]]	Cost avoidance [€/m²/y]
1	Envelope retrofitting	2.1	7.3	4.2	0.9
2	Advanced lighting concept in the supermarket	0.0	106.2	54.1	12.7
3	Replacement of refrigeration cabinets	10.3	110.5	58.7	13.5
4	Linear air diffusers	N/A	N/A	N/A	N/A
5	HVAC efficiency	78.2	-15.5	11.0	-0.2
6	HVAC-R coupling	0.0	11.4	5.8	1.4
7	GRL in the galleries	0.0	10.6	5.4	1.3
8	iBEMS	0.0	12.7	6.5	1.5
9	Smart coatings	0.0	7	3.5	0.8

5. City Syd (Norwegian demo case)

5.1. Retrofitting project description

City Syd is a suburban shopping centre, built on the outskirts of Trondheim. Opened in 1987 and covering an area of 28,500 m^2, it was redeveloped in 2000 and it is now 38,000 m^2, with 1,000 outdoor parking spaces. Its primary group of customers comes from the city of Trondheim, but it has a large catchment area and attracts customers from all over central Norway. City Syd was the largest shopping centre in the region until 2009, and remains one of the largest in central Norway.

City Syd joined the project CommONEnergy to test innovative technologies and solutions, implemented between 2013 and 2016 to be effective in 2017. The innovative technologies and solutions focus on natural ventilation, iBEMS, as well as natural and artificial lighting:

- Redesign of the lighting system, including the use of a rectangular lighting system for advanced daylighting, artificial lights and meters in the shopping centre gallery and the Jens Hoff shop, and a dome and light-tubes in the Jens Hoff shop. The goal is to reduce installed power for the whole lighting system.
- Introduction of natural ventilation with automatic shading and monitoring systems (Air Handling Unit in the common area).
- A modern energy management and monitoring system (iBEMS) allows an optimal control of all technologies, taking appropriate decisions to reduce energy consumptions.

5.2. Demonstration areas in City Syd

Within the CommONEnergy project, there are mainly four demonstration areas in which the solutions will be demonstrated. These four areas are the Jens Hoff shop and the common area which is in front of the shop, all common area and an area below a rectangular skylight in the common area. This subsection describes briefly the most relevant aspect of the demonstration areas.

Demonstration area 1 (Jens Hoff shop) description

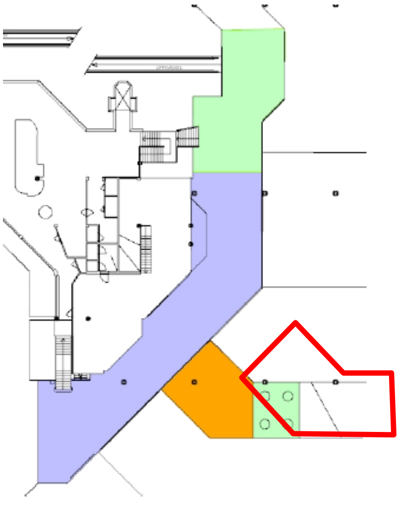


Figure 74. Jens Hoff entrance (Left picture) and location (highlighted in red in the right picture)

Dimensions of the shop: 102.8 m^2

Mechanical Ventilation system: Ve04K the central ventilation system delivers 100,000 m^3/h to all the shops (including Jens Hoff), and has manual dampers, for regulating the total airflow to the different floors. The demonstration tenant (Jens Hoff) has no local damper in their shop.

Air Conditioning system: 2 Fan-Coils type CIAT Major 2 placed along the back wall of the shop and are locally controlled (fan-speed and temperature). They are connected to the cooling water system at a temperature around 14 degrees Celsius.

Demonstration area 2 (Common area in front of Jens Hoff shop) description

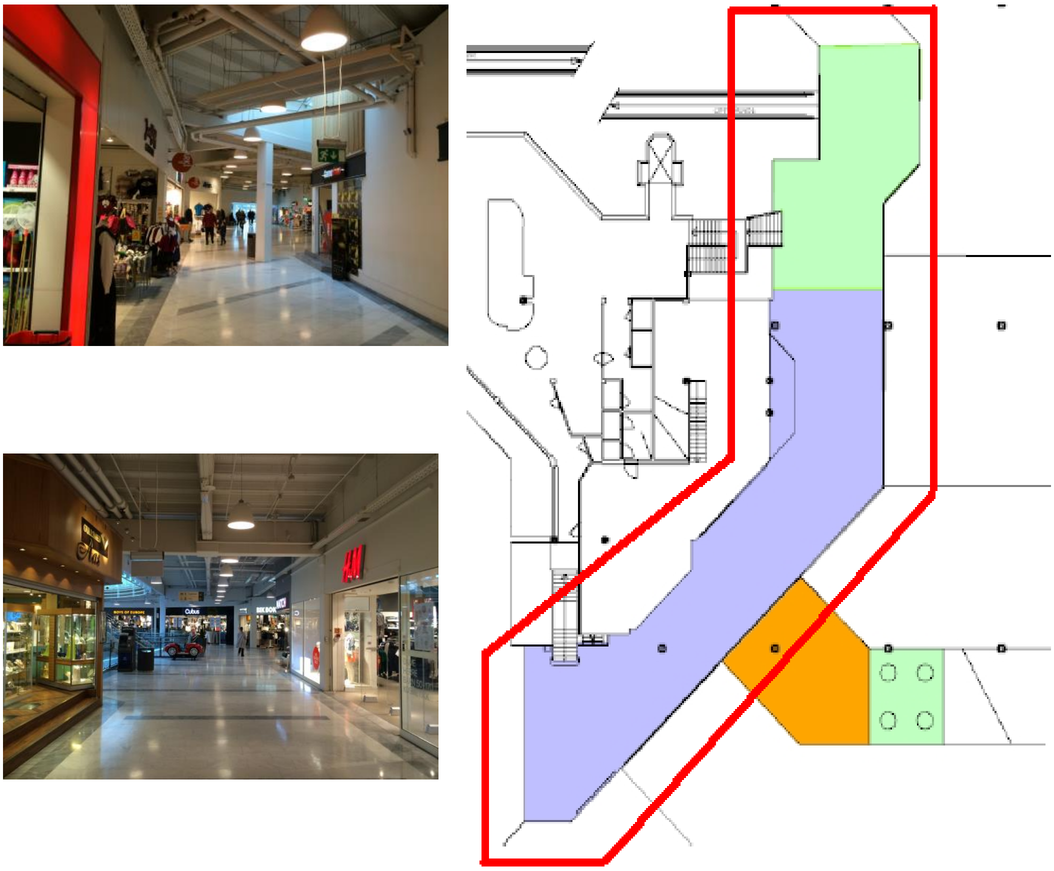


Figure 75. Common area location in front of Jens Hoff shop

Dimensions of the area: 243 m^2

Mechanical Ventilation system: Ve03K the central ventilation system delivers 20,000 m^3/h to all the common areas (including a restaurant), and has manual dampers, for regulating the total airflow to the different floors. The demonstration area has no local damper.

Demonstration area 3 (Common area for natural ventilation) description

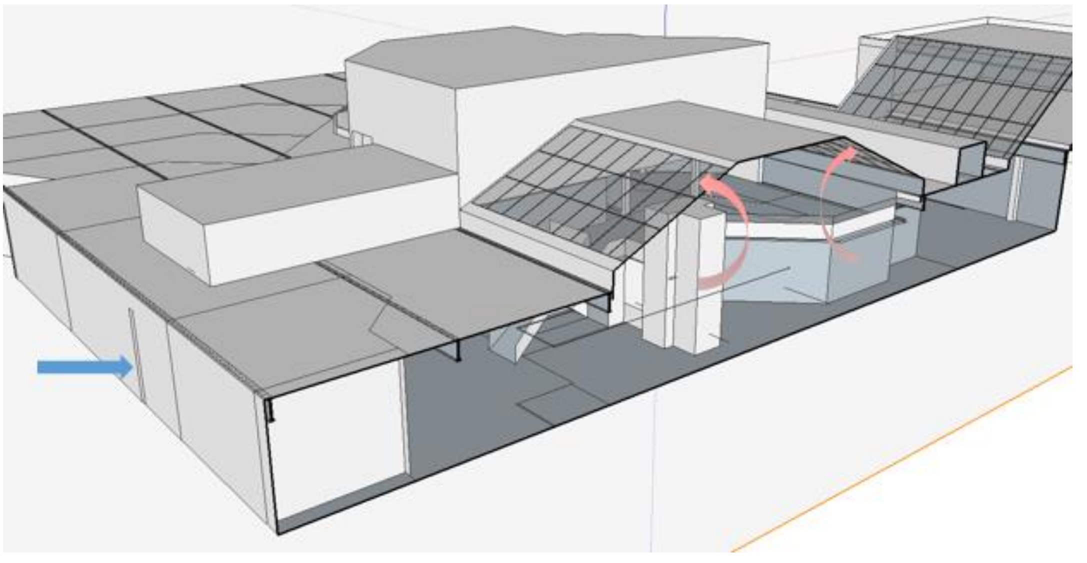


Figure 76. 3D sketch of natural ventilation

Dimensions of the area: 2,772 m^2

Mechanical Ventilation system: Ve03K the central ventilation system delivers 20,000 m^3/h to all the common areas (including demo area 3), and has manual dampers, for regulating the total airflow to the different floors. The demonstration area has no local damper. The ventilation system temperature set-point varies from about 14 (summer) to about 19 degrees Celsius (winter) depending on the outside temperature and on exhaust temperature from the atrium/common area. Heat recovery internal in the system is done by a rotating-wheel heat recovery unit. No data on the efficiency of the heat recovery are available.

Skylight openings: The skylights are approx.1.20m X 2.00 m top hinged, with an outward motion.

The angle is approx. 60 degrees off the sloping windows.

- 10 Windows oriented west.
- 10 Windows oriented east.
-

Entrance doors: The two automated sliding doors have an opening off 1.56 m x 2.30 m. They have an automated opening time of approximately 10 sec from sensor detected movement until closed. This is if 1 person passes only. If more persons come through they stay open for as long as they have movement detection. The doors are controlled by motion sensors and only local automation can be set manually open.

Common area cooling: Water cooled static coils are installed in the ceiling structure of the Ground-, and 1st Floor. These are natural convection system (no fans are employed). The system is manually operated. The common area cooling system is not in use due to some restriction in cooling water supply.

Demonstration area 4 (Common area for rectangular skylight) description

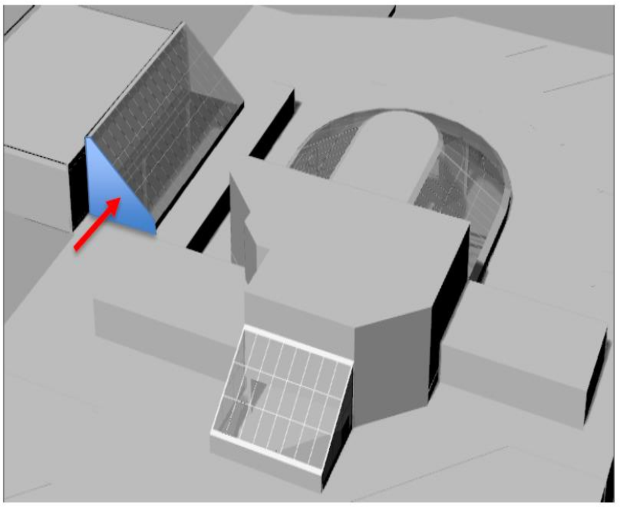


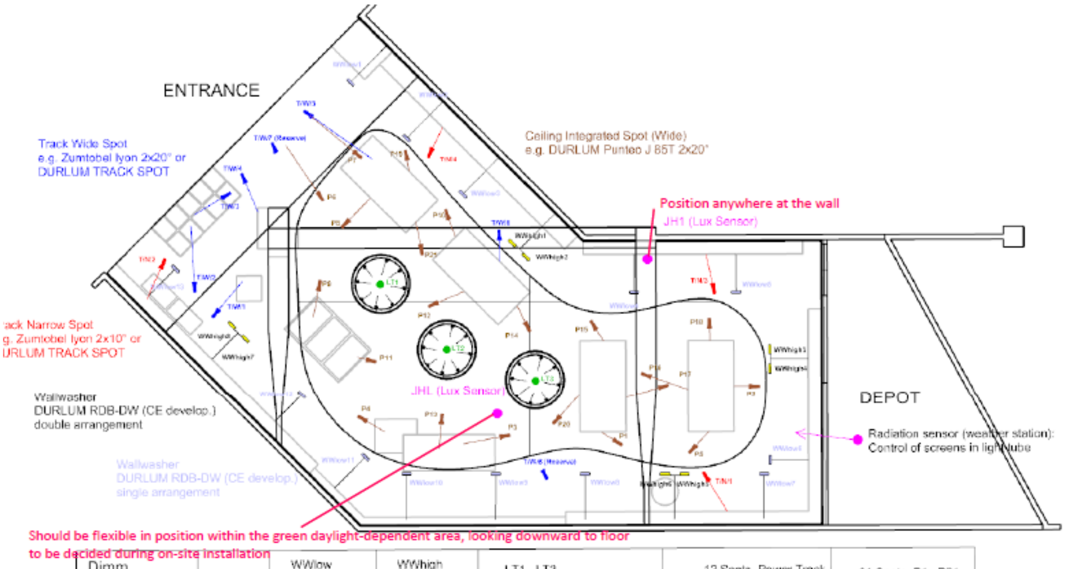
Figure 77. Common area rectangular skylight

Dimensions of the area: 60 m^2

Mechanical Ventilation system: Ve03K the central ventilation system delivers 20,000 m^3/h to all the common areas (including demo area 4), and has manual dampers, for regulating the total airflow to the different floors. The demonstration area has no local damper. The ventilation system temperature set-point varies from about 14 (summer) to about 19 degrees Celsius (winter) depending on the outside temperature and on exhaust temperature from the atrium/ common area. Heat recovery internal in the system is done by a rotating-wheel heat recovery unit. No data on the efficiency of the heat recovery are available.

5.3. ECMs implemented

ECM 1: Artificial lighting concept in Jens Hoff shop
Based on an extensive market study, the determined requirements and the new lighting concept 3 ideas were developed as a concept and evaluated by a feasibility study [11].



Dimm Status		WWlow (RDB-DW not accent.) 13 fields (13 luminaires)	WWhigh (RDB-DW accent.) 4 fields (8 luminaires)	LT1...LT3 (Integr. Artificial Light in Light Tube) (3 Luminaires, 4800 lm)	12 Spots, Power Track (1700 lm) (2 Safety) T/N (Track/Narrow) T/W (Track Wide)	21 Spots, P1...P21 Ceiling Integrated
Standard Operation (No Zoning)		13 fields: 100%	4 fields: 100%	100%	100%	100%
Energy-Efficient Operation (Zoning)	**Day (Dimming)**	13 fields: 66%	4 fields 200%	66%	100%	66%
	Night (Dimming))	33%	50%	33%	50%	33%

Key: ● Illuminance Sensor

Figure 78. Lighting plan

Figure 79 gives an overview over all applied luminaries.

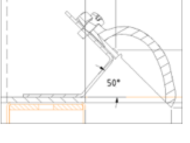
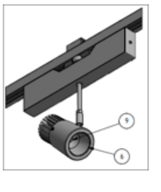
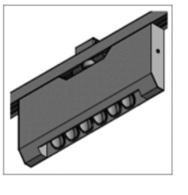
Luminaires types			
Lighttube-integrated luminaires	Ceiling-integrated spot	Spot @ powertrack	Wallwasher @ powertrack
LT 1....LT 3 (3 luminaires)	CIS 1-19 (19 luminaires)	SPOT 1-14 (14 luminaires)	WW 1 - WW 21 (21 luminaires)
 24 RDB reflector at the perimeter each RDB-DW: 270 lm @ 500mA LED, CRI > 90 2700K + 5700K 6480 lm @ 4000K (LED) Dimmable via DALI 230V / 50 Hz	 Light distribution 2x20° pivotable at 20° angle LED, CRI > 90 2700K + 5700K (1000lm + 1300 lm) (LED) Dimmable via DALI 230V / 50 Hz	 Light distribution 2x20° Surface RAL 9010, Eutrac 7 LED 2 x 15W, CRI > 90 2700K + 5700K (1000lm + 1300 lm) (LED) Dimmable via DALI 230V / 50 Hz	 Light distribution: Wall, 135° Surface RAL 9010, Eutrac 7 LED, CRI >90 2700K + 5700K 4800lm @ 4000K (LED) Dimmable via DALI 230V / 50 Hz

Figure 79. Overview of applied luminaries in the lighting concept

<u>LED Retail Wall Washer</u>

Smaller shops do have a high fraction of walls compared to their floor area which are effectively used to present merchandise or branding objects.

Most often there is no specific lighting system used to illuminate this area according to its requirements. Analysis of several shops showed that spots are the common lighting system that shows a very uneven light distribution and moreover is restricted to illumination of the wall solely. The adjacent areas in front of the wall – very important areas as customers are examining the merchandise here after removing it from the wall shelves - often are neglected by lighting planning (assuming that reflected scattered light from the spot system provides sufficient light, which often is not the case and anyhow very dependent on properties of the displayed items) and – if considered - needs to be equipped by a second system.

Wide-beam reflector (RDB-DW)

A multi-faceted, free-form reflector was developed, calculated, produced as sample, tested, refined and measured. The reflector has a dimension of 40.8mm/37mm/13mm (l/w/h) and a system efficiency of 83%.

The reflector allows homogeneous colour mixing (LEDs with 2700K und 5700K). A high visual comfort with perfect longitudinal glare control, no direct glare, low reflex glare, low light pressure and no multi-shadows was achieved. Beam angle was developed to 2x27° longitudinal direction and 115° lateral direction. Visualisation of the reflector and the light intensity distributions are reported in Deliverable 4.8 [11].

LED

A new LED board was designed following the optical, thermal and electro technical requirements and manufactured externally.

The LEDs with a colour temperature of 2,700 K and 5,000 K can be dimmed separately which allows to tune the colour temperature between those two ("tuneable white").

The luminary was developed to be mounted to a power track as power tracks are quite common in retail situations (this is also the case in the demo case Trondheim). The shape and design of the luminary was developed with the idea of a rather "light" appearance while at the same time both the necessary heat sink and the electrical components all had to be fitted into the housing. The depth of the housing therefore was design with the same dimension as the width of the power track. The novel wallwasher is designed for but not limited to the use in retail shops. Illumination is not limited to wallwasher functionality but also has a downlight component.

The application example in the Jens Hoff shop is shown in Figure 80. The prototype, test report and technical drawings can be found in deliverable D4.8 [11].

Figure 80. Application of the wallwasher in a retail shop in the demo case Trondheim.

<u>Development of integrated artificial lighting in the light pipe</u>
See more information in the section about the light tubes (EMC2).

Figure 81. Picture of the ceiling with integrated spot lights and light tubes

ECM 2: Light tubes in Jens Hoff Shop

The light tubes redirect daylight from outside to the inside in an efficient way. It mainly consists of a tube made of highly reflective anodized aluminium mounted below a skylight dome.

Integrated in the Light Pipe is an artificial lighting system which can provide additional light if the daylight is not sufficient (controlled by an external sensor). On the top of the Light Pipe 24 circularly arranged reflectors with LEDs are arranged. To be able to control the amount of daylight coming in and to reduce it if necessary a shading screen is integrated in the skylight dome.

Figure 82. Picture of light tube installed between ceiling and roof

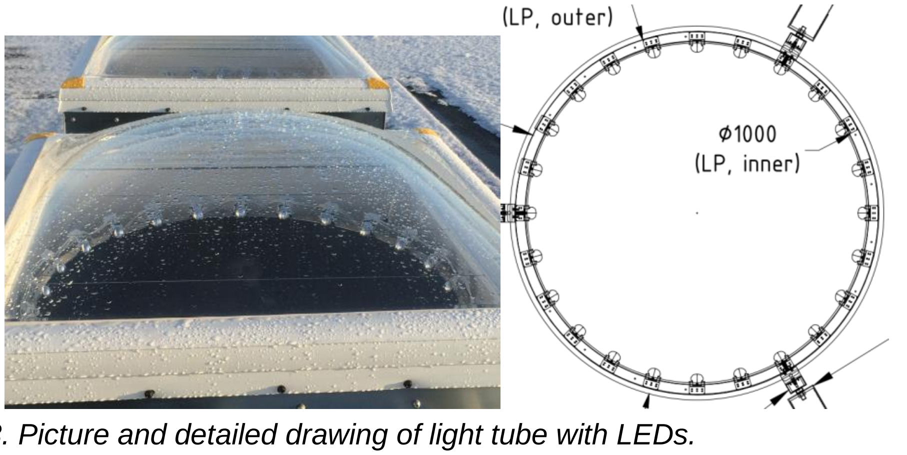


Figure 83. Picture and detailed drawing of light tube with LEDs.

ECM 3: General Retail Lighting (GRL) in common areas
The second demonstration area (230 m[2] large Common Mall Area) was chosen to be equipped with the GRL luminaries. Two daylight zones – close to the main glasses atrium und close to a smaller roof light – are included. Figure 85 gives an overview of planning and photos of the initial situation.  *Figure 84. Initial situation and situation after retrofit (showing the GRL luminaire)*

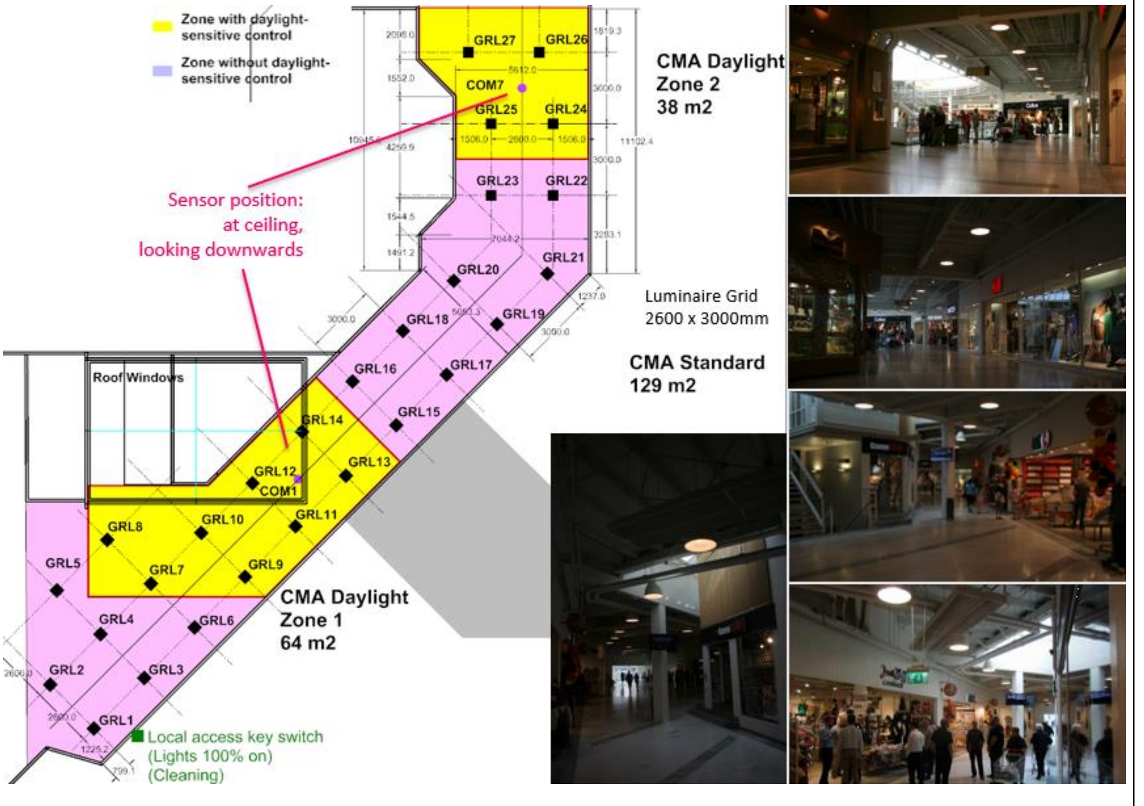


Figure 85. Left: Planning for general mall retail lighting with the GRL in 2-row- 3mx3m grid, Right: Pictures of the initial situation with a design luminary and diffuse light distribution, 1-row layout

ECM 4: Natural ventilation

The objective was to reduce ventilation need by exploiting natural ventilation during summer.

Ventilation energy use was reduced by applying new AHU with heat recovery systems with better temperature efficiency and by a better control of ventilation.

Natural ventilation through openable windows in the central atrium skylights help vent out stale air in the summer (Figure 87). Combining the effect of opened sliding doors and skylight openings which can enhance stack ventilation and ventilate/cool the common areas.

The main entrance is a full height glazed atrium with 4 sliding doors (1.56m x 2.30m each), 2 entrance doors are located at ground floor and the other 2 at first floor (Figure 86).

The doors are controlled by motion sensors, and only local automation which allows setting them manually open. The automated opening time is approximately 10 sec from movement detection until closure. If more persons are coming through, the doors stay

open as long as the sensor is detecting movement. In case of fire, there is a fire signal which overrides the motion sensor and the door stay open.
 *Figure 86. Picture of entrance door*  *Figure 87. Picture of atrium*

ECM 5: Modular roof skylight
This system illuminates the gallery in a secondary way by a mirror in the roof which reflects the light beam from a projector luminary. It replaces the other inefficient lighting solutions (suspended design luminaries are replaced) in the gallery. Although it works as a secondary system (with inherent lower system efficiency), it can be now refurbished with great efficiency enhancements by LED technology and high-class mirror systems. Due to these important advantages this system is a good choice for illumination of a multi-storey gallery: • Development of energy-efficient projector solutions (high lumen output necessary) on the base of LED light sources and advanced optics. • Projector can be maintained easily as it is mounted at the side (and not in the height of the gallery glass roof). • Good visual properties due to the secondary distribution concept via a mirror.

- At night the mirror brightens up the respective parts in the glass roof and visually borders the space. With this solution we avoid a completely dark roof/ceiling that would be perceived as unpleasant.
- The mirror can be integrated in an overall concept of a modular roof which functions in large parts as a flexible daylight system with modular case-specific application of different daylight modules. This daylight system complements the artificial light solution in the roof.

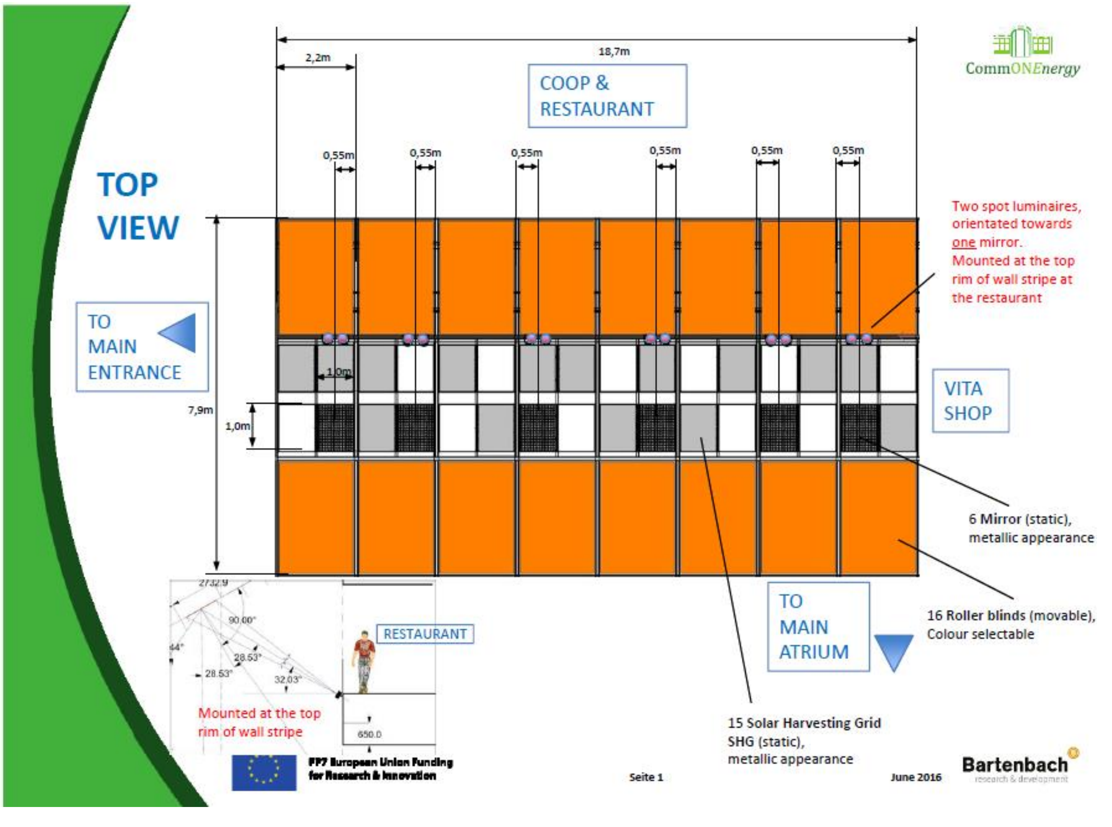


Figure 88. Principle of the modular roof skylight system with all elements

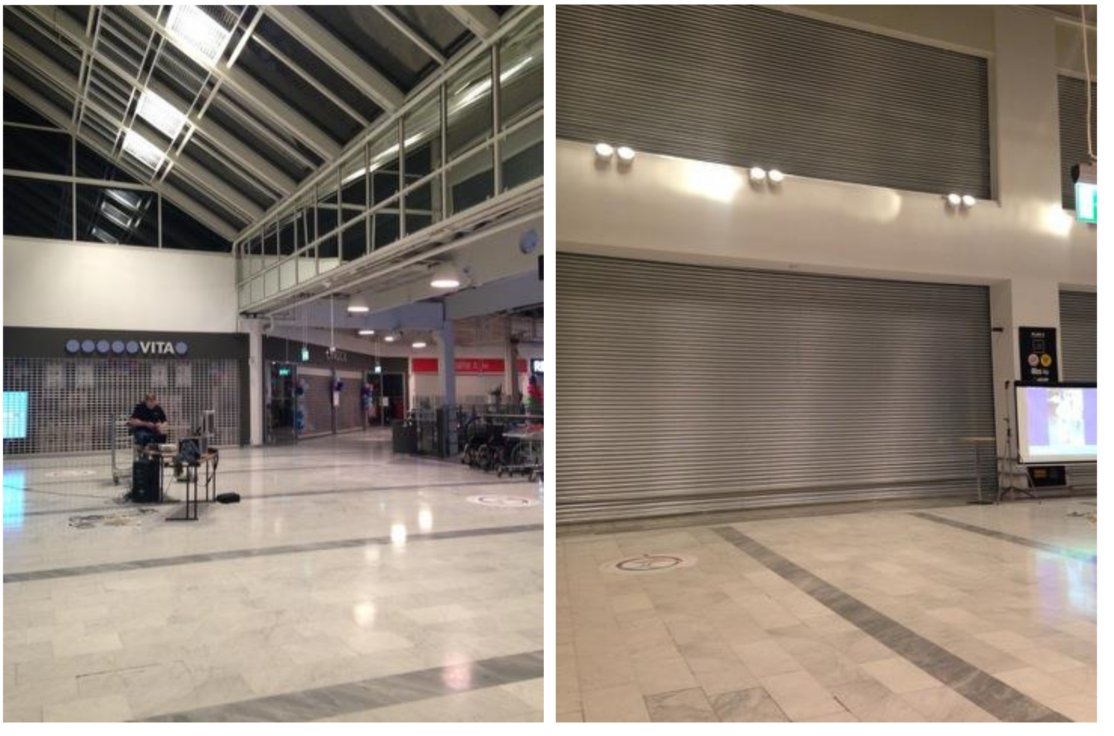


Figure 89. Modular roof skylight installed in CitySyd

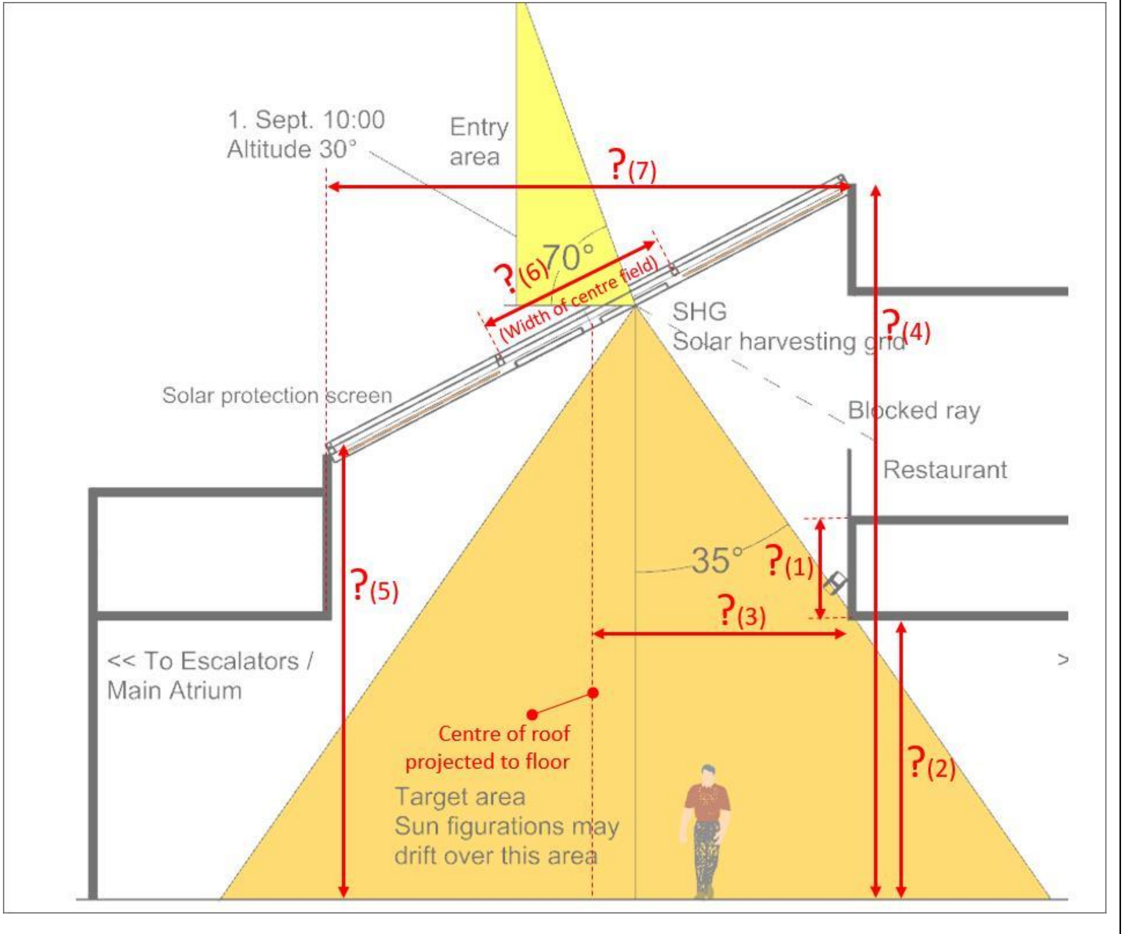


Figure 90. Section of modular roof skylight system

EMC6: iBEMS

The iBEMS monitors and controls the indoor conditions in the following areas:

- Jens Hoff Shop (artificial lights system).
- Common areas monitoring.
- Natural ventilation control.
- Rectangular skylights.

Jens Hoff Shop (artificial lights system)

In the Jens Hoff Shop, an autonomous system that communicates with the iBEMS has been designed. The autonomous system can work as an individual web server for monitoring and control the conditions of the shop.

The dedicated architecture of the Jens Hoff Shop is illustrated in Figure 91. Using the specific architecture, the installation of Jens Hoff shop can be replicated in other shops of the Trondheim demo case.

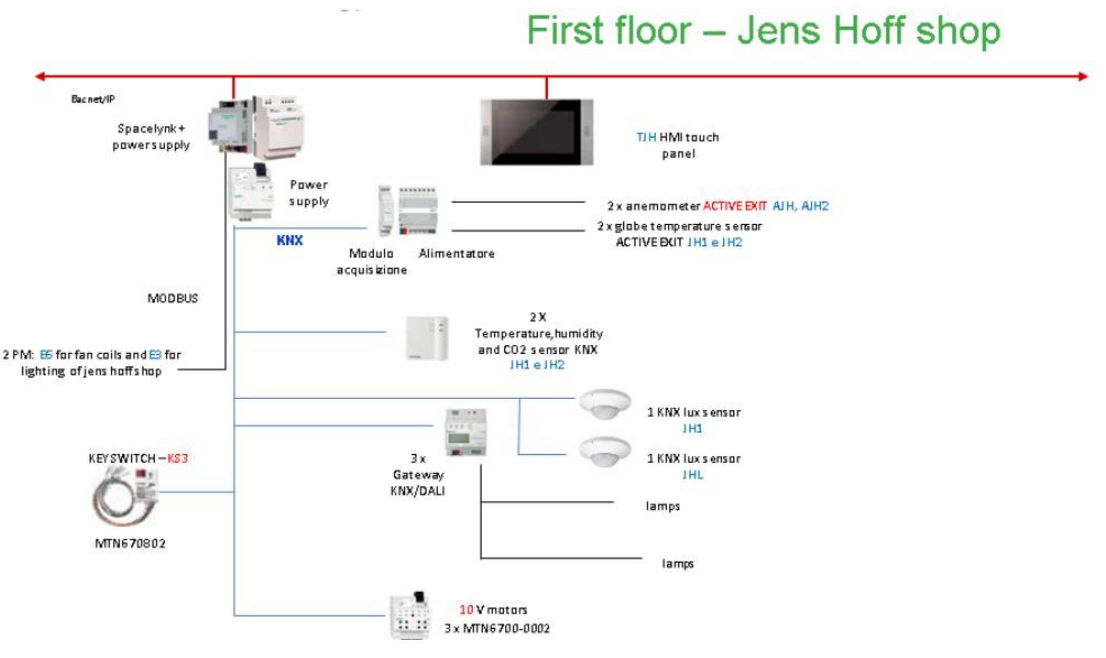


Figure 91. Dedicated autonomous architecture for the Jens Hoff Shop

Green Lighting box as a turn-key ready solution for control and monitoring in shop

Shop lighting in the future – as outlined before with the new lighting concept – needs to fulfil many requirements:

- Flexibility: shop lighting has to be dynamic with changing properties, e.g. scenes or set points, locally and over time.
- Robust implementation of dynamic behaviour, easy to understand and to handle.
- Monitoring function and energy monitoring should provide key parameters which allow immediate analysis and support for optimization.

We developed the product idea of a turn-key ready integral solution for shop lighting control that fulfils the above requirements.

More detailed information to the “Green Lighting Box” can be found in the CommONEnergy internal document “Validation of Control Strategies for the Jens Hoff Shop, City Syd Trondheim”.

Monitoring

The common area monitoring is performed in Trondheim demo case in order to evaluate the overall performance of the collected sub-systems such as the natural ventilation and rectangular skylights.

In total, the sensors are installed in the ground floor and the first floor (Figure 92) of the demo site.

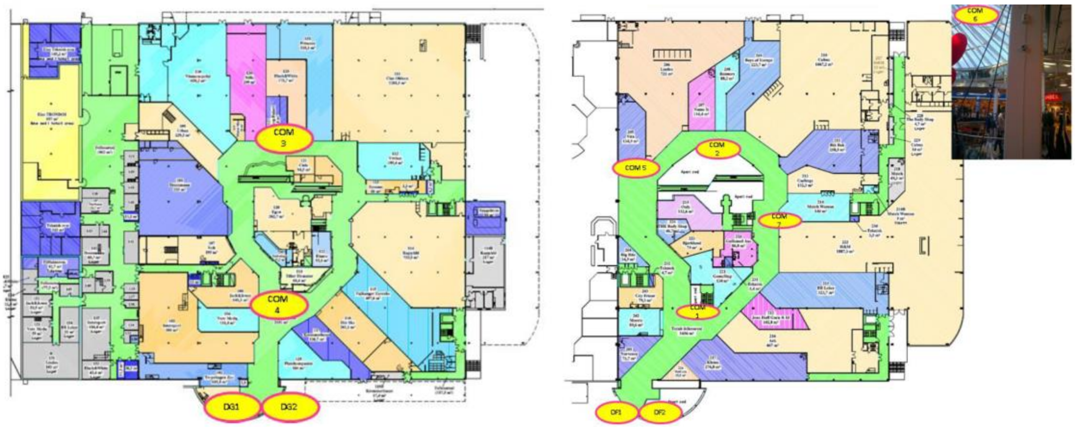


Figure 92. Ground and First Floor monitoring sensors position in CitySyd

General Retail Lighting in common areas

For a part of the common area, the artificial lights system has been upgraded using new ones which can communicate with the iBEMS. The new artificial lights are programmed to work in groups for better performance and energy savings. In parallel, for the best possible operation of lights it has been selected that dedicated users with keys can activate the lights at full operation for a specific period. The locations of the key switches are illustrated in Figure 93.

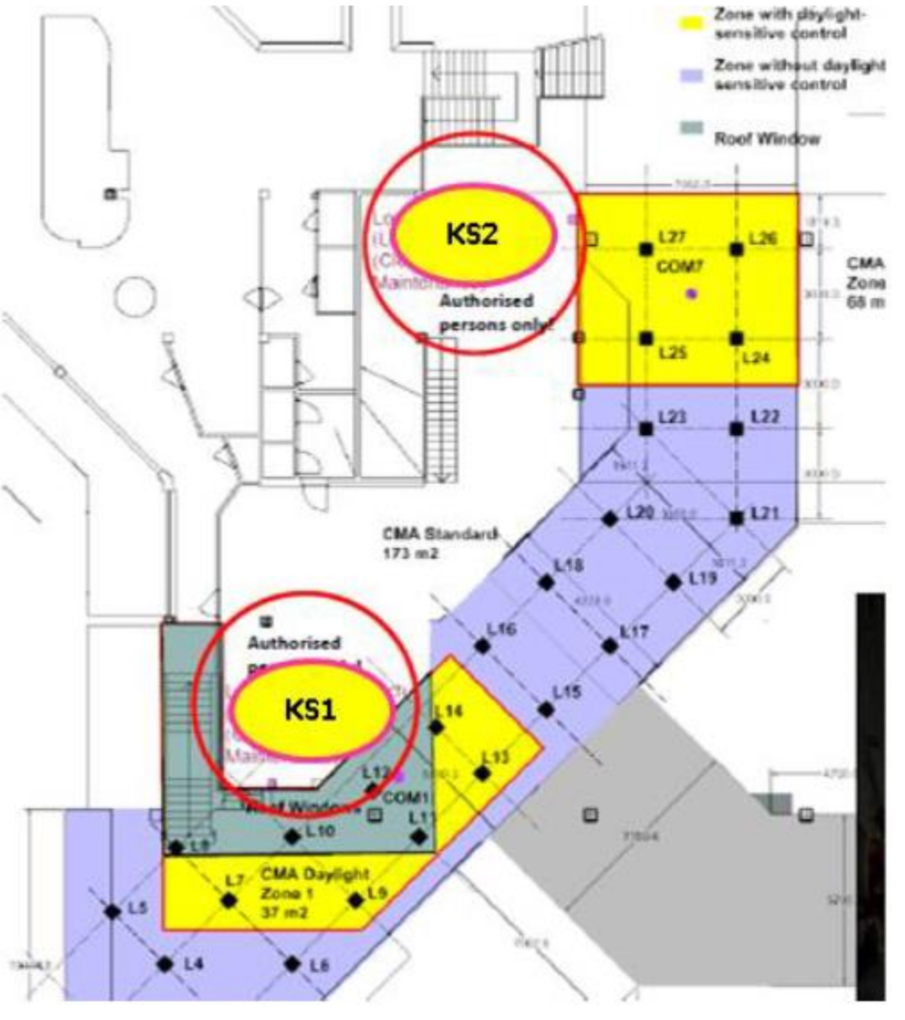


Figure 93. Key switches location in the CitySyd common areas

<u>Natural ventilation system</u>

For the natural ventilation system, the iBEMS is controlling directly the motors of the windows using a dedicated control for activating the motors. The architecture for the control of this sub-system is depicted in Figure 94. As it can be seen the specific system communicates with the demo site iBEMS hardware using the available open protocol (LonWorks) of the iBEMS hardware.

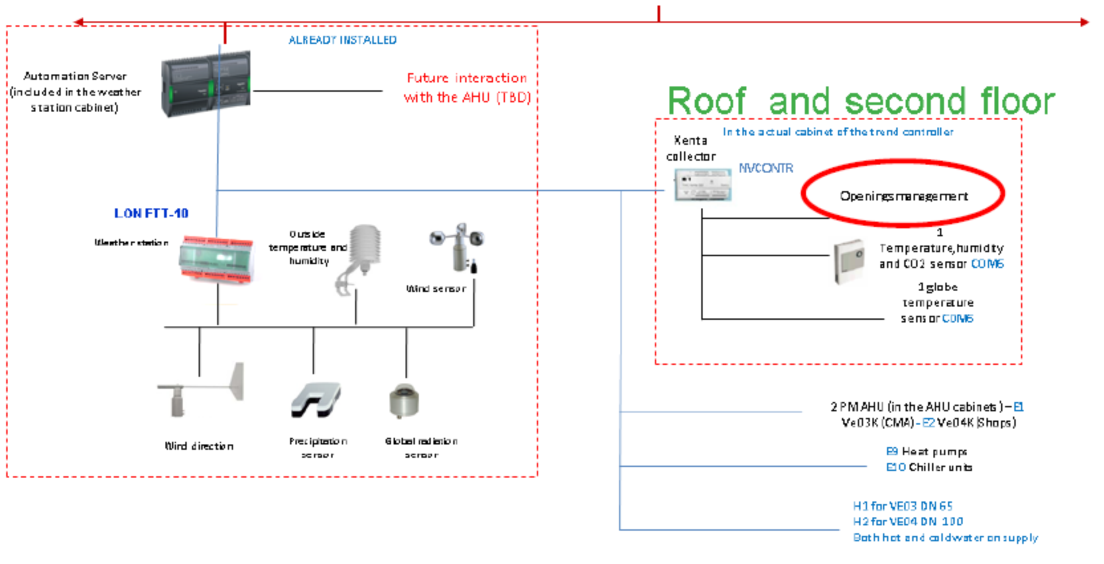


Figure 94. Natural ventilation control in CitySyd: iBEMS architecture

The operation of the motors for natural ventilation uses information from sensors located in the common area (Figure 94). Thus, the information required for the operation of this sub-system is under the same hardware installation.

The control schemes to be implemented in the iBEMS system to control natural ventilation is described in detail in D4.5 [11].

Modular roof skylight system

The latest sub-system integrated in the iBEMS of Trondheim demo is the control of the rectangular skylights. The installed motors for this system use the SMI interface which can be used by the iBEMS architecture using a dedicated KNX to SMI gateway. Similarly, the light sensors of this area will be used for the control of this sub-system.

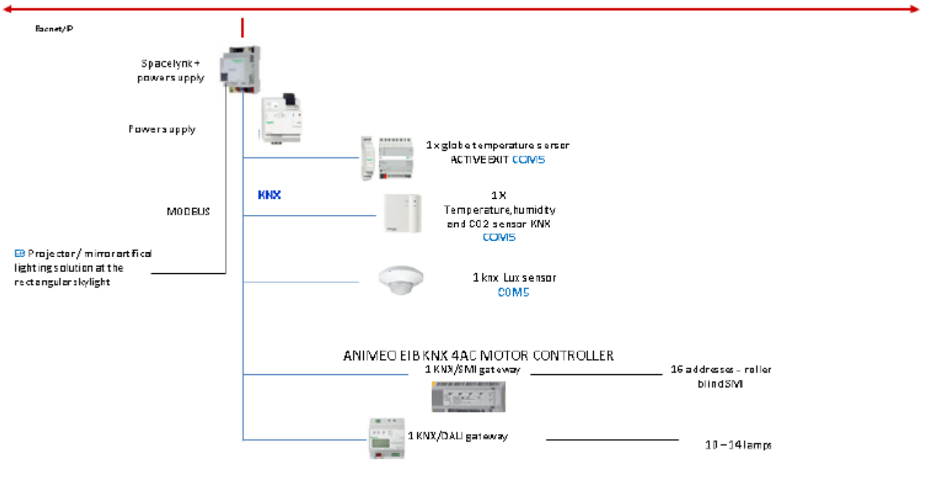


Figure 95. Modular roof skylight system control

5.4. Assessment of overall energy performance in City Syd

5.4.1. Baseline period

All the renovation projects are divided into two timing periods: baseline, the period before the intervention, and reporting period, that represents the post-retrofit period. During baseline, the analysis, diagnosis and proposed ECMs for retrofitting are the main tasks. In fact, ECMs implementation is the element that splits both periods. In the reporting period, the improvements provided by the ECMs are evaluated.

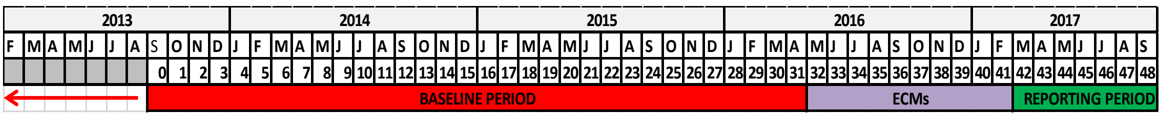
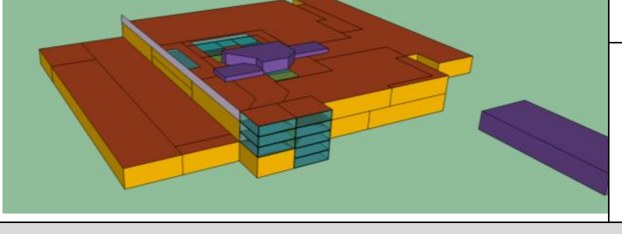


Figure 96. Baseline period schedule

Table 52 reports the input data summary for the simulation of the baseline.

Table 52. Input data for the baseline model.

General Data		
Gross floor area [m²]	20,039	
Gross Leasable Area [m²]	19,860	
Food store vending area [m²]	0	
Tenants vending area [m²]	14,612	
Common areas and galleries [m²]	2,772	
Number of opening hours per day [h/d]	13	
Number of opening days per week [d/w]	6	
Number of closing days per year [d/y]	56	
Thermal zone model		
	Zones	
	24	
Building envelope		
Opaque envelope components	U-value [W/m²K]	Solar absorptance [-]

Exterior walls	0.45 (0.22 extension)	0.7
Adjacent walls	2.134	0.6
Exterior roof	0.15	0.6
Ceiling/interior floors	1.619	0.6
Ground floor	1.336	0.6
Glazed envelope components	U_g [W/m²K]	g-value [-]
Exterior window	2.40	
Doors / ports	2.0	
Other components	various	
Air tightness (ach) [h-1]	3.0 – 7.0	
Heat recovery [%]	50 – 65	
Specific fan power [kW/(m³/s)]	3.0	
Active systems		

Table 53 summarizes the energy systems of the building and their corresponding energy source.

Table 53 Summary of the energy systems and their corresponding energy source

Sources of Energy

Service/Source	Heating system	Cooling system	Ventilation system	Lighting	Refrigeration	Electrical appliances	Sanitary wate
Electricity	X	X	X	X	X	X	(T >6
Fossil Fuel							
District energy	X						X
Renewable Energies							
Other: Snow melting systems	X						

A detailed description of the systems can be found in D6.3.

5.4.2. Meter specifications and monitoring

A large number of sensors were installed in the building with control and evaluation purposes.

The following figure (Figure 97) represents the energy monitoring layout for City Syd. It can be divided into four main areas corresponding to the four demonstration areas (as described in par. 5.2).

The signals collected in the building are being saved in the iBEMS.

A complete overview of the sensor type follows:

- Thermal energy counters.
  - H1: Thermal meter AHU Ve03K (CMA).
  - H2: Thermal meter AHU Ve04K (Shops).
- Electrical counters metering.
  - E1: Electrical meter for AHU Ve03K (CMA).
  - E2: Electrical meter for AHU Ve04K (Shops).
  - E3: Electrical meter for lights in Jens Hoff Shop.
  - E4: Electrical meter for fancoils in Jens Hoff Shop.
  - E5: Electrical meter for lights in rectangular skylight.
  - E6: Electrical meter for the Heat Pump.
  - E7: Electrical meter for the Chiller.

This means that for the demonstration areas the following monitoring data was collected:

Demonstration area 1 (Jens Hoff shop):

Thermal meter AHU Ve04K (H2).

Electrical meter for AHU Ve04K (E2).

Electrical meter for lights (E3).

Electrical meter for fancoils in Jens Hoff Shop (E4)

Demonstration area 3 (Common area for natural ventilation)

Thermal meter AHU Ve03K (H1)

Electrical meter for AHU Ve03K (E1).

Demonstration area 4 (Common area for rectangular skylight)

Electrical meter for fancoils in Jens Hoff Shop (E5).

With all these meters and sensors it is possible to have a calibrated model of City Syd new building but also to measure directly the energy consumption of some of the isolated solutions.

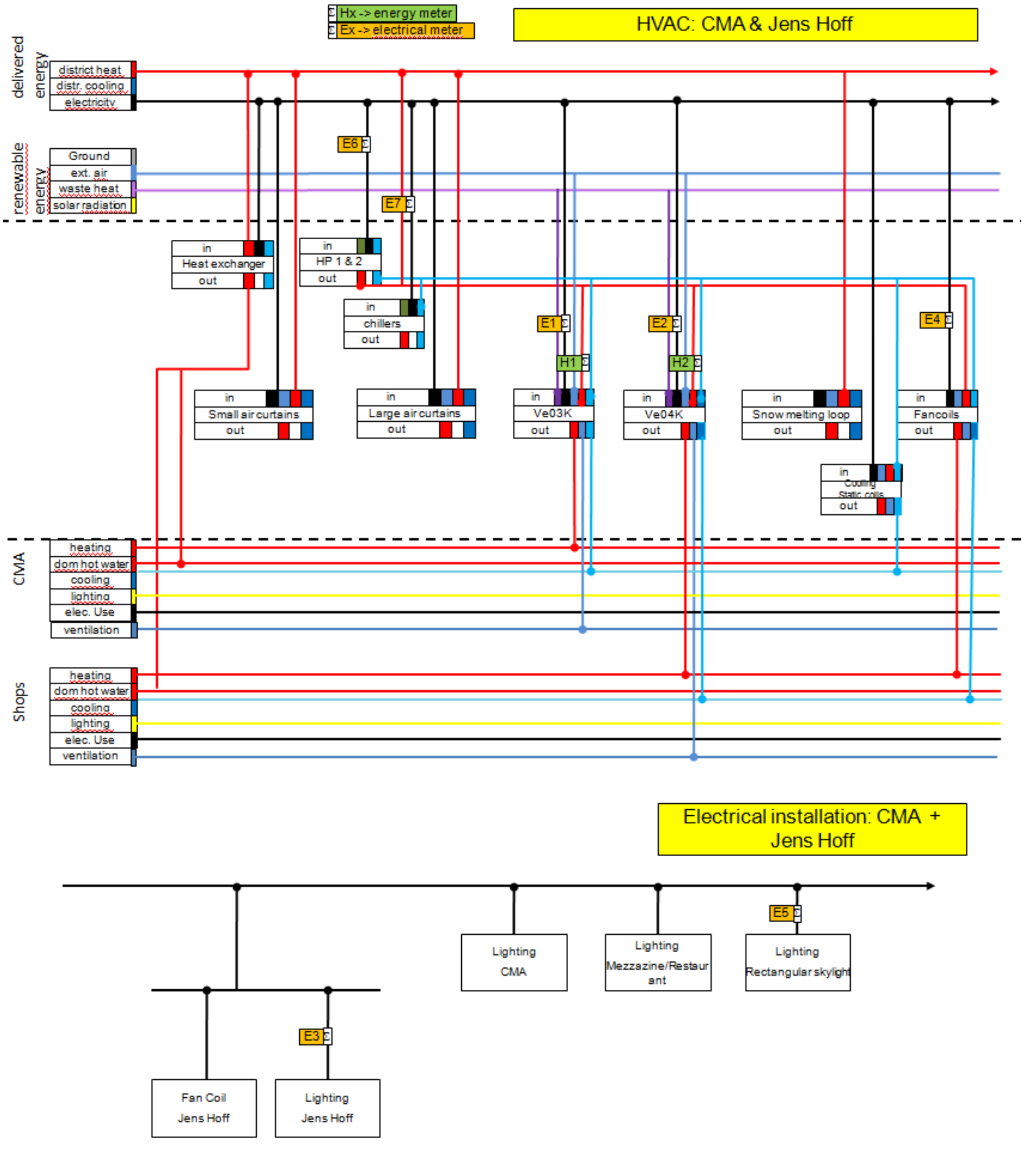


Figure 97. Installation of monitoring

5.4.3. Reporting period

The reporting period must begin once the interventions have already finished and the commissioning and test of different ECMs have finished too. According to the implementation plan the reporting period in the City Syd demo site starting date should be May 2017. However, delays in the installation were noticed.

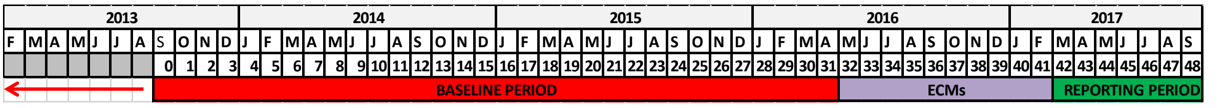


Figure 98. Reporting period schedule

The LED lighting strategy analysed are:

- Case (0)
- Case (1) New luminaries
- Case (2) constant light output (CLO)
- Case (3) zoning
- Case (4) night milieu with reduced intensity
- Case (5) light pipes

Each case is described in more detail in Table 54 and Table 55. It can be seen that the resulting power per luminary is reduced for cases (1) to (5) compared to case (0).

Table 54 Lighting control strategy

Case	Nº of luminaries	Control strategy	Power per luminary [W]
(0)	43	constantly on during op. hours	70
(1)	57	constantly on during op. hours	37.72
(2)	57	constantly on during op. hours	33.86
(3)	57	+ PREP hours	27.02
(4)	57	+ PREP hours + day/night milieu	27.02
(5)	31		32.26
Not daylit zone			
(5)	26	+ light tubes	21.15
Daylit zone			

With the installation of the three light tubes it was possible to reduce the lighting according to daylight illuminance. Table 55 shows the results of the nominal power for the demonstration shop area in the Trondheim shopping centre. It can be seen that cases (1) to (3) reduce nominal power during opening hours. Cases (3) to (5) introduce additional preparation periods with reduced nominal power. Cases (4) and (5) introduce in addition a night milieu period with again reduced nominal power.

Table 55. Lighting power installed in demonstration shop area

Case	Power per lum. (PREP) [W]	Nominal Power [kW]		
		During opening hours	During prep hours	During night milieu
(0)	-	3.39	-	-

(1)	-	2.15	-	-
(2)	-	1.93	-	-
(3)	18.95	1.54	1.08	-
(4)	18.95	1.54	1.08	1.08
(5)	22.58	1	0.7	0.7
Not daylit zone				
(5)	14.628	0.55	0.38	0.38
Daylit zone				

5.4.4. Analysis procedure for calculating results

The procedure for calculating results is as follows:

1. Comparison of KPIs in reference building model with measured data (e.g. electricity bill, district heating bill) (D5.1)
2. Definition of KPIs for reference model
3. Deduction of KPIs from reference model for ECM model
4. Deduction of KPIs from ECM model for demonstration area (e.g. installed power, schedules, areas, etc.)
5. Use of new KPIs for demo area
6. Comparison of monitoring KPIs with KPIs in demo area
7. Use of same KPIs in similar areas within the ECM model
8. Comparison of monitoring KPIs with KPIs in ECM model
9. Comparison of KPIs in ECM model with KPIs in reference model
10. Calculation of KPIs (e.g. energy consumption divided into electricity, energy need for heating and cooling, ventilation) for whole shopping centre
11. Calculation of KPIs for whole shopping centre (e.g. primary energy savings, CO2 emission reduction, based on comparison with base case)

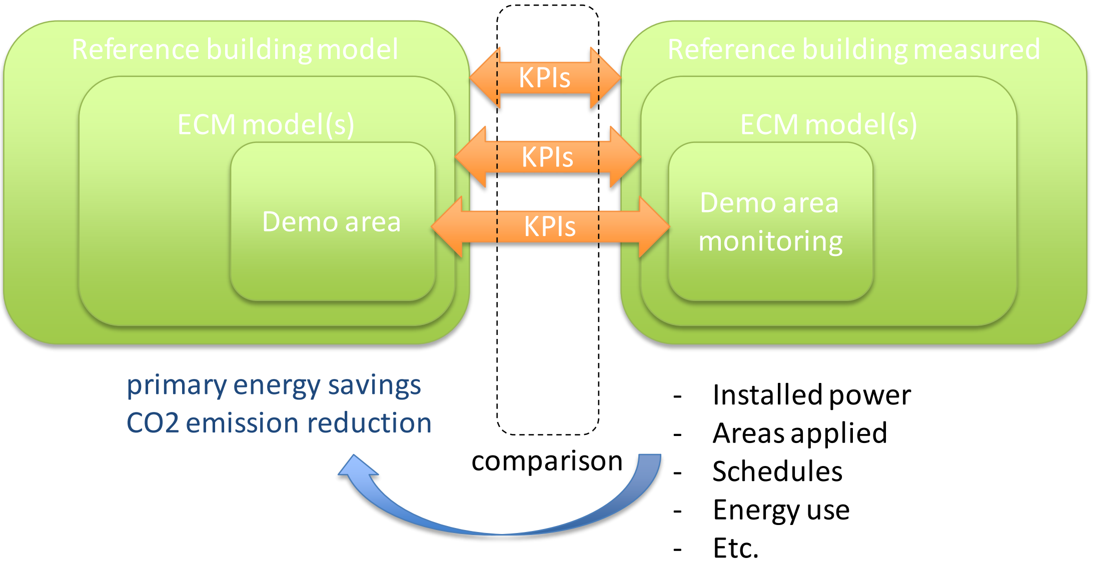


Figure 99. Scheme explaining the procedure to calculate results

Here follows the description of the baseline building model. The energy savings potential of the proposed solution was calculated according to the energy performance predicted by this reference model.

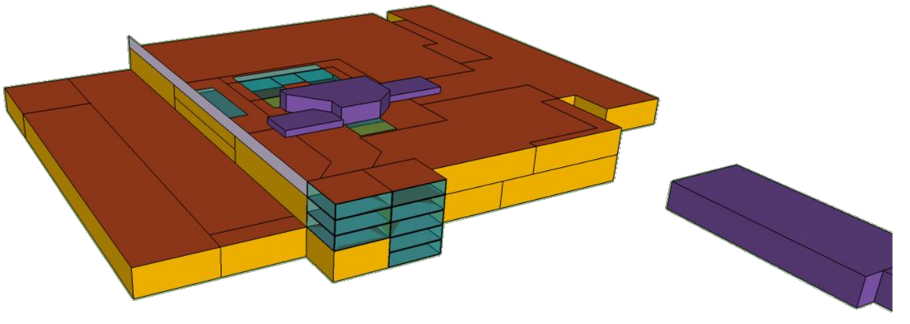


Figure 100. Building energy model in Sketchup (TRNSYS 3D plugin)

The following diagrams compare the measured data with the simulated values of the baseline model.

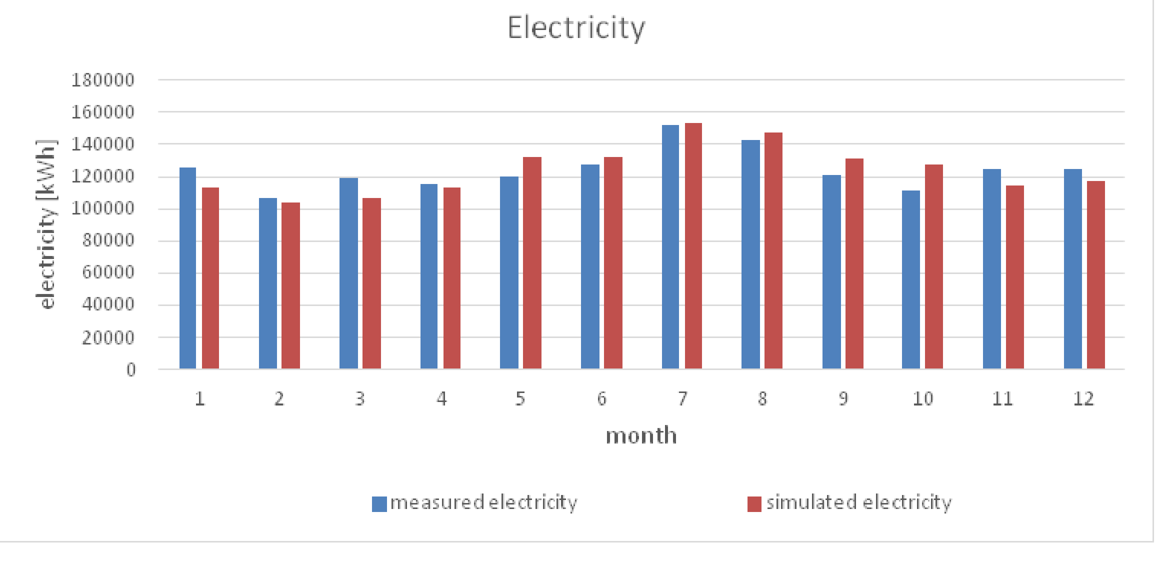


Figure 101. Measured and simulated monthly electricity of the baseline model.

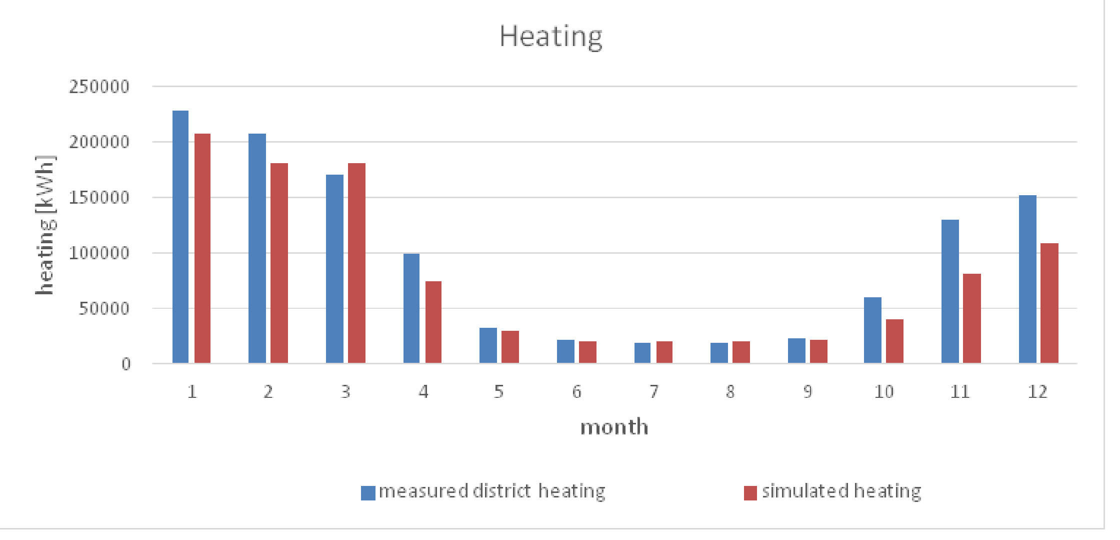


Figure 102. Measured and simulated monthly heating consumption of the baseline model.

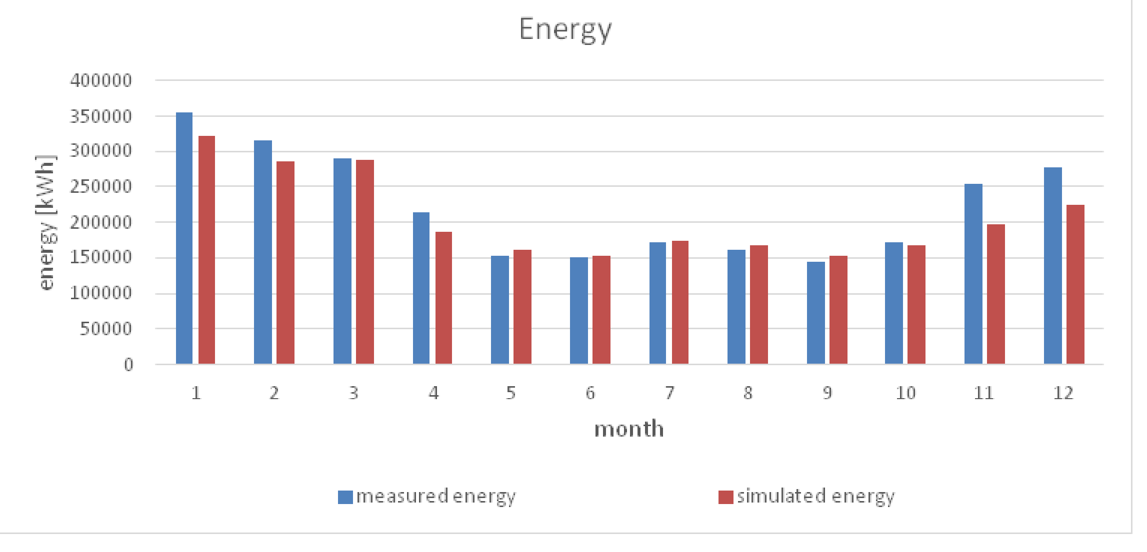


Figure 103. Measured and simulated monthly energy consumption of the baseline model.

The factors that will be used in the City Syd demo site in order to calculate energy savings, emissions and economic savings are reported in Table 56, Table 57 and Table 58.

Table 56. Energy price for the Norwegian demo-case

Energy source[10]	Price
Electricity	0.085 €/kWh
District heating	0.085 €/kWh

[10] Calculated with 0.8 NOK/kWh with an Exchange rate of 9.4 NOK/€

Table 57. CO2 emissions factors for the Norwegian demo-case

Energy source	CO2 emissions factor
Electricity	350 gCO_2/kWh
District heating	220 gCO_2/kWh

Table 58. Primary energy factors for the Norwegian demo-case

Energy source	Primary energy factor
Electricity	2.5 kWh_{PE}/kWh_{el}
District heating	0.75 kWh_{PE}/kWh_{th}

5.4.5. Energy savings results

Table 59 shows the different lighting cases analyzed. Case (0) is the base case, while cases (1) – (3) refer to LED lighting installation with various technologies and different levels of controls (iBEMS). The specific luminous flux is reduced from 2.06 klm/m^2 to 1.69 in case (1) and to 1.28 klm/m^2 in case (3). Case (4) refers to the most advanced LED lighting with the most advanced control (iBEMS) with luminous flux equal to 1.23 klm/m^2. For details see (D4.8). The energy demand per area is reduced from 39.8 W/m^2 (case 0) to 16.5 W/m^2 in case 4.

Table 60 summarizes the resulting implications for electricity use (lighting), heating, cooling and the sum when applied for different areas. The lighting cases (1) to (4) can be applied in common areas (cma) and all areas (cma + shops). It can be noticed that a reduction of lighting energy increases heating demand and reduces cooling demand. Case (5) is the solution with light tubes and can thus only be applied to the shops on the last floor.

Table 59. Energy demand of the different lighting cases applied to different shopping mall areas.

Case	Area in SC	Lighting [kWh/m^{2}y]	Heating [kWh/m^{2}y]	Cooling [kWh/m^{2}y]	Sum [kWh/m^{2}y]
(0)	-	137.3	49.5	20.1	206.8
(1)	cma	121.6	57.2	19.5	198.3
	cma+shp	109.3	58.2	16.2	183.7
(2)	cma	120.9	57.5	19.5	197.9
	cma+shp	80.1	59.9	7.0	147.0
(3)	cma	120.1	57.8	19.4	197.3
	cma+shp	55	67.5	4.0	126.5
(4)	cma	119.4	58.1	19.4	196.9

	cma+shp	50	70.4	4.0	124.4
(5)	shops on first floor	31.2	84.3	4.0	119.5

Table 60. Electrical energy results

Case	Specific yearly energy demand [kWh/m²y]	Mean specific power demand per area [W/m²]	Specific luminous flux per area [klm/m²]
(0)	178.2	39.8	2.06
(1)	113	25.3	1.69
(2)	102	22.8	1.69
(3)	77	17.2	1.28
(4)	74	16.5	1.23
(5)	68	15.2	1.23

5.5. Assessment of energy savings, payback time and CO_2 emissions avoided in each ECM

ECM 1: Artificial lighting concept in Jens Hoff shop
Analysis procedure for calculating results The process for the evaluation is based on direct monitoring (OPTION A) in the demonstration areas. Additionally, the difference from baseline to the whole building is done with simulations (OPTION D) or directly with monitoring system (OPTION A). The baseline is for one year measured data and mixed reporting period (1 week monitoring coupled with 1 year of simulation).

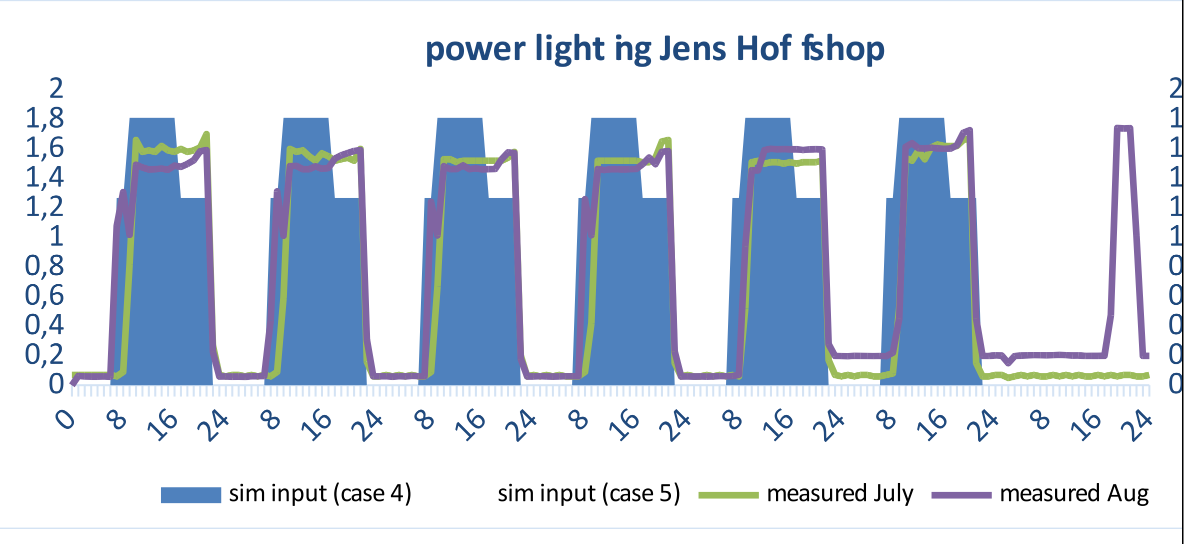


Figure 104. Simulated and measured lighting power for 1 week in July and August

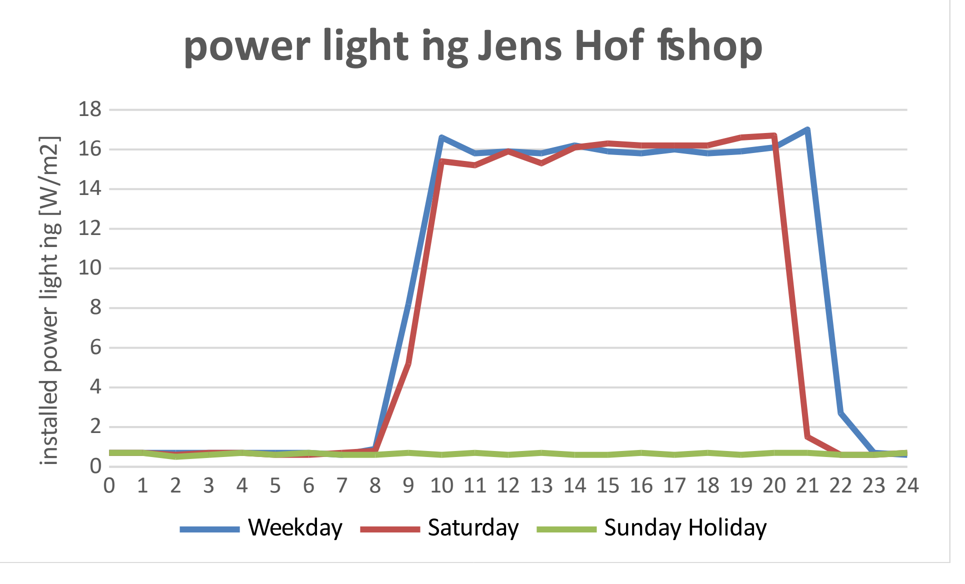


Figure 105 Measured power for 1 week in August (Daily average)

Table 61. Estimated savings results

	Energy use [kWh/m^{2}y]
Base case	197.2
Measured	65.7
Savings	131.5 (67%)

Energy savings, CO2 emissions avoided and simple payback

ECM	Thermal savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]]
ECM 1	-10,7	86	26.3

ECM 2: Light tubes in Jens Hoff Shop

Analysis procedure for calculating results

The process for the evaluation is based on direct monitoring (Option A of IPMVP) in the demonstration areas. Additionally, the difference from baseline to the whole building is done with simulations (Option D) or directly with monitoring system (Option A).

The baseline is for one year measured data and mixed reporting period (1 week monitoring coupled with 1 year of simulation).

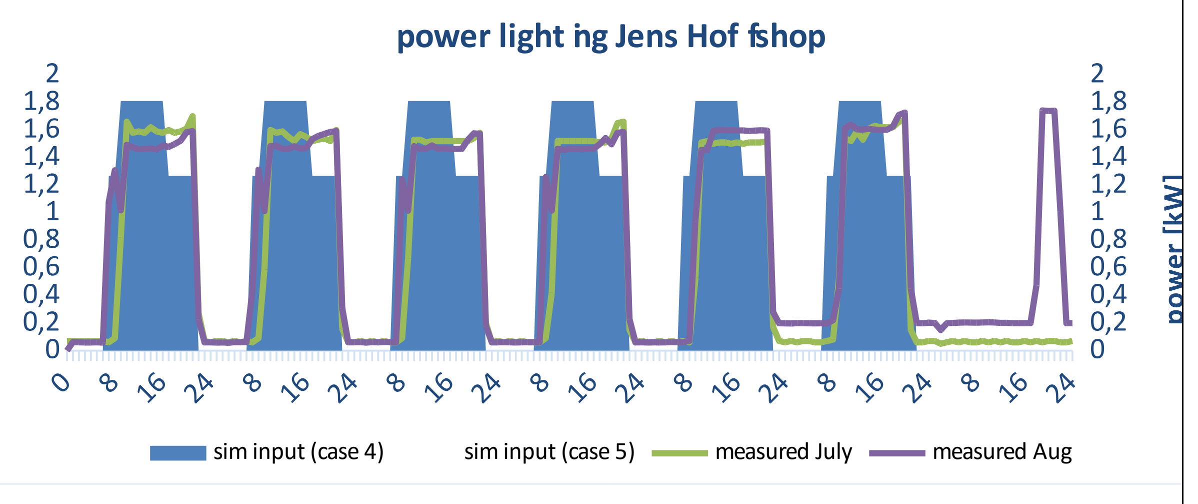


Figure 106. Simulated and measured lighting power for 1 week in July and August

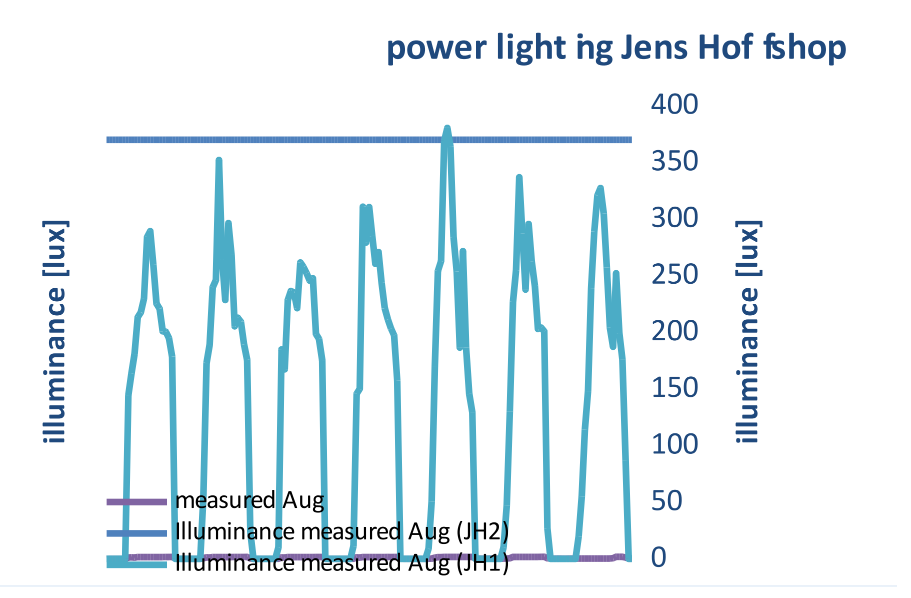


Figure 107. Measured power and illuminance for 1 week in August

ECM 3: Modular roof skylight
<u>Analysis procedure for calculating results</u> Due to several issues occurred in the prototyping phase and consequent delay in installation, it has not been possible to perform measurements on the modular roof skylight performance.

ECM 4: Natural ventilation

Analysis procedure for calculating results

Potential energy savings due to natural ventilation can be estimated only by building energy simulations. The control strategy has been implemented in an airflow network model and coupled with the thermal model created by Sintef (please refer to the simulation report for details on the model).

Baseline simulations were run in unlimited power mode, where the generation system is assumed to always have the power necessary to keep indoor temperatures within 20°C (heating set-point) and 25°C (cooling set-point) during the opening time of the shopping centre (h9:00-19:00). The mechanical ventilation is always on during opening time and provides the minimum required air change rates which are assumed to be 20,835 m³/hr (circa 1 ach).

The model neglects infiltration rates and air exchanges with the other part of the shopping centre, not object of investigation by the CommONEnergy project.

Since the HVAC model is ideal, the following efficiencies have been considered for the estimation of the electricity consumption due to heating, cooling and ventilation:

- COP = 2.36
- SPF = 0.45 Wh/m³

In order to estimate the savings in terms of operative costs, the cost of electricity is assumed to be 0.085 €/kWh.

The estimated energy savings are summarized Table 62. The total electricity consumption of the common areas over the whole reference year is reduced by a 4% thanks to the exploitation of natural ventilation.

Simulation results showed that, with the control strategy defined, natural ventilation is effective in providing the minimum required air change rates for 98% of its activation time.

Table 62. Estimated energy and cost savings due to natural ventilation

	Mechanical ventilation	Natural ventilation
Daytime natural ventilation operating hours [hr/y]	0	289
Mechanical ventilation operating hours [hr/y]	2,972	2,611
Electric energy consumed for ventilation [MWh/y]	27	23
Electric energy consumed for heating [MWh/y]	57	57
Electric energy consumed for cooling [MWh/y]	26	25
Tot electric energy consumption [MWh/y]	110	106 (-4%)
Operating costs saving [€/y]	-	-293

The operating cost savings are only 293 €, but considering the fact that the natural ventilation components, motors and actuators are already in place, the pay-back time of this solution is quite immediate.

Energy savings, CO2 emissions avoided and simple payback

Measurements of switching off the air handling unit were not possible. The control switch was just installed and programmed in the last week of project month 48. The results shown below are based on simulations.

ECM	Thermal savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]]
Natural ventilation	0	1.44	0.51

ECM5: General Retail Lighting (GRL) in common areas

Analysis procedure for calculating results

The process for the evaluation is based on direct monitoring (OPTION A) in the demonstration areas. Additionally, the difference from baseline to the whole building is done with simulations (OPTION D) or directly with monitoring system (OPTION A).

The baseline is for one year measured data and mixed reporting period (1 week monitoring coupled with 1 year of simulation.

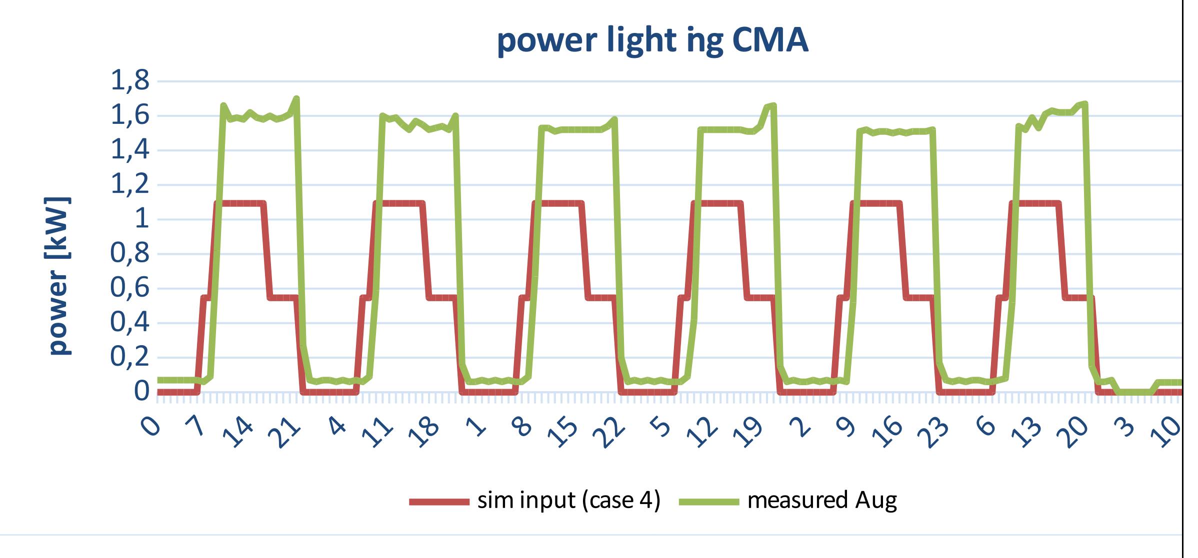


Figure 108. Simulated and measured power for lighting in CMA

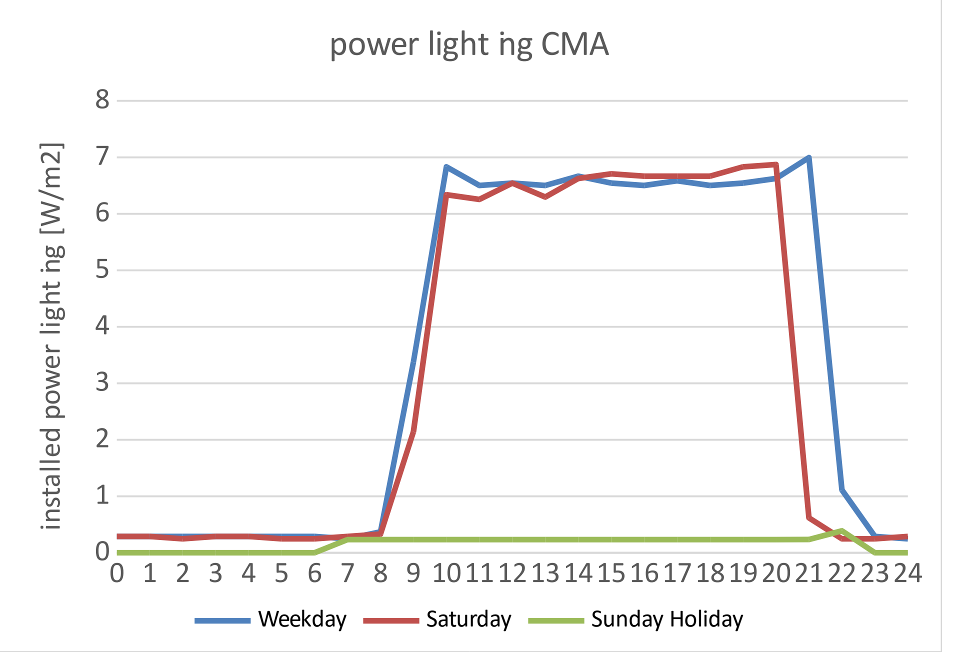


Figure 109 Measured power for lighting in CMA (Daily average)

Table 63. Estimated savings results

	Energy use [kWh/m²y]
Base case	71.7
Measured	26.9
Savings	44.8 (62.5%)

<u>Energy savings, CO2 emissions avoided and simple payback</u>

ECM	Thermal savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]]
ECM 5	-8	18	3.5

ECM 6: iBEMS

<u>Analysis procedure for calculating results</u>

The iBEMS energy savings for artificial lighting was calculated by comparing case (1) which can be a solution without control, with the actual measurements.

<u>Energy savings, CO2 emissions avoided and simple payback</u>

ECM	Thermal savings [kWh/m²/year]	Electrical savings [kWh/m²/year]	CO_2 emissions avoided [kg/m²/year]]
ECM 6	-8	27	7.0

5.6. Summary of results in City Syd

The potential of improvement with the solutions has been demonstrated in selected demonstration areas of the demo case. Table 64 shows the potential energy savings if these solutions were applied to the whole building. Especially the ECM4 (lighting) proved to be effective and also reduce cooling demand.

Due to delays in installation, the energy savings of some of the solutions have been calculated only by means of energy simulations.

The effect of increased daylighting thanks to the installed light tubes (ECM2) could not be measured because during the spot measurement campaign it was not possible to open the sun shading screens integrated in the skylight dome and thus only little daylight could enter the demonstration area. Additional measurements are recommended.

The modular roof skylight installation (ECM 5) delayed due to several issues occurred in the prototyping phase and timing as well as the installation timing, which should occur at a time when the shopping activities are not affected. Therefore, the installation was just finalized in project M48 and there was not enough time to measure and analyse the data.

The natural ventilation control (ECM 4) control strategy was implemented in 2016 with the exception of the AHU control. The integrated control of natural ventilation and AHU was just finalized in project M48. Thus there was not enough time to measure and analyze the data.

Even though the overall primary energy savings are positive, the lighting solutions causes an increase of heating demand as a result of reduction of internal loads. This is specific for the different zones and it remains difficult to generalize. It remains a challenge to distribute energy savings in specific zones (which are interconnected) of the shopping centre according to functional and/or organizational pattern.

Table 64. Summary results of the whole building performance indicators in CitySyd comparing performance before and after retrofit.

Thermal savings [kWh/m²/y]	Electrical savings [kWh/m²/y]	Primary energy savings [kWh/m²/y]	Cost avoided [€/m²/y]	CO_2 emissions avoidance [kg/m²/y]
-70.41	104	232	7.37	29.8

Table 65. Summary results of ECMs in CitySyd

Energy Conservation Measure (ECM)		Thermal savings [kWh/m²/y]	Electrical savings [kWh/m²/y]	CO_2 emissions avoided [kg/m²/y]	Cost avoidance [€/m²/y]
1	Artificial lighting concept in Jens Hoff shop	-10,7	86	26.3	6.40

2	Light tubes in Jens Hoff shop	No measured data available[11]			
3	General Retail Lighting (GRL) in common areas	-8	18	3.5	0.85
4	Natural ventilation	-	1.44	0.51	0.12
5	Modular roof skylight	No measured data available[12]			
6	iBEMS	-8	27	7.0	1.70

[11] During the spot measurement campaign it was not possible to open the sun shading screens integrated in the skylight dome and thus only little daylight could enter the demonstration area.

[12] The modular roof skylight installation was just finished in M48. Thus there was not enough time to measure and analyze the data.

6. “Marema” shopping mall – Grosseto, Italy

6.1. Project description

In addition to the three demo cases, a fourth centre was considered to implement battery energy storage system (BESS) and the electro-mobility (e-mobility).

The shopping mall is located in Grosseto (Italy), called Marema’, and includes 32,000m^2 of covered area, in which there are 35 shops, 9 restaurants and café and 80,000m^2 of parking area in common with close activities. General information about the centre are reported in Table 66.

Table 66. Information about the Marema shopping mall.

Section	Quantity
Gallery	17,110 m^2
Gallery Coop	7,029 m^2
Supermarket	4,200 m^2
Shopping points	50
Parking	3,000

The shopping centre was included in CommONEnergy project in spring 2016 and was opened at the end of October 2016. A picture of the main entrance is shown in Figure 110.

Figure 110. Marema' shopping mall in Grosseto. Source: http://www.inres.it/it/progetti

The shopping centre has 350 kWp of photovoltaic system, where 70 kWp are dedicated to CommONEnergy system, which involves the Nilar battery system (BESS), and the EV-charger provided by Schneider Electric. The proposed solution wants to maximize the use of PV energy for e-mobility supplying the e-cars directly or storing the energy into the BESS. The PV and BESS system are connected in parallel on the AC bus of the shopping mall’s gallery.

A plan of the Marema’ area and the respective location of PV, BESS and EV-charger is shown below in Figure 111.

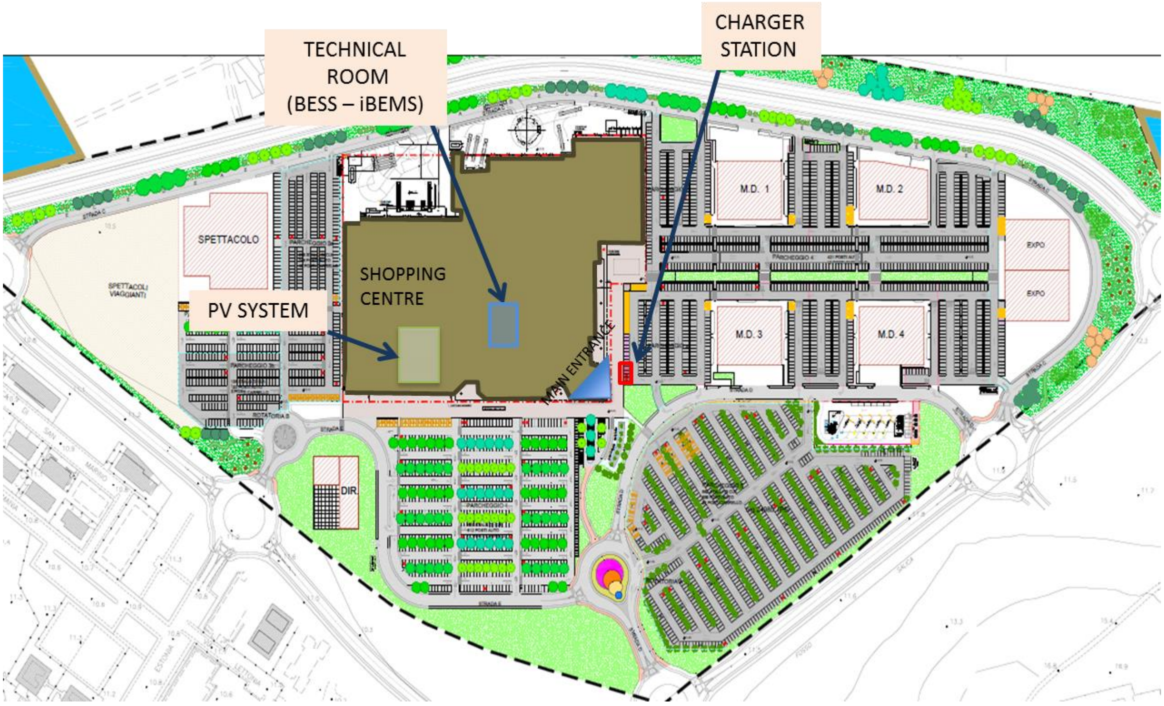


Figure 111. Plan of the shopping area in Grosseto. Source: INRES

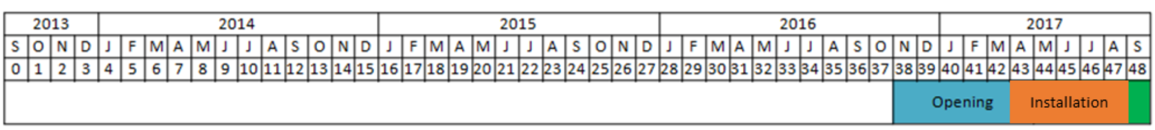
The objective of the CommONEnergy solutions for this specific demo case are:

- Increase renewable energy penetration due to the properly combination and management of photovoltaic (PV) and battery energy storage (BESS)
- Decreasing of CO_2 emissions due to “green” energy produced on-site (PV) and the e-mobility
- Incentive the diffusion of e-mobility in commercial area

6.2. Timeline of the demo case

As mentioned before, Marema’ demo-case has been included in the project during spring 2016 and the centre opened at the end of October 2016. The main phases summarized in the timelines below indicate:

- Opening of shopping mall: Oct. 2016
- Installation phase: April 2017 – Aug. 2017
- Data collection only for test and EV-charger: end of Aug. 2017
- System running: not yet due to the PV connection authorization.



6.3. Energy conservation measures

ECM1: Photovoltaic systems
A photovoltaic system of 70kWh is installed in the shopping center roof. The system is composed by 270 polycrystalline modules with a peak nominal power of 260Wp each. They are connected to three string inverter of 33 kW (inverter 1 and 2) and 27.6 kW (inverter 3). The PV modules placed on a roof structure and they are south oriented with optimal tilt angle. The yearly production is estimated around 98800 kWh.

Figure 112. Photovoltaic system installed on a portion of the roof of Marema'

ECM2: Battery energy storage
The energy storage system (ESS) is composed by a total of 40 Nickel metal-hydride (NiMH) batteries developed by Nilar and connected with 5 batteries per 8 strings (as in figure below). The total energy provided by the ESS is 48kWh. The ESS system is connected to the AC bus of the shopping mall through a bi-directional inverter which allow the charge and discharge of the ESS system on the same bus. This system is totally compliant with the Italian grid-connection regulation CEI 0-21:2015. The battery system has a deep-of-discharge (DoD) of 80%. The advantages of Nilar system are that they are safe, recycling and less expensive (in terms of euro/kWh) and with a good efficiency with respect to other technologies.

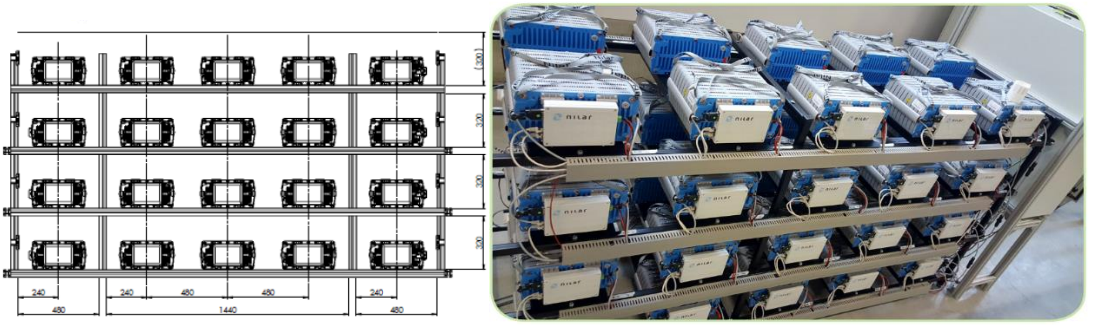


Figure 113. Battery energy storage system installed in the technical room in Marema' (Grosseto, Italy)

Figure 114. Bi-directional inverter cabinet for battery energy system installed in the technical room

ECM3: eV-charging system
Two parking lots dedicated to electrical cars. The EV-charger has two power outlets and can provide fast charge at 22 kW. Obviously, this depend from the car models and brand. There is the possibility to enable the charge with a fidelity card (dedicated to shopping mall customers), but for the moment the access is free. This is to incentive electric mobility diffusion among shopping-mall customers.

Figure 115. eV-charger installed in demo-case Maremá by Schneider Electric

ECM4: iBEMS

The overall system is managed by the iBEMs (intelligent Building Energy Management System) that manage the switching (on and off) of the diverse equipment depending on the inlet and outlet conditions.

The iBEMS enables:

- to implement advanced control strategies
- to monitor electricity production, consumption and stored;
- to optimize the use of the battery
- to assure the priority of e-cars to be supplied with PV or BESS energy

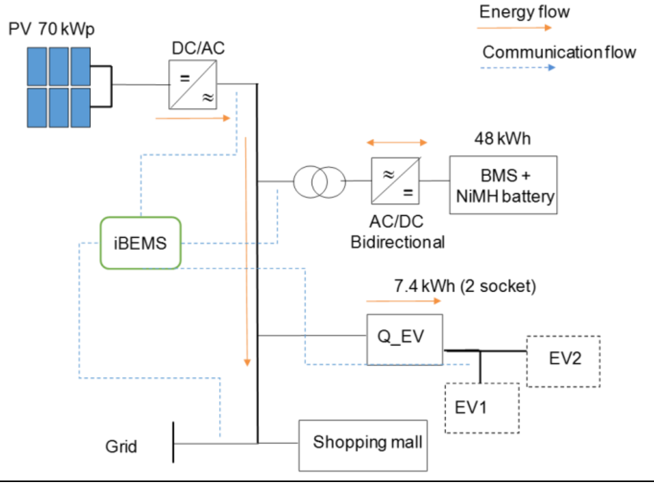


Figure 116. Simplified schema which represents communication and energy flows for PV-BESS-Evlink system

6.4 Control Rules

The control rules for the iBEMS installed in Marema' are based on the experience done in Bolzano experimental setup [12]. Even though the electrical configuration of the two system is different not only for the size but also for the energy flows, all the compatibility issues solves in down-scale prototype in Bolzano as well as technical issues related to the management of the battery has been useful to define the below logics.

In order to maximize the use of PV energy for electric mobility the purposes of the developed control rules are summarized in the following table.

Table 67. Control rules implemented in the iBEMS at Marema'

A	Priority to supply the power required by e-cars with photovoltaic or battery storage
B	Charge the battery from PV production (full-charge can be done by the grid)
C	Discharge the battery to cover part of gallery consumption when e-car is not present and battery has SOC>80%.
D	Assure full-charge with PV when possible, otherwise consider a time counter and set the full-charge every 36h
E	During the full-charge battery mode cannot be changed until the full charge is not completed
F	Full-charge from the grid has to be done during the night

A graphical representation of the control rules is shown in Figure 117, using logic gates representation. The meaning of the abbreviations used are:

- SOC = State of Charge;
- EV = electrical vehicle;
- I_{pv} = photovoltaic current:
- I_{ev} = electrical vehicle current;
- I_{ch} = charge current.

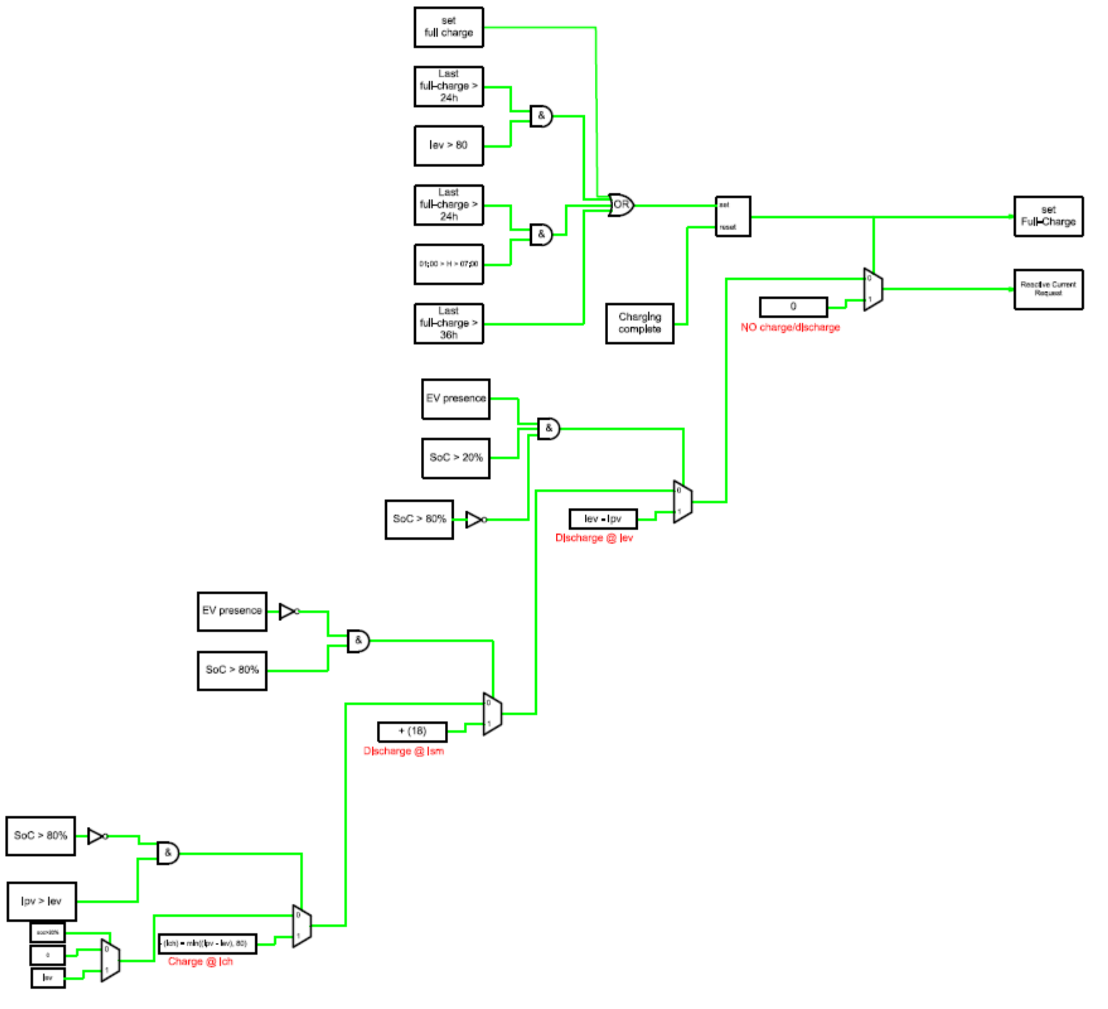


Figure 117. Logic port representation of control rules implemented in iBEMS installed in Marema' to manage the PV-BESS-EV-link energy flows

6.5 Meter specification and monitoring

In order to acquire and monitor the interested values to check the correctness of control rules as well as to verify the increase of self-consumption, the EV-charger use and the goodness of power quality (PQ), six measurement points are installed in the technical cabinets.

Five electric meters are installed in Marema' for the PV-BESS-EV link system. Three of them are multimeters and they monitor the two EV-links and the building demand. In the point of connection of PV and BESS, two power quality (PQ) meters are installed in order to analyze also possible harmonics or voltage disturbances introduced by PV or BESS in the main AC bus. For additional clarification about PQ monitoring please refer to D4.6. The measurement points configuration is shown in Figure 118.

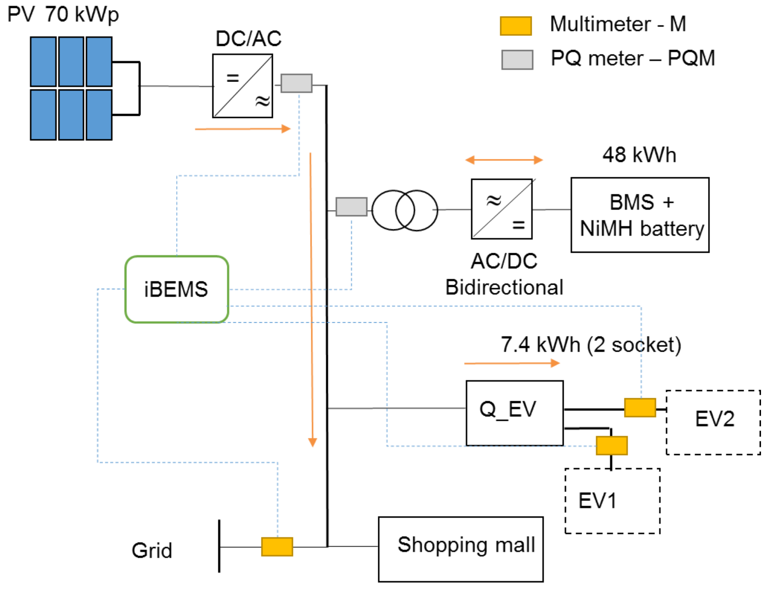


Figure 118. Measurement points configuration for PV-BESS-EV link in Marema'

In details the collected measurements are used to evaluate the following key performance indicators:

- Self-consumption: the percentage of PV production used by EV-charger and BESS;
- Energy exchanged among PV, BESS and EV-charger. In particular we want to evaluate the quantity of the energy consumed on-site and the energy imported from the grid.
- CO_2 reduction using the PV-BESS system to supply the e-cars with respect to commonly used grid;
- Statistics on e-cars occurrences
- Power quality index (e.g. Total Harmonic Distortion (THD), Harmonics, Voltage deviations))

6.6 Estimation of PV-BESS-EV charger benefits

Due to the lack of measured data, in this section we report an estimation of the possible benefits coming from the combination of PV and BESS to supply the EV charger.

By end of September the IBEMS collected EV-charger power demand and we are able to give a first estimation about the number of e-car which use the system. Currently the average is one-two cars over a period of a ten days. This means that the demand is low and the system, managed with the control rules in Figure 117, is always able to fulfill the electro-mobility consumption with the PV and BESS system.

If we assume to simulate the EV-charger energy demand, considering an average time of charge between 0.5h and 1.5h for one and two cars. The number of cars and the power profiles are shown in Figure 119 and Figure 120 respectively.

An example of the daily profiles of the energy produced by PV, required by EV-charger and stored into the battery are displayed in Figure 121. The PV production is an average profiles over the summer period and it is possible to note that it is able to perform the both actions:

cover the EV-charger demand and to charge the battery. Moreover, Figure 121 shows that in the evening (i.e. 20 hour) the BESS discharge to supply the EV charger demand, this in respect to the developed logics which give priority to the e-mobility. However, due to the current low diffusion of e-cars, the energy stored into the battery could be also used to shave the peak of the common area during the evening hours. This lead to a total reduction of CO_2 emissions for electric mobility and small reduction for the total consumption.

Nevertheless it is important to remark that the aim of the PV-BESS system is not to shave the peak of the shopping mall of increase self-consumption, but mainly to cover the EV-charger demand.

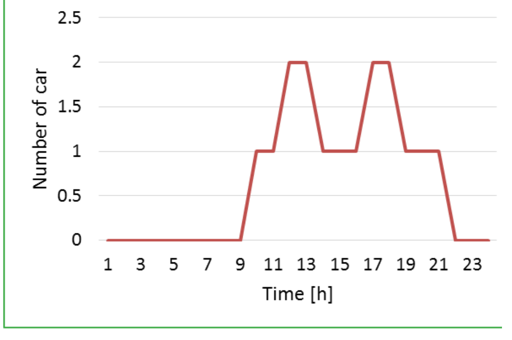


Figure 119. Hypothetical car occurrence in Grosseto during typical day

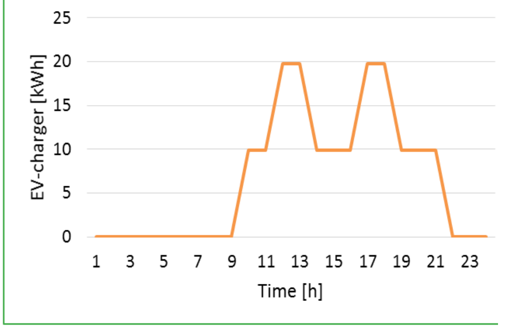


Figure 120. Power profile corresponding car occurrence

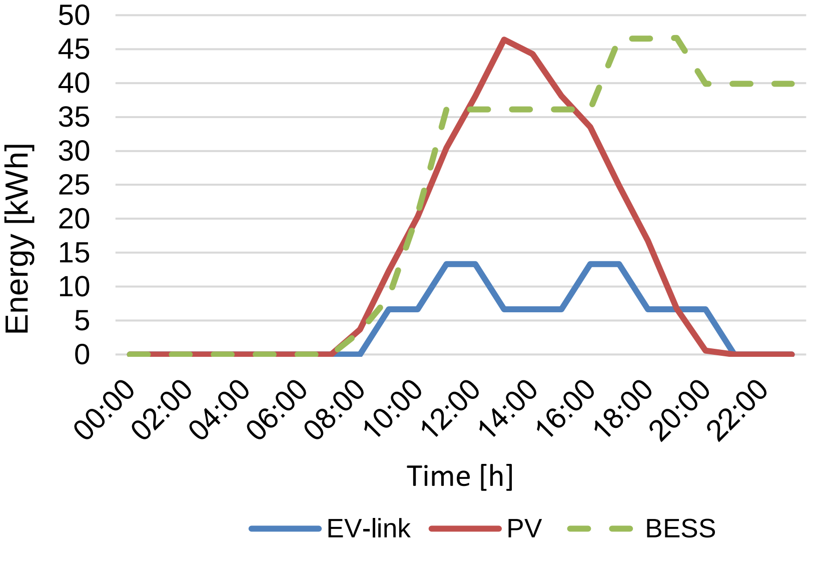


Figure 121. Example of typical daily profiles of PV production, EV-charger and BESS energy

7. Conclusions

Mercado del Val

The building has only one energy carrier which is electricity. Therefore, there are only savings in terms of electricity consumption reduction.

For the whole building comparison (old market with new market with ECMs), the electrical savings regarded heating, cooling, ventilation, lighting, appliances and refrigeration consumption. The renewable energy production was provided by the geothermal heat pump systems installed in the new building to cover all the heating and cooling needs (+Domestic Heat Water). The old building did not have any renewable system installed.

Table 68. Energy, emissions and cost savings of the retrofit intervention at Mercado del Val.

Electrical savings	Renewable energy production	Primary energy savings	CO2 emissions avoided	Cost avoided
75%	100% of the Heating and Cooling needs + DHW	75%	75%	75%

Thanks to the retrofit intervention the Mercado del Val had electrical savings of around 75%. Primary energy and CO_2 emissions avoided were proportional to the electrical energy savings. For the renewable energy production, in the new building all the heating, cooling and DHW demand was fully covered by renewable energy sources (New geothermal heat pump system).

For the individual ECMs implemented in the new building we assumed savings in terms of energy consumption for heating and cooling, as energy consumption for lighting, appliances and refrigeration was assumed to remain unchanged. Compared to the building standard retrofit (without CommONEnergy solutions), the electricity consumption for heating and cooling after the retrofit with the multifunctional façade and the iBEMS control (ECM1+ECM2) was predicted to be reduced by 26%. Additional 28% less energy consumption could be obtained with the use of geothermal heat pumps (ECM3).

Coop Canaletto

The adopted solutions fully replaced the use of gas for space heating and hot water preparation. The advanced lighting concept allowed to reduce by 76% the electricity consumption for lighting the selling and food preparation area of the supermarket. The replacement of open cabinets with closed ones and the installation of air diffuser for avoiding the mist formation also contributed on a better internal comfort and lower electric consumption.

The novelty of the solutions implemented in the Modena Canaletto demo case involved the coupling of the HVAC system with the refrigeration circuit in addition to the use of a refrigeration system that worked with CO_2 as (natural) refrigerant. The demo-case and the study behind demonstrated as also in mild climates the use of a CO_2 refrigerant had comparable performance as conventional refrigerant gas. The slightly lower performance can be overcame with an optimized use of the system temperatures.

The exploitation of the waste heat for hot water preparation, space heating and post heating drastically reduced the energy needed for these uses, but at the same time increased the consumption of the refrigeration system. The overall energy consumption was much lower than without the integration of the two systems, but a preliminary study on the set temperatures and the working conditions for the heat recovery would be needed for exploiting the best working conditions of the two systems.

Table 69. Energy, emissions and cost savings of the retrofit intervention at Coop Canaletto.

Thermal savings	Electrical savings	Primary energy savings	CO_2 avoided emissions	Cost avoided
100%	49%	46%	46%	43%

City Syd

The potential of improvement with the solutions were demonstrated in common areas. Table 70 shows the potential energy savings if these solutions were applied to the whole building. Especially the artificial lighting proved to be effective and also to reduce cooling demand.

Table 70. Energy, emissions and cost savings of the retrofit intervention at CitySyd.

Electrical savings	Renewable energy production	Primary energy savings	CO2 emissions avoided	Cost avoided
38%	0	31%	28%	28%

Due to delays in installation, the energy savings of some of the solutions were calculated only by means of energy simulations.

The effect of increased daylighting thanks to the installed light tubes (ECM2) could not be measured because during the spot measurement campaign it was not possible to open the sun shading screens integrated in the skylight dome and thus only little daylight could enter the demonstration area. Additional measurements are recommended.

The modular roof skylight installation (ECM 5) delayed due to several issues occurred in the prototyping phase and timing as well as the installation timing, which should occur at a time when the shopping activities are not affected. Therefore, the installation was just finalized in project M48 and there was not enough time to measure and analyse the data.

The natural ventilation (ECM 4) control strategy was implemented in 2016 with the exception of the connection with AHU control. The integrated control of natural ventilation and AHU was just finalized in project M48. Thus there was not enough time to measure and analyze the data.

The potential energy savings were assessed by assuming the lighting solutions were applied to the whole building, resulting in **31% of primary energy reduction**. Even though the overall primary energy savings were positive, the lighting solutions caused an increase of heating demand as a result of reduction of internal loads. This was specific for the different zones and it remains difficult to generalize, with the challenge to distribute energy savings in specific zones (which are interconnected) of the shopping centre according to functional and/or organizational pattern.

Maremá Grosseto

In the additional demo of Maremá in Grosseto (Italy) the aim was to increase the share of renewable energy (i.e. photovoltaic) through the combination with the battery energy storage system provided by the project partner NILAR, in order to cover the energy demand of the eV-charger. The PV-BESS-eV charging system was the first prototype in a shopping mall in Italy able with the implemented control rules to cover the e-cars energy demand completely by the combination of PV and BESS. This make the shopping centers possible driver for the diffusion of the sustainable mobility not only in Italy but in all Europe.

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